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HEALTH & SAFETY LABORATORY

A survey of UK tram and light railway systems relating to the wheel/rail interface

FE/04/14

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CONTENTS

EXECUTIVE SUMMARY

Unlike the British railway network, the modern UK tram and light rail systems have been designed and constructed without the benefit of any national standards or guidance. In an endeavour to promote the formulation of these HM Railway Inspectorate is supporting a programme of research focused on defining best practice in relation to the safety aspects of the wheel/rail interface.

This report contains the findings from the first phase of this project that set out to survey information relevant to the wheel/rail interface for all UK tram and light rail systems.

The collection of this information would not have been possible without the willing assistance of the many people associated with the operation and maintenance of Britain's varied Light Rail Transit systems.

Besides detail information relevant to each of the nine systems investigated, the report contains many tables summarising the data considered germane to the wheel/rail interface. Also included is a comprehensive set of drawings for the rail and wheel tread profiles currently in use as is a summary of general observations made throughout the work. The report highlights a number of areas of concern relating to UK practice in which wheels with square flange tips (which were developed for flange tip running through crossings) interact adversely with small radius turnouts constructed from flat bottom rail.

Systems such as the Tyne & Wear Metro have developed directly from heavy rail practice. However, the majority have not developed in such a way and have been found to have greater wheel spacings (back-to-back measurement) which significantly affects the design of switches and crossings.

1 INTRODUCTION

As the first generation of UK trams virtually disappeared in the 1960s much of the associated knowledge base went with them. So in the development of the new systems there has been limited past experience upon which to draw. Also, with the demise of the UK railway rolling stock industry the vehicles for most of the modern systems have been constructed on the continent to European practice. Unlike the national railway network that is constructed, maintained and operated according to UK Group Standards, the modern UK tram and light railway systems have developed piecemeal. Each system appears to have been built without the benefits of standardisation or interoperability, with all the attendant maintenance and financial implications.

To bring together all those with a direct interest in UK tram and light rail systems HM Railway Inspectorate (HMRI) hosted a seminar in early October 2003. This saw strong support from the industry. The purpose of the meeting was to outline an HMRI funded project intended to address some of the safety related aspects of the wheel/rail interface and to enlist the help of delegates in the collection of relevant information. The ultimate objective of this project is to encourage the setting of standards and developing guides to good practice relevant to UK systems. This survey of wheel and rail related information for each of the main UK undertakings was seen as the essential first step that would guide subsequent project phases and provide a suitable database.

The main features of the brief for this survey were:

- The collection of information concerning wheel profiles, rail section profiles and switch rails as used on the systems at Birmingham, Blackpool, Croydon, Docklands, Manchester, Nottingham, Sheffield, Tyne & Wear and The National Tramway Museum.
- To collect information concerning systems operation with particular reference to derailments, potential to wheel flange climb, wheel wear and the success of modifications.
- Information to be gathered through meetings, correspondence and by searching the literature.
- Provide some insight into European practice and standards.
- Analyse and present the information collected.

Upon starting out Andy Steel (then General Manager of Travel Midland Metro the operators of the Midland Metro system) and Joe Brown (Parsons Brinkerhoff/Permanent Way Institution) assisted in setting the scope of the survey. This was followed by contact and meeting those involved in the day-to-day operation of systems. Without their willing assistance this work would not have been possible.

A further seminar hosted by HMRI, was held in late October 2004 at which provisional findings from the survey were presented. This event again saw strong support from the industry.

The report has been arranged such that each system examined is the subject of a chapter. These can be found in Chapters 2 to 10. Information concerning European practice is collected together in Chapter 11. An attempt has then been made in constructing comparative tables in Chapter 12 which summarise the data collected. Observations made during the course of the study are presented in Chapter 13. The appendices of Chapter 14 contain drawings which show the rail and wheel tread profiles that are, or have been tried, on the systems. Finally the References and Bibliography of Chapters 15 and 16 give details of information sources, and an attempt has been made to construct a glossary of common tram and light railway terminology in Chapter 17.

2 BLACKPOOL AND FLEETWOOD TRAMWAY

2.1 INTRODUCTION

The tram system at Blackpool is the oldest in the UK, having started operation in 1885 along the Promenade. It is now a municipally owned company that is operated by Blackpool Transport Services Ltd. The system extends for a distance of 18km along the Lancashire coast, from Fleetwood in the north to Starr Gate in the south.

Blackpool Borough Council have responsibility for the track and Blackpool Transport Ltd maintain and run the tram service.

The system is now in need of upgrading and developing to reflect changes in legislation and inshore residential developments. To address these issues Blackpool Borough and Lancashire County Councils commissioned the consultants Steer Davies to examine options for upgrading and developing the tramway. Following initial work by the TAS Partnership a plan was submitted to the government in July 2001.

This plan set out a three-phase development. The first phase, requiring no legislation, proposes upgrading the existing line to facilitate reduced journey times, and the introduction of modern or modernised rolling stock with low floors. The ability to offer a heritage service would be retained. The second phase envisages a short loop to connect with Blackpool North railway station, and a link from the centre of Blackpool, initially on former railway trackbed, to Lytham via the airport and St Anne’s. A new extensive loop line connecting Broadwater on the existing line with Thornton, Poulton and Blackpool North station comprises the phase three proposal. The second and third phases will require new legislation. Proposals for a £170m upgrade are currently on hold following their rejection by the Government in July 2004. The two authorities are now preparing a new submission to meet a request for reduced financial risk, reduced government funding and better value for money.

2.2 SYSTEM DETAILS

Schematic route map: See Figure 2.1.

Route distances:

In total there are just under 18km of mainly double track that runs from Starr Gate, on the Lytham St. Anne’s boundary in the south, to Fleetwood in the north. For most of the route the tramway has its own reserved tracks, as shown in Figure 2.2 and 2.3. There is a small amount of street running in the vicinity of the North Pier tram stop (see Figure 2.4) and 1.6km in Fleetwood from Ash Street to the Ferry loop. There is a loop at each end of the line, so trams are driven from the same end throughout their period in service.

There is a double track loop at Pleasure Beach, and a single-track loop at Little Bispham, which can be used to turn vehicles. There are passing loops at Tower, North Pier, Cabin, Bispham, Thornton Gate and at the Ferry. There are also a number of cross-overs and turnbacks throughout the system.

Route details are given in Table 2.1 below.

Table 2.1 Blackpool and Fleetwood tramway route details

From	*To*	*Distance (km)*[1]	*Track*[2]
Starr Gate	Harrowside	0.80	Single (loop)/0.28km ballasted Double/0.52km grooved rail
Harrowside	Pleasure Beach	1.13	Double/grooved rail
Pleasure Beach	South Pier	0.32	Double/grooved rail
South Pier	Rigby Road	1.29	Double/grooved rail
Rigby Road	Foxhall	0.16	Double/grooved rail
Foxhall	Tower	0.80	Double/grooved rail
Tower	Talbot Square	0.32	Double/grooved rail
Talbot Square	Pleasant Street	0.64	Double/grooved rail
Pleasant Street	Gynn Square	0.97	Double/grooved rail
Gynn Square	Cabin	0.48	Double/grooved rail
Cabin	Bispham	1.29	Double/1.06km ballasted Double/0.23km grooved rail
Bispham	Norbreck	0.80	Double/1.58km ballasted Double/0.19km grooved rail
Norbreck	Little Bispham	0.97	
Little Bispham	Cleveleys	1.45	Double/1.37km ballasted Double/0.08km grooved rail
Cleveleys	Thornton Gate	0.64	Double/0.36km ballasted Double/0.28km grooved rail
Thornton Gate	Rossall Lane	1.45	Double/4.18km ballasted Double/1.14km grooved rail
Rossall Lane	Broadwater	0.97	
Broadwater	Stanley Road	1.45	
Stanley Road	Ash Street	0.48	
Ash Street	Kent Street	0.97	
Kent Street	Pharos Street		
Pharos Street	Fleetwood Ferry	0.48	Single (loop)/grooved rail
Rigby Road	Rigby Road Depot	0.32	Double & Single/grooved rail

Notes:

[1] Based on mileage table (to nearest 0.1 mile)
[2] Partial distances estimated from a rail length inventory

Power supply:

Overhead line equipment supplies trams with power at a nominal voltage of 550Vdc.

There are eight sub-stations, taking their supply at 6.6kV from Norweb, as listed in Table 2.2.

Table 2.2 Location of Blackpool and Fleetwood tramway electrical sub-stations

Distance (km)[1]	*Location*
1.9	Pleasure Beach
3.9	Rigby Road Depot
5.3	Metropole
6.4	Gynn Square
8.2	Bispham
10.0	Little Bispham
12.1	Thornton Gate
15.9	Copse Road

Notes:
[1] Approximate distances from Starr Gate

Tunnels:

There are no tunnels on the system.

Passenger Service Vehicles

There is a total vehicle fleet of 80, many of which are ‘heritage’ units. For the timetabled services the fleet of eight Centenary Class single decker one man operated vehicles together with two one man operated “Balloon” double deckers are used. For the summer timetable 12 vehicles are required, and 7 for winter. In summer up to 40 vehicles may be required to run extra services over the centre part of the route.

Journeys per route:

Winter Timetable (from November):

Monday to Friday there is a service frequency of 20 minutes both ways with daytime services starting from Fleetwood Ferry and Starr Gate at 06:32hrs and 07:22hrs respectively until 18:00hrs. The Evening service from 18:00hrs has a 30 minute frequency until the last full service run leaves Fleetwood Ferry and Starr Gate at 22:590hrs and 23:30hrs respectively.

The Saturday service between Pleasure Beach and Cleveleys is more intensive with a 10-minute daytime frequency.
The Sunday service starts from Fleetwood Ferry and Starr Gate at 07:02hrs and 8:12hrs respectively, and operates with the Monday to Friday frequency until 18:00hrs.

Summer Timetable (from July):

Monday to Saturday there is a service frequency of 10 minutes Starr Gate to Fleetwood and a 10 minute Starr Gate to Cleveleys which gives a 5 minute frequency from Pleasure Beach to Cleveleys. The first service from Fleetwood is at 06:27hrs, and from Starr Gate at 07:19hrs.The last service from Fleetwood Ferry is at 23:07hrs and Starr Gate at 23:19hrs.

The Sunday full service starts from Fleetwood Ferry and Starr Gate at 07:07hrs and 07:59hrs respectively, and then operates as the Monday to Friday frequency and times.

Tram stops:

The service vehicles call at stops by request, except for Starr Gate, Pleasure Beach, Manchester Square, North Pier, Bispham, Cleveleys, Thornton Gate, Broadwater and Fleetwood Ferry at which stops are made to meet service timings.

There are a total of sixty tram stops.

2.3 TRACKWORK

2.3.1 Plain track

Grooved track (street running):

The grooved rail used throughout the system is Ri 60 (see Appendix 4 for profile).

Corus manufactured the rail in France and Austria, which was supplied in 18m lengths.

The rail has been laid by continuously welding three 18m lengths and then fastening to the next similar length by fishplates. The rail is secured to maritime pine sleepers by rail spikes either side of the rail section (four spikes per sleeper). There are 22 sleepers per 18m rail length. The softwood sleepers are 130mm deep x 250mm wide x 2.5m long. The rail spikes measure 127mm long x 16mm square. Tie bars are installed every 2.245m.

The sleepers are laid on a 150 to 250mm deep base of 40mm single sized limestone, with 14mm single sized limestone packing ballast between sleepers. A sand and stone infill provides a base for a concrete flag topping level with the rail head. A cross-section through the trackbed typical of that used on the Promenade is shown in Figure 2.5. A section of such track, without infill, is shown in Figure 2.6.

For street running track, as shown in Figure 2.4, including all but one level crossing, the method of track construction is illustrated in Figure 2.7. This consists of a 0.2m thick concrete foundation slab upon which a 25mm thick layer of tar and chipping mix is laid beneath the position of the rails. The grooved rail welded and fishplated as described above, held to gauge by tie bars, sits on the tar and chipping layer. A cement compound infill of about 0.1m thickness is used to build up the surface between and around the rails, securing the tie bars. A layer of coarse asphalt topped by a finishing asphalt layer provides the road surface level with the railhead and keeper flange.[1]

There are no fixed lubrication systems associated with grooved rails.

Drain boxes, an example of which is shown in Figure 2.2(b), provide drainage. Pairs of boxes are connected prior to emptying into the street drains. Originally they drained directly into the sea.

Grooved track (design) dimensions are given in Table 2.3:

Table 2.3 Blackpool and Fleetwood tramway nominal grooved track dimensions

Gauge (straight track)	1435mm
Gauge (curved track)	Up to 1445mm
Rail inclination	Vertical
Minimum track radius	18.3m
Maximum track cant	Zero
Maximum track gradient	(Gynn Square) 2.5%
Rail running surface relative to road	Level
Wear tolerance of keeper flange	Visual inspection

Ballasted track:

Rail types	- Bull head BS 95RBH is used for the majority of ballasted track (profile as shown in Appendix 8) - BS 113A flat bottom rail (profile as Appendix 12) is now being introduced (4km since 2001)

Corus supplied the rail in 18.3m lengths.

For bull head track the method of construction is illustrated in Figure 2.8. The rail has been laid by continuously welding three 18.3m lengths and then fastening to the next similar length by fishplates. The rail is secured to maritime pine sleepers by cast steel chairs of type S1 (two chairs per sleeper). There are 23 sleepers per 18.3m rail length. The softwood sleepers are 130mm deep x 250mm wide x 2.5m long. The chairs are secured to the sleepers by galvanised chair screws 162mm long x 25mm diameter and plastic ferrules, three per chair[2]. Spring steel keys are used to secure the bull head rail in the chairs. Special chairs manufactured by Horwich Castings are used on curves where check rails are required, the flangeway being 35mm. There is one level crossing in which bull head rail is used with check rails to act as a keeper rails.

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[1] The ‘keeper flange’ or ‘keeper rail’ is 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 (see Figure 2.7).

[2] See BS 4521: Part 1: Section 1.1: 1971

The track construction with BS 113A flat bottom rail also uses three 18.3m continuously welded rails lengths fastened by fishplates to similar continuously welded rail sections. On straight track sections the rail is secured to concrete sleepers by Pandrol clips. On curves the timber sleepers are used with plates and Pandrol clips so that the gauge can be widened.

The sleepers are laid on a 150 to 250mm deep base of 40mm single sized limestone placed on a geotextile layer, with 14mm single sized limestone packing ballast between sleepers. There is a 1.37m spacing, between outer rail heads, of double track running lines.

Grease is manually applied to the rails of tight curves, such as those at Starr Gate.

The drainage of bull head tracks is taken to the sea or soakaways. The drains of the more recent flat bottom track are connected to the main sewers

The nominal plain ballasted track (design) dimensions are given in Table 2.4.

Table 2.4 Blackpool and Fleetwood tramway plain ballasted track dimensions

Gauge (straight track)	1435mm
Gauge (curved track)	Up to 1445mm
Rail inclination	1 in 20
Minimum track radius	Starr Gate loop 18.3m

2.3.2 Switches & Crossings

Grooved track (street running):

The system is equipped throughout (except for one bull head rail unit) with flange tip running turnouts as shown in Figure 2.9. Edgar Allen Engineering Ltd., Sheffield, supplied these to drawing No. C33040 (06.12.71) using Ri 60 grooved rail. The cast point units are 3.66m long and incorporate removable pivoted blades (tongues) of 2.46m length that are pivoted at the heel, as shown in Figure 2.10(a). The blades are connected 0.96m from the toe, the rod and spring return being housed in a connecting box. An example of a flange tip running crossing is shown in Figure 2.10(b).

The method of construction for all turnouts throughout the system is the same as that for street running plain grooved track shown in Figure 2.7 using timber sleepers, rail spikes and tie bars, except that the asphalt layers are replaced by concrete.

Wear to the top and bottom of the switch rails is countered by adding a liner to the seating. The crossing noses are repaired by welding each year.

There are 0.10m diameter drainage holes at the connecting box and heel positions each side, and a 0.08m diameter drain nozzle in the centre of the connecting box.

The nominal grooved turnout (design) dimensions are given in Table 2.5.

Table 2.5 Blackpool and Fleetwood tramway grooved turnout dimensions

Gauge	1435mm
Radius	(1 in 6) 45.7m
Switch rail type	Pivoted at heel
Flangeway	(For length of switch rail) 38.1mm
Switch opening	Matches rail groove
Flange tip running	All turnouts and diamond crossings

Ballasted track:

One set of turnouts constructed from BS 95RBH rail (see Appendix 8 for profile) is located at Thornton Gate tram stop, giving access to a permanent way yard. Service vehicles approach them in the trailing direction. They are constructed in a similar way to plain bull head track illustrated in Figure 2.8, with the special chairs for check rails, as used for check rails on plain track. They are of A4 design with the switch rails to BR Specification 1211.

Table 2.6 Blackpool and Fleetwood tramway plain ballasted turnout dimensions

Gauge	1435mm
Radius	A4
Switch rail type	Flexible
Check rail flangeway gap	35mm
Additional sleeper bracing to maintain alignment	Not used

2.3.3 Switch operation

All turnouts are operated manually. Drivers are required to visually confirm the setting of facing turnouts.

Switch mechanisms are inspected and cleaned weekly.

2.3.4 Track maintenance

There is no ultrasonic rail inspection.

Corrosion is found in the lower part of the web and flange of grooved rail used on the Promenade that is exposed to sea water.

2.4 VEHICLES

Centenary class tramcars:

Single decker Centenary class one man operated trams are used for the majority of timetabled service running. These were built in the period 1984 to 1987. The bodies were typical of the conventional bus construction methods then prevailing, and were supplied by East Lancashire Coachbuilders Ltd. The external appearance of these vehicles is shown in Figures 2.12. The bogie design is shown in Figure 2.11.

The vehicle passenger capacity is 55 seated and 20 standing.

Centenary class leading dimensions: See Table 2.7.

Table 2.7 Blackpool and Fleetwood tramway Centenary class dimensions

Overall length	15.700m
Length over body	15.240m
Body shell width	2.438m
Floor height above head of rail	926mm
Distance between bogie centres	8.125m
Bogie axle spacing	1.660m
Wheel diameter	686mm

Centenary class vehicle weights:

Tare weight = 17.5t

“Balloon” double decker tramcars:

English Electric built these tramcars from 1934 to 1935, and some of them were produced originally with open tops, though only one vehicle is now in this condition. The external appearance of these vehicles is shown in Figures 2.13 & 2.14.

The vehicle seated passenger capacity is 94.

“Balloon” double decker leading dimensions: See Table 2.8.

Table 2.8 Blackpool and Fleetwood tramway "Balloon" double decker dimensions

Overall length	12.878m
Width	2.286m
Floor height above head of rail	820mm
Distance between bogie centres	5.944m
Bogie axle spacing	1.450m
Wheel diameter	686mm

Centenary and double decker bogie details: See Table 2.9.

Table 2.9 Blackpool and Fleetwood tramway bogie details

Motor bogie	Two motor bogies (one each end) Motors are English Electric Type 305/1E (42.5kW) One powered axle per bogie (not coupled) Conventional wheelsets (two wheels per axle) Traction motors axle hung Rubber/metal primary suspension Rubber/metal secondary suspension See Figure 2.11

Wheel details: See Table 2.10.

Table 2.10 Blackpool and Fleetwood tramway vehicle – details of tyred wheels

Type	Tyre shrink fit on 558.8mm diameter wheel centre
Tyre Manufacturer	Cockerill Forges & Ringmill s.a., Serang, Belgium
Diameter	686mm (new) 623mm (worn)
Profile	See Appendix 14 for details
Re-profiling criteria	Based on visual assessment
Vehicle running distances between wheel re-profiling (approximate)	120000km (Major bogie overhauls)
Wheel discard criteria	Tyre thickness at 32mm (63.6mm thick when new)
Tyre material	BS 101/1929 Grade 'Y'
Wheelset back-to-back	1389.1mm
Lubrication	No on-vehicle system

All vehicles have sanding equipment associated with the driven wheels of each bogie.

2.5 OPERATIONS INFORMATION

Vehicle operations

The maximum speed through facing turnouts, level crossings and severe curves is 6.5km/h, and that through trailing switchs is 19.3km/h.
Other speed limits are:

26km/h - Starr Gate to Cabin
56km/h - Cabin to Fleetwood, except for the Orion curve between Little Bispham to Cleveleys for which the limit is 19km/h.

There are a number of 6.4km/h limits and compulsory stops at road crossings.

The braking of a Centenary tramcar has been demonstrated to achieve $0.2m/s^2$ deceleration during tests carried out in April 1997.

Operating environment

A road/rail cleaning vehicle with a rotary brush is used to remove the sand and debris from street and Promenade grooved track, including the rail groove. If the sand becomes compacted in the bottom of the groove it has to be manually removed with a bar or long bristled, narrow, wire brush.

2.6 OPERATING CHALLENGES

Maintenance

At low tide wind blown sand from a dry beach in summer at three locations can result in electrical return problems and sand blockage of drains. Sand and sea spray also present a hostile operating environment for the vehicles.

Sea debris can be deposited onto tracks during high tides at three locations when the sea overtops the sea wall, at which times services are suspended for about four hours.

In very hot weather some buckling of ballasted track can occur in the mid-afternoon, following steady heating by the sun through the day. Curved track is more prone to buckling than straight. As ballasted track is made up from 55m lengths of continuously welded rail with fishplates it is important to maintain the expansion gap and ensure that fishplates are not rusted and seized.

Rail wear

Excessive bull head rail wear is experienced at the Starr Gate loop, and with grooved rail on the four curves of the Fleetwood loop (see Figure 2.15).

There is a comprehensive programme of rail welding throughout the year. Rail replacement is made when there is 50% head wear after several repairs by building up with welding have been made.

Track quality

Tie bar failure can occur on grooved track on the Promenade, resulting in gauge changes, due to track movement initiated by high tides.

All concreted grooved rail track suffers from corrugations and gives rise to excessive noise. Rail grinding is carried out every two to three years. Rail corrugation is also found at tram stops.

Traction:

Problems with traction can occur on the inclined track between the tram stops at Gynn Square and Cliffs Hotel (about 500m) due to salt spray.

2.7 FIGURES

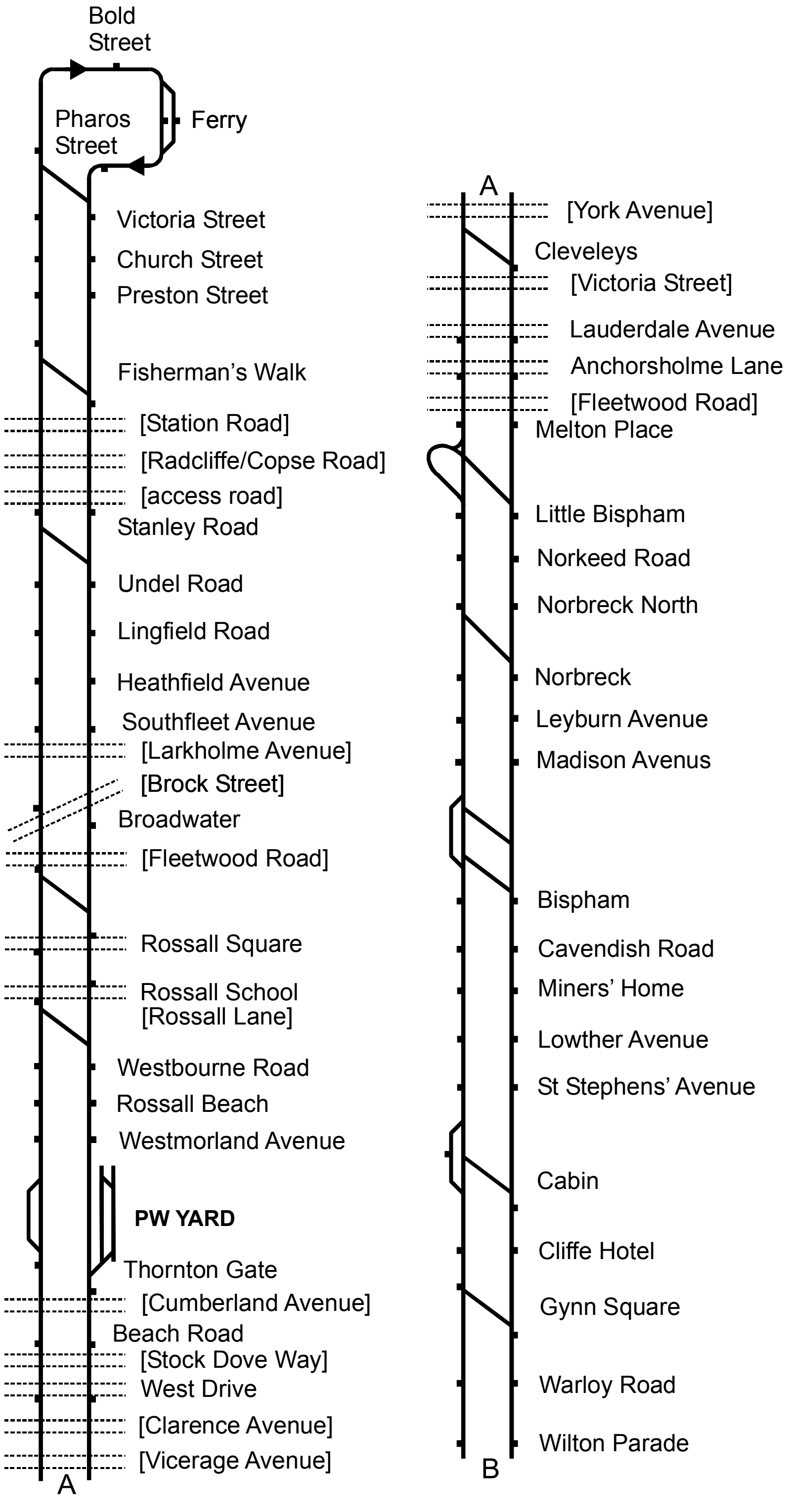


Figure 2.1(a) Schematic route map of the northern section of the Blackpool and Fleetwood tramway system

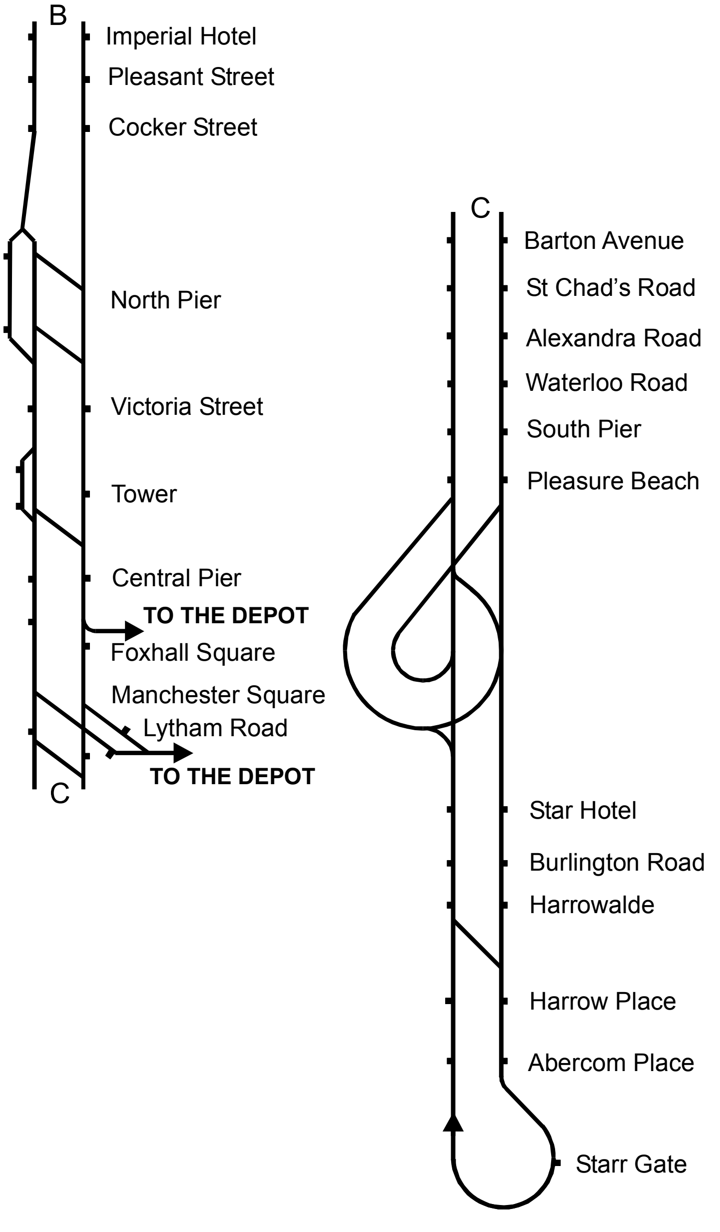


Figure 2.1(b) Schematic route map of the southern section of the Blackpool and Fleetwood tramway

EJH290304-04

(a) View of trackbed

EJH290304-05

(b) Detail view of drain

Figure 2.2 Blackpool and Fleetwood tramway reserved grooved rail track along the Promenade (29.03.04)

(a) Ballasted track and level crossing

FES0410-01/24

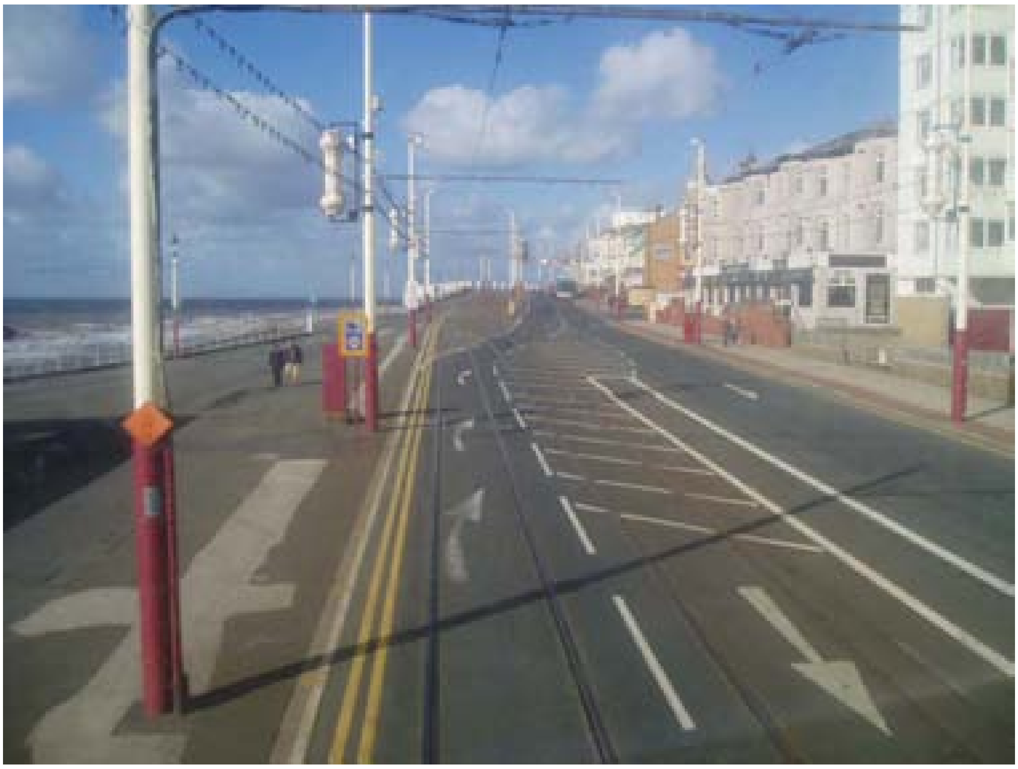
FES0410-01/25

(b) Ballasted track with check rails

Figure 2.3 Examples of Blackpool and Fleetwood tramway reserved ballasted track (04.10.04)

FES0410-01/14

(a) In the vicinity of North Pier



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(b) Between North Pier and Cocker Street

Figure 2.4 Examples of Blackpool and Fleetwood tramway street running tracks (04.10.04)

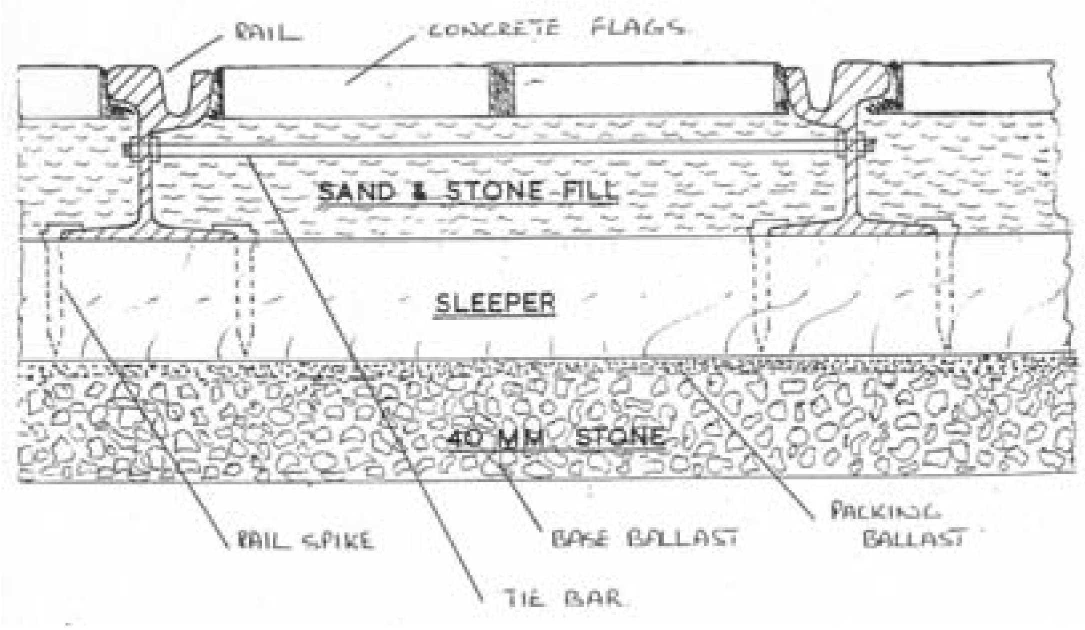

Figure 2.5 Schematic diagram of Blackpool and Fleetwood tramway grooved rail track construction as used on the Promenade

FES0410-01/28

Figure 2.6 Example of Blackpool and Fleetwood tramway grooved rail track construction without infill at transition to bull head rail

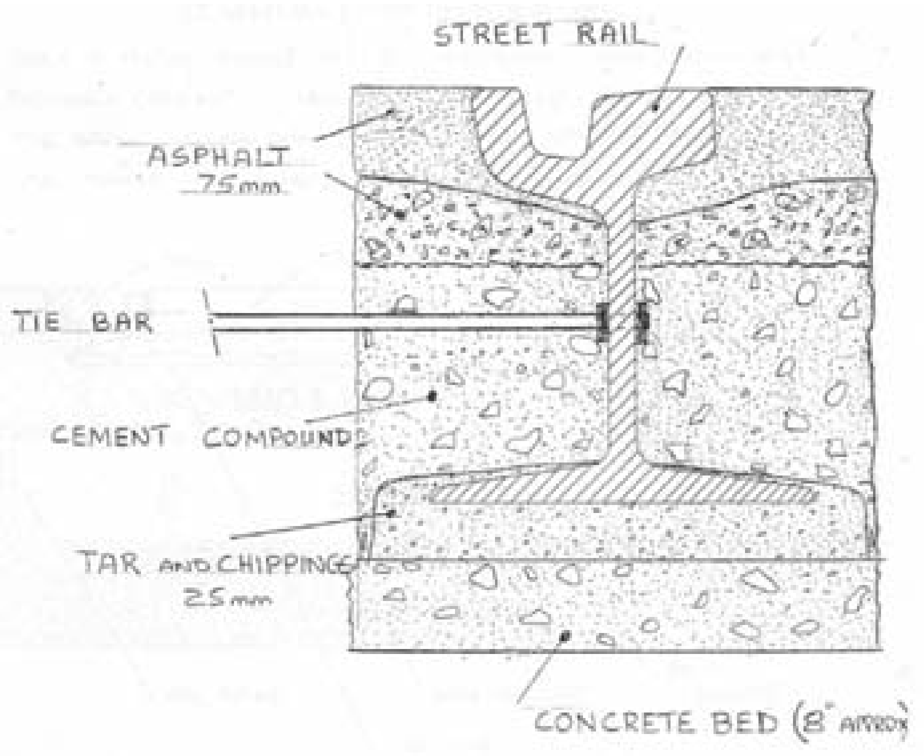

Figure 2.7 Schematic diagram of Blackpool and Fleetwood tramway grooved rail track construction as used for street running tracks and level crossings

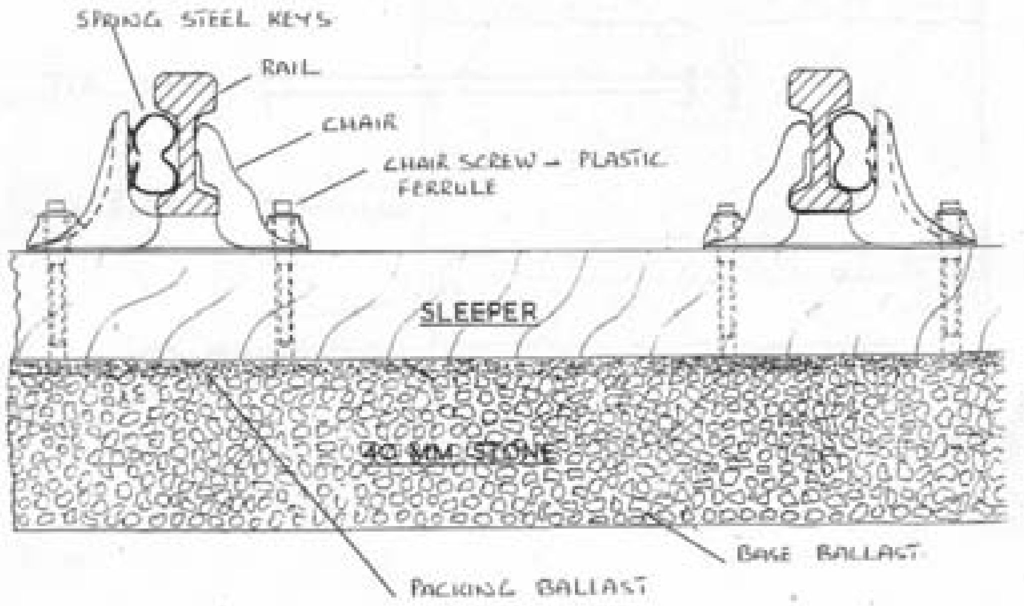

Figure 2.8 Schematic diagram illustrating Blackpool and Fleetwood tramway bull head rail track construction

FES0410-01/01

Figure 2.9 Blackpool and Fleetwood tramway grooved rail turnout (04.10.04)

FES0410-01/11

(a) Pivoted blade and cast rail housing

FES0410-01/04

(b) Flange tip running crossing

Figure 2.10 Turnout detail from segregated Promenade tracks on the Blackpool and Fleetwood tramway (04.10.04)

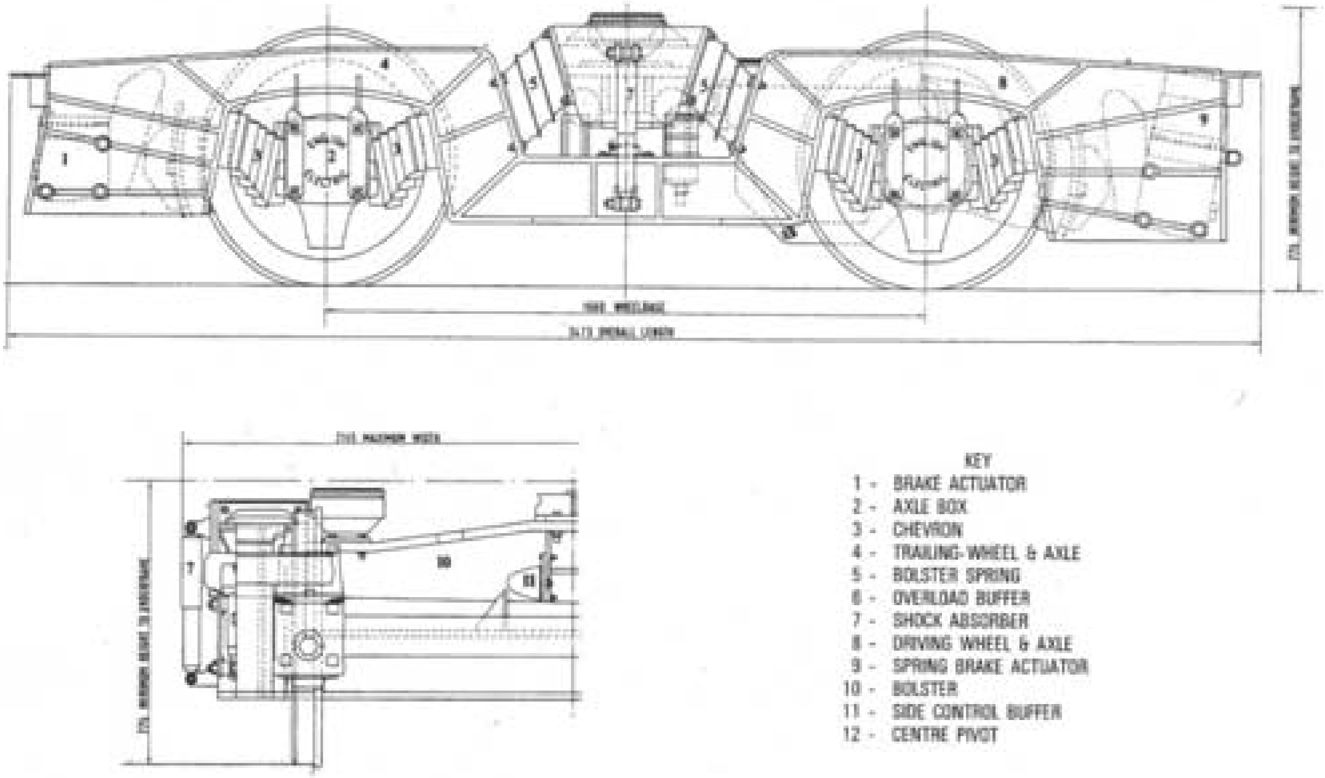

Figure 2.11 Bogie unit of the Blackpool and Fleetwood tramway single decker Centenary class tram

EJH290304-02

Figure 2.12 Blackpool and Fleetwood tramway Centenary class tram No. 646 (29.03.04)

HSE0305-019/4

Figure 2.13 Blackpool and Fleetwood tramway “Balloon” double decker tram No. 723 (17.09.01)

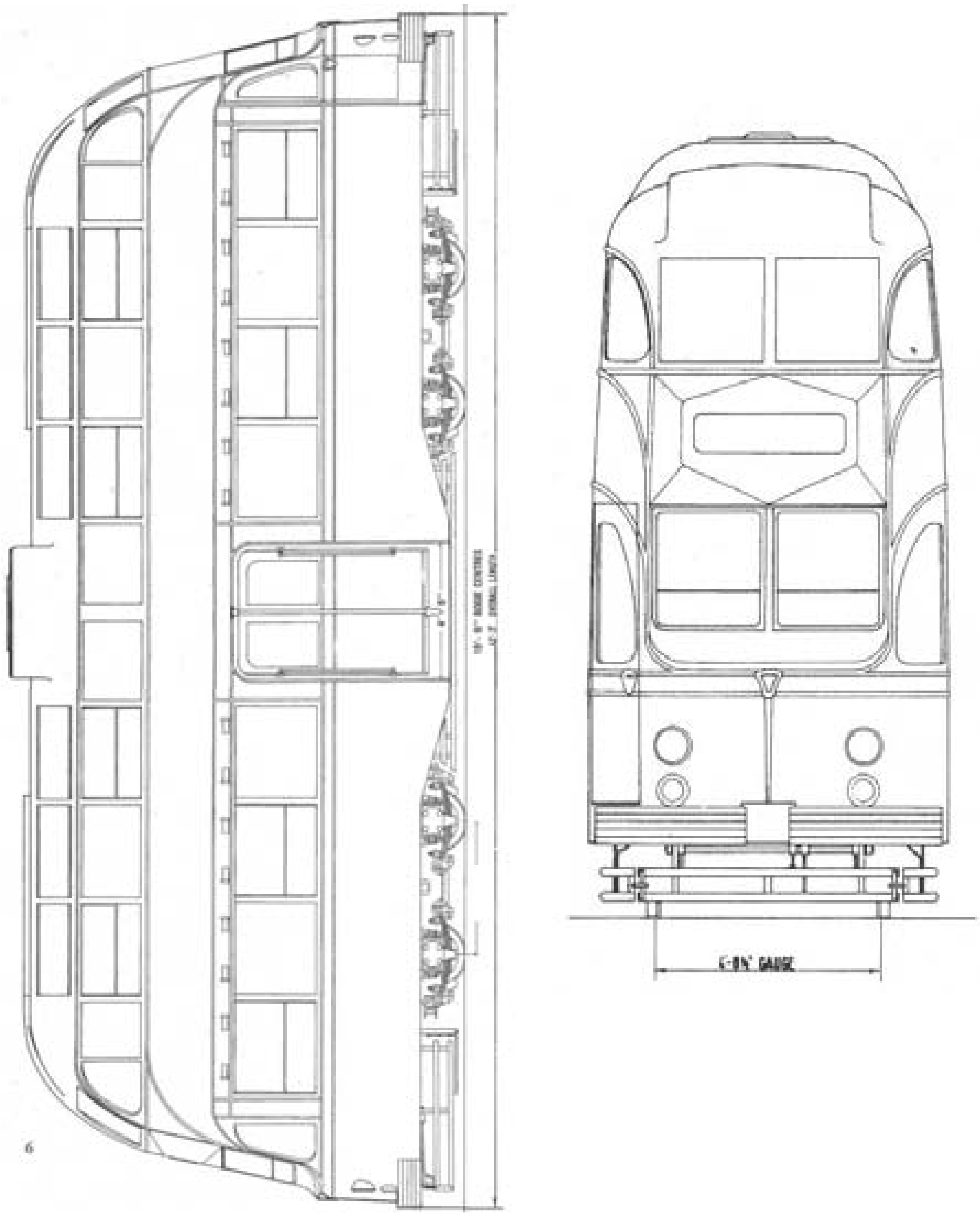

Figure 2.14 Blackpool and Fleetwood tramway “Balloon” double decker tram

FES0410-01/05 FES0410-01/29

(a) The Promenade (b) Fleetwood Euston Hotel

FES0410-01/38

(c) Repair to keeper flange, Fleetwood Ferry

FES0410-01/42

(d) Wheel wear mark on rail head at Fleetwood Ferry

Figure 2.15 Examples of grooved rail wear on the Blackpool and Fleetwood tramway

3 CROYDON TRAMLINK

3.1 INTRODUCTION

Following completion of the township of New Addington, which was developed as overspill housing for inner Croydon, residents were reliant on a bus service following a hilly route and taking up to 45 minutes to reach Croydon. Various studies were carried out following completion of the last major house building in the 1970s. As Croydon is Britain's tenth most populous town outside central London, with the largest concentration of office space and largest urban shopping centre in the south-east, the provision of a light rail was considered to be the best transport system at helping Croydon sustain its development, as an alternative to costly road schemes.

In 1990 a final detail study was conducted to define a light rail system. This became the basis for the deposition of a Parliamentary Bill by London Transport and London Borough of Croydon in 1991. The Croydon Tramlink Act was passed in July 1994. A competition was launched under the Private Finance Initiative in late 1994, such that a formal construction start date of 25th November 1996 was agreed with Tramtrack Croydon Ltd (TCL) under a 99 year concession to design, build and maintain the system.

The Tramtrack Croydon Ltd consortium originally consisted of:
First Group Tram Operations - operators
Bombardier Transportation - design, build, maintenance and repair of trams
Royal Bank of Scotland and 3i - finance
Sir Robert McAlpine/Amey Construction Ltd - construction

Of these, First Group and Bombardier have since withdrawn as shareholders and remain simply as contractors to TCL.

Tramlink utilises former railway for almost half its length, which, as a condition of the Act, had to be fully separated from Railtrack infrastructure. Eight kilometres of the 16 inherited from Railtrack was refurbished and reused, with a further 1km reused in the Depot.

The main infrastructure was completed in July 1999 and all the 24 trams had been delivered to the Therapia Lane depot by June 1999. Trams were running on the system from September 1999.

3.2 SYSTEM DETAILS

<u>Schematic route map:</u>

See Figure 3.1.

<u>Route distances:</u>

See Table 3.1 below. A fully annotated detailed route map showing distances can be found at [http://tramlink.trap-door.co.uk/info/infra/maps.shtml].

In total there are just less than 52 track kilometres making up the 28km system. The Wimbledon and Beckenham branches are a mixture of twin and single track. Croydon town centre consists of a single track 'loop' with twin track extending to Sandilands in the east. The New Addington branch is all twin track with the exception of a short length, just before the terminus at New Addington.

Table 3.1 Croydon Tramlink route details

Line	*From*	*To*	*Distance (km)*	*Main Track Type*
1	Wimbledon	Reeves Corner	9.54	Double/ballasted single/ballasted
1,2,3	Reeves Corner	Sandilands Junction	2.22	Single/grooved rail Double/grooved rail
1,3	Sandilands Junction	Arena Junction	2.51	Double/ballasted
1	Arena Junction	Elmers End	0.91	Single/ballasted
2	Sandilands Junction	New Addington	7.24	Double/ballasted
3	Arena Junction	Beckenham Junction	4.18	Single/ballasted Double/ballasted

There is only 3.5km on-street route distance out of a total of 28km, with the majority segregated from other traffic. The Depot at Therapia Lane has 3.4km of track. The total length of grooved rail track is 6.9km.

Track distances according to track type are shown in Table 3.2 below:

Table 3.2 Croydon Tramlink track distances by type

Distance (km)	*Track Type*
1.3	Double grooved rail (street) track
2.4	Single grooved rail (street) track
0.5	Double grooved rail segregated track
16.0	Double ballasted track
8.5	Single ballasted track

For convenience the distances between tram stops are summarised in the tables below:
Table 3.3 – Wimbledon to East Croydon
Table 3.4 – West Croydon to New Addington
Table 3.5 – Sandilands to Beckenham Junction

Table 3.3 Croydon Tramlink tram stop distances between Wimbledon and East Croydon

From	*To*	*Distance (km)*	*Track*[1]
Wimbledon	Dundonald Road	0.473	Double/ballasted
Dundonald Road	Merton Park	0.623	Double/ballasted
Merton Park	Morden Road	0.805	Double/ballasted
Morden Road	Phipps Bridge	0.954	Single/ballasted
Phipps Bridge	Belgrave Walk	0.383	Double/ballasted
Belgrave Walk	Mitcham	0.656	Double with some interlacing/ballasted
Mitcham	Mitcham Junction	1.117	Single/ballasted
Mitcham Junction	Beddington Lane	1.073	Single/ballasted
Beddington Lane	Therapia Lane	1.058	Double/ballasted
Therapia Lane	Ampere Way	0.529	Double/ballasted
Ampere Way	Waddon Marsh	0.721	Double/ballasted
Waddon Marsh	Wandle Park	0.499	Double/ballasted
Wandle Park	Reeves Corner	0.650	Single/ballasted (0.399km) & plinth Single/grooved rail (0.049km) Double/grooved rail
Reeves Corner	West Croydon **[East bound]**	0.690	Single/grooved rail
West Croydon **[East bound]**	Wellesley Road **[East bound]**	0.653	Single/grooved rail
Wellesley Road **[East bound]**	East Croydon	0.437	Single & double/grooved rail
East Croydon	George Street **[West bound]**	0.457	Single & double/grooved rail
George Street **[West bound]**	Church Street **[West bound]**	0.392	Single/grooved rail
Church Street **[West bound]**	Wandle Park	0.846	Single & double/grooved rail
Church Street	West Croydon	0.703	Single/grooved rail

Notes:
[1] Distances taken from Parascandolo (2004)

Table 3.4 Croydon Tramlink tram stop distances between East Croydon and New Addington

From	*To*	*Distance (km)*	*Track*[1]
East Croydon	Lebanon Road	0.545	Double/grooved rail
Lebanon Road	Sandilands	0.512	Double/grooved rail
Sandilands	Lloyd Park	1.599	Double/ballasted
Lloyd Park	Coombe Lane	1.586	Double/ballasted
Coombe Lane	Gravel Hill	1.398	Double/ballasted
Gravel Hill	Addington Village	0.831	Double/ballasted
Addington Village	Fieldway	0.873	Double/ballasted
Fieldway	King Henry's Drive	0.678	Double/ballasted
King Henry's Drive	New Addington	0.385	Double & single/ballasted & slab track

Notes:

[1] Distances taken from Parascandolo (2004)

Table 3.5 Croydon Tramlink tram stop distances between Sandilands and Beckenham Junction

From	*To*	*Distance (km)*	*Track*[1]
Sandilands	Addiscombe	0.828	Double/ballasted
Addiscombe	Blackhorse Lane	0.612	Double/ballasted
Blackhorse Lane	Woodside	0.406	Double/ballasted
Woodside	Arena	0.723	Double/ballasted
Arena	Harrington Road	1.121	Double/ballasted
Harrington Road	Birkbeck	0.756	Single/ballasted
Birkbeck	Avenue Road	0.569	Single/ballasted
Avenue Road	Beckenham Road	0.553	Single/ballasted
Beckenham Road	Beckenham Junction	1.233	Single/ballasted
Arena	Elmers End	0.958	Single/ballasted

Notes:

[1] Distances taken from Parascandolo (2004)

Services from the New Addington and Beckenham Junction termini include loop running around the centre of Croydon. The Wimbledon to Elmers End service is between termini.

Power supply:

Overhead line equipment supplies trams with power at a nominal 750 Vdc from 13 substations rated at either 600MVA or 1000MVA (town centre section).

The 13 sub-stations are detailed in Table 3.6 below:

Table 3.6 Location of Croydon Tramlink electrical sub-stations

Distance (km)[1]	*Location*
10.1	Dundonald Road
7.3	Belgrave Walk
5.6	Mitcham Lane
3.4	Therapia Lane (divided into Main Line & Depot)
1.0	Jubilee Bridge
0.0	East Croydon
1.2	Sandilands
3.6	Oaks Road
6.5	Addington Village
8.4	New Addington
2.9	Woodside
4.8	Harrington Road
7.8	Blakeney Road

Notes:
[1] Approximate distances from East Croydon station

Tunnels:

There are three tunnels located between Sandilands Junction and Lloyd Park Tram Stop, as indicated on the map in Figure 3.1. These tunnels accommodate double ballasted tracks, details as Table 3.7 below:

Table 3.7 Croydon Tramlink tunnel details

Length (metres)	*Name*
243	Woodside Tunnel
112	Park Hill Tunnel
144	Coombe Road Tunnel

Passenger Service Vehicles:

Twenty-one vehicles out a fleet of twenty-four are required to operate a full service.

Tram stops:

The service vehicles call at all stops in each direction (Line 1: 24 stops, Line 2: 14 stops and Line 3: 12 stops).

Start of services:

Line 3, Croydon to New Addington, was the first to be opened for service on 11 May 2000. Line 2, Croydon to Beckenham Junction, opened on 23 May and Line 1, Wimbledon to Elmers End, followed this on the 27 May 2000.

3.3 TRACKWORK

3.3.1 Plain track

Grooved track (street running):

Rail types
- Ri 60 is used for the majority of track (see Appendix 4 for profile)
- Ri 59 (with wider flangeway) is used on curves with radii less than 75m (see Appendix 3 for profile)

The type of rail wear gauge used is shown in Figure 3.2

British Steel manufactured the rail.

The continuously welded grooved rails are embedded in slots cut into a reinforced concrete track slab. A cold-curing polymer holds the rails to gauge and provides electrical and vibration insulation. For those sections shared with road traffic a more durable finish was used than for the segregated track sections. Examples of grooved rail track are shown in Figure 3.3 and 3.4 that also show how drainage of the rail groove to the street drainage system is provided. The consequence of poor track and street drainage is illustrated in Figure 3.5.

Road surface faults adjacent to the rail keeper flange are shown in Figure 3.6

There are no fixed lubrication systems associated with grooved rails.

Grooved track (design) dimensions are given in Table 3.8:

Table 3.8 Croydon Tramlink nominal grooved track dimensions

Gauge (straight & curved track)	1435mm
Rail inclination	Vertical
Minimum track radius	25m
Maximum track cant	15mm (To allow track to conform to the highway camber
Maximum track gradient	9%
Rail running surface relative to road	-3mm +/-3 (As designed)

The plain grooved rail track maintenance tolerances are given in Table 3.9:

Table 3.9 Croydon Tramlink plain grooved rail track maintenance tolerances

Gauge - absolute value	-3/+6mm
- relative per metre	2mm
Horizontal alignment (straight line)	
- absolute	+/-10mm
- relative (20m base)	4mm
- relative (10m base)	3mm
Horizontal alignment (curve)	
- absolute	+/-10mm
- relative (versine[3] on 20m chord)	4mm
- relative (versine on 10m chord)	3mm
Vertical alignment	
- absolute value	-20/+10mm
- relative value on 30m base	5mm
Cant (maximum divergence from theoretical)	+/-4mm
Twist - on 3m base (additional to cant)	1 in 200

Ballasted track:

Rail type: - Flat Bottom BR 109lb, BS 110A and BS 113A profiles, reused from the previous Railtrack lines (see Appendices 9, 11 & 12)
- S 49 (see Appendix 13)

An example of a wear gauge for S 49 rail is shown in Figure 3.7.

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[3] Versine ~ The offset to the circumference at the centre of a chord of a circle measured at right angles to the chord.

British Steel supplied the BS 110A and BS 113A rail and Voest-Alpine Stahl GmbH (VAE) the S 49.

Pandrol rail fastenings secure the BS 110A and BS 113A rail to either concrete or timber sleepers. Vossloh Type W14 fastenings secure the S 49 rail to pre-stressed monobloc sleepers, as shown in Figure 3.8. All rails are continuously welded, with expansion joints bracketing sharp curves.

Examples of curved track, together with bracing, are shown in Figures 3.9 and 3.10. Straight track with vertical irregularities is shown in Figure 3.11, and an expansion switch example is illustrated in Figure 3.12.

There are 12 track mounted lubrication units positioned on the tightest curves.

There are 22 highway level crossings. At such locations the plain track, with S 49 rail, is fitted with checkrails to retain the bitumen embedment.

The nominal plain ballasted track (design) dimensions are given in Table 3.10.

Table 3.10 Croydon Tramlink plain ballasted track dimensions

Gauge (straight & curved track)	1435mm
Rail inclination	1 in 20
Minimum track radius	25m
Maximum track cant	150mm
Maximum track gradient	8%

The plain-ballasted track maintenance tolerances are given in Table 3.11.

Table 3.11 Croydon Tramlink plain ballasted track maintenance tolerances

Gauge - absolute value	-3/+10mm
- relative per metre	2mm
Horizontal alignment (straight line)	
- absolute	+/-20mm
- relative (20m base)	6mm
- relative (10m base)	4mm
Horizontal alignment (curve)	
- absolute	+/-25mm
- relative (versine on 20m chord)	6mm
- relative (versine on 10m chord)	4mm
Vertical alignment	
- absolute value	+/-25mm
- relative value on 30m base	7mm
Cant (maximum divergence from theoretical)	+/-6mm
Twist - on 3m base (additional to cant)	1 in 200

3.3.2 Switches & Crossings

Grooved track (street running):

The system is equipped with plain turnouts supplied by Voest-Alpine Division Bahnsysteme (VAE), as the example shown Figure 3.13. Crossing and switch rail detail is shown in Figure 3.14

Drainage slots in the rail groove are connected to the street drain system.

The nominal grooved turnout (design) dimensions are given in Table 3.12.

Table 3.12 Croydon Tramlink grooved turnout dimensions

Gauge	1435mm
Radius	50m and 100m
Switch rail type	Flexible
Flangeway	22.5mm
Switch opening	(Set by switch mechanism) 40mm
Flange tip running	None

Turnouts are maintained to the same limits as for plain grooved track.

Ballasted track:

All turnouts were supplied by VAE and fabricated from S 49 rail using timber sleepers and Vossloh Type KS fasteners, and installed on a ballast track bed, as shown in Figures 3.15 and 3.16. Cess drainage is used. There are no fixed rail lubrication systems fitted at turnouts.

Examples of switch rail tips and crossing nose wear are given in Figure 3.17 and 3.18.

The nominal plain ballasted turnout (design) dimensions are given in Table 3.13.

Table 3.13 Croydon Tramlink plain ballasted turnout dimensions

Gauge	1435mm
Radius	(25m in Depot) 50m and 100m
Switch rail type	Flexible
Crossing flangeway gap	22.5mm
Switch opening	60mm (Reduced from 100mm)
Additional sleeper bracing to maintain alignment	Fitted to about 4 turnouts

Turnouts are maintained to the same limits as for plain ballasted track.

An example of sleeper bracing and over-rail check plate are shown in Figure 3.19

3.3.3 Switch operation

Grooved track (street running):

Hanning & Kahl supplied the electrical and mechanical point setting mechanisms for throw-over and sprung points, as set out in Table 3.14 below.

Table 3.14 Croydon Tramlink Hanning & Kahl turnout mechanisms for grooved rail track

Quantity	*Type*	*Description*
9[1]	HWE 60/100 AVV-ZVV	Electro-hydraulic units
3	HWU 40 D-Z	Manual units
7	HWU 40	Manual units for sprung points

Notes:
[1] HN0F point controls with HFP-HFK track circuit protection was supplied for these units

Ballasted track:

Hanning & Kahl also supplied the mechanical point setting mechanisms for throw-over and sprung points for flat bottom rails, as set out in Table 3.15 below.

Table 3.15 Croydon Tramlink Hanning & Kahl turnout mechanisms for ballasted track

Quantity	*Type*	*Description*
19	HWU 160 D-Z	Manual setting mechanism for sprung points
10	HWU 160	Manual setting mechanism for sprung points

Schreck-Mieves roller supports, as shown in Figure 3.20, have been fitted beneath switch rails to reduce frictional effects previously incurred with switch operation.

Switch detection system (all track):

Hanning & Kahl proximity switches are fitted to all facing points. These are a four switch configuration that checks the open/closed condition of both switches.

Maintenance regime (all track):

Gauging and other checks are made every 28 days.

Permitted open gap (all track):

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

3.3.4 Track maintenance

There is no ultrasonic rail inspection.

No rail corrosion has yet been found.

Long straight sections of ballasted track are tensioned with curves being unstressed. There is no intention to undertake further stressing.

3.4 VEHICLES

All vehicles are to the same design and consist of two similar main bodies (A & B), with motor bogies at the outer ends. They are connected by a short central section (C) that sits on a central unpowered axle-less truck, as shown in Figure 3.21 and 3.22, and carries the inner ends of the A and B car bodies. Bombardier Transportation manufactured the vehicles at their Vienna factory. Classified as CR-4000, they are closely based on the proven K-4000 trams, over 120 of which are in use in Cologne, Germany. They are 76% low floor at 400mm above rail height with entrances at 350mm. As a consequence of the low floor all the traction equipment is located on the roof of the tram. Kiepe Electrik GmbH & Co., Düsseldorf, supplied the electrical and traction equipment.

The vehicles run on resilient wheels manufactured in Germany by Bochumer Verein Verkehrstechnik GmbH. The advantages claimed for these wheels are that they absorb structure-borne sound, improve ride quality by absorbing shock loads and reduce tread wear.

The vehicle passenger capacity (normal load) is 70 seated and 138 standing.

Leading dimensions: See Table 3.16.

Table 3.16 Croydon Tramlink vehicle dimensions

Length over body	31.00m
Body shell width	2.650m
Height of body shell	3.360m[1]
Floor height above head of rail	400mm[1]
Distance between bogie/truck centres	11.550m
Bogie/truck axle spacing	(Bogies and truck) 1.800m
Wheel diameter	630mm[1]

Notes:
[1] With new wheels

Bogie/truck details: See Table 3.17.

Table 3.17 Croydon Tramlink vehicle bogie details

Motor bogie	Two motor bogies (one each end) Two powered axles per bogie (not coupled) Conventional wheelsets (two wheels per axle) Bogie centre bearing/pivot is friction damped One traction motor per wheelset Traction motors attached to the bogie frame Rubber/metal primary suspension Coil spring secondary suspension See Figure 3.23
Trailer truck	Unpowered Independent four wheel truck (four stub axle/wheel units) Adjacent axle boxes connected by linkages at ends Rubber/metal primary suspension Coil spring secondary suspension See Figures 3.24 & 3.25

Vehicle weights:

Tare weight (nominal) = 36500kg

Wheel details: See Table 3.18.

Table 3.18 Croydon Tramlink vehicle wheel details

Type	Type BO 54 (Bochum single-ring resilient wheel) (See Figure 3.27)
Manufacturer	Bochumer Verein Verkehrstechnik Gmbh (previously VSG Verkehrstechnik)
Diameter	630mm (new) 550mm (worn)
Profile	See Appendix 15 for details
Re-profiling criteria	Maximum hollow wear of tread = 3mm Minimum flange thickness (measured at 14mm above tread) = 15mm No check made of flange angle Figure 3.26 shows a worn profile
Vehicle running distances between wheel re-profiling (approximate)	40000km
Wheel discard criteria	Minimum 550mm diameter (machined tell-tale on outer wheel face)
Wheelset back-to-back	1380(+4/-0)mm
Lubrication	Flange lubrication by ‘solid stick’ units on all four wheels of the centre (trailer) bogie (See Figure 3.25)

3.5 OPERATIONS INFORMATION

Vehicle operations

The maximum line speed is 80km/h, though 60-70km/h is normal. The on-street maximum is 50km/h.

The maximum speed through turnouts is 25km/h, except straight routes into facing spring turnouts when 40km/h is permitted.

Acceleration and braking is limited to 1.1m/s^2 and 1.3m/s^2 respectively.

Operating environment

In significant hot periods there is some track distortion on curves.

The vehicles are fitted with auto sanding equipment to control slip/slide.

3.6 OPERATING CHALLENGES

Rail wear

No information is available on the rates of rail wear.

Up to 3mm of wear on the gauge side of 50m curves has been observed.

Track quality

No evidence has been found of gauge spreading.

Rail corrugations, of random pitch, are found either side of tram stops.

3.7 FIGURES

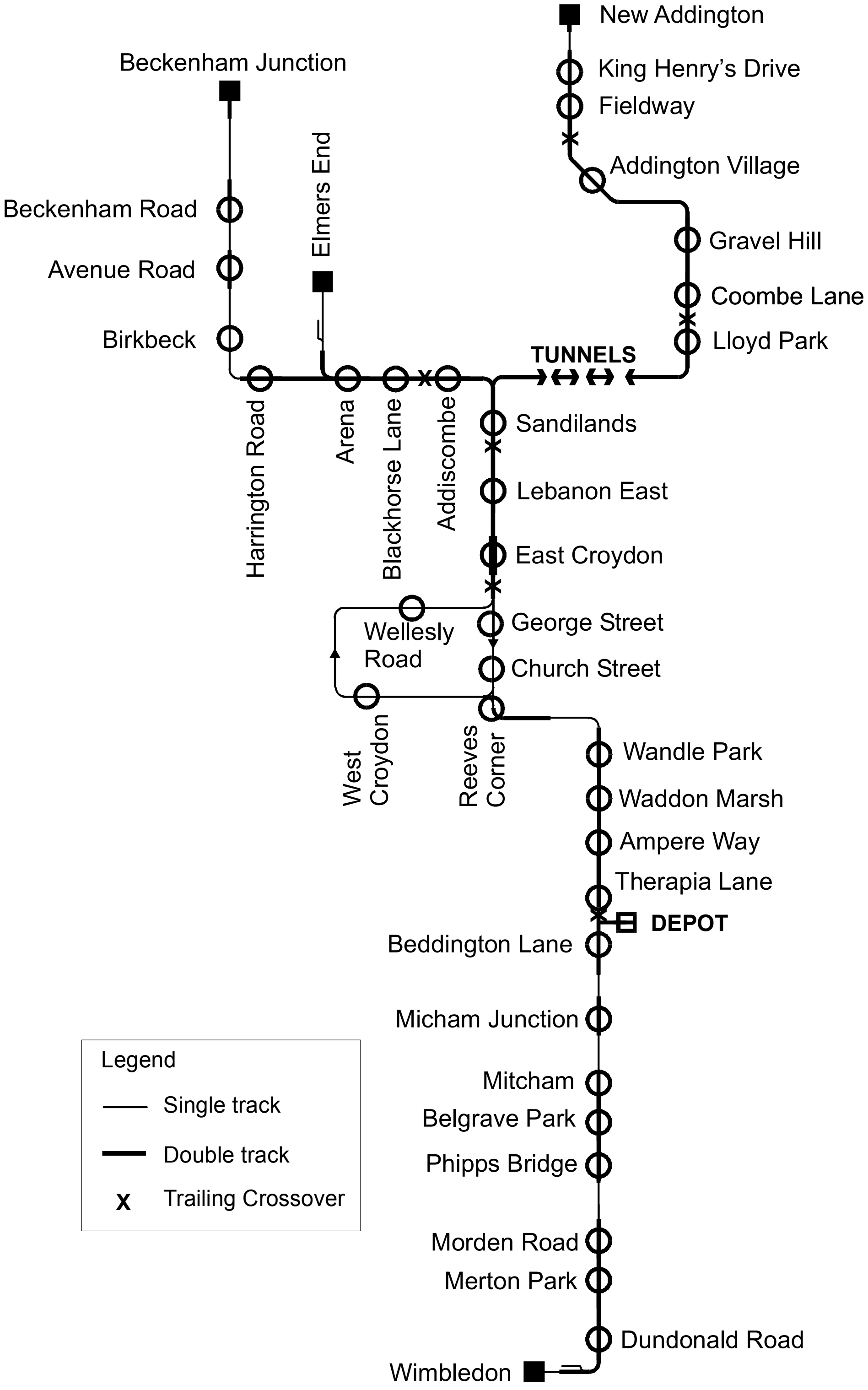

Figure 3.1 Schematic route map of Croydon Tramlink

J Brown

Figure 3.2 Ri 59 and Ri 60 grooved rail wear gauge, Croydon Tramlink

J Brown

Figure 3.3 Grooved rail track at Croydon, Croydon Tramlink

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FES0402-01/23

Figure 3.4 Example of grooved rail drainage at East Croydon station (12.02.04), Croydon Tramlink

J Brown

Figure 3.5 Submerged track at Croydon (April 2002), Croydon Tramlink

J Brown

Figure 3.6 Road surfacing at West Croydon (12.07.02), Croydon Tramlink

J Brown

Figure 3.7 S 49 flat bottom rail wear gauge, Croydon Tramlink

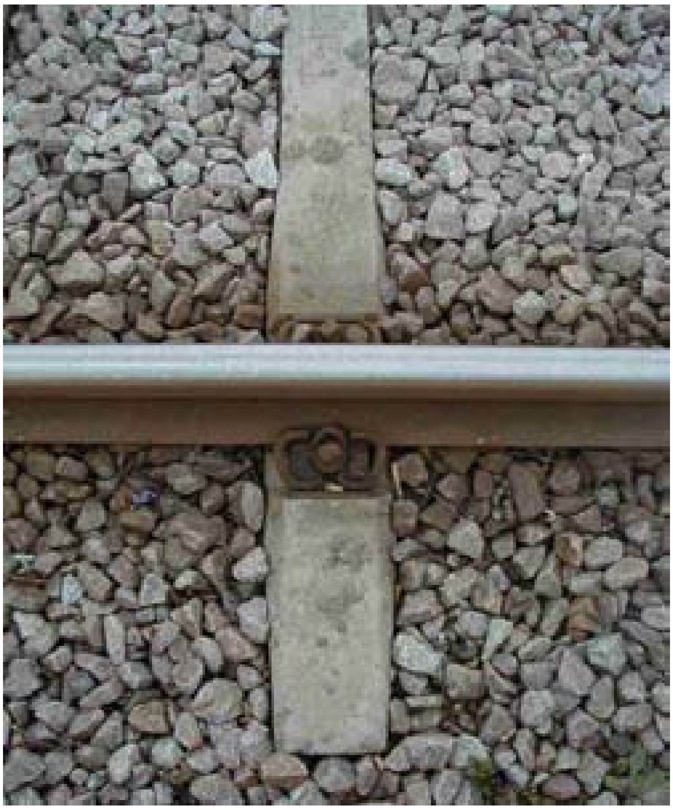

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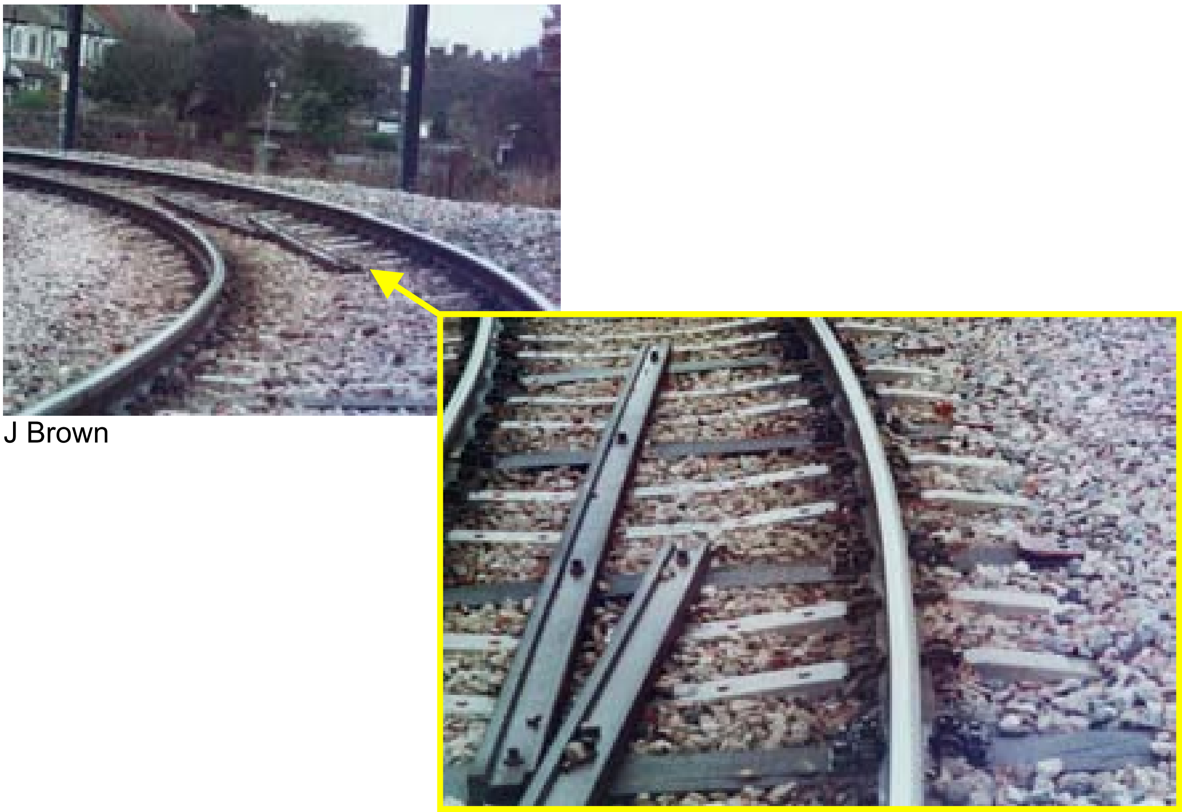
Figure 3.8 An example of ballasted track construction with S 49 rail, concrete sleepers and Vossloh Type W14 fastenings (12.02.04), Croydon Tramlink

J Brown

Figure 3.9 Curved ballasted track on the line to Beckenham Junction, Croydon Tramlink



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J Brown

Figure 3.10 Bracing fitted to ballasted track, Croydon Tramlink

J Brown

Figure 3.11 Irregular vertical track geometry at Mitcham Junction (07.08.02), Croydon Tramlink

J Brown

Figure 3.12 Ballasted track expansion switch (07.08.02), Croydon Tramlink

FES0402-01/2

(a) Crossing

FES0402-01/28

(b) Switch rails

Figure 3.13 Grooved rail turnout on the approach to the East Croydon Tram Stop from Wimbledon (12.02.04), Croydon Tramlink

J Brown

(a) Crossing

J Brown

(b) Switch rail at East Croydon

Figure 3.14 Switch and crossing turnout detail, Croydon Tramlink

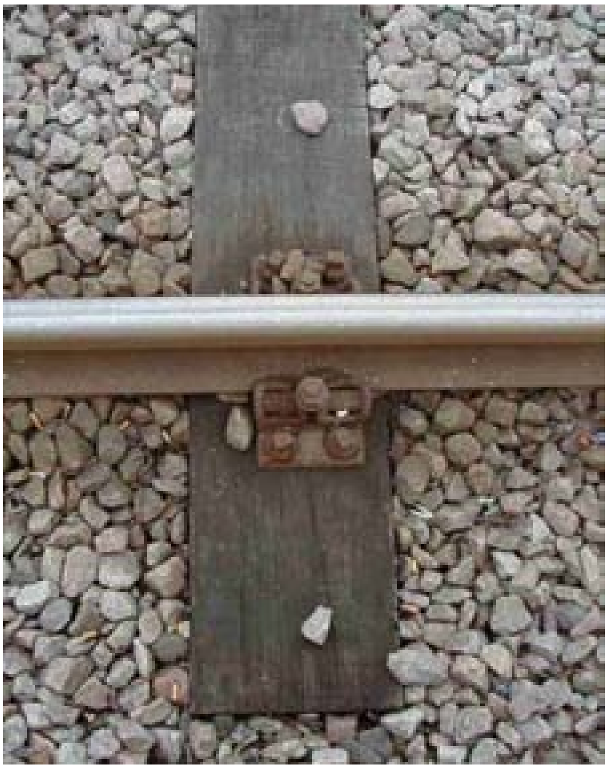

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Figure 3.15 An example of ballasted track turnout construction with S 49 rail, timber sleeper and Vossloh Type KS fastenings (12.02.04), Croydon Tramlink

J Brown

Figure 3.16 Arena Junction looking towards Elmers End (17.07.02), Croydon Tramlink

J Brown

(a) Blade tip in good condition (07.08.02) at Elmers End

J Brown

(b) Worn blade tip (10.07.02)

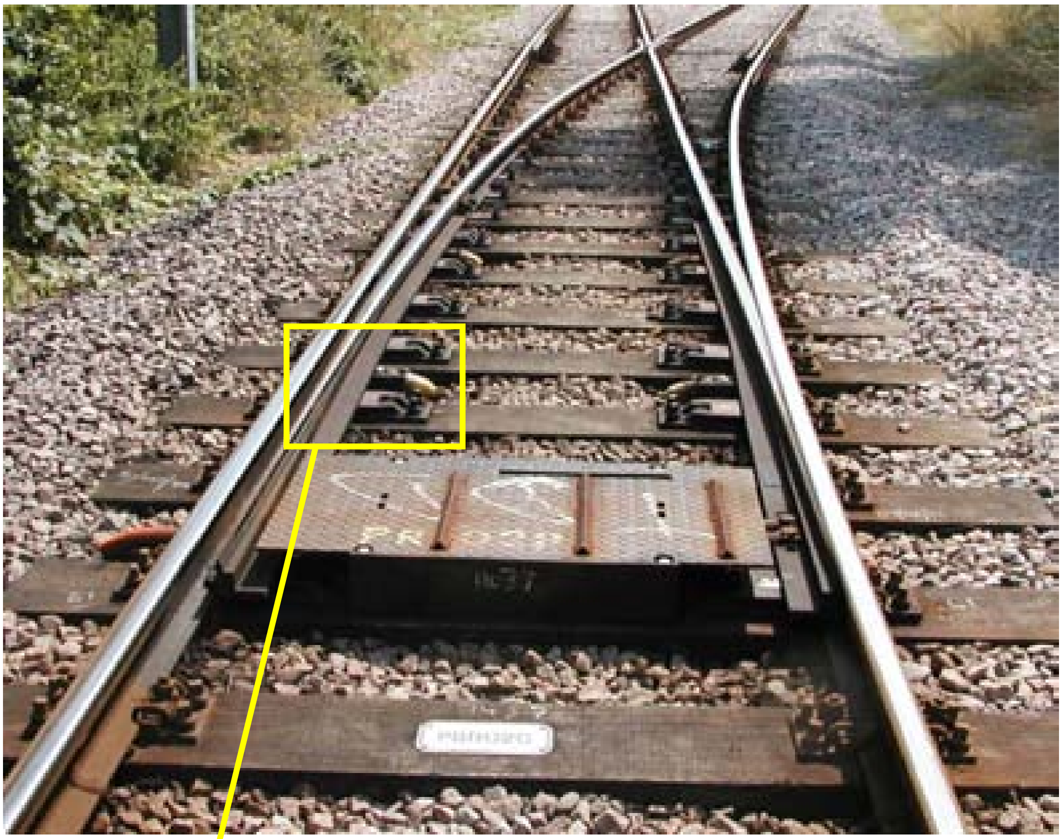
Figure 3.17 Switch rail tips, Croydon Tramlink

J Brown

Figure 3.18 Crossing nose wear at Morden Road (07.08.02), Croydon Tramlink

J Brown

Figure 3.19 Over-rail turnout check plate at the Croydon Depot (07.08.02), Croydon Tramlink



J Brown

(a) Turnout looking towards Croydon

J Brown

(b) Detail of a Schreck-Mieves roller support

Figure 3.20 Ballasted turnout at Phipps Bridge fitted with switch blade roller supports (07.08.02), Croydon Tramlink

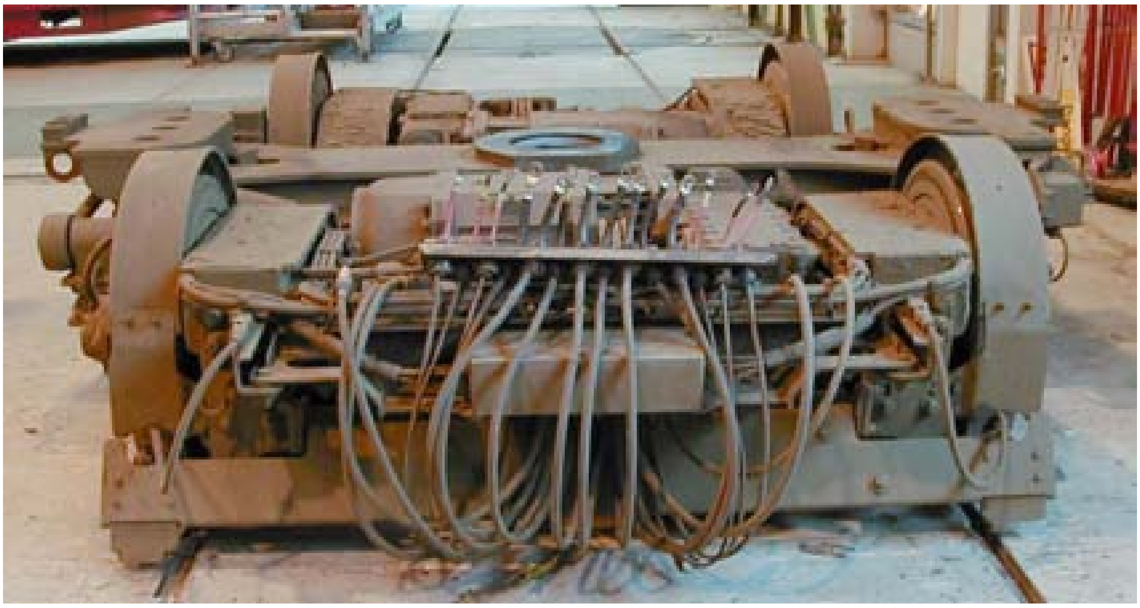
Figure 3.21 Bombardier Transportation CR-4000 tram

HSE0305-10/6

Figure 3.22 Croydon Tramlink tram No. 2543 at East Croydon railway station (16.08.01)

FES0402-1/02

(a) Side view



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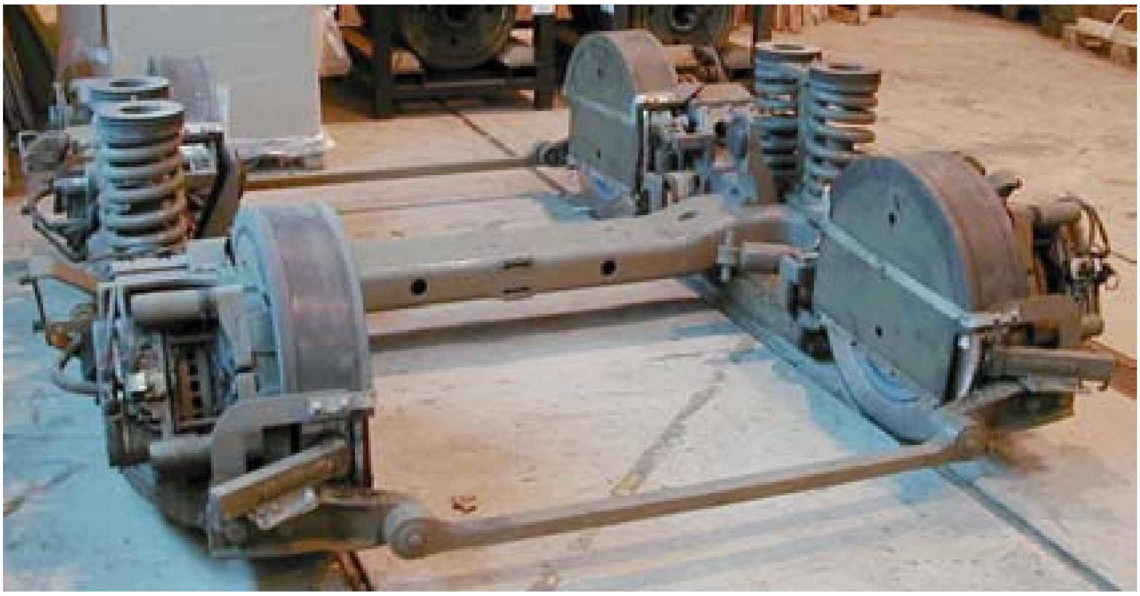
(b) End view

Figure 3.23 Croydon Tramlink CR-4000 motor bogie (12.02.04)

FES0402-1/08

(a) Side view



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(b) End view

Figure 3.24 Croydon Tramlink CR-4000 trailer truck (12.02.04)

FES0402-1/11

Figure 3.25 Trailer truck wheel/stub axle detail showing solid stick lubricator bearing on wheel flange root, Croydon Tramlink (12.02.04)

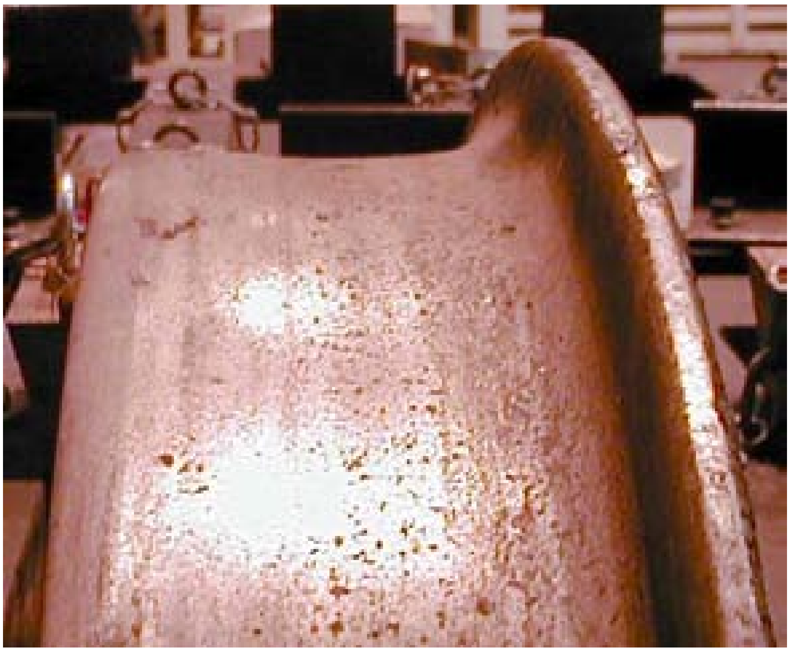

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Figure 3.26 Croydon Tramlink wheel tread profile prior to re-profiling (12.02.04)

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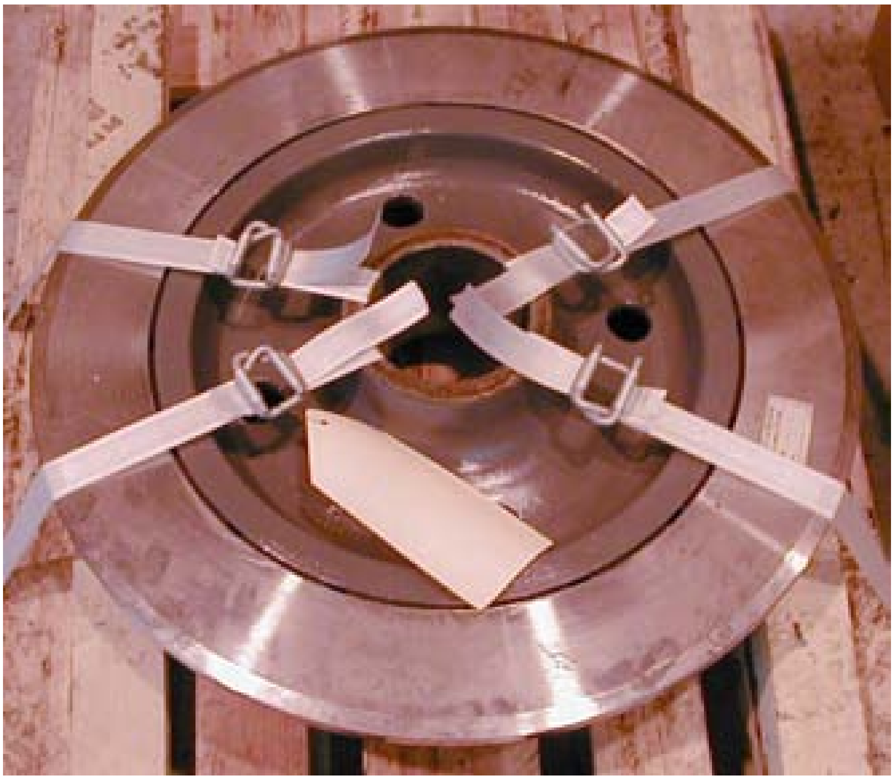
(a) View showing tread profile



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(b) Back face of wheel showing construction

Figure 3.27 New wheels awaiting installation, Croydon Tramlink (12.02.04)

4 DOCKLANDS LIGHT RAILWAY

4.1 INTRODUCTION

Starting in 1972 the London Docklands Study Team investigated the possibility of redeveloping the 8.5 square miles of London's docks area that were suffering from urban dereliction. Future transport demands for the area were considered insufficient to justify the construction a heavy railway or Underground line. Instead a light rail system connecting with the existing rail systems was proposed as being appropriate.

The Greater London Council together with the Boroughs Greenwich, Lewisham, Newham, Southwark and Tower Hamlets formed the Docklands Joint Committee in 1974 with the object of quickly developing the Docklands area. However, the light rail options proposed at this time were viewed as too expensive. A further study encouraged London Transport to obtain parliamentary powers for an extension of the Underground, but following a change of government in 1979 the scheme was abandoned, and a review of lower cost options ordered. The formation of the London Docklands Development Corporation (LDDC) in July 1981 focused the need for a solution. London Transport was commissioned to examine low-cost rail-based solutions to satisfy the needs of the development. Capacity problems ruled out direct links to existing rail systems. The final proposal in June 1982 was for a 'west-south' line from the City to the Isle of Dogs and a 'north-south' route from Mile End Station to the Isle of Dogs. Three months after this government funding was committed for construction of the Docklands Light Railway, prior to parliamentary powers being obtained, which were given in April 1984.

It was necessary to gain further parliamentary powers with Royal Assent in April 1985 for a change to the proposed Mile End section of the route, where street running had been initially proposed. This allowed for a totally segregated line that would now run to a disused bay platform at Stratford Station. A segregated system was favoured by the LDDC as this would readily permit the use of a high-tech automated system, their preferred solution.

Following government direction in mid-1984 tenders for a single design and build contract were invited. A contract was placed with GEC-Mowlem Railway Group in August 1984 for a fully segregated railway with automatic train operation. During the three years of construction it became clear that the planned passenger capacity had been underestimated and planing work to upgrade the system began before the public opening. This required a remodelling of the main junction at Poplar and longer platforms to accommodate two-unit trains.

The system when opened to the public on 31 August 1987 ran from Tower Gateway to Island Gardens and Stratford.

Two-thirds of the 12.1km of the initial 1987 double track system uses former disused or under-used heavy rail alignment. The original terminus at Tower Gateway is built on a reinforced concrete viaduct.

A further design and build contract was awarded to Edmund Nuttall Ltd in July 1987 for the 1.5km westward extension of the line from a junction at Royal Mint Street, which was close to the Tower Gateway terminus, to Bank station below the Underground station of the same name. This was opened on 29 November 1991.

The 8.4km extension from before Poplar to Beckton consists of approximately one-third each of ground level, underpass level and elevated double tracks. This was opened on 28 March 1994.

The 4.4km extension from beyond Crossharbour to Lewisham was opened on 20 November 1999.

A 4.5km extension to the London City Airport and King George V has recently been opened on 2 December 2005 which joins the Beckton branch a short way south of Canning Town (towards Royal Victoria), as shown in Figure 4.6. The City Airport Rail Enterprise (CARE), a consortium of AMEC and the Royal Bank of Scotland, undertook the design, build and maintenance of the extension. A further 2.5km extension tunnelling beneath the Thames is now under construction to Woolwich Arsenal, which is due to open in 2009.

A Stratford International route, linking Canning Town and Stratford with a link to the Channel Tunnel Rail Link (CTRL) Stratford International station, is currently the subject of a Transport and Works Act (TWA) application by Docklands Light Railway Limited.

4.2 SYSTEM DETAILS

Schematic route map: See Figure 4.1

Route distances: See Table 4.1 below.

Table 4.1 Docklands Light Railway route details

From	*To*	*Route (km)*[1]
Bank	Shadwell	2.377
Tower Gateway	Shadwell	1.273
Shadwell	Westferry	2.063
Westferry	West India Quay	0.593
West India Quay	Lewisham	6.029
West India Quay	Poplar	0.295
Westferry	Poplar	0.736
Poplar	Stratford	4.689
Poplar	Canning Town	2.170
Canning Town	Beckton	6.196
Canning Town	King George V	4.5[2]

Notes:
[1] Based on the average inter-station run distances
[2] Approximate distance

On double tracks left hand running is normal, but there is provision for bi-directional operation if required.

Power supply:

Traction current is distributed at 750 Vdc by means of an I-section aluminium conductor rail with a stainless steel contact surface bonded to the underside. This conductor rail is of the bottom contact type as shown in Figure 4.27, with an inverted U-section plastic shroud, and is supported on brackets fastened to the top of every fourth sleeper. This helps to reduce electrocution risks and minimises problems with snow and ice. Vehicle motor bogies are fitted with centrally mounted glass reinforced plastic arms on both sides that carry carbon collection shoes that contact the underside of the conductor rail.

There are eight sub-stations as detailed in Table 4.2 below.

Table 4.2 Location of Docklands Light Railway electrical sub-stations

Distance (km)[1]	*Location*
3.629	Royal Mint Street
0.0	Poplar[2]
1.943	Crossharbour
3.655	Cutty Sark
5.877	Elverson Road
2.683	Bow Church
3.717	Custom House
8.366	Beckton[2]

Notes:
[1] Approximate distances from Poplar
[2] These substations feed both the main line and depots

Tunnels:

The 1.2km underground section between the Royal Mint Street junction and Bank station consists of twin bore tunnels of 5m internal diameter with precast concrete segmental linings, at depths greater than 30m below ground level. There is a raised walkway at one side. The Bank terminus station, which has an island platform, is within a 7m-bore tunnel section that is 42m below ground level. To the west of the station, beneath the Mansion House, is a step-plate junction (constructed as a series of decreasing tunnel diameters) that accommodates the junction of the Up and Down lines with a headshunt beyond, which gives Up trains (towards central London) access to the Down line.

On the approach to Bow Church, in the direction of Stratford, is a rectangular concrete tunnel containing double tracks built to allow the air space above the railway to accommodate housing.

At Mudchute, on the line to Lewisham, the line goes underground for 1.5km starting with two single bore tunnels constructed by cut and cover, that then enter Island Gardens station, which is in a below ground box and partially roofed over. After Island Gardens the twin bore tunnels take the line beneath the River Thames, with gradients of up to 6% at each side. Each tunnel has a raised side walkway, and they are interconnected at the central lowest point where a sump and pumping equipment are located. On reaching the south bank of the river the tunnels enter Cutty Sark station, which is contained in a box, constructed by cut and cover. A further section of bored tunnels ends with double tracks in a covered way beneath the Greenwich heavy rail station.

The approach to the Lewisham terminus is in tunnel, which passes beneath the earlier elevated Lewisham heavy rail station, to reach the ground level platform area.

The further extension to the City Airport branch will include a tunnel under the Thames to Woolwich Arsenal station.

Elevated Sections:

The North Quay Viaduct, to the west of the North Quay Junction adjacent to Poplar station, is a standard steel and concrete composite structure, as shown in Figure 4.2. The elevated double track sections of the Beckton extension (totalling approximately 2.8km), principally in the Poplar to Brunswick Wharf, Connaught and near Gallions Reach areas, are carried on substantial all concrete structures, as illustrated in Figure 4.3.

To the south of the North Quay Junction are three 65m span fabricated steel bridges that carry the double tracks over three docks with an 8m headroom.

Between Greenwich and Deptford Bridge stations the double tracks are carried on a 20 span 800m long post-tensioned concrete viaduct that follows the banks of the Deptford Creek and Ravensbourne, which it also crosses.

From the junction with the Becton line the City Airport extension climbs onto an embankment and then onto 3.7km of viaduct with elevated stations at West Silvertown, Pontoon Dock and London City Airport before ramping down to street level.

Passenger Service Vehicles

Seventy two vehicle units out of a total of ninety four are required to operate the full service. The units are operated in pairs.

Journeys per route:

The service plan shown in Table 4.3 commenced on 07.02.04 and is expected to operate until opening of the London City Airport extension in 2005.

Table 4.3 Docklands Light Railway service plan

Service	***Headway in minutes***						
	Early	***am Peak***	***Off Peak***	***pm Peak***	***Evening & Late***	***Weekend & Early/Late***	***Weekend Middle***
Bank-Lewisham	10	3.5	10	4.2	10	10	10
Bank – Canary Wharf			10				
Stratford – Lewisham		10.5	10				20
Stratford – Crossharbour	10	21		7	10 (until 20:30)		20
Stratford – Canary Wharf					10 (until 20:30)	10	
Tower Gateway – Lewisham							20 (11:00-18:00)
Tower Gateway – Beckton	10	7	10	7	10	10	10
Units required	32	70	42		38/30	30	40

<u>Stations:</u>

Trains stop at each station. The average inter-station run distances are given in the following tables:
Table 4.4 - City to the West India Quay
Table 4.5 - West India Quay to Stratford
Table 4.6 - West India Quay to Lewisham
Table 4.7 - Westferry to Beckton
Table 4.8 - Canning Town to King George V

Table 4.4 City to the West India Quay

From	*To*	*Distance (m)*	*Track*
Bank	Royal Mint Street Junction	1547	Double/twin bore tunnel
Tower Gateway	Royal Mint Street Junction	443	Double/ballasted on viaduct
Royal Mint Street Junction	Shadwell	830	Double/ballasted on new & ex-heavy rail viaduct
Shadwell	Limehouse	1118	Double/ballasted on ex-heavy rail & new viaduct
Limehouse	Westferry	945	Double/ballasted on ex-heavy rail viaduct (listed 1840 brick built)
Westferry	West India Quay	593	Double/ballasted (with ballast mats)

Table 4.5 West India Quay to Stratford

From	*To*	*Distance (km)*	*Track*
West India Quay	Poplar	295	Double/ballasted
Poplar	All Saints	714	Double/ballasted
All Saints	Devons Road	1347	Double/ballasted
Devons Road	Bow Church	623	Double/ballasted (short tunnel)
Bow Church	Pudding Mill Lane	996	Single/ballasted & slab track
Pudding Mill Lane	Stratford	1010	Single/ballasted

Table 4.6 West India Quay to Lewisham

From	*To*	*Distance (m)*	*Track*
West India Quay	Canary Wharf	199	Quad & treble/slab track on viaduct
Canary Wharf	Heron Quays	280	Treble & double/slab track on viaduct
Heron Quays	South Quay	451	Double/ slab track on viaduct
South Quay	Crossharbour	810	Double/ slab track on viaduct
Crossharbour	Mudchute	489	Double/ slab track at ground level
Mudchute	Island Gardens	447	Double/ slab track in twin bore tunnels
Island Gardens	Cutty Sark	775	Double/ slab track in twin bore tunnels
Cutty Sark	Greenwich	661	Double/ slab track in twin bore tunnels
Greenwich	Deptford Bridge	744	Double/ ballasted & slab track on viaduct
Deptford Bridge	Elverson Road	817	Double/ slab track at ground level
Elverson Road	Lewisham	446	Double/ ballasted & slab track (short tunnel)

Table 4.7 Westferry to Beckton

From	*To*	*Distance (km)*	*Track*
Westferry	Poplar	736	Double/ballasted (with ballast mats)
Poplar	Blackwall	677	Double/ballasted & viaduct slab track
Blackwall	East India	391	Double/viaduct slab track
East India	Canning Town	1102	Double/viaduct slab track
Canning Town	Royal Victoria	982	Double/viaduct slab track
Royal Victoria	Custom House	565	Double/ballasted
Custom House	Prince Regent	519	Double/ballasted
Prince Regent	Royal Albert	917	Double/viaduct slab track
Royal Albert	Beckton Park	649	Double/viaduct slab track & ballasted underpass track
Beckton Park	Cyprus	627	Double/ballasted underpass track
Cyprus	Gallions Reach	738	Double/ ballasted underpass track & viaduct slab track
Gallions Reach	Beckton	1197	Double/ballasted track (some in trough)

Table 4.8 Canning Town to King George V

From	*To*	*Distance (km)*	*Track*
Canning Town	West Silvertown	-	Double/ballasted/viaduct slab
West Silvertown	Pontoon Dock	-	Double/viaduct slab
Pontoon Dock	London City Airport	-	Double/viaduct slab
London City Airport	King George V	-	Double/viaduct slab/ballasted

Start of services:

31.08.87	Tower Gateway to Poplar Poplar to Stratford Poplar to Island Gardens
29.11.91	Bank to Royal Mint Street junction
20.11.99	Mudchute to Lewisham (making the earlier Mudchute to Island Gardens section redundant)
28.03.94	Poplar to Beckton
02.12.05	Canning Town to King George V

A further contract has been awarded to continue the City Airport (King George V) extension beneath the river to Woolwich Arsenal.

4.3 TRACKWORK

4.3.1 Plain track

Slab track:

The rail used for slab track is flat bottom BS 80A (see Appendix 10) secured by Pandrol e1809 clips to resilient baseplates except on the City Airport extension were Pandrol Fastclip FC1501 clips are used. These are in turn fixed to the track slab by studs secured in drilled holes by grout, which is also used beneath the baseplates for levelling. Four designs of resilient baseplate are installed two of which incorporate coil springs, as illustrated in Figures 4.8 to 4.11. Pandrol VIPA-SP resilient baseplates are used on the City Airport extension as shown in Figure 4.12 and 4.13. A type of resilient baseplate, known as ‘Cologne Eggs’ after the German city where they were first installed, are shown in Figures 4.14(a), 4.19, 4.20, 4.22 and 4.23. These are used at locations were noise reduction is required.

British Steel supplied the original rail.

Rail joints are made using welding or fishplates. Expansion joints are widely used as a consequence of the many viaduct and slab track sections. Two types of expansion joints are used. The original switch design is shown in Figure 4.14(b), and the more recent type in Figure 4.14(a).

Guard rails, as shown in Figure 4.8, are used on curves below 75m radius together with rail lubricators.

Concrete slab base construction is used at both ground level and elevated locations, as illustrated in Figure 4.4 and 4.7. Much of the curved track below 120m radius is constructed as slab track.

On the Beckton line drain holes (225mm x 100mm), on the track centreline, are cast into the concrete trackbed at 3m spacing and are connected to drain units located between the trackbed and structural deck.

There are no level crossings.

The nominal Dockland Light Railway slab track dimensions are given below in Table 4.9:

Table 4.9 DLR nominal slab track dimensions

Gauge (straight & curved track)	1435mm
Rail inclination (including expansion joints)	1 in 20
Minimum track radius	Running lines 40m Depot 39m
Maximum track cant	150mm
Maximum track gradient	Bank station approach & Thames tunnels 6%
Working face of guard rail inner rail gauge face	1380(+4/-8)mm

Ballasted track:

Rail types: - Flat bottom BS 80A (see Appendix 10), on curves of 100m and less the rail has been head hardened)
- Flat bottom BS 110A and BS 113A (as Appendices 11 & 12) is used on part of the Bank/Tower Gateway to Poplar route

British Steel were the original rail suppliers.

Rail joints are made using welding or fishplates.

Pre-stressed concrete and some timber sleepers are used for ballasted track. The concrete sleepers have cast-in malleable iron shoulders either side the rail positions into which type e1809 Pandrol rail clips are inserted to secure the rail, as shown in Figure 4.15(b). Timber sleepers are fitted with steel baseplates for securing the rail clips, as shown in Figure 4.16(a).

To reduce noise levels the concrete sleepers of some track sections are fitted with ‘rubber boots’.

Track bed construction is of ballast (minimum 200mm) with cess drains, as shown in the typical section through ballasted tracks at ground level in Figure 4.17. Ballasted track is also used on some of the viaduct sections, and the form of these and the ballast mats used beneath the ballast are shown in Figure 4.5. A transition from ballasted to slab track is shown in Figure 4.15(a).

In station areas timber spacers are used as shown in Figure 4.16(b). These ensure that the minimum vehicle/platform clearance is maintained by butting up to the face of the platform wall. They are located approximately 2.5m from platform ends, and with a 5m intermediate pitch.

The design of expansion switch used on the Beckton line is shown in Figure 4.18.

There are no fixed rail lubricators associated with ballasted track, but some guard rails do have lubricators for the wheel backflange.

The exposed rails on the gradient from Bank to Royal Mint Street junction are heated over about 100m to help keep them dry to assist trains restart following a signal check.

There are no level crossings on the main lines.

The nominal Dockland Light Railway ballasted track dimensions are given below in Table 4.10:

Table 4.10 DLR nominal ballasted track dimensions

Gauge (straight & curved track)	1435mm
Rail inclination (including expansion joints)	1 in 20
Minimum track radius	120m
Maximum track cant	150mm
Maximum track gradient	6%

Standards applicable to both slab and ballasted plain track

Reverse curves have no intervening straight section.

Vertical curves are not less than 1000m radius.

The plain track main line maintenance tolerances are given in Table 4.11

Table 4.11 DLR slab and ballasted plain track maintenance tolerances

Gauge - target value	+4/-3mm
- maintenance threshold	+8/-4mm
Horizontal alignment (straight line)	
- target value	+/-5mm
- maintenance threshold	+/-9mm
Horizontal alignment (curve - 5m intervals/10m chord))	
- target value	+/-5mm
- maintenance threshold	+/-9mm
Vertical alignment (running rails)	
- target value	+/-5mm
- maintenance threshold	+/-9mm
Cant (maximum divergence from theoretical)	
- target value	+/-5mm
- maintenance threshold	+/-9mm
Twist - on 3m base (additional to cant)	
- target value	1 in 750
- maintenance threshold	1 in 400
Voids – Max deflection of rail under traffic on concrete plain sleeper track	
- target value	3mm
- maintenance threshold	5mm
Voids – Max deflection of rail under traffic on rubber boot sleeper track	
- target value	7mm
- maintenance threshold	8mm
Voids – Max deflection of rail under traffic on slab track with soft pads on a grout base	
- target value	3mm
- maintenance threshold	5mm

4.3.2 Switches & Crossings

Slab track:

All turnouts are constructed from flat bottom BS 80A rail (see Appendix 10) and are of vertical design.

The method of construction, including drainage, was similar to that for plain track.

The nominal Docklands Light Railway slab track turnout dimensions are given in Table 4.12:

Table 4.12 DLR slab track turnout dimensions

Gauge	1435mm
Radius	(Curved & straight crossings) 40m & 100m[1] (Pivoted swing nose crossing) 100m, 200m & 245m[2]
Switch rail type	Flexible
Crossing flangeway gap	44mm
Check rail flangeway gap	44mm
Minimum flangeway through switches	50mm
Switch opening	105mm
Flange tip running	None

Notes:

[1] Also SV-245 (=CV-9.25) & DV-10.75

[2] Pivoted swing nose turnouts designated SV-100 (6 units), Y-200 (2 units) & SV-245 (1 unit)

Figure 4.19 shows turnouts and diamond crossing forming part of the Delta Junction close to West India Quay. Turnouts with pivoted cast manganese crossing noses, as shown in Figure 4.20, are located at Canary Wharf and Bow Church to help reduce noise levels. These replaced turnouts originally fitted with swing nose crossings, such as that shown in Figure 4.21.

The construction of turnouts on the City Airport extension is illustrated in Figures 4.22 and 4.23.

<u>Ballasted track:</u>

All turnouts and diamond crossings are constructed from flat bottom BS 80A rail (see Appendix 10 and are of vertical design fastened to timber sleepers with type e1809 Pandrol rail clips and steel baseplates, as shown in Figure 4.24 and 4.25.

The nominal DLR ballasted turnout dimensions are given in Table 4.13:

Table 4.13 DLR ballasted track turnout dimensions

Gauge	1435mm
Radius	(Curved & straight crossings) 40m (Curved crossing) 100m (Straight crossing) 245m (Depot) 40m
Switch rail type	Flexible
Crossing flangeway gap	44mm
Check rail flangeway gap	44mm
Minimum flangeway through switches	50mm
Switch opening	105mm
Additional sleeper bracing to maintain alignment	Bracing blocks used on Depot 40m radius units

Standards applicable to both slab and ballasted turnouts

A summary of the standard design dimensions associated with turnouts on the Beckton line is given in Table 4.14 below, which is associated with Figure 4.26.

Table 4.14 DLR standard dimensions for ballasted turnouts on the Beckton line

Turnout Type	*Turnout Radius*	*Angle at IP*[1]		*Lead to fine point*	*Fine point to nose*	*Crossing Heel*	*Stock rail front*	*Stock rail front to IP*	*IP to crossing heel*	*Tangent length*	*Overall length*
	R(m)	*1 in N*	*degrees*	*A(m)*	*B(mm)*	*C(m)*	*D(m)*	*E(m)*	*F(m)*	*G(m)*	*H(m)*
Sv-40	41.585	3.798	15.00	10.210	66	2.724	1.000	5.760	8.240	5.475	14.000
Cv-40	41.585	3.000	18.93	10.210	66	2.724	1.000	7.205	6.795	6.930	14.000
Cv-100	100.000	4.611	12.38	16.283	96	3.923	1.650	10.667	10.633	10.844	21.300
Sv-245	245.564	9.250	6.19	24.877	148	4.110	1.650	13.253	17.532	13.274	31.785

Notes:

[1] IP - Intersection Point

The maintenance tolerances for turnouts and crossings are given in Table 4.15

Table 4.15 DLR slab and ballasted turnout and crossing maintenance tolerances

Longitudinal position of switch tip from design position (level with first slide chair)	
- target value	+/-5mm
- maintenance threshold	+/-8mm
Max wear on dry slide chairs	
- target value	1mm
- maintenance threshold	2mm
Switch tip fit (max gap between switch point & stock rail in closed position)	
- target value	2.0mm
- maintenance threshold	3.5mm
Head wear on crossing wing rails	
- target value	3mm
- maintenance threshold	5mm
Head wear on crossing nose	
- target value	3mm
- maintenance threshold	5mm
Max wear of crossing flangeway gap (from 44mm) at 50mm from crossing nose along the vee	
- target value	2mm
- maintenance threshold	4mm
Max wear of check rail flangeway gap (from 44mm)	
- target value	2mm
- maintenance threshold	4mm
Swing nose crossing max gap between swing nose & swing rail at 50mm from swing nose along vee	
- target value	2.0mm
- maintenance threshold	3.5mm
Max gauge variation at the switch point & crossing nose	
- target value	+/-2mm
- maintenance threshold	+4/-2mm

4.3.3 Switch operation

All tracks:

British Rail type clamp lock machines with hydraulic drive operate all conventional turnouts.

The swing nose crossing units are operated by GEC/Alstom type HW mechanisms.

Switch detection system (all track):

Micro-switches provide detection.

Maintenance regime (all track):

A two level inspection regime is in operation, depending on use, based on a six-week cycle.

Permitted open gap (all track):

The switches are set to make at 3mm and break at 5mm

4.3.4 Track maintenance

Ultrasonic rail inspection, using hand held units, is carried out at least annually.

No abnormal rail corrosion has been found.

Standard rail stressing is carried out based on a temperature of 27deg C.

4.4 VEHICLES

The fleet is made up of 94 units of class B92 three bogie articulated vehicles all manufactured by BN Constructions Ferrovaires et Metalliques, Brugge, Belgium (now Bombardier BN). Typical examples are shown in Figure 4.28. They consist of two similar bodies with motor bogies at the leading/trailing ends, and articulation at the central unpowered bogie, as shown in Figure 4.29. The 'H' bogie frames (motor and trailing bogies) sit within the wheels, such that the axles run on internal bearings. The floor height throughout is 1025mm.

The vehicles run on rubber-cushioned Bochum 54 or Bochum 84 wheels manufactured by Bochumer Verein Verkehrstechnik GmbH in Germany. No sanding units are fitted to vehicles.

The seating capacity of a unit is 70, though a Passenger Services Agent (PSA) may take up two seats if present, and two wheelchairs can occupy four tip-up seat locations. A maximum of 228 standing passengers can be accommodated, though this has been increased for 20 of the units (numbers 32, 45 & 50-67) by removing ten seats around the centre door area in each car. These cars are used on train formations used on services to Bank at peak times. The vehicles are currently undergoing interior refurbishment that will include changes to the seating arrangements.

Leading dimensions: See Table 4.16.

Table 4.16 Docklands Light Railway vehicle dimensions

Length over couplers	28.800m
Length over body	28.000m
Body width over doors	2.650m
Body shell width	2.500m
Height (rail to roof)	3.468m
Floor height above head of rail	1025mm
Distance between bogie centres	10.000m
Bogie axle spacing	1.900m
Wheel diameter (new)	740mm

Bogie details: See Table 4.17.

Table 4.17 Docklands Light Railway vehicle bogie details

Motor bogie	Two motor bogies (one each end) Internal ‘H’ frame with internal axleboxes Two powered axles per bogie One brake disc per axle One 140kW mono-motor per bogie Motors are mounted longitudinally Motor continuously rated at: 675V/230A/1783rpm Rubber springs either side the axleboxes form the primary suspension Air bags provide secondary suspension
Trailer bogie	Similar in basic design to the motor bogie One brake disc per axle

Vehicle weights: See Table 4.18.

Table 4.18 Docklands Light Railway vehicle weights

Tare weight (two car unit)	36000kg
Weight of crush laden two car unit (M3 load)	54000kg
Crush laden distribution:	
Car body A	27000kg
Car body B	27000kg

Vehicle braking systems: See Table 4.19.

Table 4.19 Docklands Light Railway vehicle braking systems

Disc brakes	One disc per axle on motor bogies One disc per axle on the trailer bogie (Total of six disc brakes)
Track brakes	None
Rheostatic brake	Regenerative that automatically becomes rheostatic if the line is not receptive

Wheel details: See Table 4.20.

Table 4.20 Docklands Light Railway vehicle wheel details

Type	Type BO 54 & 84 (Bochum resilient wheel)
Diameter	740mm (new) 660mm (worn)
Profile	DLR1 profile (similar to BR P8 as Appendix 24) - prone to high wear DLR2 profile (based on the worn DLR1 profile, as Appendix 16) - prone to sidewear of rail/flange DLR5 profile (developed from the DLR2 profile) - profile now used, as Appendix 17
Wheel discard criteria	Telltale on wheel rim (660mm diameter) (Tyre scrapping thickness following the German Eschede rail incident(1998))
Wheelset back-to-back	1362(+0.5/-1.5)mm
Lubrication	Flange lubrication by 'solid stick' Applied to the flange root radius bearing on wheels of the leading /trailing axle of the motor bogies on each unit

4.5 OPERATIONS INFORMATION

Vehicle operations

The maximum service speed on level and down gradients is 70km/h and 60km/h on up gradients. Service acceleration and braking is limited to $1.1 m/s^2$ (average) and $0.8 m/s^2$. The maximum hazard braking rate is $1.3 m/s^2$.

Operating environment

Points are fitted with heaters. On damp mornings in autumn low adhesion can give rise to difficulties with braking.

4.6 OPERATING CHALLENGES

Rail wear

On the sharper curves head hardened rail has been introduced. There has also been an increasing use of guard rails.

Excessive cyclic rail side wear is occurring on straight sections of track and is controlled by rail grinding. An investigation is underway to help develop improved control methods.

Track quality

A programme of progressive track refurbishment is taking place at Canning Town and Lewisham (on viaducts) to overcome poor construction quality giving rise to loose rail fastenings. At Tower Gateway the crossover with 100m radius turnouts is receiving attention to rectify loose rail fastenings and crumbling concrete.

Rail corrugations are found on all sharp curves, which is treated by rail grinding.

Poor ride quality is associated with the three bogie design of the vehicles, the monomotor bogie design, and the problems with wheel profile and rail wear.

An annual noise survey is carried out which highlights any remedial action required.

Braking on some early morning trains can be problematic. A braking rate as low as $0.4m/s^2$ can still be too large to prevent slide, and a rate of $0.3m/\ s^2$ has now been added to the Automatic Train Control system.

4.7 FIGURES

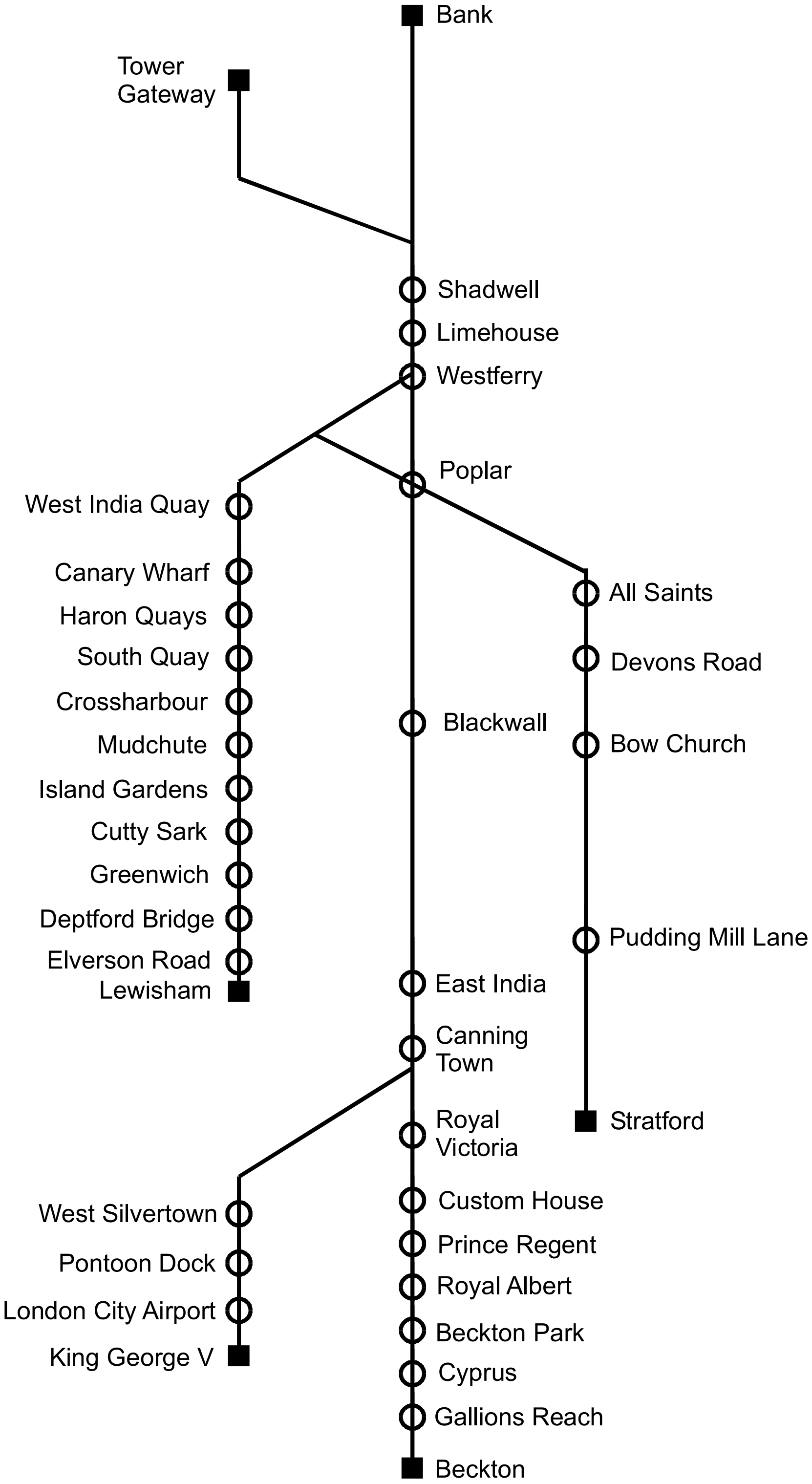

Figure 4.1 Schematic route map of the Docklands Light Railway

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Figure 4.2 The North Quay Junction and North Quay Viaduct (background), Beckton Link (foreground) and the New West India Down Viaduct (right, background) of the Docklands Light Railway (22.10.04)

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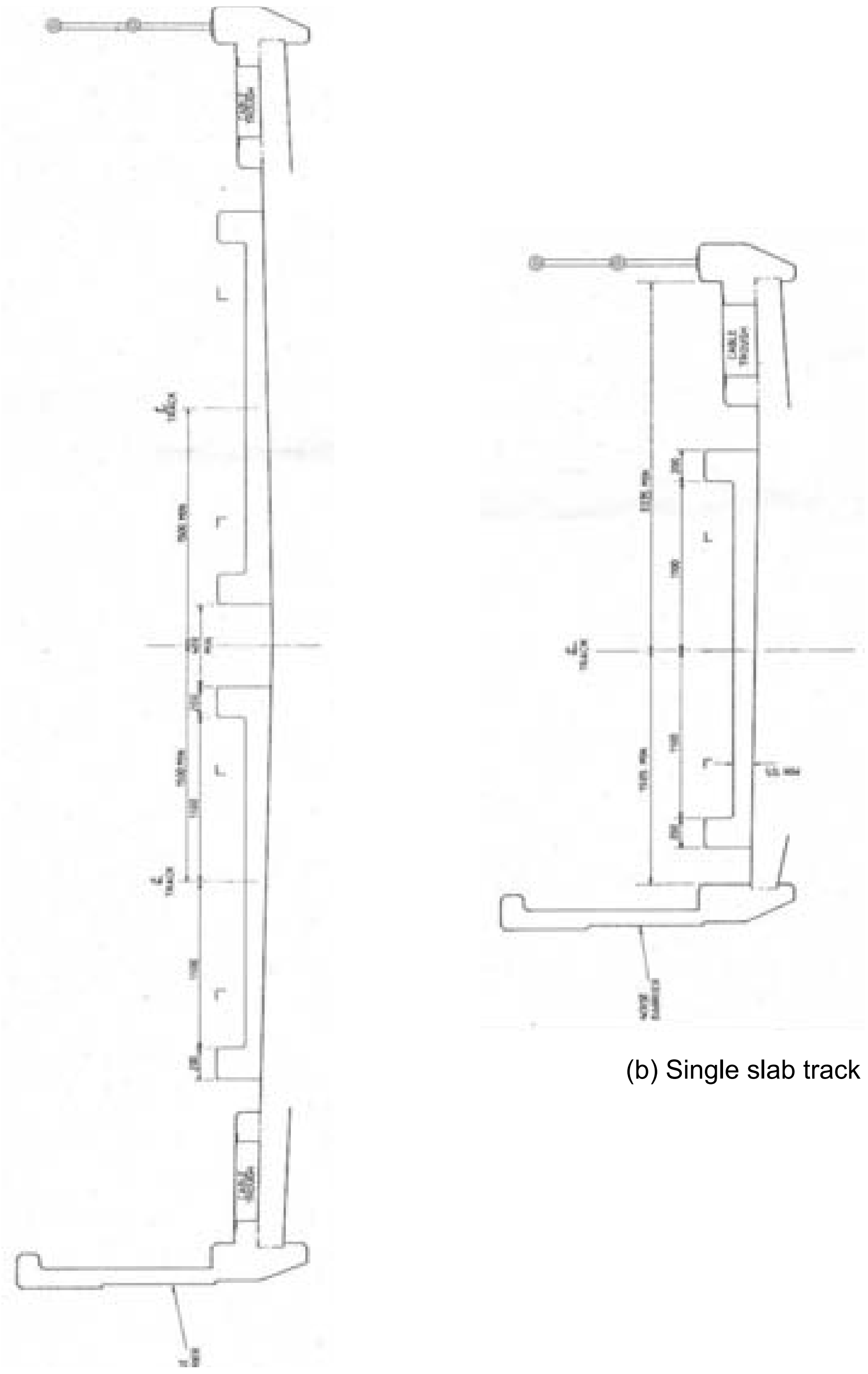
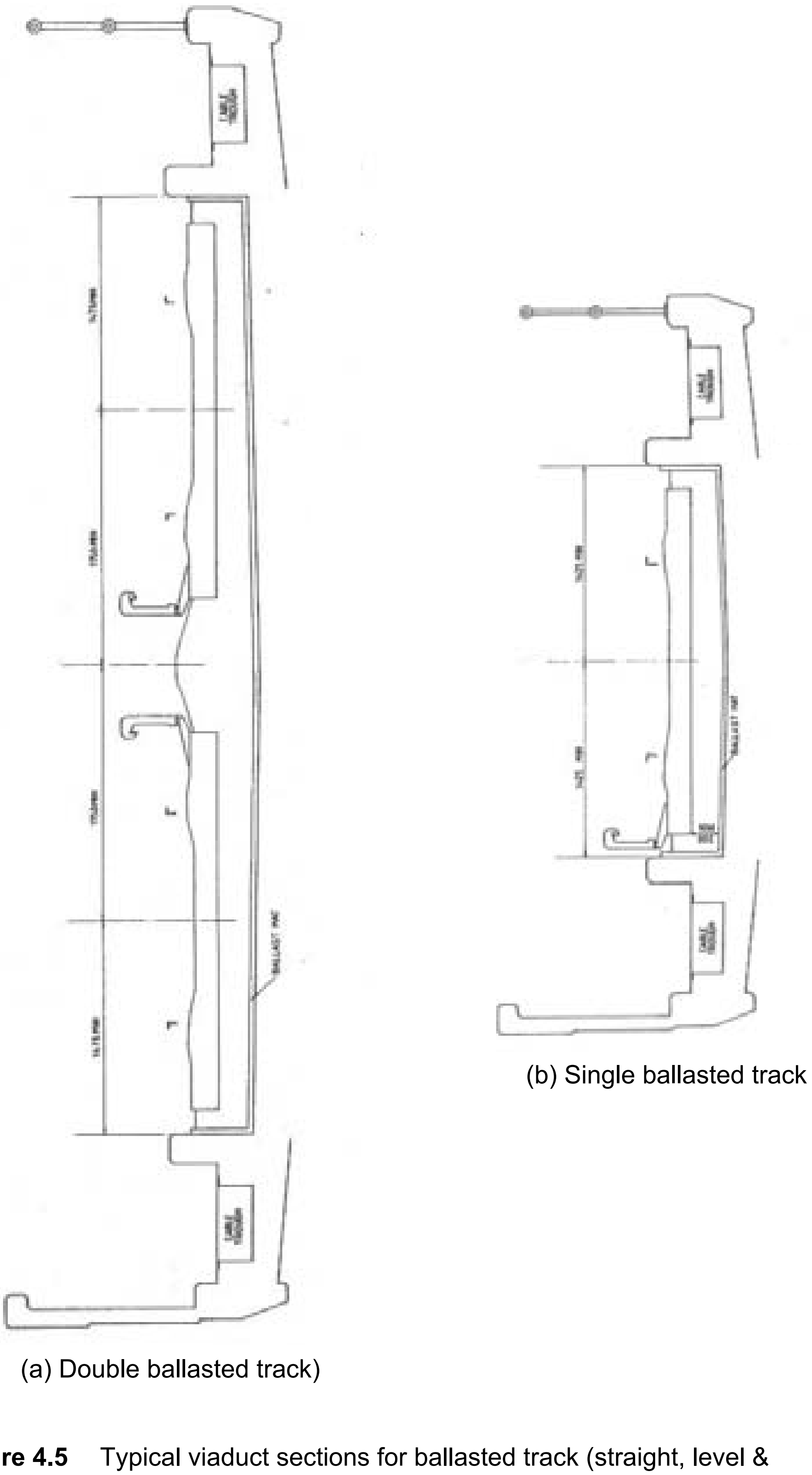
Figure 4.3 Elevated section of the Docklands Light Railway Beckton line (22.10.04)



(b) Single slab track

(a) Double slab track)

Figure 4.4 Typical viaduct sections for slab track (straight, level & uncanted) on the Docklands Light Railway Beckton line



(b) Single ballasted track

(a) Double ballasted track)

Figure 4.5 Typical viaduct sections for ballasted track (straight, level & uncanted) on the Docklands Light Railway Beckton line

FES0410-04/53

Figure 4.6 Docklands Light Railway City Airport extension under construction beyond the overbridge (22.10.04)

Photo courtesy of Pandrol UK Ltd

Figure 4.7 Slab track under construction, City Airport extension of the Docklands Light Railway

FES0410-04/11

Figure 4.8 Slab track plain line and guard rail resilient fastenings on the Docklands Light Railway (22.10.04)

FES0410-04/13

Figure 4.9 Alternative plain line slab track resilient fastenings on the Docklands Light Railway (22.10.04)

FES0410-04/14

Figure 4.10 Slab track resilient rail fastening on the Docklands Light Railway (22.10.04)

FES0410-04/14

Figure 4.11 Slab track resilient rail fastening on the Docklands Light Railway (22.10.04)

(a) Pandrol VIPA-SP resilient track fastening

I Raxton

(b) Baseplate positioned for grouting

Photo courtesy of Pandrol UK Ltd

(c) Formwork around baseplates prior to pouring grout

Photo courtesy of Pandrol UK Ltd

Figure 4.12 Pandrol VIPA-SP track fastenings used on the City Airport extension of the Docklands Light Railway

Photo courtesy of Pandrol UK Ltd
(a) Baseplate grouting completed

Photo courtesy of Pandrol UK Ltd
(b) Baseplate grouting completed

Figure 4.13 Completed slab track on the City Airport extension of the Docklands Light Railway

FES0410-04/07

(a) ‘Cologne Egg’ resilient rail fastenings

FES0410-04/24

(b) Plain line

Figure 4.14 Slab track rail expansion joints on the Docklands Light Railway (22.10.04)

FES0410-04/53

(a) A transition between ballasted and slab track on

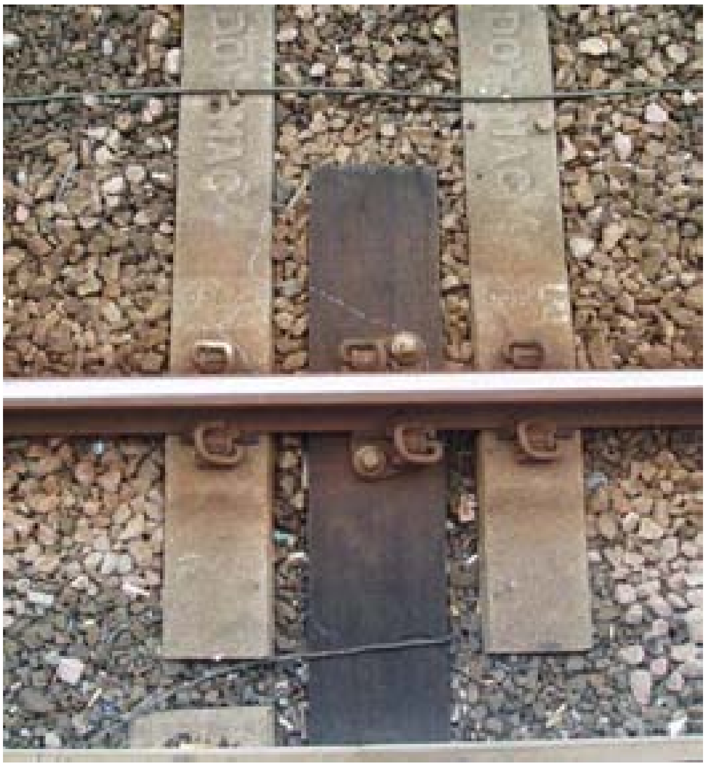
FES0410-04/04

(b) Plain track

Figure 4.15 Ballasted track on the Docklands Light Railway (22.10.04)

FES0410-04/43

(a) Timber sleepers



(b) Timber platform spacer

FES0410-04/44

Figure 4.16 Ballasted track on the Docklands Light Railway (22.10.04)

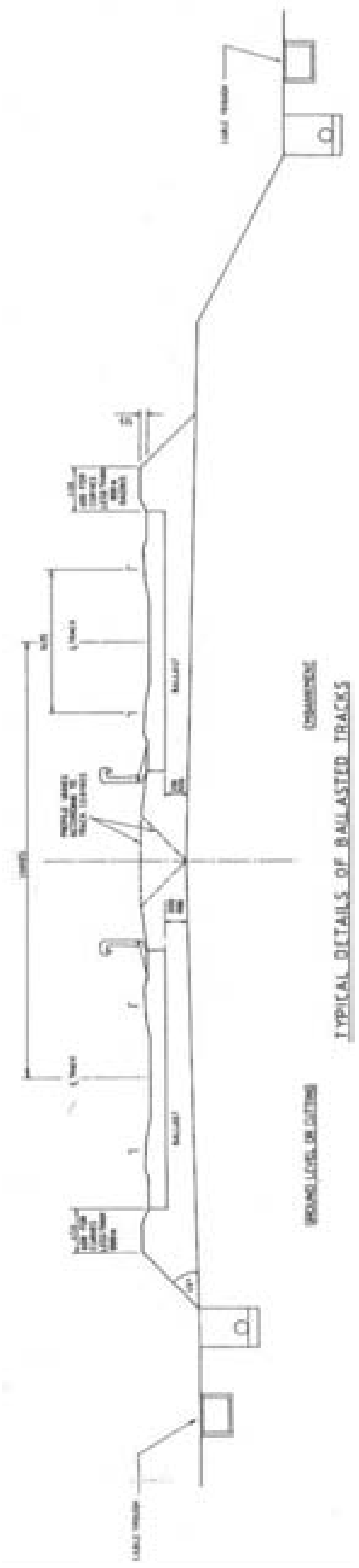
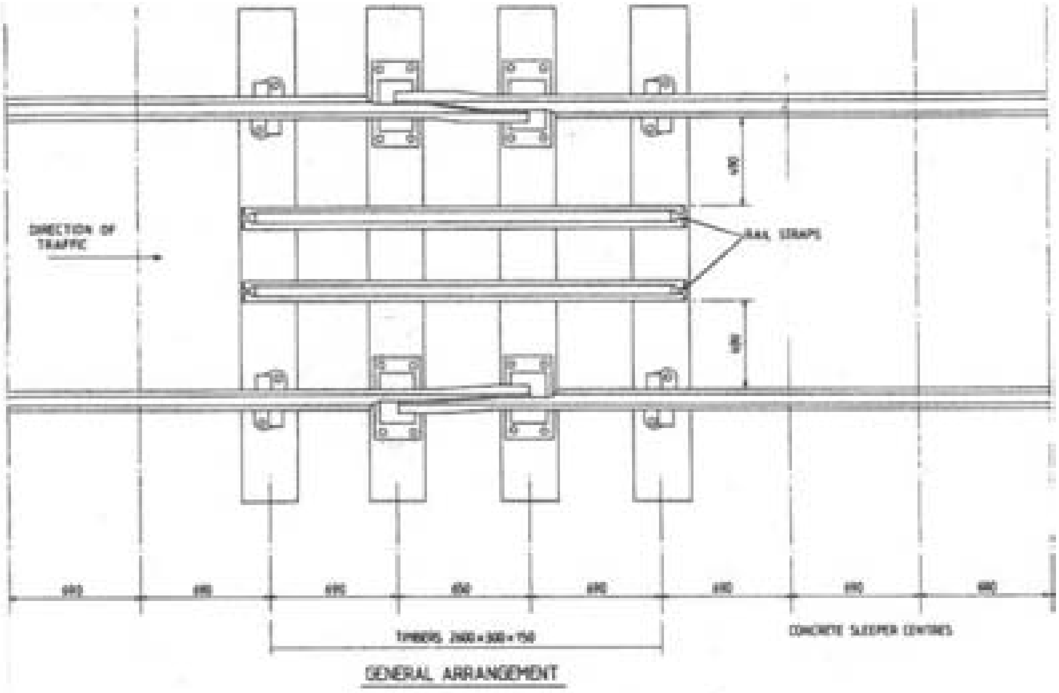


Figure 4.17 Typical section through ballasted tracks at ground level, Docklands Light Railway

FES0410-04/60

(a) Expansion joint (22.10.04)



(b) Plan view of expansion joint

Figure 4.18 Typical rail expansion joint for ballasted track, Docklands Light Railway

FES0410-04/06

Figure 4.19 Slab track turnout at the North Quay Junction on the Docklands Light Railway (22.10.04)

FES0410-04/38

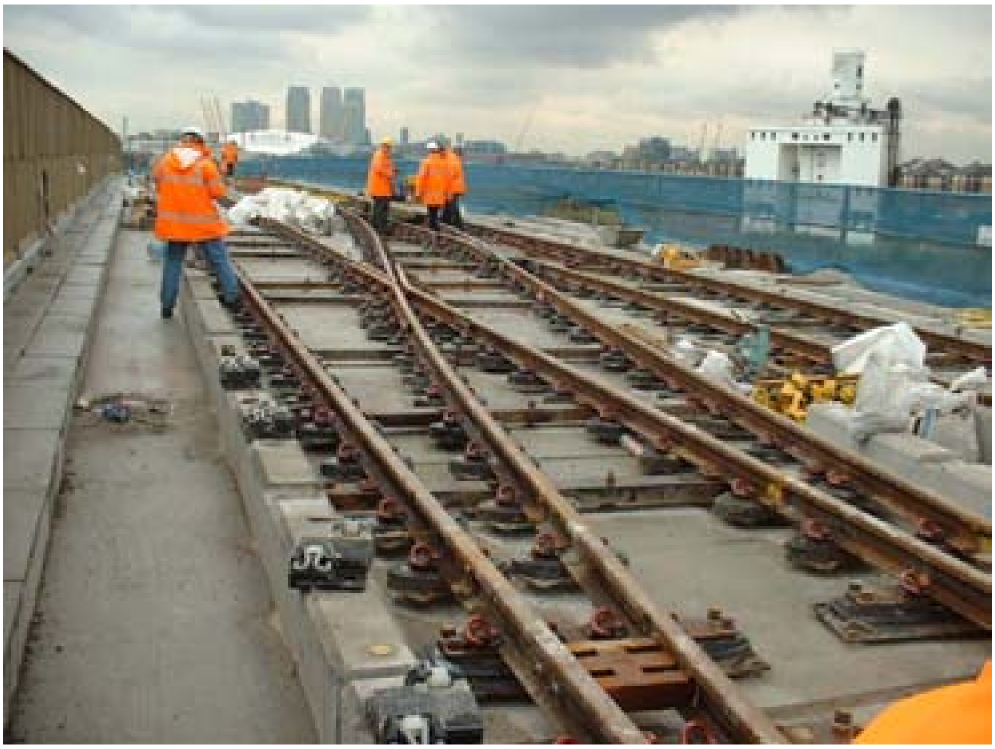
Figure 4.20 Slab track pivoted crossing nose turnout at Canary Wharf on the Docklands Light Railway (22.10.04)

DL Bateman

Figure 4.21 The original design of slab track swing nose turnout Docklands Light Railway

I Raxton

Figure 4.22 Slab track turnout ‘Cologne Egg’ rail fastening, City Airport extension of the Docklands Light Railway



I Raxton

(a) Crossing

I Raxton

(b) Switch rails

Figure 4.23 Slab track turnout under construction using 'Cologne Egg' rail fastenings, City Airport extension of the Docklands Light Railway

I Raxton

Figure 4.24 Ballasted track turnout linking the Beckton Up line to the City Airport extension of the Docklands Light Railway

FES0410-04/12

Figure 4.25 Scissors crossover at Lewisham on the Docklands Light Railway (22.10.04)

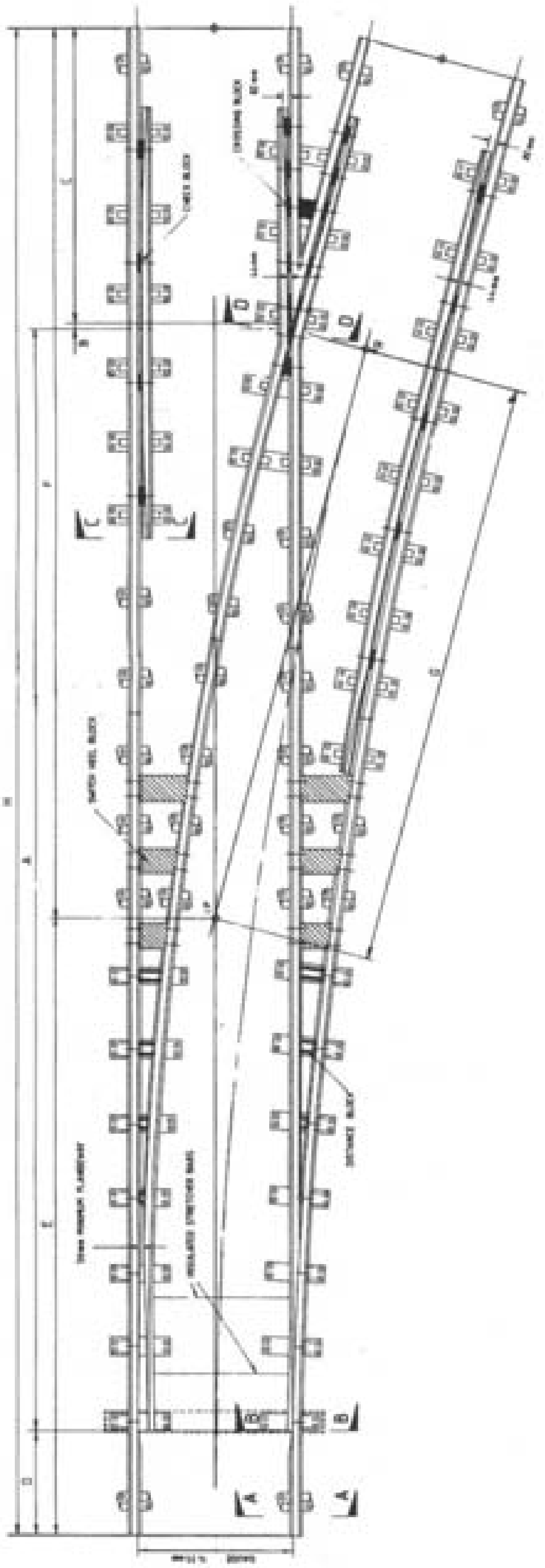


Figure 4.26 Docklands Light Railway standard turnout form with terminology

I Raxton

Figure 4.27 Conductor rail expansion joint prior to installation of the protective shroud, City Airport extension of the Docklands Light Railway

HSE0305-012/2

Figure 4.28 Docklands Light Railway Class B92 Units 58 & 79 at Poplar (16.08.01)

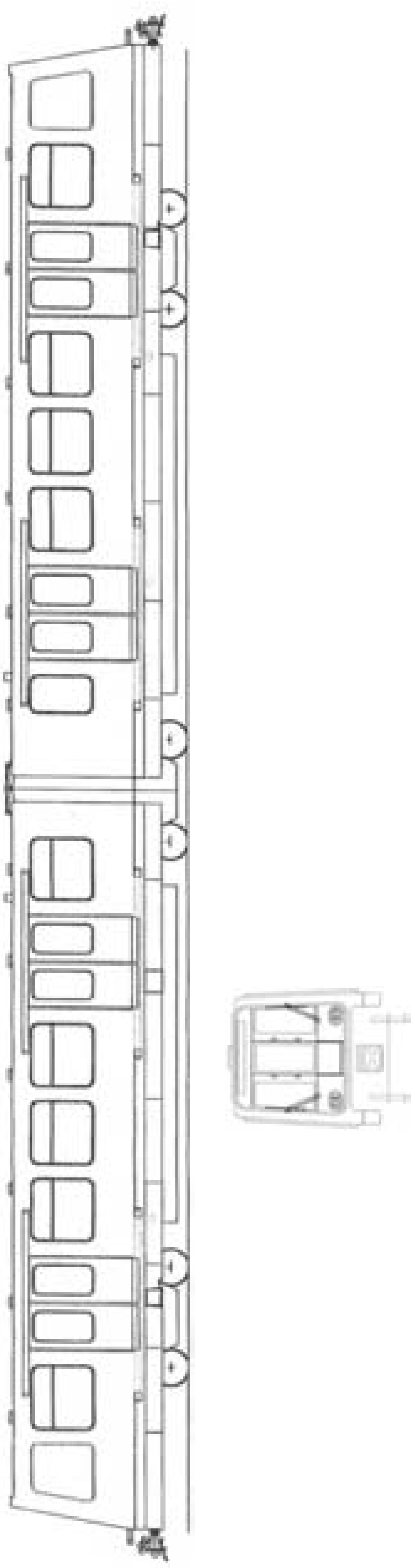


Figure 4.29 Docklands Light Railway Type B92 articulated vehicle

5 MANCHESTER METROLINK

5.1 INTRODUCTION

In the early 1980's the Greater Manchester Passenger Transport Executive studied the local rail network to see which lines could be converted to light rail operation. A six-line scheme was originally proposed. Funding considerations required the network to be built in stages. The Altrincham and Bury lines together with City Centre street running tracks were selected to form phase one of the network. Construction started in 1989, and phase one was completed throughout by June 1992. Phase two, started in April 1997, consisting of an extension from Cornbrook to Eccles. This was opened in July 2000.

In March 2000 the Government accepted that construction of the remaining Metrolink extensions would be better as a single project rather than line-by-line. The construction bidding process by consortia is still underway.

5.2 SYSTEM DETAILS

Schematic route map: See Figure 5.1.

Route distances: See Table 5.1 below:

Table 5.1 Manchester Metrolink route details

From	*To*	*Distance (km)*	*Track*
Altrincham[1]	Manchester (G-Mex)	12.2	double/ballasted
Manchester (G-Mex)	Victoria	3.1	double/grooved rail
Piccadilly Gardens	Piccadilly	0.7	double/grooved rail
Victoria	Bury	15.9	double/ballasted
Cornbrook	Eccles	6.5	double/grooved rail/ ballasted & direct rail fixing to viaduct

Notes:
[1] A short section is single track at the Navigation Road stop.

Power supply:

Overhead line equipment supplies trams with power at a nominal voltage of 750Vdc. There are 16 feeder stations and one sub-station at High Street, as detailed in Table 5.2 below.

Table 5.2 Manchester Metrolink electrical feeder and sub-stations

Location	*Comment*
Bury	100m south of Station
Radcliffe Station	
Prestwich Station	
Woodlands Road Station	
Victoria Station	
High Street	Sub-station under 22 High Street
Gmex Station	
Trafford Bar	500m south of station
Cornbrook Station	
Stretford	500m north of station
Dane Road Station	
Timperley Sidings	
Altrincham Station	
Broadway Station	
Eccles Station	
Queens Road Depot	Not connected to the main line
Piccadilly Station	Not operational

Tunnels:

Details of the four tunnels on the system are given in Table 5.3 below.

Table 5.3 Manchester Metrolink tunnel details

Length (metres)	*Name*
61	Whitefield
635	Heaton Park
385	Collyhurst[1]
130	Trafford Bar

Notes: [1] Situated between the Depot and Victoria on the Bury Line

Passenger tram units:

Typical weekly services required 29 tram units of which 6 are required for the Piccadilly/Eccles service. A total of 32 trams are available of which 9 are capable of operation to Eccles.

Journeys per route:

Typical Bury – Piccadilly – Altrincham service every 12 minutes.

Bury – Altrincham service every 12 minutes.

Piccadilly – Eccles service every 12 minutes.

The Bury – Piccadilly – Altrincham and Bury – Altrincham services alternate to provide a 6 minute service between 07:00hrs and 19:00hrs.

Tram stops: Trams call at each stop as follows:

Altrincham/Bury	- 21 stops
Piccadilly/Eccles	- 10 stops
Common to both routes	- 6 stops

Start of services:

Phase 1:

Victoria Station/Bury	- 06.04.1992
G-Mex/Victoria Station	- 27.04.1992
Altrincham/G-Mex	- May 1992
Piccadilly Gardens/Piccadilly	- 20.06.1992

Phase 2:

Broadway/Eccles	- 21.07.2000
Cornbrook/Broadway	- 06.12.1999

5.3 TRACKWORK

5.3.1 Plain track

Grooved track (street running):

Rail types - Phase 1: Ri 59 manufactured in Luxemburg (see Appendix 3 for profile)

- Phase 2: SEI 35G (see Appendix 5 for profile)

Rail manufacturers are not known. The rail for Phase 2 was delivered to site encapsulated with ALH Rail Coatings Ltd (Hyperlast/GrantRail Ltd joint venture) 'Series-six' polyurethane.

The average foundation depth of street track is 0.5m below the road surfacing. A thin layer of blinding concrete was overlaid with two layers of reinforcing mesh, separated by concrete blocks, and a structural concrete slab cast to below rail foot level. The steel mesh also acts as a stray current conductor. A second concrete slab was added to the first to provide two channels to accommodate the rails as shown in Figure 5.2.

The rails were delivered to site in straight 18m lengths. Following welding to form continuous lengths and bent to suite the alignment. Once aligned and levelled the rails were embedded in a pourable grade polymer. A second finishing pour of polymer bulked with sand was made.

The replacement of life expired grooved rail track is illustrated in Figures 5.3 and 5.4. To replace the rails it is necessary to cut through sections of the rail and then pull the polymer encased rail out of the pavement. The vertical metal strips, which formed permanent formwork to aid pouring of the polymer rail encasement, can be seen in Figure 5.3(a). Encapsulated rail, as that used in the construction of Phase 2, is used for replacement. Aluminothermic welding is used to make rail joints, as shown in Figure 5.4(a), before the rails are shimmed and wedged to set the gauge and cross level, and cast into place with concrete poured to half rail height, as Figure 5.4(b). The pavement surface is then reinstated. A close-up of the worn Ri 59 rail section is shown in Figure 5.5.

Drainage of the rail groove to the street drainage system is provided.

There are no fixed lubrication systems associated with grooved rails.

The nominal grooved track (design) dimensions are given in Table 5.4.

Table 5.4 Manchester Metrolink grooved track dimensions

Gauge (straight & curved track)	1432mm
Rail inclination	1 in 40
Minimum track radius	25m
Maximum track cant	35mm
Maximum track gradient	5.56%
Rail running surface relative to road	Nominally level
Wear tolerance of keeper flange	Visual inspection only

Ballasted track:

Rail types - Bullhead: BS 95RBH
- Flat Bottom: BR 109lb, BS 80A, BS 110A & BS 113A (currently standardising on BS 113A)

See Appendix 8 for the BS 95RBH profile, Appendix 9 for BR 109lb, Appendix 10 for BS 80A, Appendix 11 for BS 110A, and Appendix 12 for BS 113A.

Rail manufacturers are not known.

There are examples of all types of rail fastening on the system used in conjunction with either timber or concrete (monobloc or twin block type) sleepers. Pandrol clips of type PR401A were used on Phase 1, and E1809 and E1810 on Phase 2. Rail joints are made using fishplates or by welding. Expansion joints terminate welded rail runs. The track bed construction is of ballast, typical of heavy rail practice, with cess drains.

Some BS 80A flat bottom rail is fastened directly to concrete plinth track bed such as at the Pomona Curve shown in Figure 5.6.

At a number of locations on the Eccles Line (Phase 2) ‘Grasscrete’ has been used to provide a robust grassed surface level with the rail head, as shown in Figure 5.7. The BS 80A rail concrete sleepered track has been cast into a concrete base that has then been overlaid with Grasscrete panels.

Detail of an expansion switch located on the Broadway Curve, also on the Eccles Line, is shown in Figure 5.8. This unit is located on the curve as this length of continuously welded track connects two (unused) turnouts shown in Figures 5.8(b) & (c) associated with a proposed future extension.

There are no fixed lubrication systems associated with the ballasted track.

Of the two level crossings the one at Haggside, Bury is constructed from Bomac elements (concrete blocks with a rim of steel) laid on a concrete sill. The second level crossing, at Navigation Road, is on a section of track owned and maintained by Network Rail.

The nominal plain ballasted track (design) dimensions are given in Table 5.5.

Table 5.5 Manchester Metrolink plain ballasted track dimensions

Gauge (straight & curved track)	1435mm
Rail inclination	1 in 20
Minimum track radius	(Cornbrook) 121.3m
Maximum track cant	(Cornbrook) 150mm
Maximum track gradient	5.18%

5.3.2 Switches & Crossings

Grooved track (street running):

The Phase 1 part of the system is equipped with KIHN S.a. (17 rue de l'Usine, L-3754 Rumelanger, Luxemburg) 30m radius standard turnouts using Ri59 rail section, which incorporate removable flexible switch rails. These units are bolted directly to the concrete slab track bed as Figure 5.9(a).

A scissors crossover incorporating turnouts of 25m radius manufactured by Edgar Allen Engineering Ltd, Sheffield was installed at London Road, Piccadilly as part of the Phase 1 system. This was fastened to the concrete foundation slab with base plates that were drilled in-situ. Figure 5.9 (b) shows a plate in position prior to drilling (on the left of the picture). Edgar Allen also supplied the switches and crossings used on the Phase 2 system. An example of street track shortly after construction is shown in Figure 5.10.

A turnout located at a road crossing on Mosley Street is shown in Figure 5.11.

Drainage slots in the rail groove are connected to the street drain system.

The turnouts are cleaned (using vacuum) and lubricated twice weekly.

The nominal grooved turnout (design) dimensions are given in Table 5.6.

Table 5.6 Manchester Metrolink grooved turnout dimensions

Gauge	1432mm
Radius	25m & 30m
Switch rail type	Flexible removable unit
Flangeway	35mm (Phase 1) 28mm (Phase 2)
Switch opening	55mm (minimum)
Flange tip running	None

Ballasted track:

All turnouts are vertical common crossing design of type CV (1 in 9.25) fabricated from BS 113A flat bottom rail, except for those at Victoria and Piccadilly Undercroft which use 80lb flat bottom rail. Pandrol rail fasteners and timber sleepers are used for turnout construction on a ballast track bed. Balfour Beatty Rail Engineering supplied the S&C units. Cess drainage is used. There are no fixed rail lubrication systems fitted.

The nominal plain turnout (design) dimensions are given in Table 5.7.

Table 5.7 Manchester Metrolink plain ballasted turnout dimensions

Gauge	1435mm
Radius	(FB rail CV 1 in 9.25) 245.8m
Switch rail type	Flexible
Switch rail top planing	Standard CV switch
Crossing flangeway gap	(Heavy rail standard) 41mm
Crossing gap	50mm
Check rail flangeway gap	44mm (The check rails are raised by 50mm above rail level)
Minimum flangeway through switches	41mm
Switch opening	102mm
Additional sleeper bracing to maintain alignment	None

5.3.3 Switch operation

Grooved track (street running):

Hanning & Kahl HW 60 electro hydraulic point setting mechanisms are used.

Proximity switches on the switch rails and Facing Point Lock (FPL) provide switch detection. The maintenance regime consists of a four weekly test of the FPL, a 16 week machine service and detection test and a 5 year overhaul.

Ballasted track:

Alstom electric HW 1000 and HW 2000 point setting mechanisms are used.

Switch detection is provided by cam driven contacts.

The maintenance regime consists of a four weekly test of the Facing Point Lock (FPL), a 16 week machine service and detection test and overhaul based on the number of operation cycles.

5.3.4 Track maintenance

All ballasted track (flat bottom rail) is ultrasonically inspected every 12 months.

5.4 VEHICLES

The two car articulated vehicles used on the system were supplied by Firema Trasporti (Italy). The units used for the Bury-Altrincham service are of Type T68, and Type T68/A for the Eccles service. The leading dimensions and external appearance of the two types are very similar, though the T68/A vehicles are fitted with skirting to bogies, concealed couplers and other features to enable the on-highway operation required for the route to Eccles. The T68 is shown in Figure 5.12 and 5.13.

The vehicle passenger capacity (normal load) is 82 seated and 119 standing (this is reduced to 111 standing when carrying two wheelchairs).

Leading dimensions: See Table 5.8 below.

Table 5.8 Manchester Metrolink vehicle dimensions

Length over couplers	29.840m
Length over body	29.000m
Body shell width	2.570m
Width at door steps	2.650m
Height of body shell	3.360m[1] 3.350m[2]
Floor height above head of rail	940mm[1] 915mm[2]
Distance between bogie centres	10.700m
Bogie axle spacing	2.065m
Wheel diameter	740mm[1] 710mm[2]

Notes:
[1] Tare laden/new wheels
[2] Half crush laden/half worn wheels

Bogie details: See Table 5.9.

Table 5.9 Manchester Metrolink vehicle bogie details

Design	Firema Trasporti
Motor bogie	Type M048E Two motor bogies (one at each end) Two powered axles per bogie (Axles 1,2,5,6 from the 'A' end) Traction motors attached to the bogie frame Motor drive is via a flexible drive to an axle hung gearbox Two rubber scroll springs per wheel primary suspension Two rubber air springs per bogie secondary suspension
Trailer bogie	Type P048E One bogie central to the vehicle Articulation between bogie & body units Central circular floor area fixed to bogie Two un-powered axles (Axles 3 & 4 from the 'A' end) Two rubber scroll springs per wheel primary suspension Two rubber air springs secondary suspension

Vehicle weights: See Table 5.10.

Table 5.10 Manchester Metrolink vehicle weights

Tare weight	(Type T68) 48964kg (Type T68 A) 49561kg
Weight of crush laden	(Type T68) 68017kg (Type T68 A) 68979kg
Crush laden distribution (Type T68):	
Motor bogie A	22903kg
Trailer bogie C	22881kg
Motor bogie B	22232kg
Crush laden distribution (Type T68 A):	
Motor bogie A	22950kg
Trailer bogie C	23074kg
Motor bogie B	22954kg

Wheel details: See Table 5.11.

Table 5.11 Manchester Metrolink vehicle wheel details

Type	Type BO 54 (Bochum single-ring resilient wheel)
Diameter	740mm (new) 680mm (worn)
Tyre width	127mm
Profile	MML-2 (modified British Rail P8) (See Appendix 18 for details)
Re-profiling criteria	Maximum flange width wear = 2mm Maximum flange height wear = 6.5mm (As flange width is maintained hollow tread wear does not develop.)
Vehicle running distances between wheel re-profiling approximate)	(T68 units) 60000km (T68A units) 34000km
Wheel discard criteria	Minimum 680mm diameter
Tyre material	BS5892 Part 4 Grade B6E (UIC810-1 Grade B6E)
Wheelset back-to-back	1362 +0/-2mm (As this is a 'tram/train' wheel profile the distances between the flanges proper is 1380mm. Ballasted turnouts have raised check rails, see Table 5.7)
Lubrication	Solid stick lubricant onto the flange (Four sticks on the trailing wheels of each end bogie)

5.5 OPERATING CHALLENGES

Environment:

Leaf fall in autumn gives rise to significant traction problems so 'Sandite' is locally applied to those sections of ballasted track that are affected. Problems with ice are also encountered.

Traction on street running tracks can be affected by oil, rubber and salt contamination.

Rail wear:

The small radius curves with grooved rail show signs of excessive wear. The low rails exhibit keeper wear and the high rails side wear. In order to undertake electric arc weld repairs to extend rail life the rail metal has to be pre-heated. However, this is not possible as the rail is embedded in polymer that can be a source of toxic fume if heated. To overcome this Cold Weld Build-up systems are under development, and it is hoped that this can be used for future repairs.

It has been observed that block paving is not sufficiently robust to withstand the constant vibration of passing trams. Much of the paving installed in the streets of Manchester have been laid on a bed of sand. Experience has shown that vibration causes settlement of the blocks after only a few years creating an uneven walking surface. The use of block paving, unlike tarmac surfaces that are associated with road traffic, encourages pedestrians to walk along the tracks.

Criteria for rail replacement are under development. A start has been made on rail measurement to enable prediction of replacement timing.

Track quality observations:

Wear to a grooved rail turnout on Mosley Street, Manchester, shown in Figure 5.11, has been observed which significantly reduces the working life of its components. This unit is sited such that a traffic lane ensures bus wheels pass across the switch rail area at regular intervals.

There are many locations on the system, for both grooved and flat bottom rail, where short wave corrugations are found.

The holding down bolts securing the rail base plates of the BS 80A rail on the Pomona Curve shown in Figure 5.6 are regularly found to have failed in shear. This is believed to be a consequence of the tight curve radius, and the lack of cant and rail lubrication at this location. At this location turnouts are proposed, associated with a spur to the Trafford Centre. The rails also exhibit excessive side wear and corrugation.

The high rails of the tight radius Broadway Curve shown in Figure 5.7(a) also suffer from excessive side wear. As turnouts were constructed at either side of the curve to cater for a future extension, the curve could not be laid with an equilibrium cant to match the vehicles and line speed. To accommodate the turnouts and the continuously welded rail an expansion switch was installed at the centre of the curve. As consequence of this the switch suffers from significant sidewear, as can be seen in Figure 5.8(a).

Though providing a good walking surface that is environmentally friendly Grasscrete construction prevents the condition of sleepers to be inspected and also creates channels about the rails, as shown in Figure 5.7(b), which readily fill with silt and debris that require regular removal and cleaning with water jets.

The use of 'Sandite' has been discontinued following 'wrong side' signal failures. The use of a 'conductive Sandite' may be considered.

5.6 FIGURES

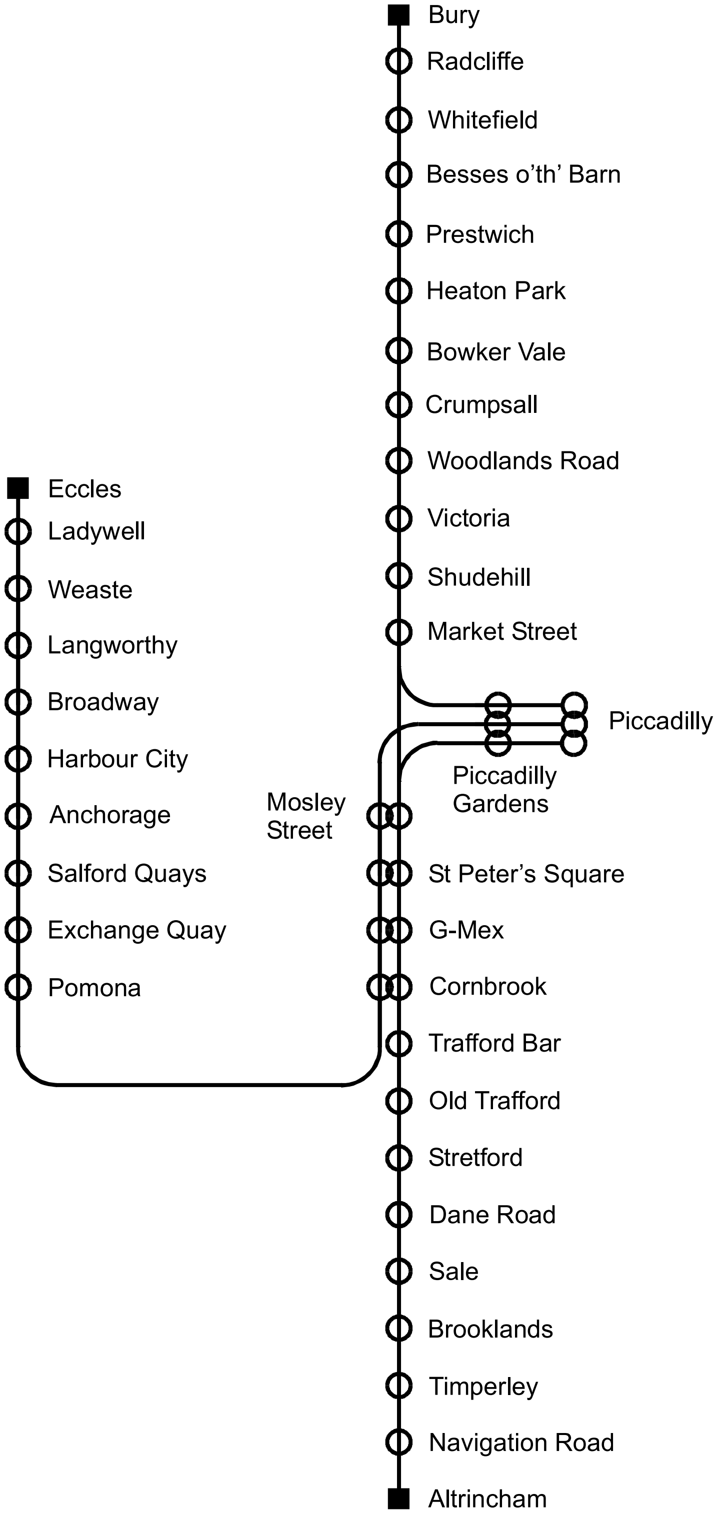


Figure 5.1 Schematic route map of Manchester Metrolink

(a) Concrete track slab

D Keay

(b) Installing grooved rail

D Keay

(c) Rail installed

D Keay

Figure 5.2 Manchester Metrolink street track during construction

M Howard

(a) Rail removed from concrete channel

M Howard

(b) New polymer coated rail ready for installation

Figure 5.3 Replacing worn grooved rail track, Manchester Metrolink

M Howard

(a) Welding a rail joint

M Howard

(b) Rail concreted in place

Figure 5.4 Reinstating grooved rail track, Manchester Metrolink

M Howard

Figure 5.5 Life expired rail section following removal, Manchester Metrolink

M Howard

(a) Pomona Curve

M Howard

(b) BS 80A rail fixed to the concrete plinth

Figure 5.6 Manchester Metrolink concrete plinth track

M Howard

(a) Broadway Curve

M Howard

(b) The rail channel

Figure 5.7 ‘Grasscrete’ construction, Manchester Metrolink

M Howard

(a) Broadway Curve adjustment switch

M Howard

(b) Unused turnout (looking west)

M Howard

(c) Unused turnout (looking east)

Figure 5.8 Track formation details associated with the proposed extension to the Lowry Centre at the Broadway Curve, Manchester Metrolink

(a) Turnout

D Keay

S Dale

(b) Crossover at London Road, Piccadilly

Figure 5.9 Construction of grooved rail turnouts, Manchester Metrolink

D Keay

Figure 5.10 Grooved rail street track following construction, Manchester Metrolink

M Howard

Figure 5.11 Bus lane crossing a turnout on Mosley Street, Manchester Metrolink

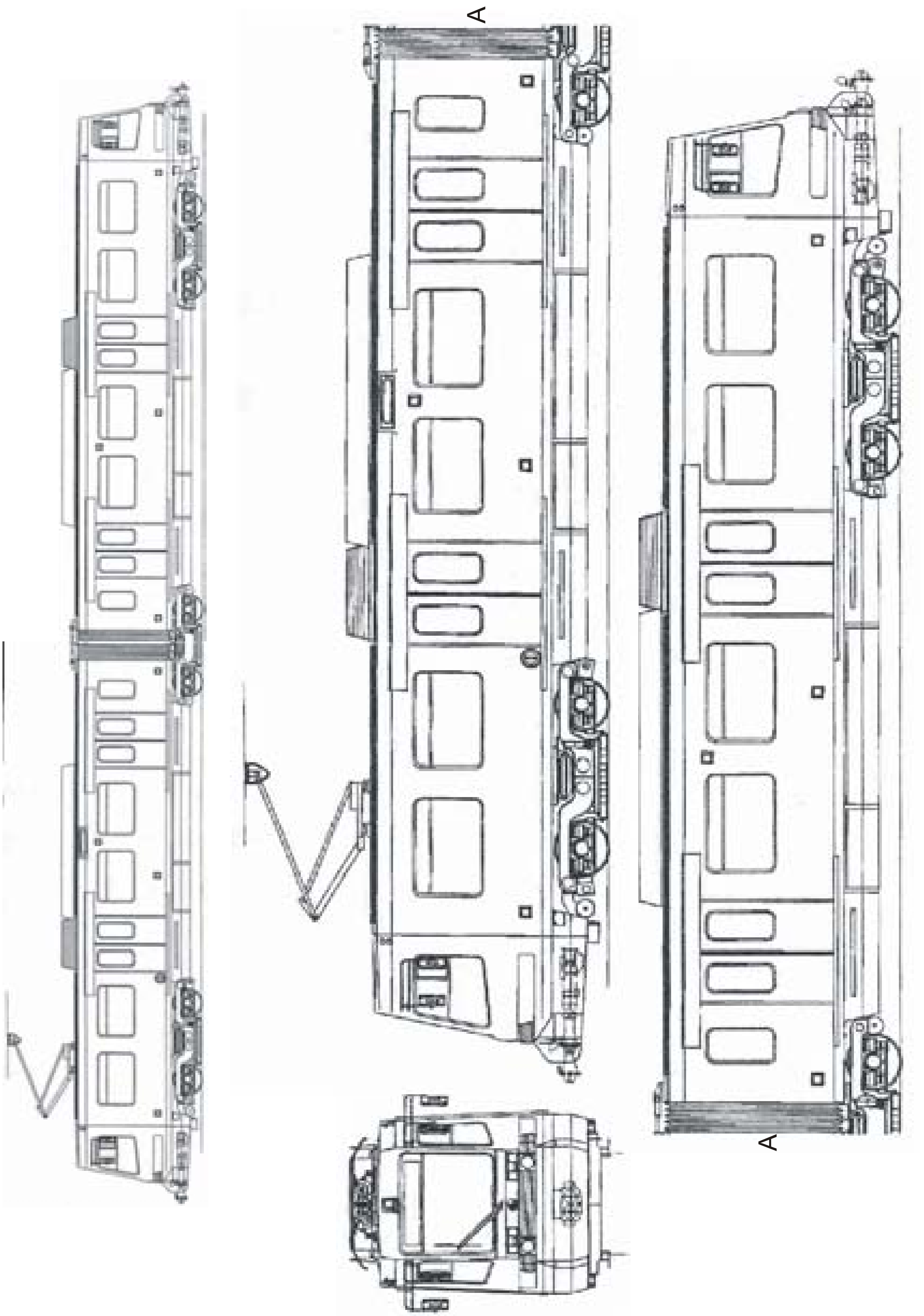


Figure 5.12 Side and end views of typical Metrolink vehicles

HSE0305-018/4

Figure 5.13 Metrolink tram No. 1013 at Aytoun Street, Manchester (17.09.01)

6 MIDLAND METRO

6.1 INTRODUCTION

A Joint Transportation Planning Unit, set up by the West Midlands County Council and Passenger Transport Authority in 1980, started on a review of alternative transport strategies, of which a light rail transit system was one. A 1984 report recommended four corridors radiating from Birmingham city centre. However, the whole concept of rapid transit was put on hold due to local government reform in 1986.

In September 1987 the Midland Metro rapid transit concept was launched by the Black Country Councils. The first route, between Birmingham and Wolverhampton, was announced in February 1988, and a Parliamentary Bill was deposited in November 1988. The Act was passed a year later. Funding applications started in April 1990 that resulted in a Government grant to enable Centro (the renamed Passenger Transport Executive) to carry out an enabling study and also plan project management and investigate private funding. After initial difficulties a contract was signed on 3 August 1995 to design, build and operate Line 1 of Midland Metro (three years construction, 20 years operation) by Altram, a consortium of Ansaldo Trasporti and John Laing.

Construction commenced on 13 November 1995. Travel West Midlands (part of the National Express Group the area’s largest bus operator) joined the consortium in 1996. As the National Express Group also own Central Trains there is more intermodal integration than elsewhere in the UK. GrantRail started track laying in November 1997 after completion of a 60m split-spine girder bridge at Middlecross in the July. The installation of the overhead electric system started during the summer of 1997.

Late delivery of trams seriously delayed opening of the system, which took place on 30 May 1999, though there were only sufficient vehicles to operate a 10-minute service rather than the 6-minute one planned for the first weeks of operation.

Considerable operational problems were experienced in the first two years until a wheel lathe was acquired in the summer of 2001.

An unwanted knock-on effect of the deprivation of some of the areas served by the line has been the repeated theft of overhead wiring and general vandalism.

6.2 SYSTEM DETAILS

Schematic route map:

See Figure 6.1

Route distances:

The current system consists of a 20.1km terminal-to-terminal line of double tracks (except for a short section of single track close to Birmingham Snow Hill). The majority of the line uses former railway alignment except for some 2km of street running (grooved rail) along the A41 from Priestfield to Wolverhampton. The last kilometre into Wolverhampton is on a central reservation, with some track near the terminus on side reservation. The off-street track is laid on ballast except at stops.

Power supply:

Overhead line equipment supplies trams with power at a nominal 750 Vdc. There are six sub-stations as detailed in Table 6.1 below.

Table 6.1 Location of Midland Metro electrical sub-stations

Distance (km)[1]	*Location*
1.06	Chillington Street
2.58	Priestfield
8.10	Wednesbury Great Western Street
10.40	Black Lake
18.18	All Saints Street
19.69	Snow Hill

Notes:
[1] Approximate distances from Wolverhampton St Georges

Tunnels:

There are five tunnels on the system as shown on the map in Figure 6.1, though four of these are extended cut-and-cover rail and road over bridges. These tunnels accommodate double ballasted tracks. Details are as Table 6.2 below (listed in order from Wolverhampton to Birmingham):

Table 6.2 Midland Metro tunnel details

Length (metres)	*Name*
345	Hill Top Tunnel
144	Hockley No.2 Tunnel
123	Hockley No.1 Tunnel
15	Kenyon Street Tunnel
37	Livery Street Tunnel

Passenger Service Vehicles

Thirteen two-car Type T69 trams out of a fleet of 16 are required to run a six to seven minute interval service, but latterly constraints have resulted in ten trams providing an eight to ten minute service.

Journeys per route:

Each day the normal service (Monday to Saturday) equates to 115 return journeys between Birmingham and Wolverhampton. The Sunday and Bank Holiday service is equivalent to 91 return journeys. The end-to-end journey time is 37 minutes.

Tram stops:

The service vehicles call at all 23 stops in each direction.

Start of services:

The public service started on 31 May 1999 with a ten-minute frequency service. This was upgraded to the intended six to seven minute frequency some weeks later.

6.3 TRACKWORK

6.3.1 Plain track

Grooved track (street running):

Rail types - SEI 35G is used throughout (see Appendix 5 for profile)

Corus Rail (SOGA, France) supplied the rail, which was delivered to site in 18.3m lengths encapsulated with ALH Rail Coatings Ltd (Hyperlast/GrantRail Ltd joint venture) 'Series-six' polyurethane.

The continuously welded grooved rail was fastened by flange clamps to base plates which where themselves mounted on the concrete slab as Figure 6.2. The concrete foundation slab consisted of a first pour of 200mm thick concrete with a second pour of 25 -30mm under the rail base. A 50mm second pour was used for the Wolverhampton St Georges crossover formation. There are no tie-bars between rails. Following fastening of the rails a further concrete layer was added to form the paved/road surface level. This was topped with an anti-skid layer where required. Pre-curved rail was supplied for curves of 110m radius or below. Where the track radius is less than 200m rail joints are fishplated.

Expansion joints are used between ballasted and grooved rail track and at each end of the girder ('wishbone') bridge at Middlecross as shown in Figure 6.4. These expansion joints in grooved SEI 35G rail (supplied by Grant Lyon Eagre) are supported by baseplates that hold the rail vertical and which are secured by spring loaded rail-clamping plates.

Drainage of the rail groove was originally provided with cut-outs in the rail keeper flange discharging into drain boxes. As the lids to the drain boxes were individually made there are interchangeability problems when lids require replacement. To avoid blockage the keeper rail has been cut away completely in the vicinity of the boxes, as shown in Figure 6.18. Several boxes are blocked.

There are no fixed lubrication systems associated with grooved rails.

The nominal grooved track (design) dimensions are given in Table 6.3.

Table 6.3 Midland Metro grooved track dimensions

Gauge (straight & curved track)	1435(+3/-0)mm
Rail inclination	Vertical
Minimum track radius	40m
Maximum track cant	Absolute maximum: 150mm
Maximum track gradient	3.317% with a short section of 4.264%
Rail running surface relative to road	Nominally level

Measurements of grooved rail track gauge have been found in the range 1435mm to 1440mm.

No keeper plate wear tolerance is specified, though side wear by wheel flanges is apparent.

<u>Ballasted track:</u>

Rail type - Flat bottom BS 80A (see Appendix 10 for profile)
- Short section of flat bottom BS 113A (see Appendix 12)

Corus Rail supplied the rail.

Stanton Bonna twin block sleepers, type VAX U21, are used for all ballasted track together with Pandrol twin leg shoulders of type 7008, 10mm studded rubber pad type 4760, e1809 clips and insulators of type 4477. All rails are continuously welded with expansion joints and fishplates used on either sides of turnouts. At stops, the rail is secured by Grant Rail baseplates secured to the concrete track slab that is tapered at the ends towards the ballast interface. Problems have been experienced with this transition from concrete to ballast. Continual tamping has been found necessary to avoid 'dips' in the track.

Grant Lyon Eagre supplied the scarf type expansion joint in the BS 80A rail used on the concrete deck of the Queens Head Viaduct.

Fishplates are used at the rail joints of turnouts on the main line and on sidings and track within the depot.

Portec track mounted lubrication units are used.

At the Swan Lane level crossing BS113A rail is used on Dowmac concrete sleepers with a 1 in 20 rail inclination. Polysafe Level Crossing Systems Limited supplied the concrete road-crossing surface.

Omni Holdfast supplied pedestrian crossings.

The nominal plain track (design) dimensions are given in Table 6.4.

Table 6.4 Midland Metro plain ballasted track dimensions

Gauge (straight & curved track)	1435(+3/-0)mm
Rail inclination	1 in 40 (At Swan Lane level crossing there is a short section with rail at 1 in 20)
Minimum track radius	25m 40m (Depot)
Maximum track cant	Abs. max: 150mm Desirable max: 110mm
Maximum track gradient	3.3% with a short section of 3.364% at Priestfield

<u>Standards applicable to both grooved rail and ballasted track</u>

Stops are on straight track, except at Bilston Central.

The minimum radius of vertical curves is 1000m except at Wolverhampton Ring Road and Birmingham Canal Bridge.

The plain track main line maintenance tolerances are given in Table 6.5.

Table 6.5 Midland Metro grooved and ballasted plain track maintenance tolerances

Gauge - target value	+3/-2mm
- maintenance threshold	+8/-5mm
Horizontal alignment (straight line)	
- target value	+/-15mm
- maintenance threshold	+/-20mm
Horizontal alignment (curve - 5m intervals/10m chord))	
- target value	7mm
- maintenance threshold	8mm
Vertical alignment (running rails)	
- target value	+/-15mm
- maintenance threshold	+/-20mm
Cant (maximum divergence from theoretical)	
- target value	+/-10mm
- maintenance threshold	+10/-15mm
Twist - on 3m base (additional to cant)	
- target value	+/-4mm
- maintenance threshold	+/-5mm

The need for re-profiling of rails is based on visual inspection for corrugation, side wear and noise generation.

The maximum permissible wear to the rail top and the side is 5mm. When rails are subject to both top and side wear the maximum permitted top wear is reduced by 1mm for each 1mm of side wear, and with a similar reduction to the permitted side wear.

6.3.2 Switches & Crossings

Grooved track (street running):

The system is equipped with Edgar Allen Ltd turnouts constructed from SEI 35G rail (see Appendix 5). The rail is fastened to the concrete foundation slab by flange clamps. Tie bars are incorporated to maintain track gauge. Examples of turnout crossings and switch rail are shown in Figure 6.5.

At the Wolverhampton St George's terminus there are four grooved rail turnouts with cast blades and recessed stock rails comprising:

one motorised unit
one 'flip-flop' unit
two spring return units

There are two motorised units in the trailing cross-over at The Royal.

The one diamond crossing at Wolverhampton St Georges is shown in Figure 6.6.

Drainage is by flangeway slots and drain boxes to the street drainage system. There are problems with water entering point boxes.

The nominal grooved turnout (design) dimensions given in Table 6.6.

Table 6.6 Midland Metro grooved turnout dimensions

Gauge	1435(+3/-0)mm
Radius	25m (x3) and 100m (x1) at Wolverhampton St Georges 25m (x3) at The Royal
Switch rail type	Flexible cast units
Check rail flangeway gap (sacrificial plates)	26mm
Flange tip running	One cast steel diamond crossing at Wolverhampton St Georges

Re-profiling is carried out when there is visual side wear.

Ballasted track:

GrantRail Limited (Corus) supplied all turnouts.

Pandrol e1809 clips and cast baseplates are used to fasten the BS 80A rail to timber sleepers of ballasted track turnouts. Examples of such turnouts are shown in Figure 6.7, with crossing and switch rail detail given in Figure 6.8

To allow the use of 'heavy-rail' maintenance vehicles the 100m radius turnouts are equipped with check rail that can be adjusted to a flangeway gap of 44m by the removal of spacers to match the 1362mm wheel back-to-back of such vehicles, as shown in Figure 6.9. At emergency crossovers adjustable check plates are provided to create a 26mm check rail flangeway gap, as shown in Figure 6.10. These are mounted above the conventional checkrails set for a 44mm gap for use by maintenance vehicles fitted with 'heavy rail' wheel profiles.

The nominal plain ballasted turnout (design) dimensions are given in Table 6.7.

Table 6.7 Midland Metro plain ballasted turnout dimensions

Gauge	1435mm
Radius	Mainline 100m (Wednesbury Parkway) Emergency crossovers 40m Depot 25m
Switch rail type	Flexible[1,2]
Switch rail top planing	Overall length of planing = 2.5m From 0.0m to 1.25m slope = 9.6mm/m From 1.25m to 2.5m slope = 3.2mm/m
Crossing flangeway gap	44mm
Check rail flangeway gap	26mm For heavy rail maintenance vehicles adjustable check rails (shims removed) and check plates allows a 44mm gap to be set
Switch opening	Variable
Additional sleeper bracing to maintain alignment	Bracing fitted outside the gauge on some units

Notes:
[1] There is no relief of switch rail flange.
[2] There is chamfering on the underside of the rail heads to accept the switch rails.

Damage to crossing noses has been found.

Re-profiling is carried out when there is the presence of visual side wear and/or corrugations.

6.3.3 Switch operation

Grooved track (street running):

Hanning & Kahl supplied the HWE 40 electro-hydraulic point setting mechanisms together with proximity switches.

The permitted open gap is 2.0mm.

An experience based maintenance schedule is in operation.

Ballasted track:

Ansaldo Trasporti supplied all point setting mechanisms. Switch detection is by limit switch.

The permitted open gap is 2.5mm.

An experience based maintenance schedule is in operation.

6.3.4 Track maintenance

Ultrasonic rail inspection is carried out.

Rail corrosion has been found in Hill Top Tunnel.

The stressing of continuously welded rail associated with ballasted track is maintained.

6.4 VEHICLES

All of the 16 identical three-section, bi-directional vehicles of Firema type T69 used on the system were supplied by Firema Engineering (now Ansaldo Breda).

The external appearance is shown in Figure 6.11 & 6.12. To permit a low floor height throughout the whole vehicle the centre portion is mounted on an unpowered truck, which has stub axles that allow the wheels to rotate independently.

The vehicle passenger capacity (normal load) is 60 seated and 100 standing (this is reduced to 56 seated when carrying two wheelchairs).

Leading dimensions: See Table 6.8.

Table 6.8 Midland Metro vehicle dimensions

Length over three sections (one coupler unfolded)	24.740m
Length over three section body	24.240m
Body shell width	2.600m
Width at door steps	2.650m
Height of body shell	3.550m
Floor height above head of rail	850mm[1] 350mm[2]
Distance between body articulation centres at centre section	1.74m
Distance between motor bogie centres and adjacent centres of body articulations	7.75m
Bogie axle spacing	1.800m
Wheel diameter	(New) 680mm

Notes:
[1] Above motor bogies at ends
[2] 57% of total floor between motor bogies

Bogie details: See Table 6.9.

Table 6.9 Midland Metro vehicle bogie details

Design	Firema
Motor bogie	M046 Two motor bogies (one each end) Two powered axles per bogie One 210kW motor per bogie Motors mounted longitudinally Rubber spring primary suspension Air spring secondary suspension See Figure 6.13
Trailing truck	Four unpowered independent wheels Wheels mounted on stub axles Rubber spring primary suspension Air spring secondary suspension See Figure 6.14

Vehicle weights: See Table 6.10.

Table 6.10 Midland Metro vehicle weights

Tare weight	35900kg
Weight of crush laden	49485kg
Crush laden distribution:	
Motor bogie A	16811kg
Trailer bogie C	15397kg
Motor bogie B	17277kg

Wheel details: See Table 6.11.

Table 6.11 Midland Metro vehicle wheel details

Type	Resilient
Diameter	680mm (new) 620mm (worn)
Tyre width	125mm
Profile	See Appendix 19 for original profile (DIN 34) See Appendix 20 and Figure 6.15(a) for revised profile now in use
Re-profiling criteria	Currently wheels are re-profiled every month regardless of wear condition, see Figure 6.15(b)
Draft re-profiling criteria	Minimum allowable flange thickness = 19.0mm Maximum allowable flange height = 29.0mm Maximum allowable diameter differences: Motor bogie (same axle) = 1.0mm Motor bogie (same bogie) = 2.0mm Trailer bogie = 2.0mm Maximum allowable 'hollow wear' = 3.25mm Motor bogie back-to-back to be within 1377 to 1381mm
Vehicle running distances between wheel re-profiling (approximate)	12000km
Wheel discard criteria	Minimum 620mm diameter
Wheelset back-to-back	1379mm
Lubrication	Originally by flange lubrication sticks Now manual greasing of rail at selected sites

6.5 OPERATIONS INFORMATION

Maximum line speed = 70km/h

Maximum acceleration = 1m/s^2

Maximum service braking rate = $1.2\ \text{m/s}^2$

Maximum hazard braking rate = $3.6\ \text{m/s}^2$

6.6 OPERATING CHALLENGES

Wheel wear:

Uneven wear to the flanges of wheels on the trailer trucks, when compared side-to-side, has been observed and is currently under investigation. This is illustrated by the example in Figure 6.16 & 6.17.

Effects of weather on system:

During hot weather the OLE tensions can be affected.

All turnouts are fitted with heaters for cold weather operation.

Leaf fall:

The line passes through wooded areas in the vicinity of The Crescent and Trinity Way where leaf fall is found.

Rail wear by road vehicles:

No significant wear has been observed, but heavy road vehicles have damaged drain box lids as can be seen in Figure 6.18.

Rail wear:

There is excessive switchblade wear at the turnout into Birmingham Snow Hill station. This has been rebuilt twice by welding deposition. Further welding/replacement is under review.

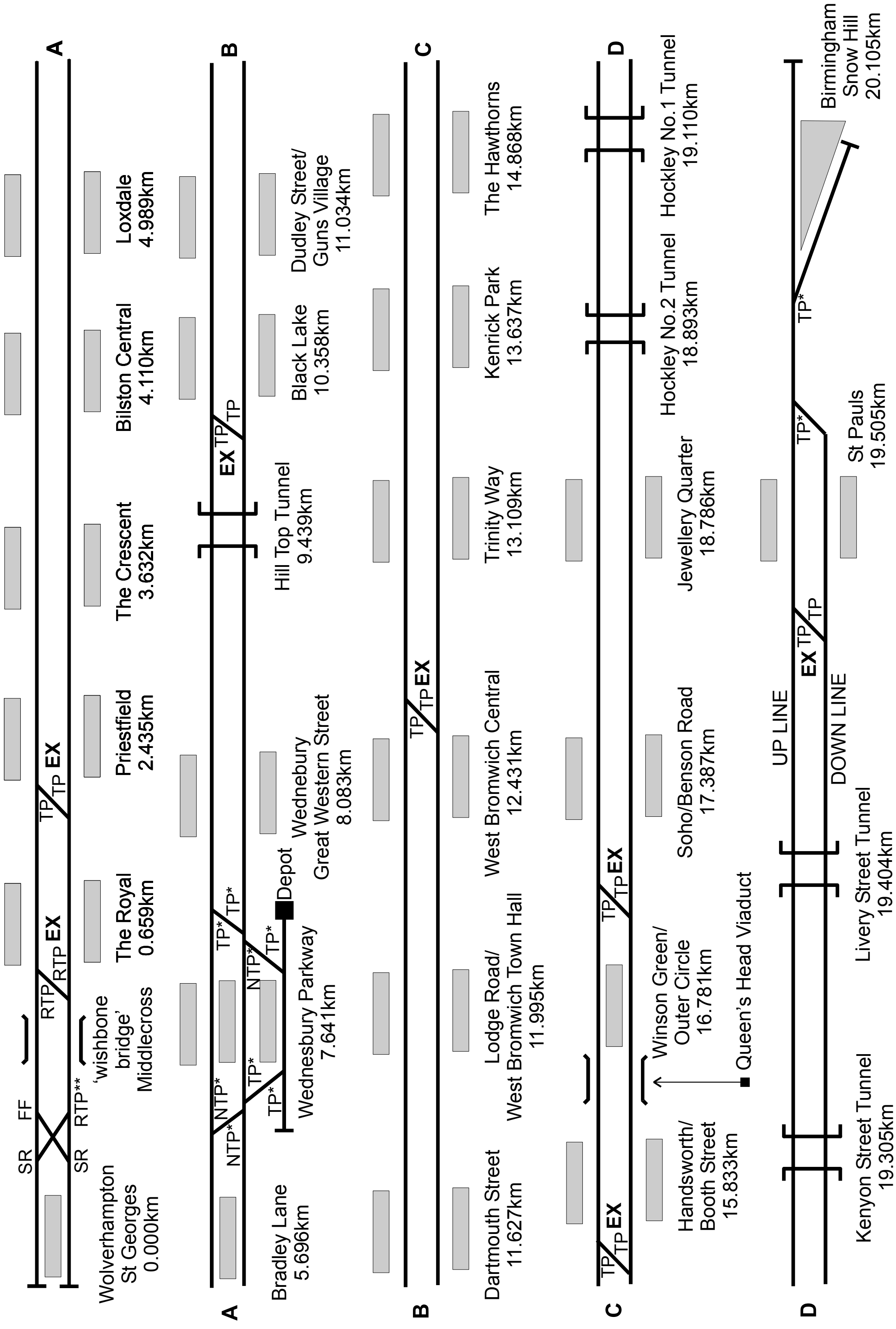
Rail corrugations:

Regrinding has been necessary to remove rail corrugations on the Up Line at the Birmingham Canal bridge, Bilston Road, and at other street-running locations.

Noise:

Wheel/rail noise is experienced on the street running section on Bilston Road.

6.7 FIGURES



Key to point types: SR - Spring Return FF - Flip-flop RTP - Road Trailable (Powered) TP - Trailable (Powered) NTP - Non-Trailable (Powered)

Note: 1. Though some points are trailable, as denoted above, current operation does not allow this type of use.
2. The point denoted '**' at Wolverhampton St George's can be controlled by Drivers and the Control Room.
3. The points denoted '*' at Wednesbury Parkway and Birmingham Snow Hill are Control Room operated.
4. All the Emergency crossovers, denoted 'EX', are only operated by Drivers.

Figure 6.1 Schematic route map of Midland Metro

J Brown

Figure 6.2 Midland Metro grooved rail track during construction

J Brown

Figure 6.3 Midland Metro grooved rail keeper flange wear at Wolverhampton St Georges (11.06.02)

J Brown

(a) Keeper flange wear

J Brown

(b) Worn expansion switch

Figure 6.4 Midland Metro grooved rail on the ‘wishbone bridge’ at Middlecross

J Brown

(a) Turnout crossing at Wolverhampton St Georges

J Brown

(b) Turnout switch rail at The Royal

Figure 6.5 Examples of Midland Metro grooved rail turnout construction, The Royal (11.06.02)

J Brown

(a) General view

J Brown

(b) Groove filled with debris

Figure 6.6 The Midland Metro diamond crossing at Wolverhampton St Georges (11.06.02)

J Brown

(a) Emergency cross-over at Priestfield (11.06.02)

J Brown

(b) Turnout in the Depot

Figure 6.7 Examples of Midland Metro ballasted turnouts

J Brown

(a) Crossing detail

J Brown

(b) Switch rail (Wednesbury Parkway)

Figure 6.8 Midland Metro ballasted turnout detail

J Brown

Figure 6.9 Midland Metro adjustable check rail with spacers associated with 100m radius turnout

J Brown

Figure 6.10 Midland Metro adjustable check plate associated with a 40m radius emergency cross-over turnouts

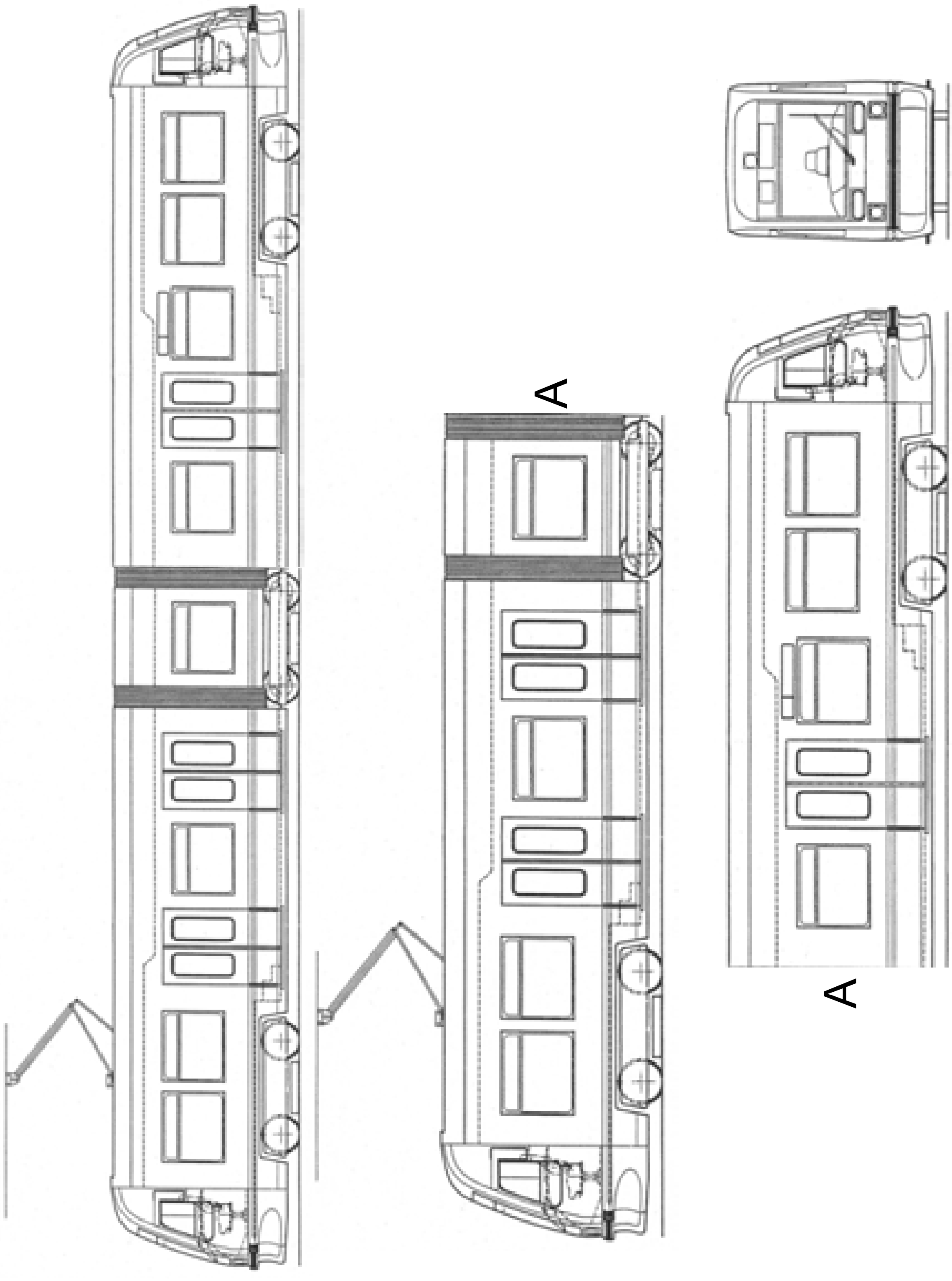


Figure 6.11 Firema Trasporti S.p.A. T69 tram

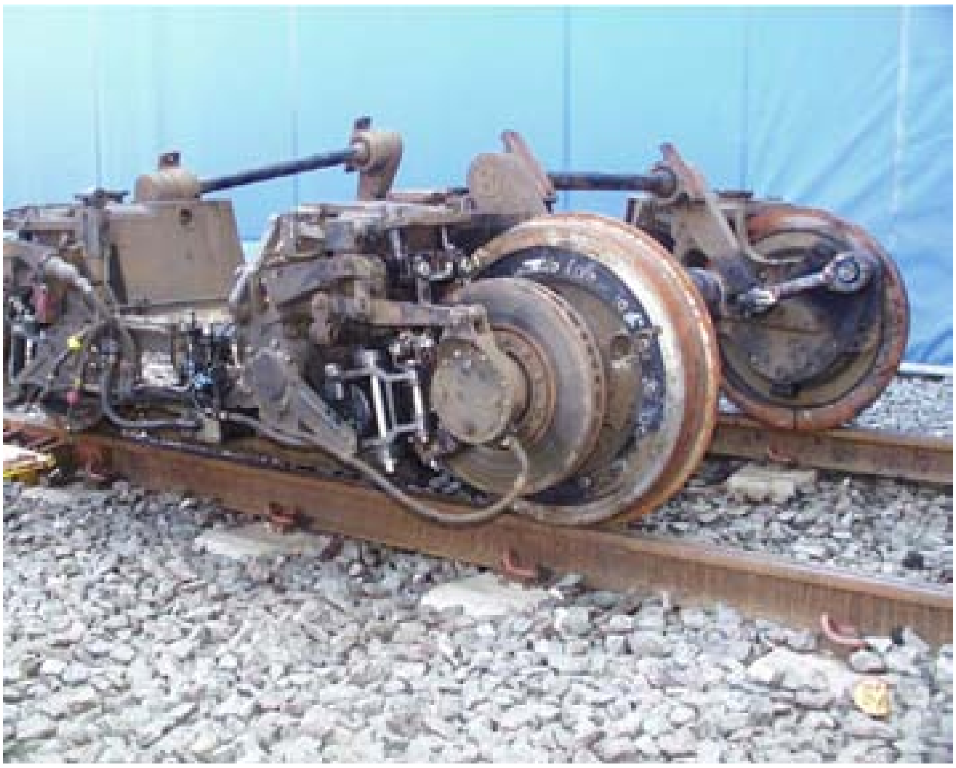
HSE0305-28/13

HSE0305-28/09

Figure 6.12 Midland Metro tram No. 15 at Birmingham Snow Hill Station (20.09.01)

A Steel

Figure 6.13 Midland Metro Firema M046 motor bogie on the wheel lathe



A Steel

(a) General view of truck

J Brown

(b) Back face of an independent wheel

Figure 6.14 Midland Metro Firema unpowered trailer independent wheel truck

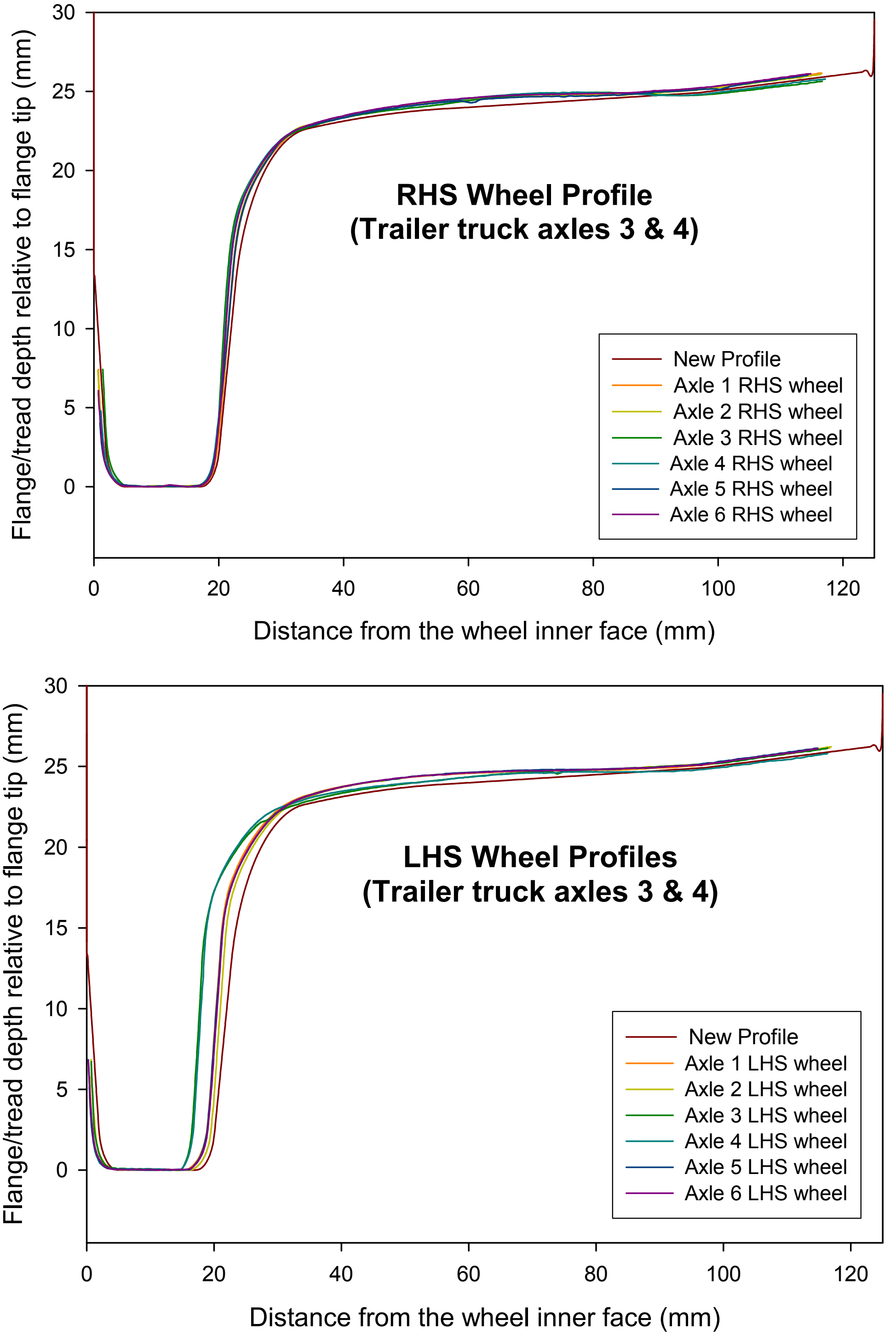
J Brown

(a) New wheel profile

J Brown

(b) Worn wheel profile

Figure 6.15 Midland Metro wheels



Note: Axles 1, 2, 5 & 6 are motor bogie axles
Axles 3 & 4 are trailer 'notional wheelsets' (independent wheels mounted on stub axles)

Figure 6.16 Examples of Midland Metro wheel profiles from Tram 8 after running 11571km (as measured on 07.07.04)

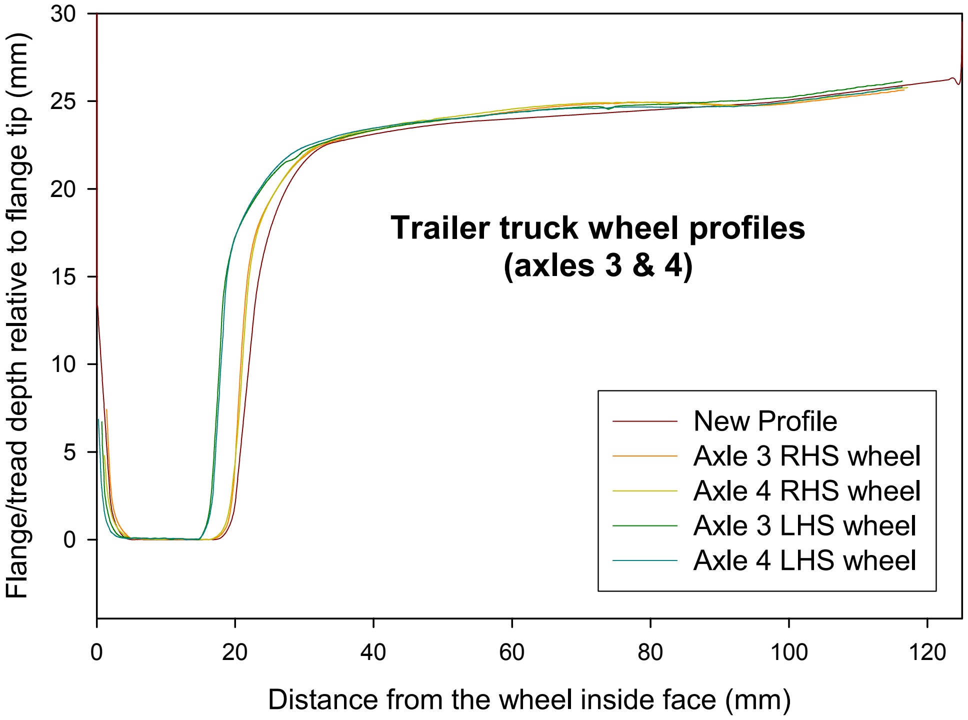


Figure 6.17 Comparison of wheel profiles associated with independent 'notional wheelsets' from the trailing bogie of Tram 8 (07.07.04)

J Brown

Figure 6.18 Drain box covers on Bilston Road (A41)

7 NATIONAL TRAMWAY MUSEUM

7.1 INTRODUCTION

The Tramway Museum Society was founded in 1955 with the aim of creating a working tramway museum. In 1959 the museum was established at Crich on the site of a former quarry, originally owned and operated by the railway pioneer George Stephenson. The Society became a company limited by guarantee in 1962. It is also a registered charity and a designated museum. Since 1959 the Society has laid approximately 1.6km of heritage tramway to allow the operation of heritage tramcars to be demonstrated. A general view of the main street at Crich is shown in Figure 7.1. A Depot complex enables the society to house, restore and maintain their fleet of heritage trams. The running lines are accessed from the Depot by a connecting track system.

7.2 SYSTEM DETAILS

The tramway runs from ‘Crich Townend’ to ‘Glory Mine’, a distance of approximately 1.6km. This route is entirely on private land, but is part paved to give the heritage experience of running through a public street. Tramcars interface with pedestrians and road vehicles in the street area in the traditional manner. The Road Traffic Acts apply to all road vehicles when being operated or parked in the museum’s street. Double tracks run along the paved street area, which extends for approximately 0.5km. Approximately 50m of these tracks are ‘interlaced’, as shown in Figure 7.2 where the line passes beneath a bridge. This demonstrates how double tracks can be accommodated in an area with restricted width without the use of turnouts.

Beyond the street is 0.5km of single-track tramway laid across the floor of the quarry area, which runs to a 100m long passing loop at Wakebridge. There is also a short siding at Wakebridge with a one-tramcar capacity.

The final section of single track takes the tramway out on the edge of an escarpment and where the line climbs to the terminus at Glory Mine. The track layout is in the form of an equal sided loop followed by a stub headshunt. There is also a short siding at Glory Mine, with a two-tramcar capacity.

Work started in 1960 with construction of a short section of single line track running from Crich Townend to the approximately location of the overbridge. Operation with horse tramcar commenced in 1963, followed by electric tramcar operation in 1964. This single line section was doubled and the system further extended northwards as single track into the former quarry area in 1965.

A further single-track extension to Wakebridge, with a ‘Y’ terminus at Wakebridge, was completed in 1968. Glory Mine was reached in 1978 by single track and installation of a passing loop at Wakebridge.

The line is laid entirely in grooved rail.

Schematic route map: See Figure 7.3

Power supply:

The line is electrified at 600Vdc (nominal). Tramcars collect current from the overhead wire system by trolley pole, bow collector or pantograph.

Current is taken from the electricity company's supply at Wakebridge at 11kV and is transformed and rectified to 600 Vdc in the museum's own substation.

Alternative supply to the overhead wires can also be provided from a secondary powerhouse that is located adjacent to the main tram depot which houses both an ac/dc motor-generator set connected to the local three-phase supply in Crich village and a diesel generator set.

Tunnels:

There are no tunnels.

Passenger Service Operations

The tramway is operated daily during spring/summer (1st April to 31st October), after which there is only weekend operation during autumn/winter until Christmas. During the winter services are only provided during the February schools half term and at weekends during March.

A three-tramcar service is provided during the spring/summer period, which is reduced to a two-tramcar service during autumn/winter.

When a three-tramcar service is in operation, the tramcars pass at Wakebridge and on the double track in the street. When a two-tramcar service is in operation, the tramcars pass on the double track in the street. The service normally operates from 10:30hrs to 17:00hrs (weekdays), and 10:30hrs to 17.30hrs at weekends.

On special event days and other special occasions up to 16 to 18 tramcars can be operated and tramcars proceed in convoys of two or three through the single track sections. The convoys pass each other on the double track in the street, at Wakebridge Loop and at Glory Mine terminus. On such occasions tram may be operated in the hours of darkness.

Tram stops:

Details of the tram stops are given in Table 7.1.

Table 7.1 Details of National Tramway Museum tram stops

Northbound (uphill) Stops	***Comments***
Townend Terminus	Passengers board
Bandstand	Passenger request stop
Wakebridge	Passenger request stop
Glory Mine Terminus	Passengers remain on tramcar
Southbound (downhill) Stops	***Comments***
Glory Mine	Compulsory stop before leaving
Wakebridge	Compulsory stop before entering the loop Passenger request stop
Bandstand	Compulsory stop Passenger request stop
Stephenson Place	Compulsory stop Passengers set down

7.3 TRACKWORK

7.3.1 Plain track

Grooved track (street and segregated running):

Rail type	- the majority is BS 7 and BS 8 (see Appendix 1 and 2) recovered from a number of first generation tram systems - 366m of SEI 35G (see Appendix 5) is in place either side the Wakebridge loop

The whole of the line has had the rail head ground to 35G profile.

The line is constructed entirely in grooved rail, fastened to reused concrete sleepers obtained from British Rail or the Ministry of Defence. Some timber sleepers have been used in the construction of points and crossings). The rail fastenings consist bolts and clips to concrete sleepers and dog spikes into timber sleepers. Tie bars are installed at approximate 3m centres on straight track, and at smaller spacing on curves.

Prior to the setting up of the museum there had been an extensive metre gauge quarry railway system on the site, and much of the street section was laid on the former trackbed. In the early years of construction ash ballast was used on the non-street segregated tracks but this has been replaced with stone ballast since 1965.

For track using BS 7 and 8 rail the joints are made using eight-bolt fishplates. The sections of track laid with SEI 35G rails are joined by thermit welding. Future rail replacement will be with SEI 35G.

The cobbled street section has conventional street drains, and the ballasted sections have side drains.

Rail lubricators have been installed at two locations, but currently are not in use though reinstatement work is in hand.

The gauge of straight and curved track is 1435mm

7.3.2 Switches & Crossings

As the purpose of the museum is to display and demonstrate the many different aspects of first generation tramway practice, a wide variety of turnouts and crossings have been incorporated in the system. Traditional cast manganese steel turnouts and crossings have been used. Edgar Allen Ltd or Hadfields Ltd, both of Sheffield, manufactured the majority of these at various times during the 20th century.

The different types of unit incorporated in the museum system are:

Single blade and dummy mate turnout:
When moved to the diverging road a single moveable blade guides the inside wheel flange into the curve. At the same time the other wheel flange tip is supported on a raised section in the cast flangeway to lift the wheel tread clear of the railhead and support it whilst it runs through the open part of the railhead in the casting. Both these elements are shown in Figure 7.4. An equal sided unit, in which both routes out of the turnout are on a curve is shown in Figure 7.5.

Double bladed turnout:
As shown in Figure 7.6, a tie rod that is located in a cast iron conduit covered with a lid, links the two pivoted blade units. When set for the diverging road the outer blade guides the wheel into the curve.

Raised groove crossing:
As a wheel passes through one of these crossings the flange tip is supported on the raised groove that lifts the wheel tread clear of the railhead. At the same time the tread of the other wheel is in full contact with the railhead. Smooth running is experienced with this type of crossing as the wheel is fully supported as it passes through the crossing, as is shown by the bright contact line in the crossing groove shown in Figure 7.7.

'Bump-over' crossing:

For crossings that see only little use, such as emergency crossovers and sidings, a 'bump-over' crossing allowed the through running rail to maintain its full form, as seen in Figure 7.8. This example has been fabricated from plain rail sections, but Edgar Allen Ltd did manufacture castings that could be bolted to the running rail to achieve the same configuration.

7.3.3 Switch operation

All turnouts are sprung in the normal direction and manually operated.

7.3.4 Track maintenance

Some rail corrosion has been found.

7.4 VEHICLES

The museum has about 50 tramcars on display, which includes an operational fleet of approximately 16 to 18 tramcars during the spring/summer months, reducing to 4 to 6 tramcars in the winter period. A selection of tramcars in the Depot is shown in Figure 7.9. To demonstrate the wide variety of heritage tramcars, those selected for operation at any one time will be of different types.

Primarily there are two main types of tramcar, the four-wheel tramcar that runs on a rigid four-wheel truck, and the larger tramcar that runs on a pair of four-wheel bogies.

All tramcars are fitted with manually-operated sanding gear which is tested at the commencement of a tramcar's operating day in addition to the regular planned maintenance.

Trucks for four-wheel tramcars

There are many types of four-wheel truck each with different wheelbase lengths. The principal types operated at the museum are the Brill 21e and the Peckham P 22. The Brill 21e dates from about 1900 and was developed by J G Brill Co of Philadelphia, USA. Peckham Ltd of New York, USA, developed the P22 that dates from 1912. British rolling stock manufacturers used both designs under licence.

As can be seen in Figure 7.10 these trucks have a very basic suspension system and no hydraulic damping, although the secondary suspension leaf springs provide some friction damping.

The trucks of this kind that are operated at the museum have wheelbases varying between 1.829m to 2.591m with wheel diameters in the range 686mm to 838mm. Axle loadings vary between 4 to 6 tonnes.

Maximum traction tramcar bogies

Tramcar bogies are of two types: equal-wheel and 'maximum traction'. Equal-wheel bogies may have one or both axles powered whereas maximum-traction bogies are only driven on the axle with the larger diameter wheels.

The maximum-traction bogie, illustrated in Figure 7.11, was developed to give the economies of a four-wheel truck while enabling a longer tramcar to be built that could negotiate sharp curves. The principal feature of this kind of truck is the large diameter driving wheels and the smaller diameter pony wheels. The driving wheels carry over of 70% of the weight borne by each bogie, giving optimum wheel/rail adhesion. The function of the pony wheels is to give directional guidance. Tramcars fitted with this type of bogie were suited to operation on systems with moderate gradients.

The museum operates a number of different tramcars that incorporates a later Brill 39e type that have driving wheels of 838mm diameter and pony wheels of 559mm diameter. Normally these bogies were arranged such that the pony wheel axles faced towards the centre of the tramcar. In the case of the Gateshead and Oporto tramcars operated by the museum the pony wheel axles are at the outer ends. The weights of the Gateshead and Oporto tramcars are approximately 11 and 16tonne respectively. The maximum-traction truck, of various types, was widely used with large double deck tramcars in London and other major cities in the UK.

Equal wheel tramcars bogies

Equal-wheel tramcar bogies can be of two types depending on whether separate traction motors on each axle are used to power one or both bogie axles. The single-motor type is sometimes referred to as the mono traction bogie, but this should not be confused with the mono-motor bogie used on some second-generation light rail systems in the UK.

The museum operates two double deck and three single deck tramcars with the single motor type of bogie, a typical example is shown in Figure 7.12. The advantage of this configuration is that a long tramcar, such as that shown in Figure 7.13, can be operated with the economies of a four-wheel two motor tramcar, whilst having the advantage of a much improved ride quality. However with this arrangement there is no compensation for weight distribution, which can results in poor wheel/rail adhesion on wet or greasy rails, when accelerating or braking.

The museum also operates a number of tramcars with bogies that have all the axles powered, such as that shown in Figure 7.14, a configuration developed in the 1930's for the large tramcars common on UK city systems. These bogies were usually fitted with powerful high-speed traction motors making them suitable for both hilly and high-speed routes. Typically this type of tramcar was double deck, weighed about 14tonnes, and had a wheel diameter of 711mm.

Tramcar wheel and flange profiles

The museum standardised from its very early days of operation on the wheel profile set out in British Standard BS 101: 1929 (see Appendix 21). In accordance with Sheffield Corporation Tramway's practice of the time, the back-to-back measurement between the backs of the tyres has been increased from the BS nominal standard of 1389mm to 1392mm. This maintains the same flange/wheel tread profile but causes the tramcar to run slightly tighter to gauge. This was done to reduce 'tail wag' on the longer wheel-based four-wheel tramcars of which Sheffield operated a large fleet, several hundred having 2.591m wheelbase and their most modern and last batch of 36 tramcars having a 2.743m wheelbase.

Most wheel/flange wear experienced with museum tramcars is associated with flange thinning, with very little sign of hollow tread wear. Flange wear is measured and assessed using a former Sheffield Corporation Tramways 'worn' profile gauge.

Only one tramcar is fitted with flange lubrication.

7.5 OPERATIONS INFORMATION

Maximum line speed = 24.1km/h

Maximum speed through facing turnouts = 3.2km/h

7.6 OPERATING CHALLENGES

Effect of weather on system:

Tramcars do operate in snow or icy conditions, but it takes only a minor snowfall for operations to be suspended.

Gaps at rail joints on the Wakebridge to Glory Mine section have been increased to overcome problems with rail expansion in hot weather.

Leaf fall:

As all year round operations have increasingly taken place leaf fall, particularly in the woods at Wakebridge, have given rise to adhesion problems. Manual rail cleaning is used to overcome this.

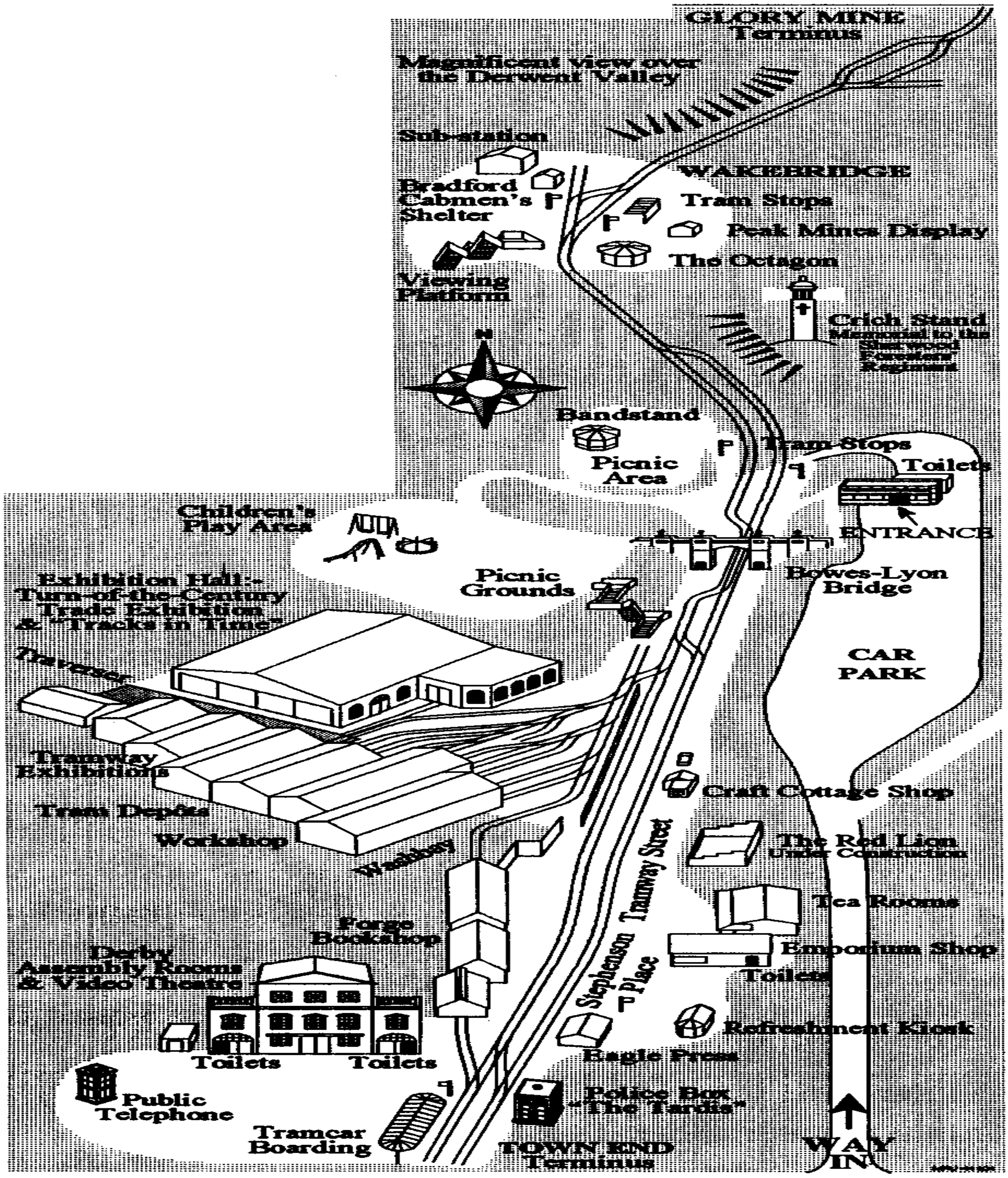
7.7 FIGURES

The Tramway Museum Society

Figure 7.1 Chesterfield tramcar No 7 operating in the street at The National Tramway Museum

The Tramway Museum Society

Figure 7.2 Interlaced track used at a road width restriction at The National Tramway Museum



The Tramway Museum Society

Figure 7.3 Site map of The National Tramway Museum, Crich

The Tramway Museum Society

Figure 7.4 A single movable blade and ‘dummy mate’ turnout at The National Tramway Museum

The Tramway Museum Society

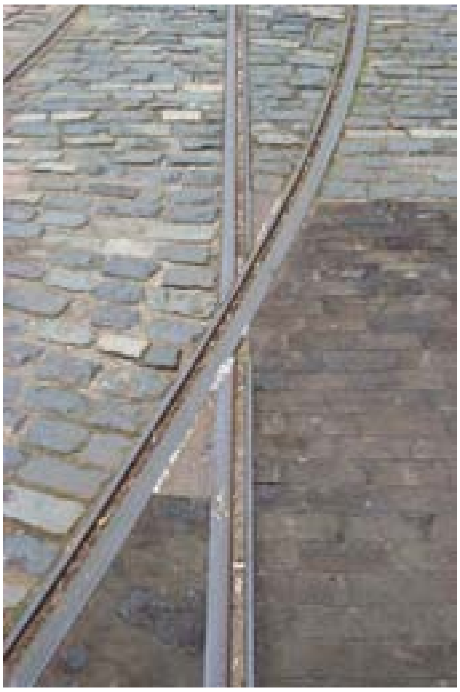
Figure 7.5 A pair of grooved bladed turnout castings with dummy mates at The National Tramway Museum

The Tramway Museum Society

Figure 7.6 A double-bladed turnout at The National Tramway Museum

The Tramway Museum Society

Figure 7.7 A raised groove crossing at The National Tramway Museum



The Tramway Museum Society

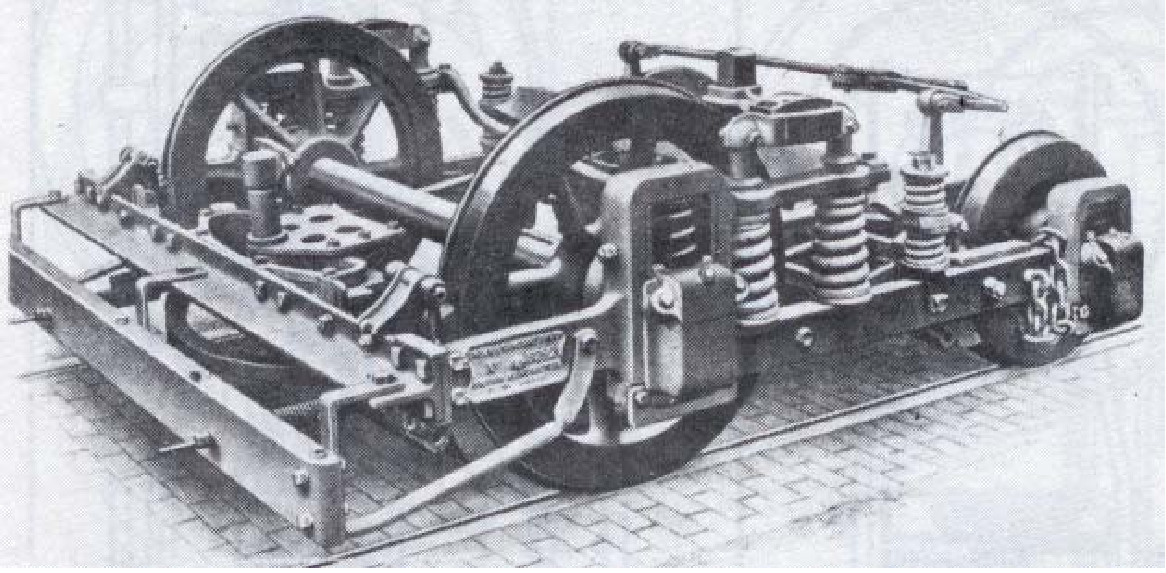
Figure 7.8 A 'bump over' crossing at The National Tramway Museum

The Tramway Museum Society

Figure 7.9 The depot yard area at The National Tramway Museum showing the wide variety of tramcar types operated

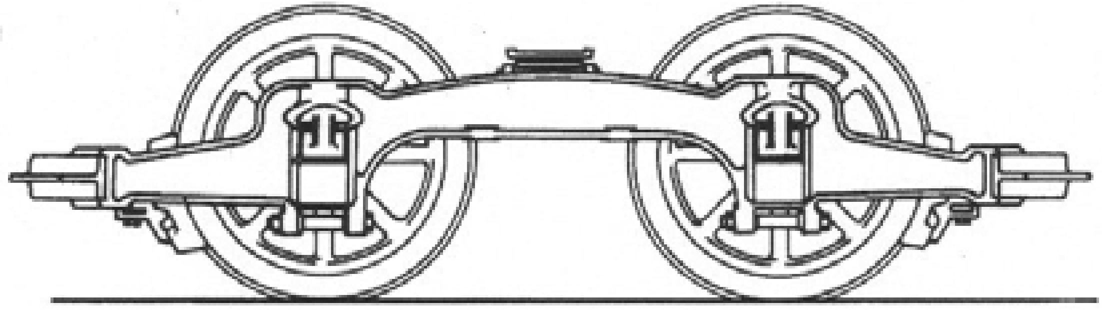
The Tramway Museum Society

Figure 7.10 A P22 truck showing the primary coil and secondary leaf spring suspension, at The National Tramway Museum



The Tramway Museum Society

Figure 7.11 The Brill 22e maximum traction truck



The Tramway Museum Society

Figure 7.12 An equal wheel bogie truck similar to the type used by Blackpool and Fleetwood tramways prior to 1934

The Tramway Museum Society

Figure 7.13 Blackpool tramcar No 167 dating from 1927 at The National Tramway Museum

The Tramway Museum Society

Figure 7.14 Liverpool tramcar No 869 from 1936 standing in the siding at Wakebridge, The National Tramway Museum

8 NOTTINGHAM EXPRESS TRANSIT

8.1 INTRODUCTION

In 1988 Nottingham City Council and Nottinghamshire County Council came together with Nottingham Development Enterprise to promote the city's future transport needs. Nottingham needed a public transport system that could move large numbers of people without contributing to further road congestion and pollution. A feasibility study into a light rail system for Greater Nottingham was commissioned in 1989. A corridor between the Midland railway station (south of the city centre) and the northwest suburb of Hucknall was identified as offering the best potential.

The County Council was already pursuing a scheme to re-open the closed heavy rail line from Nottingham to Worksop to provide a suburban service to the city. It was seen that a light railway could provide additional intermediate stations to the heavy rail stations at Hucknall, Bulwell and Basford and a direct route to the city centre along street tracks. A westerly branch from Old Basford to a former colliery site was seen as providing for park-and–ride traffic from the nearby M1 motorway. Various options for reaching Hucknall alongside the heavy rail alignment were considered.

Following the appointment of consultants to carry out detailed design work a private Bill was submitted to Parliament in November 1991 to obtain legal authority for the project. The original promoters formed a joint venture company, Greater Nottingham Rapid Transit Ltd (GNRT), which was successful in securing private sector funds towards development work. The Greater Nottingham Rapid Transit Act was passed in July 1994.

In 1997 GNRT appointed the Arrow Consortium to implement the project as Nottingham Express Transit (NET). This consortium was made up of:

Bombardier Transportation - electrical and mechanical engineering
Carillion Construction - civil engineering
Transdev and Nottingham City Transport - operation and maintenance
Innisfree and Galaxy Fund - venture capital finance

The construction phase contract structure is illustrated in Figure 8.1.

Following financial restructuring to conform to Private Finance Initiative principles the final approval to start construction was given on 11th May 2000. The diversion of services over the 5km street section started shortly afterwards on 12th June 2000, and was completed by early 2002. The first rails were laid in October 2001.The system opened throughout on the 9th March 2004.

8.2 SYSTEM DETAILS

Schematic route map: See Figure 8.2

Route distances:

The system extends from a terminus at Station Street, adjacent to Nottingham Station, to a terminus at Hucknall, a distance of 12.3km. There is a 1.3km branch to Phoenix. Park Driving end changes are made at termini. Street running accounts for 4 km of the route. There is 300m of elevated tracks.

The distances and times between tram stops are given in Table 8.1 below:

Table 8.1 Distance and times between NET tram stops

From	*To*	*North Bound*		*South Bound*		*Track*
		Distance (km)	*Time[1] (s)*	*Distance (km)*	*Time[1] (s)*	
Station Street	Lace Market	0.569	60	0.569	240	Double/grooved rail & plinth
Lace Market	Old Market Square	0.367	180	0.376	60	Double/grooved rail
Old Market Square	Royal Centre	0.302	60	0.294	180	Double/grooved rail
Royal Centre	Nottingham Trent University	0.379	120	0.375	60	Double/grooved rail
Nottingham Trent University	High School	0.678	60	0.677	120	Double/grooved rail
High School	The Forest	0.550	240	0.557	60	Double/grooved rail
The Forest	Noel Street	0.248	60			Single/grooved rail
Noel Street	Beaconsfield Street	0.339	60			Single/grooved rail
Beaconsfield Street	Shipstone Street	0.307	60			Single/grooved rail
Shipstone Street	Wilkinson Street	0.331	180			Single/grooved rail
Wilkinson Street	Radford Road			0.449	60	Single/grooved rail
Radford Road	Hyson Green Market			0.432	60	Single/grooved rail
Hyson Green Market	The Forest			0.394	240	Single/grooved rail
Wilkinson Street	Basford	1.239	120	1.236	180	Double/ballasted
Basford	David Lane	0.443	60	0.445	60	Double/ballasted
David Lane	Highbury Vale	0.749	120	0.745	60	Double/ballasted
Highbury Vale	Bulwell	1.181	180	1.183	120	Double/ballasted
Bulwell	Bulwell Forest	0.838	60	0.836	120	Single/ballasted
Bulwell Forest	Moor Bridge	0.981	120	0.980	120	Single/ballasted

From	To	North Bound		South Bound		Track
		Distance (km)	Time[1] (s)	Distance (km)	Time[1] (s)	
Moor Bridge	Butlers Hill	1.616	120	1.615	120	Single/ballasted
Butlers Hill	Hucknall	1.150	120	1.154	60	Single/ballasted
David Lane	Highbury Vale (spur)	0.793	120	0.800	120	Double/ballasted
Highbury Vale (spur)	Cinderhill	0.663	60	0.662	120	Single/ballasted
Cinderhill	Phoenix Park	0.437	120	0.436	60	Single/ballasted

Notes:
[1] Time Table journey time

Power supply:

An overhead conductor system at a nominal 750Vdc supplies the trams with power from six sub-stations which are detailed in Table 8.2 below:

Table 8.2 Details of NET sub-stations

Distance (km)[1]	Location	Capacity (kVA)
0	Station Street	1400
2.817	The Forest	1600
4.087	Wilkinson Street	1400
6.503 (mainline) 6.517 (branch)	Highbury Vale	1600
9.502	Moor Bridge	1200
11.114	Butler's Hill	1100

Notes:
[1] Distances measured from Station Street

Tunnels:

There are no tunnels on the system.

Passenger Service Vehicles

Thirteen out of a total of fifteen vehicles are required to operate the full service. Eleven vehicles are required off-peak.

Journeys per route:

The service frequency is given in Table 8.3 below:

Table 8.3 Details of NET service frequency (minutes between trams), Spring 2005

Monday to Friday	*Highbury Vale to City Centre*	*Hucknall/ Phoenix Park to City Centre*
06:00-07:15	10	20
07:15-09:30	5	10
09:30-15:00	6	12
15:00-18:30	5	10
18:30-00:00	10	20
Saturday		
06:00-09:00	10	20
09:00-18:00	6	12
18:00-00:00	10	20
Sunday		
08:00-10:00	15	30
10:00-17:00	10	20
17:00-23:00	15	30

Tram stops:

There are a total of 23 tram stops details of which are given in Table 8.4 below. The trams call at all stops by request (except termini).

Table 8.4 Details of NET tram stops

Tram stop	*Style*
Station Street	2 x Bay platforms (one of tram length x 2 + one of tram length x 1)
Lace Market	Two side platforms
Old Market Square	Two side platforms
Royal Centre	Two side platforms
Nottingham Trent University	Two side platforms
High School	Two side platforms
The Forest	One island + one side platform
Noel Street	Side platform
Beaconsfield Street	Side platform
Shipstone Street	Side platform
Radford Road	Side platform
Hyson Green Market	Side platform
Wilkinson Street	Two side platforms
Basford	Two side platforms
David Lane	Two side platforms
Highbury Vale (mainline)	Island platform
Highbury Vale (branch)	Island platform
Bulwell	Island platform
Bulwell Forest	Island platform
Moor Bridge	Island platform
Butlers Hill	Island platform
Hucknall	Two bay platforms
Cinderhill	Side platform
Phoenix Park	Island platform

Start of service:

The NET opened throughout on 09.03.04.

8.3 TRACKWORK

8.3.1 Plain track

Grooved track (street running):

The grooved rail used throughout the system is SEI 41GP (see Appendix 7 for profile) supplied by Corus. The rail is continuously welded.

The rail was supplied coated with a 10mm thickness of ALH6 polymer, as Figure 8.4(a), and was fixed to a continuously reinforced concrete slab by means of fixing plates on levelling bolts shown in Figure 8.4(b). The concrete slab was 2.300m wide and 200mm thick as shown in Figure 8.3(a). In those locations sensitive to ground-borne noise and vibration a horizontal vibration absorbing membrane (Getzner Sylomer R30) was laid beneath the 280mm thick track slab as shown in Figure 8.3(b). The rail was then encast with a second stage layer of reinforced concrete up to rail head level, which provided permanent load-bearing fixity, and rendered the fixing plates redundant. The surface varies according to location, and includes blacktop between concrete upstands, and full width impressed concrete. A typical cross section through the floating track slab is shown in Figure 8.3, and the track bed under construction is illustrated in Figures 8.5, 8.6 & 8.7.

A procedure for the replacement of on-street grooved rail has been prepared and demonstrated.

Rail drain boxes connected to the street drainage system, as shown in Figure 8.8, are used to drain the rail groove. The system incorporates rodding boxes to assist drain cleaning. Cross drains have been installed at the transition from slab to ballasted track to try and prevent rainwater carrying debris into the ballast and creating drainage problems in this critical area.

There are no fixed lubrication systems associated with grooved rails. Manually applied bio-degradable heavy duty grease is used.

The nominal NET grooved track dimensions are given below in Table 8.5:

Table 8.5 NET nominal grooved track dimensions

Gauge (straight & curved track)	1435mm
Rail inclination	Vertical
Minimum track radius	(Lace Market) 18m
Maximum track cant	35mm
Maximum track gradient	(Both sides of The Forest) 8.5%
Rail running surface relative to road	Level

An example of completed grooved rail track is shown in Figure 8.9.

Ballasted track:

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

Corus supplied the rail.

Stanton Bonna twin block concrete sleepers together with Pandrol rail clips of type e1809 and 10mm rubber pads are used for ballasted track, as shown in Figure 8.14. The rail is continuously welded. At termini, the northerly approach the tram over rail bridge close to the Wilkinson Street stop and David Lane the concrete sleepers are embedded in concrete, as shown in Figure 8.11. Prominent in Figure 8.12(a), and seen in detail in Figure 8.12(b) & (c) are double reliance fastenings which provide a transition from ballasted to concrete embedded sleeper track. The elevated ballasted tracks approaching the Station Street terminus are shown in Figure 8.19 during construction.

There is plain track within the Depot yard that has timber sleepers, as Figure 8.15. Expansion switches are also fastened to timber sleepers, a typical example of which is shown in Figure 8.16.

There is one Portec fixed track lubrication unit on the 23m radius curve at Wilkinson Street.

Level crossings were constructed from Bomac rubber elements or use grooved rail embedded in concrete.

Buffer units are used, such as the example shown in Figure 8.13.

The nominal NET ballasted track dimensions are given below in Table 8.6:

Table 8.6 NET plain ballasted track dimensions

Gauge (straight track)	1435mm
Gauge (curved track)	(Over a 10m distance at Lace Market) 1441mm
Rail inclination	1 in 40
Minimum track radius	(Wilkinson Street) 25m (Depot) 23m
Maximum track cant	100mm
Maximum track gradient	3.37%

8.3.2 Switches & Crossings

Grooved track (street running):

All turnouts are constructed from SEI 41GP rail (profile as Appendix 7), and were supplied by Edgar Allen Engineering Ltd. The turnout types are listed in Table 8.7 below:

Table 8.7 NET grooved turnout types

Switch Type	*Crossing Type*	*Left Switches*	*Right Switches*
Interlaced	Unknown	-	1 (FOP6)
4G	1 : 4.06	7	2

The method of track bed construction and rail fixing was similar to that for plain track.

Turnouts have drains beneath the switch machine boxes.

The nominal grooved turnout (design) dimensions given in Table 8.8.

Table 8.8 NET grooved turnout dimensions

Gauge	1435mm
Radius	25m & 100m (see Table 8.7)
Switch rail type	4G
Checkrail flangeway gap	28mm
Switch opening	47mm to 54.8mm (depending on radius)
Flange tip running	There is no flange tip running
Diamond Crossings	Two units (Noel Street stop & near the Depot)

<u>Ballasted track:</u>

Corus Cogifer Switches & Crossings Ltd. supplied all turnouts, which were fabricated from BS 80A flat bottom rail (profile as Appendix 10) with timber sleepers and Pandrol e1809 fastenings. Some turnouts are equipped with heaters. The turnout types are listed in Table 8.9 below:

Table 8.9 NET ballasted turnout types

Location	*Switch Type*	*Crossing Type*	*Left Switches*	*Right Switches*
Reserved track including stops	BV8	1 : 1.8	11	9
	SV40	1 : 3.8	2	-
	CV40	1 : 3.8	3	3
Depot	SV40	1 : 3.8	4	-
	CV40	1 : 3.8	4	8

The nominal plain ballasted turnout (design) dimensions are given in Table 8.10.

Table 8.10 NET plain ballasted turnout dimensions

Gauge	1435mm
Radius	See Table 8.9
Switch rail type	Flexible[1]
Crossing flangeway gap	44mm to 60mm
Check rail flangeway gap	28mm For heavy rail maintenance vehicles adjustable check rails allow a 42mm gap to be set
Minimum flangeway through switches	35mm
Switch opening	60mm
Additional sleeper bracing to maintain alignment	Concrete embedment of sleepers

Notes:
[1] The Depot units have flange relief of the stock rail to ease manual operation.

8.3.3 Switch operation

Grooved track (street running):

Grooved track turnouts are equipped with Hanning & Kahl type HWE61AVV-ZVV electro-hydraulic point setting mechanisms (twin solenoid and hydraulic damping) or manually set sprung units with end position damping of type HWU 40D.

Ballasted track:

Hanning & Kahl type HWE61AVV-ZVV electro-hydraulic units (twin solenoid and hydraulic damping) are used on the ballasted track turnouts on the mainline with HWU 160D manually set sprung units with end position damping in the Depot.

Maintenance regime (all track):

Weekly detection test and clean.
Five weekly interval switches and crossings inspection.
Six monthly switch machine service.

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 2mm and break at 3mm.

8.3.4 Track maintenance

Four weekly inspections. Maintenance planned according to condition monitoring

Annual ultrasonic rail inspection is planned.

Full stressing records are available for the ballasted track.

8.4 VEHICLES

All of the 15 identical fixed set, articulated, five segment, Incentro vehicles used on the system were supplied by Bombardier Transportation. A typical vehicle is shown in Figure 8.24.

The vehicles external appearance is shown in Figure 8.25. The vehicles run on three trucks with four independent wheels per truck, which permits 100% low floor. A separate traction motor powers each wheel of the two end trucks. The four wheels of the centre truck are unpowered.

The vehicle passenger capacity (normal load) is 54 fixed seats plus 4 tip-up and 2 perch seats, giving a total seating capacity of 64. The total maximum seated plus standing capacity is 194.

Leading dimensions: See Table 8.11.

Table 8.11 NET vehicle dimensions

Length over couplers	33.000m
Body shell width	2.400m
Height of body shell	3.350m
Floor height above head of rail	300mm
Distance between body articulation centres	6.700 + 5.00 + 6.700m
Distance between truck centres	11.700m
Truck axle spacing	1.800m
Wheel diameter	(New) 660mm

Bogie details: See Table 8.12.

Table 8.12 NET vehicle bogie details

Design	Bombardier Transportation
Motor truck	Two motor trucks One truck each end Four independent wheels per truck Each wheel powered by own asynchronous traction motor Integral dive and wheel hubs Coil spring primary and secondary suspension Sanding system
Trailer truck	One centre truck Four independent wheels per truck Coil spring primary and secondary suspension Flange lubrication

Vehicle weights: See Table 8.13.

Table 8.13 NET vehicle weights

Tare weight	39300kg
Weight of crush laden	59875kg

Wheel details: See Table 8.14.

Table 8.14 NET vehicle wheel details

Type	SAB Resilient wheels (Gutehoffnungshütte Radsatz GmbH wheel profile drawing No. P-3-102639)
Diameter	660(+/-0.5)mm (new) 580mm (worn)
Tyre width	110(+1/-0)mm
Profile	See Appendix 22 (Flange width to be maintained within 18 – 24mm)
Re-profiling criteria	Awaiting operating experience
Wheel discard criteria	Minimum 580mm diameter (machined tell-tale on outer wheel face)
Tyre material	Special steel V101 (tensile strength: 950-1080N/mm^2)
Wheelset back-to-back	1380(+1/-3)mm
Lubrication	Delimon flange lubrication system fitted to wheels of the trailer (centre) truck acting on both inner and outer flange faces

The wheel lathe, located in the Depot, is shown in Figure 8.26.

8.5 OPERATIONS INFORMATION

Vehicle operations

The maximum line speed on segregated track is 80km/h, and 50km/h on street.
National speed limits are observed during on-street running.

The maximum service acceleration is 1.2m/s^2.

The vehicles can achieve maximum service braking of 1.4m/s^2 and hazard braking of 2.5m/s^2.

Operating environment

The vehicles are fitted with air blown sand units that can apply sand to all wheels of the leading motor bogie. The sanding is controlled automatically, though the driver can also directly control sand application with a ‘sand’ button on the control console. The first daily service run in each direction may experience some slip/slide that requires sanding on hills.

Flooding has occurred at The Forest due to leaves and sand blocking drains. This stop is located on the side of a valley with the switch tips in the valley bottom. Larger drain sizes for both the road and tram track are required to prevent this.

8.6 OPERATING CHALLENGES

Noise

A benchmark inter-stop noise level of 76dB has been set.

Ride quality

A benchmark value of 38mg has been set.

8.7 FIGURES

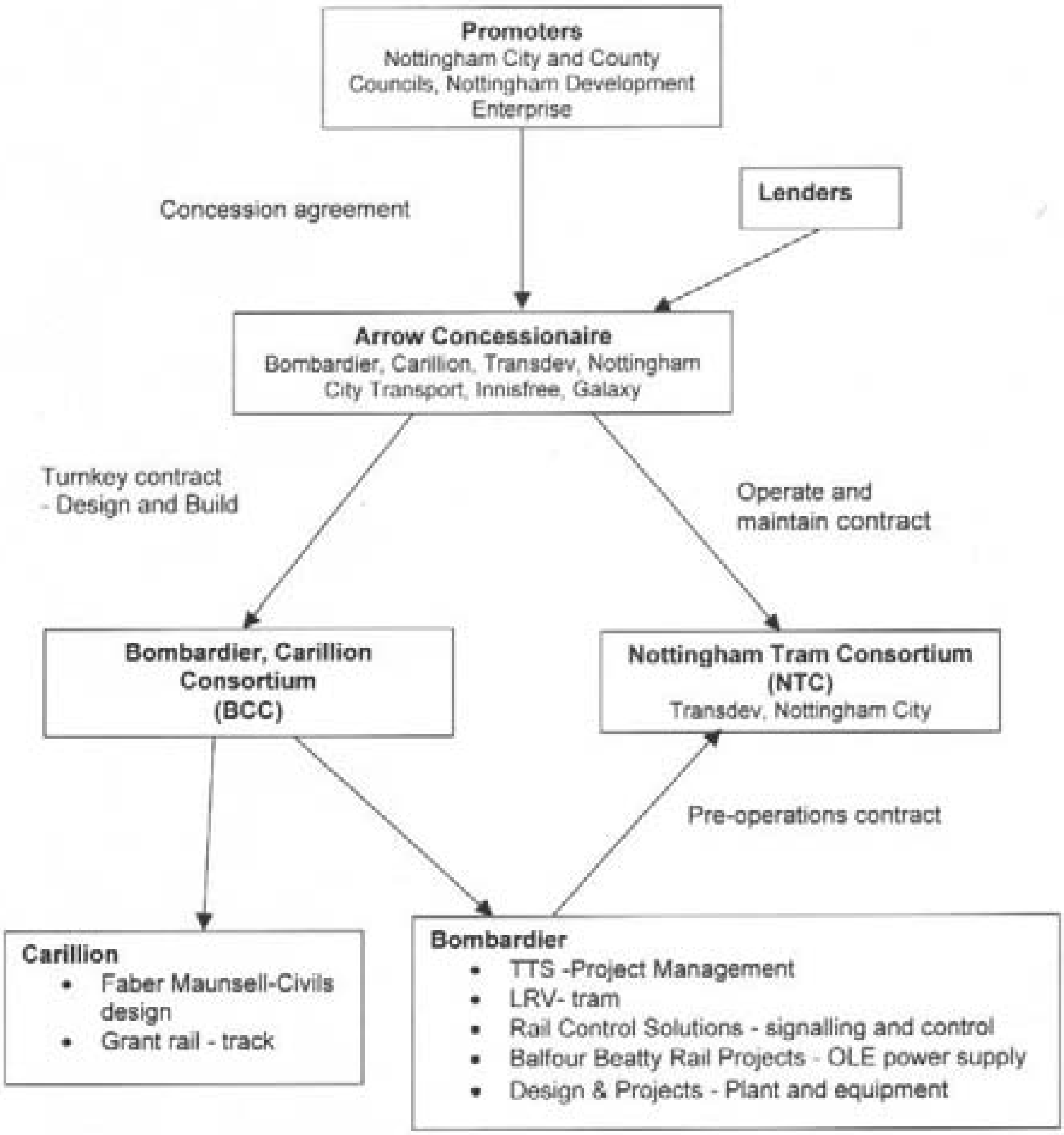


Figure 8.1 Contract structure of Nottingham Express Transit (NET)

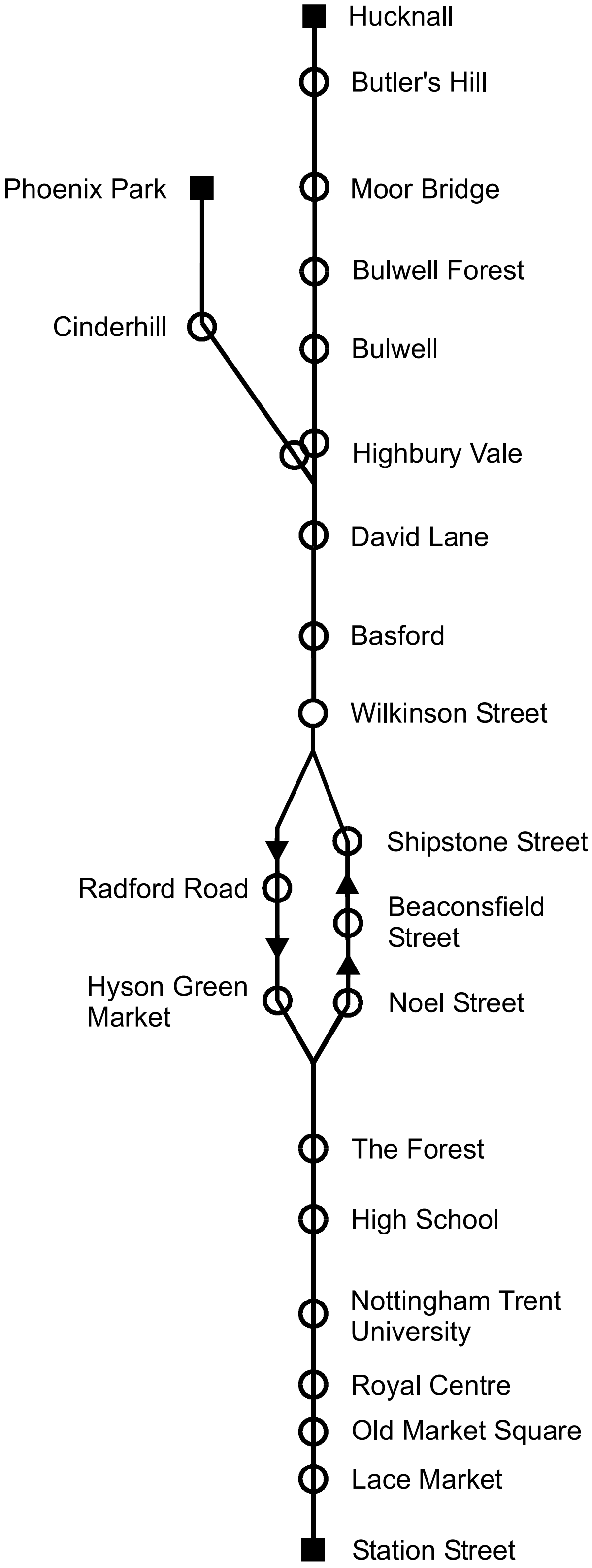


Figure 8.2 Schematic route map of Nottingham Express Transit (NET)

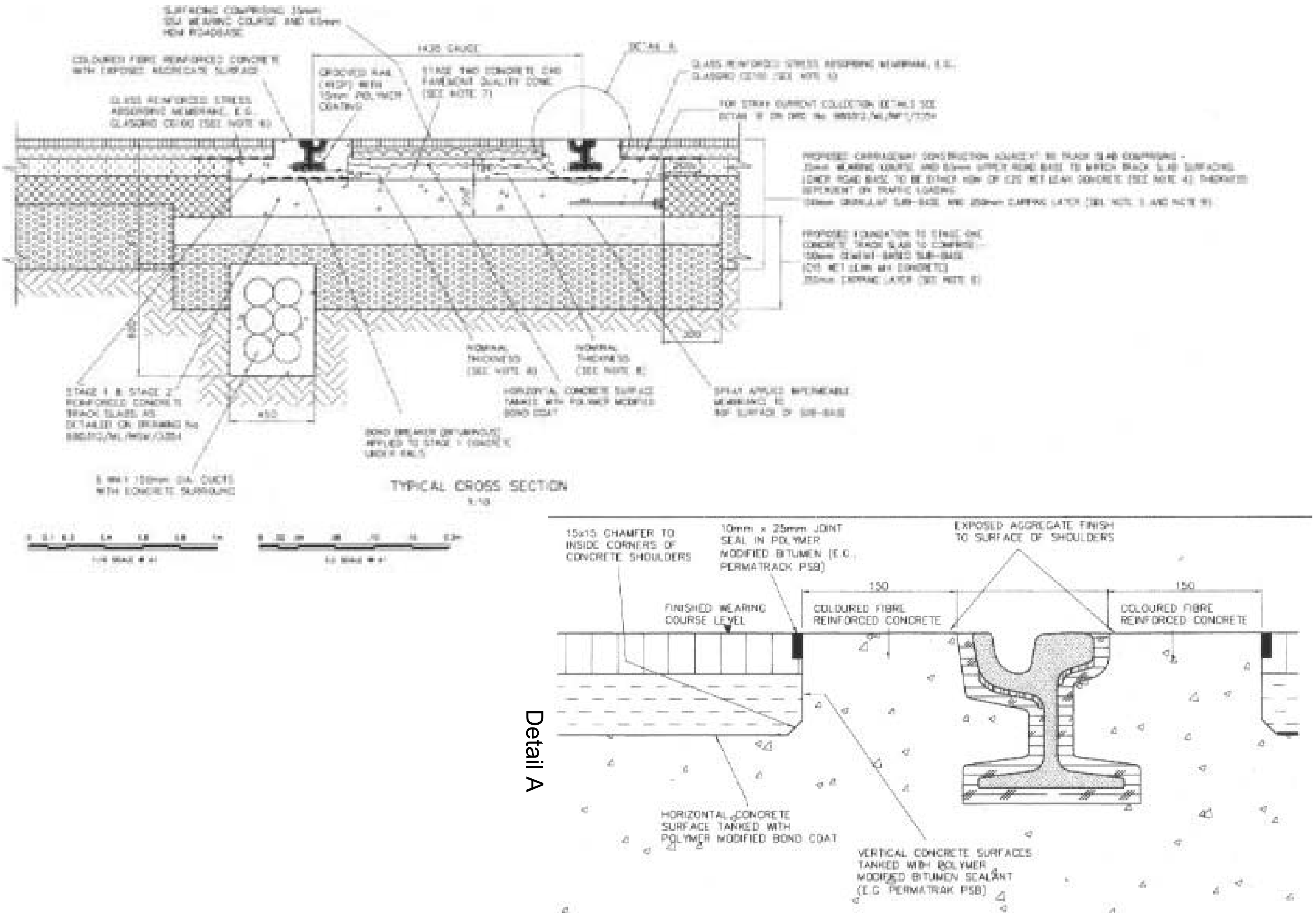


Figure 8.3(a) Drawing showing a typical cross section through on street in traffic NET trackform (by courtesy of Carillion)

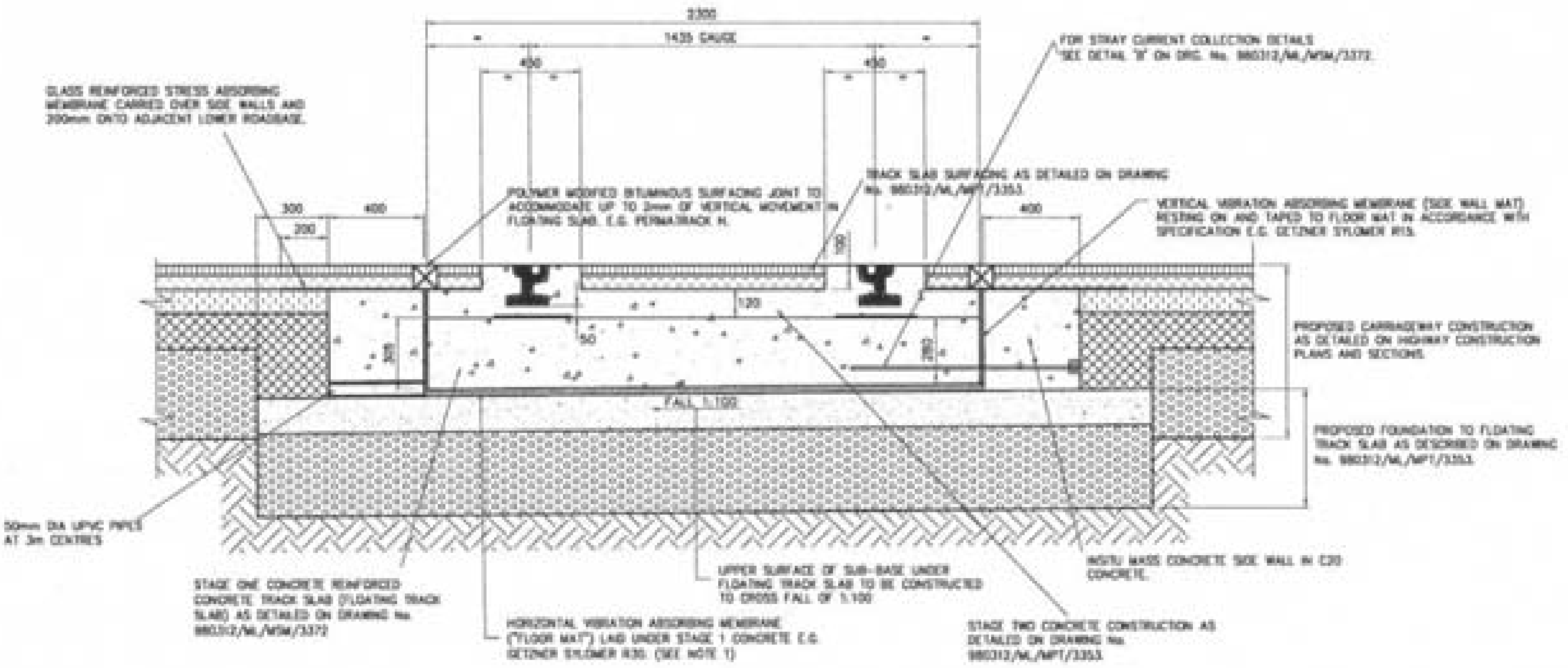
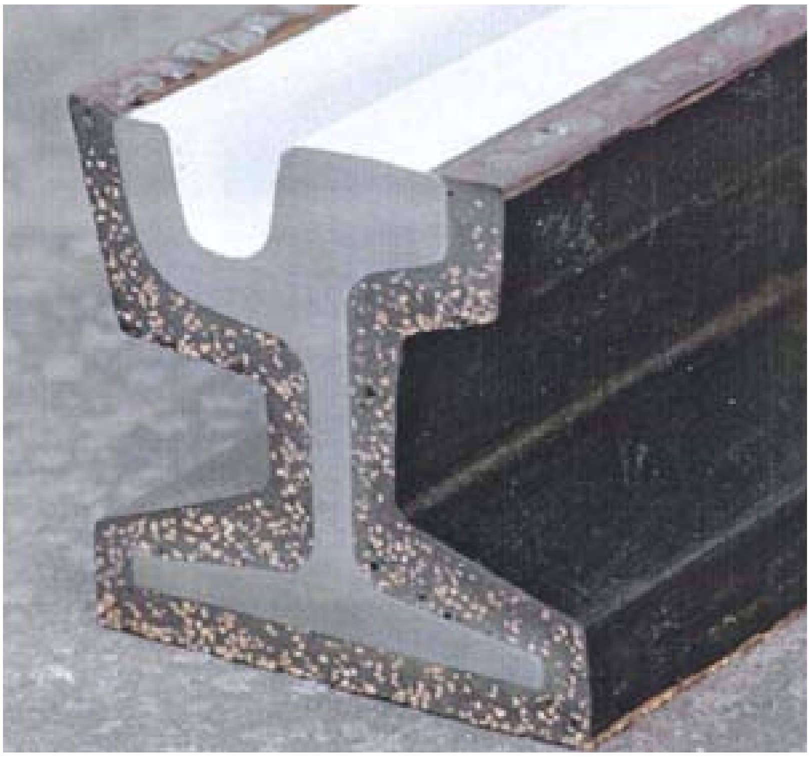


Figure 8.3(b) Drawing showing a typical cross section through NET on street track slab that incorporates vibration absorbing mat (by courtesy of Carillion)



NTC

(a) SEI 41GP grooved rail pre-coated with ALH6 polymer

D Keay 3141

(b) Detail of fixing plate and levelling bolt (05.12.01)

Figure 8.4 NET grooved rail track construction

D Keay 3487

(a) Installation of rail on concrete slab (05.02.02)

J Brown

(b) Completed track and crossing at the junction of Noel Street and Terrace Street (27.08.03)

Figure 8.5 NET grooved rail track on Noel Street

NTC

(a) Straight track

J Brown

(b) Interlaced track at The Forest (08.04.03)

Figure 8.6 Grooved rail track construction at the concrete second stage, NET

NTC

(a) Completed second stage concrete awaiting the blacktop

D Keay 3489

(b) Completed track

Figure 8.7 The final stage of NET grooved rail track construction

J Brown

(a) Rail and street drainage

D Keay 3490

(b) Rodding access

D Keay 3491

(c) Track drain

Figure 8.8 Details of NET grooved track street drainage


NTC

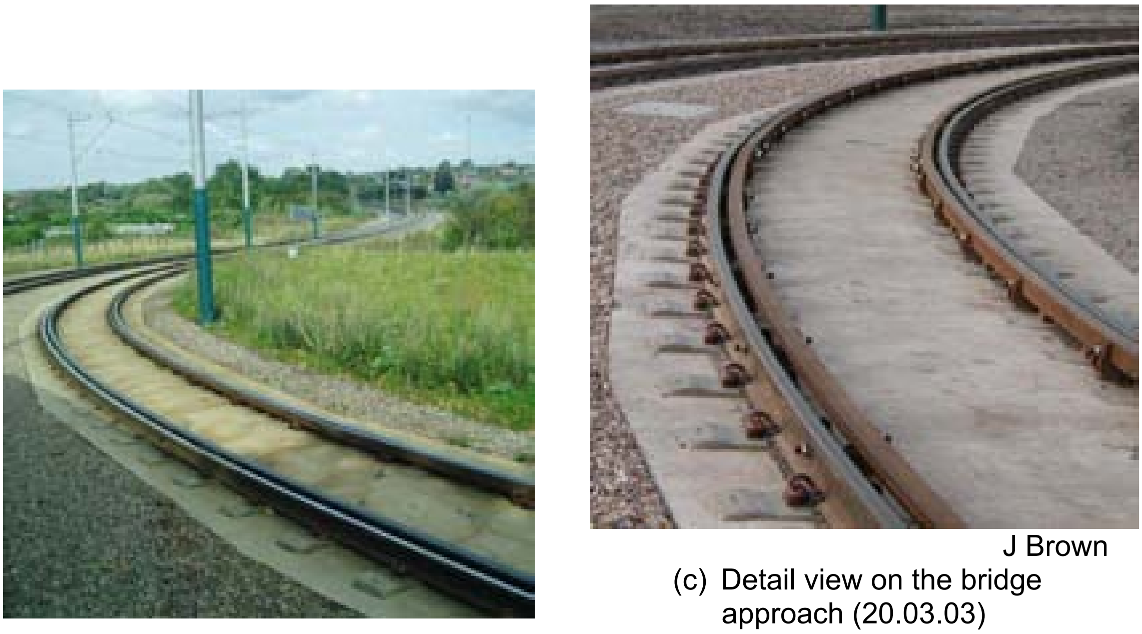
Figure 8.9 Completed NET grooved rail track, 18m radius curve (05.02.02)


J Brown

Figure 8.10 Grouting of NET flat bottom rail fastenings to the track slab at Station Street (08.04.03)

J Brown

(a) David Lane (20.03.03)



J Brown

(c) Detail view on the bridge approach (20.03.03)

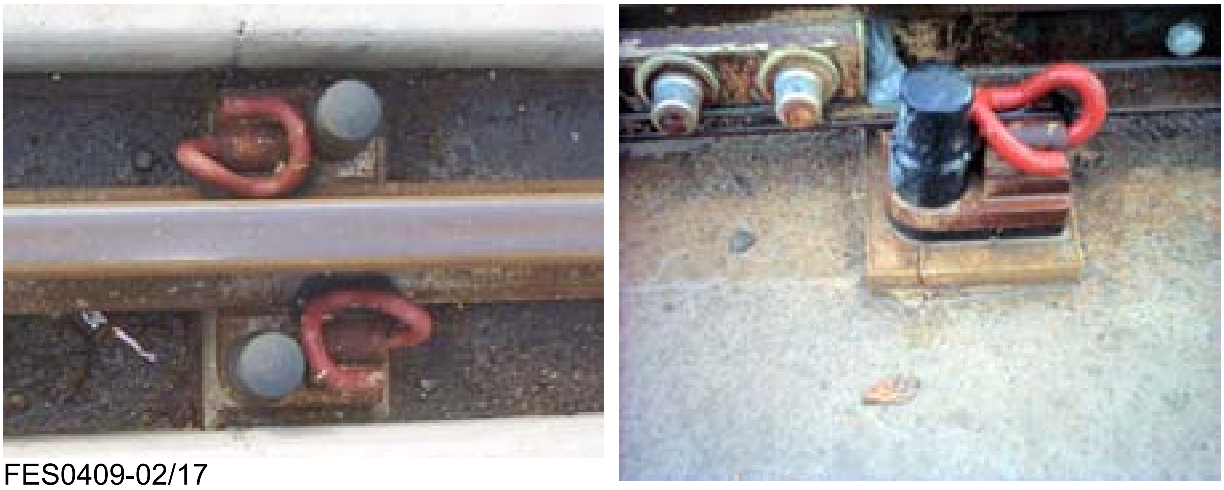
FES0409-02/07

(b) Wilkinson Street approach to tram over rail bridge (11.09.04)

Figure 8.11 NET concrete embedded sleepered track

FES0409-02/15

(a) Transition from double resilience to standard fastenings



FES0409-02/17

NTC

(b) Detail plan view of fastening (c) Detail side view of fastening

Figure 8.12 Double resilience fastenings at the transition to ballasted track from concrete embedded sleepered track, Hucknall terminus (11.09.04)

FES0409-02/25

Figure 8.13 Buffer unit on concrete embedded sleepered track at the Hucknall terminus (11.09.04)

FES0409-02/29

Figure 8.14 NET ballasted track with concrete sleepers (11.09.04)

FES0409-02/02

Figure 8.15 Example of track with timber sleepers in the NET Depot yard (11.09.04)

J Brown

Figure 8.16 NET ballasted track expansion switch at Highbury Vale (20.03.03)

J Brown

Figure 8.17 Check rail fitted to Depot curved track

J Brown 0653

Figure 8.18 View of the Delta junction from the Wilkinson Street stop (Depot leg entering from the left)

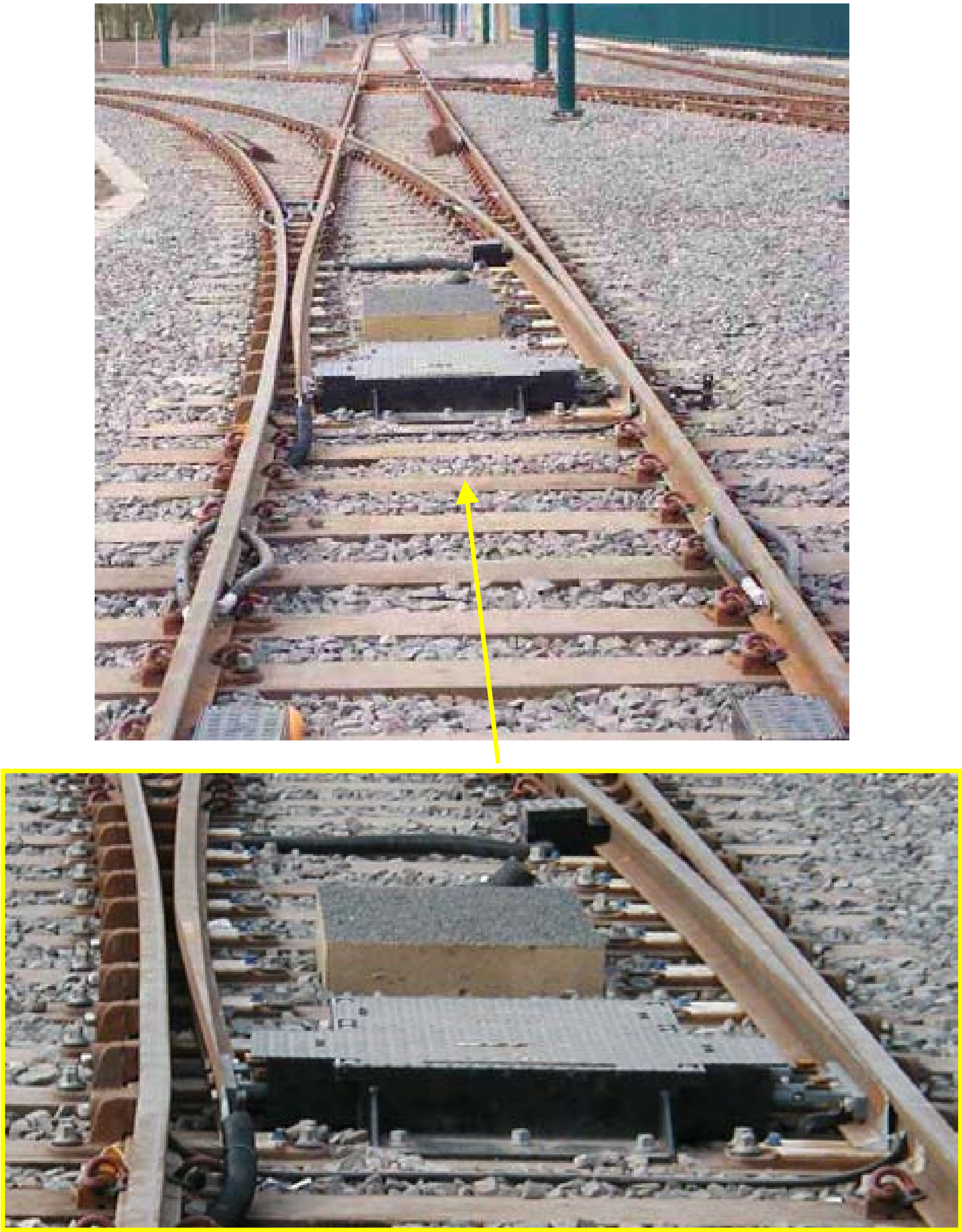
J Brown

(a) During construction looking towards Station Street terminus

J Brown

(b) Completed formation looking towards the Lace Market (08.04.03)

Figure 8.19 Scissors crossover on the approach to the Station Street terminus



J Brown

Figure 8.20 NET ballasted turnout at Highbury Vale

J Brown

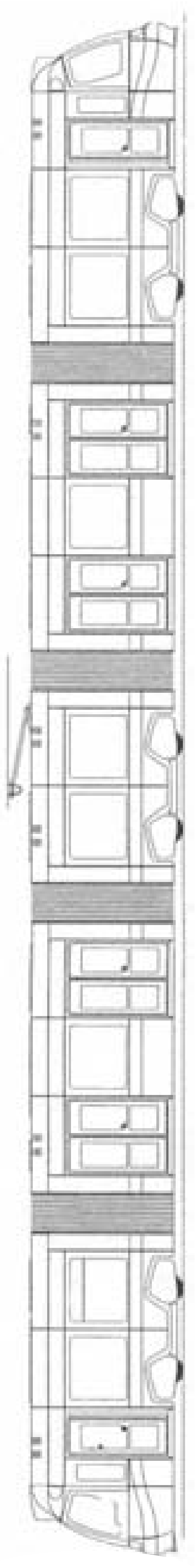
Figure 8.21 Turnout crossing nose of at Station Street, NET (08.04.03)

J Brown

Figure 8.22 NET switch rail tip (27.03.03)


J Brown

Figure 8.23 Hanning & Kahl switch mechanism at Phoenix Park (08.04.03), NET



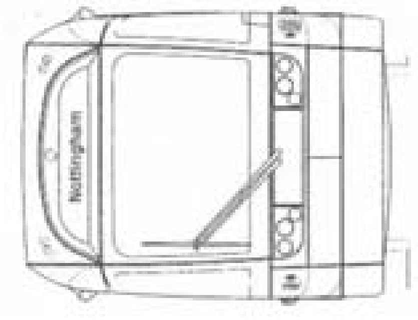


Figure 8.24 The NET Incentro tram

NTC

(a) View of the leading end Vehicle 214

J Brown

(b) View of the trailing end of Vehicle 213

Figure 8.25 NET Bombardier 'Incentro' tram

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(a) The lathe pit

FES0409-02/42

(b) Detail of the wheel lathe

Figure 8.26 The NET wheel lathe at the Depot (11.09.04)

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

<u>Schematic route map:</u> See Figure 9.1

<u>Route distances:</u>

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.

Power supply:

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

<u>Ballasted track:</u>

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.

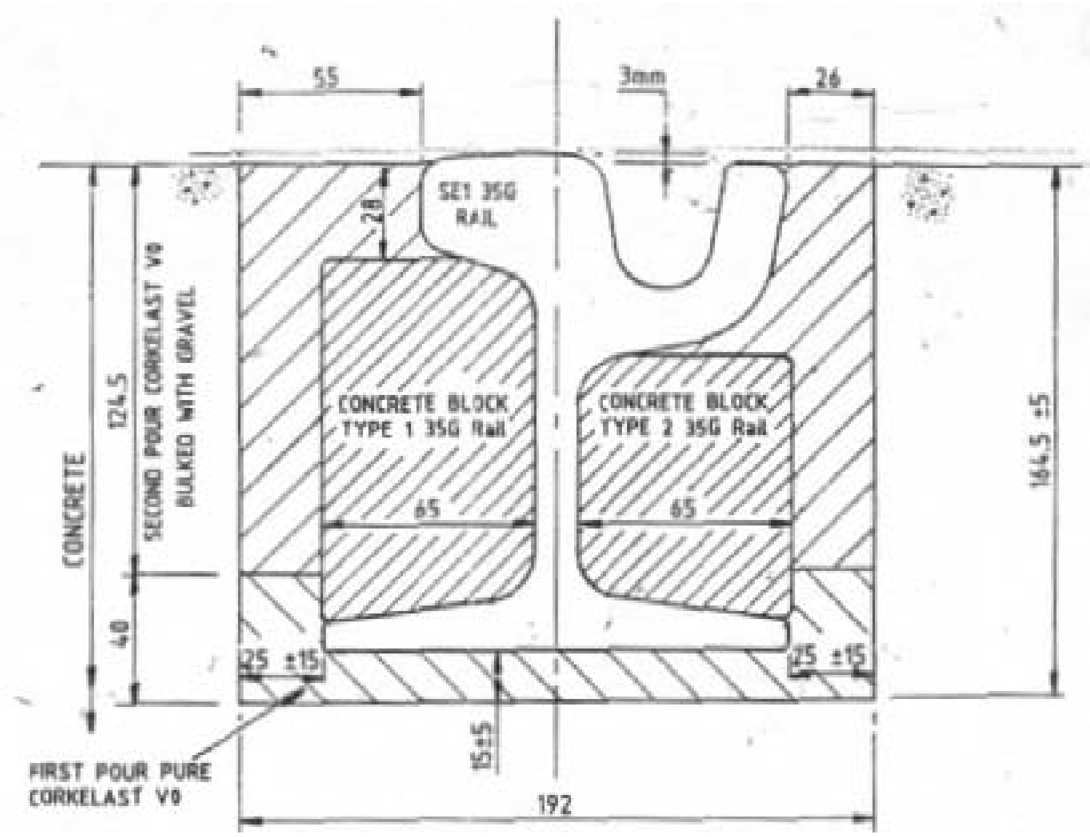
Rail corrugation is found all over the system due to acceleration and braking.

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

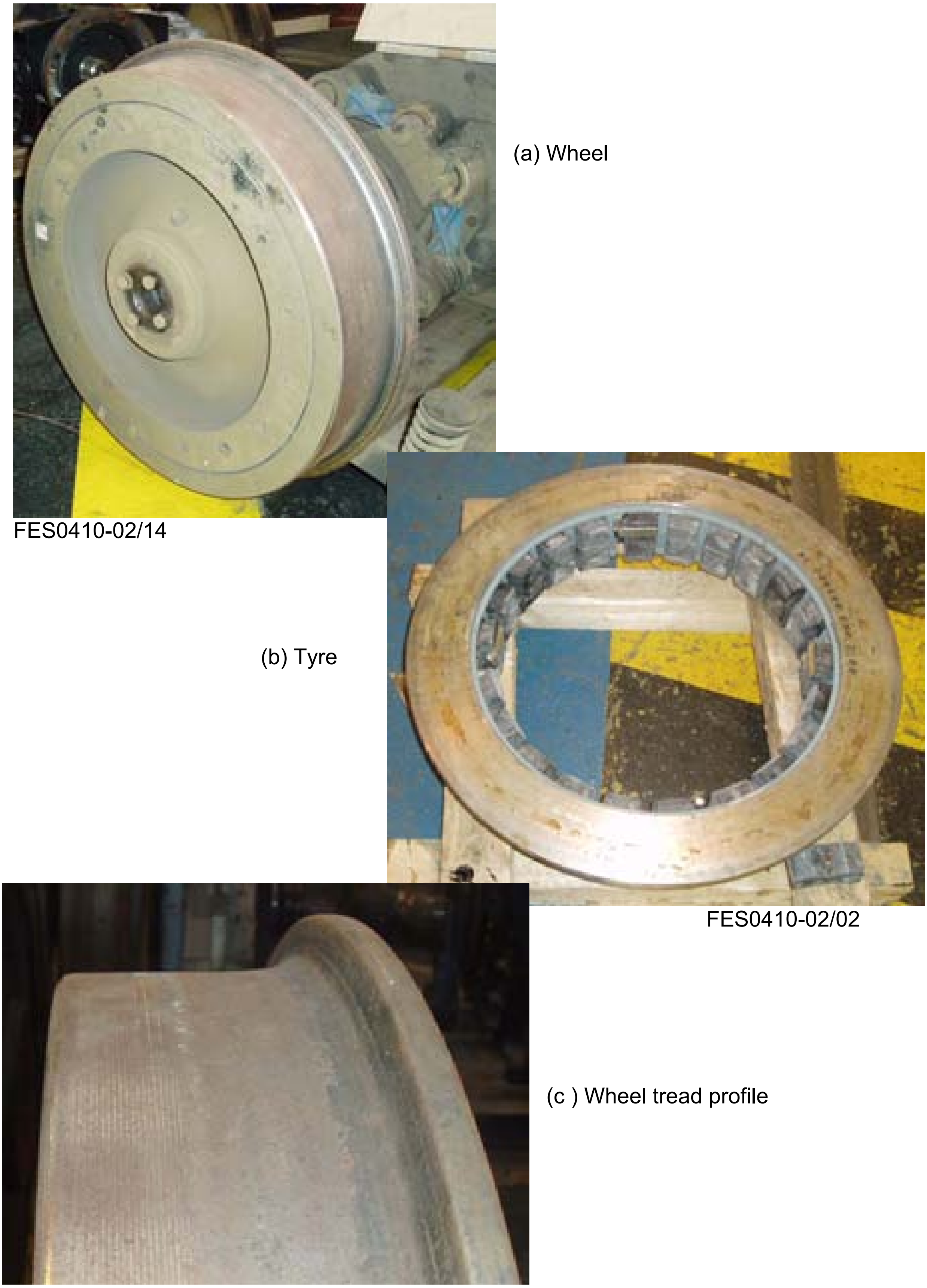
(b) Gearbox, flexible drive and brake disc

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

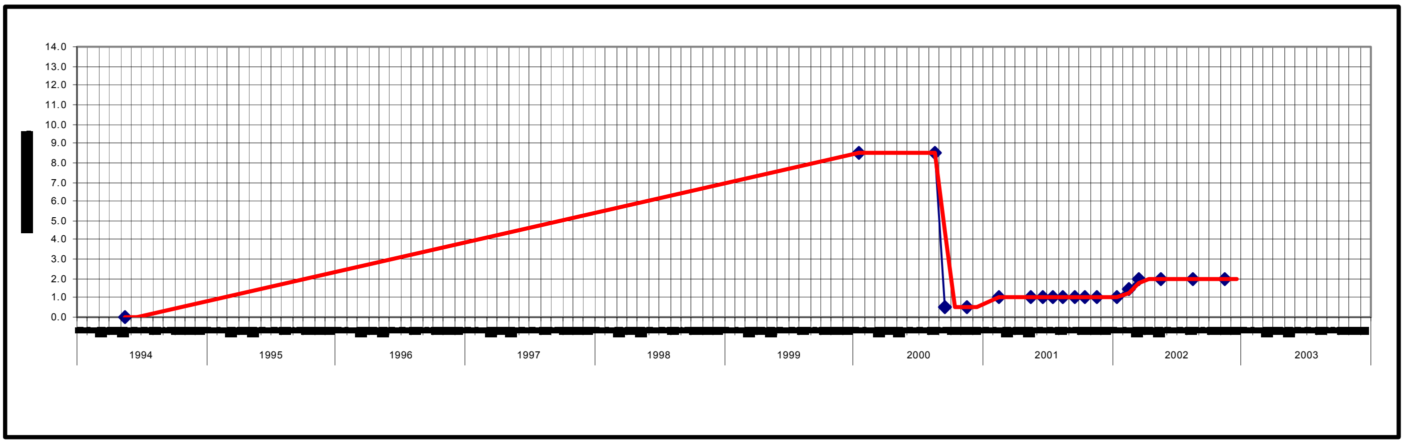
FES0410-02/02

(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.

Leading dimensions: 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

Bogie details: 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

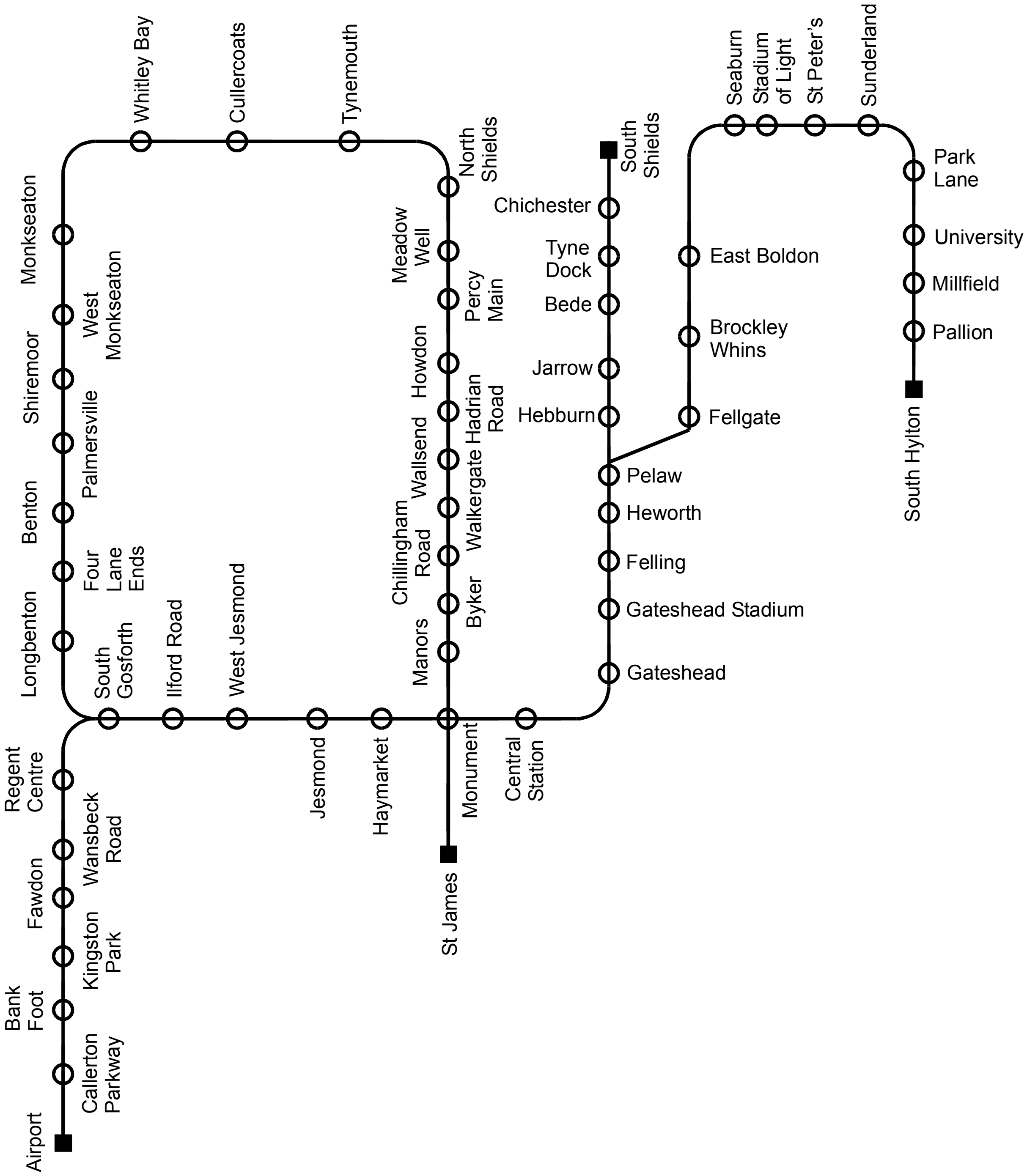


Figure 10.1 Schematic route map of the Tyne & Wear Metro

HSE0305-026/5

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

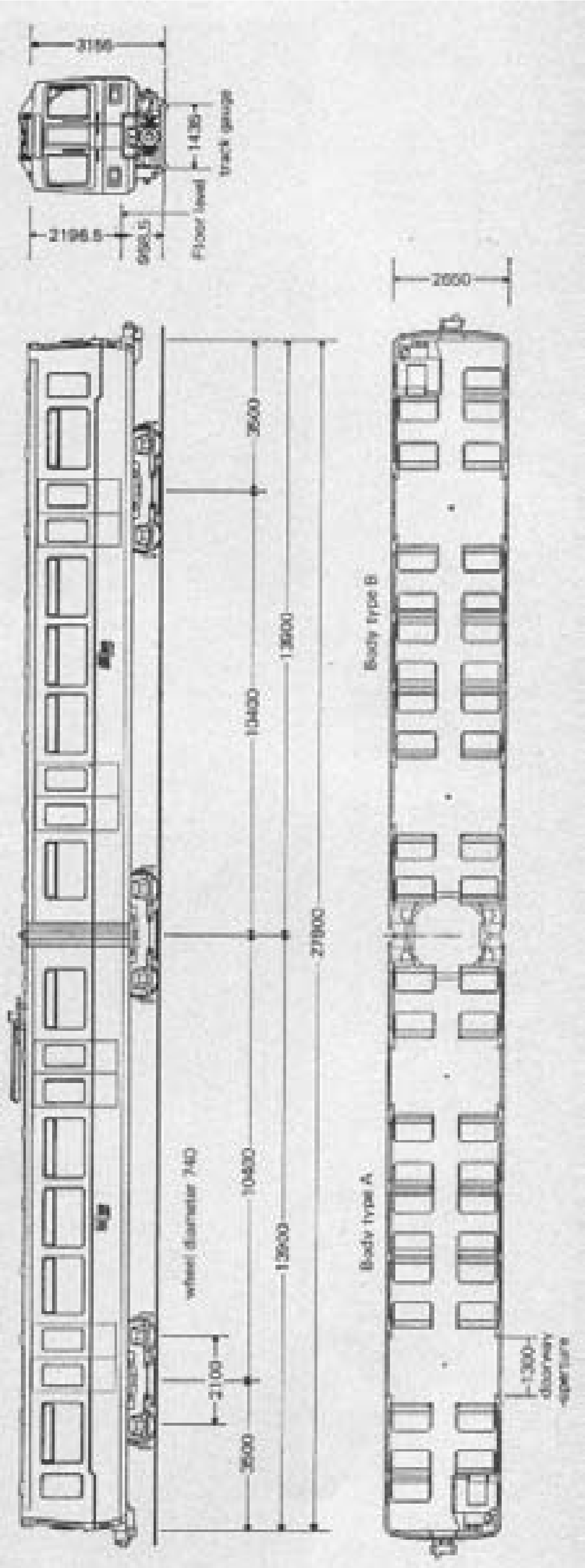
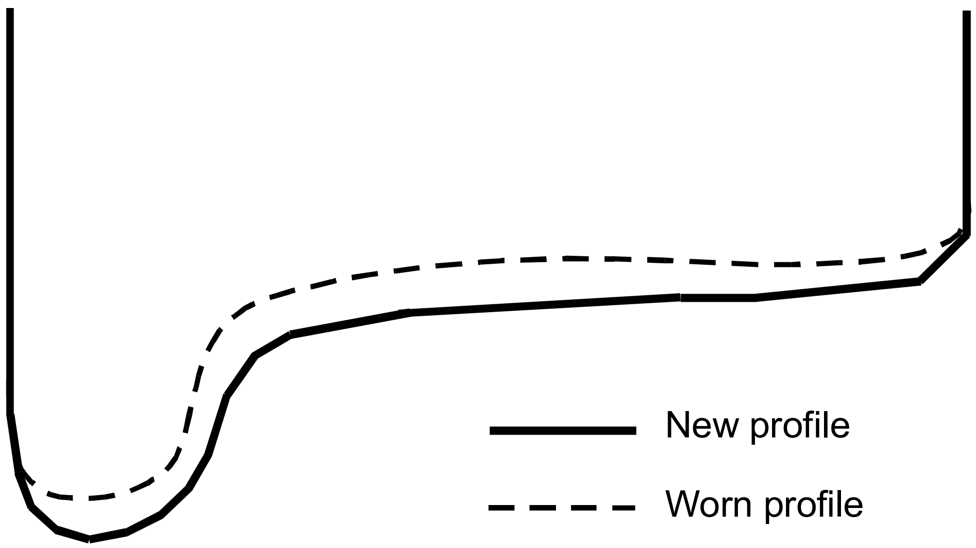


Figure 10.3 Metro-Cammell articulated two-car vehicle for the Tyne & Wear Metro



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:

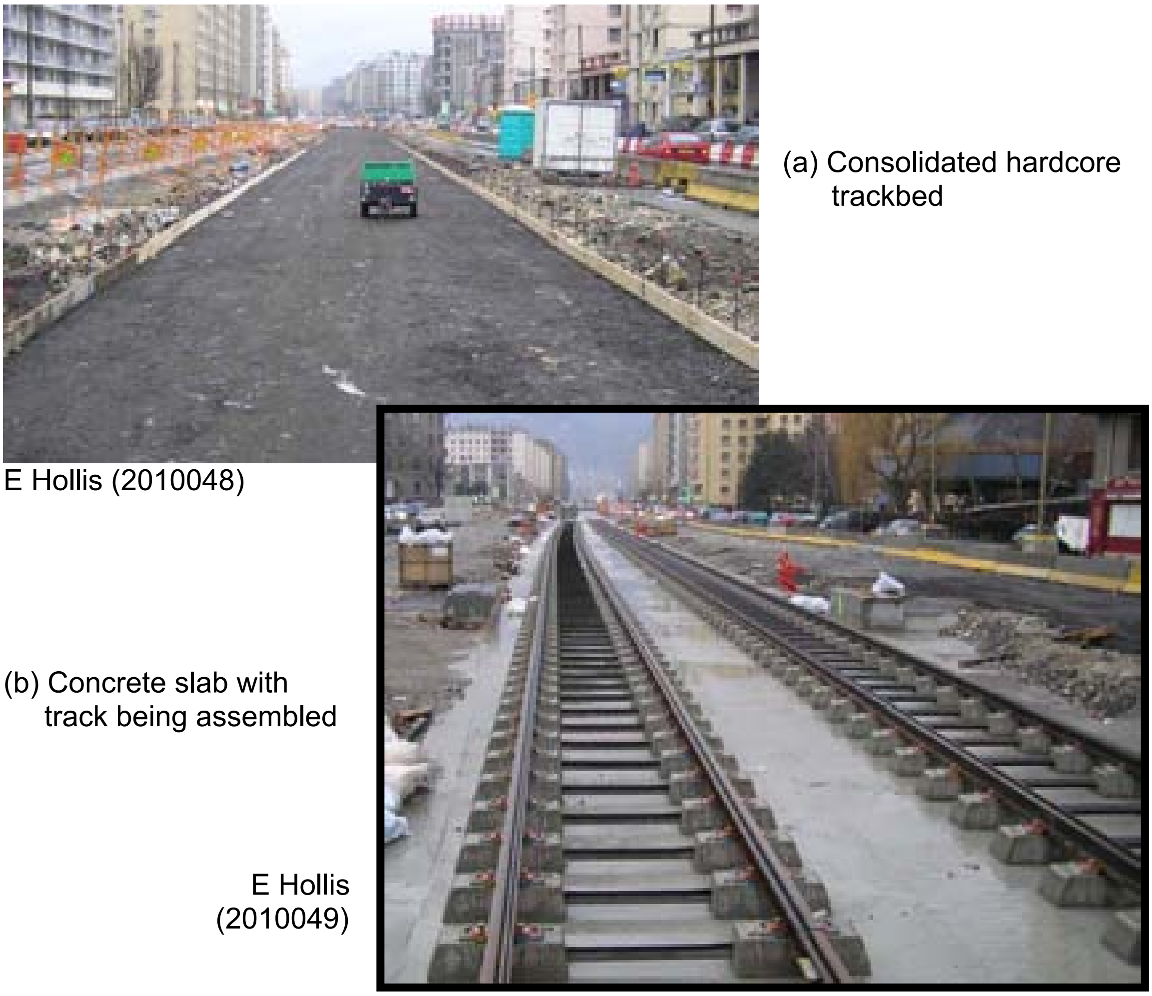
Alstom supplied all the 53 identical three-section bi-directional vehicles of type TFS (formerly a French standard) between 1986 and 1997. These vehicles are partly low floor. The external appearance is shown in Figures 11.7 & 11.8. An example of the wheel profile is given in Figure 11.9(a) and the markings 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 $1.55\text{x}10^6$km and $0.95\text{x}10^6$km 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)

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

Figure 11.3 Street running track,
TAG Grenoble (02.02.05)

E Hollis (2020173)

E Hollis (2010028)

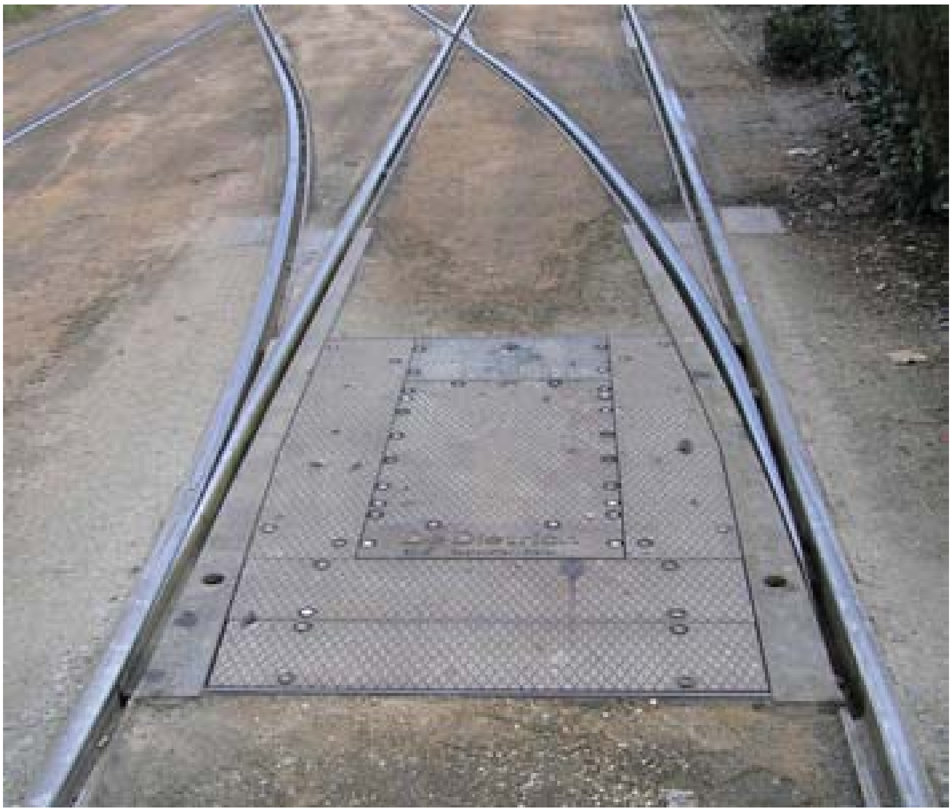
(a) Segregated track

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.

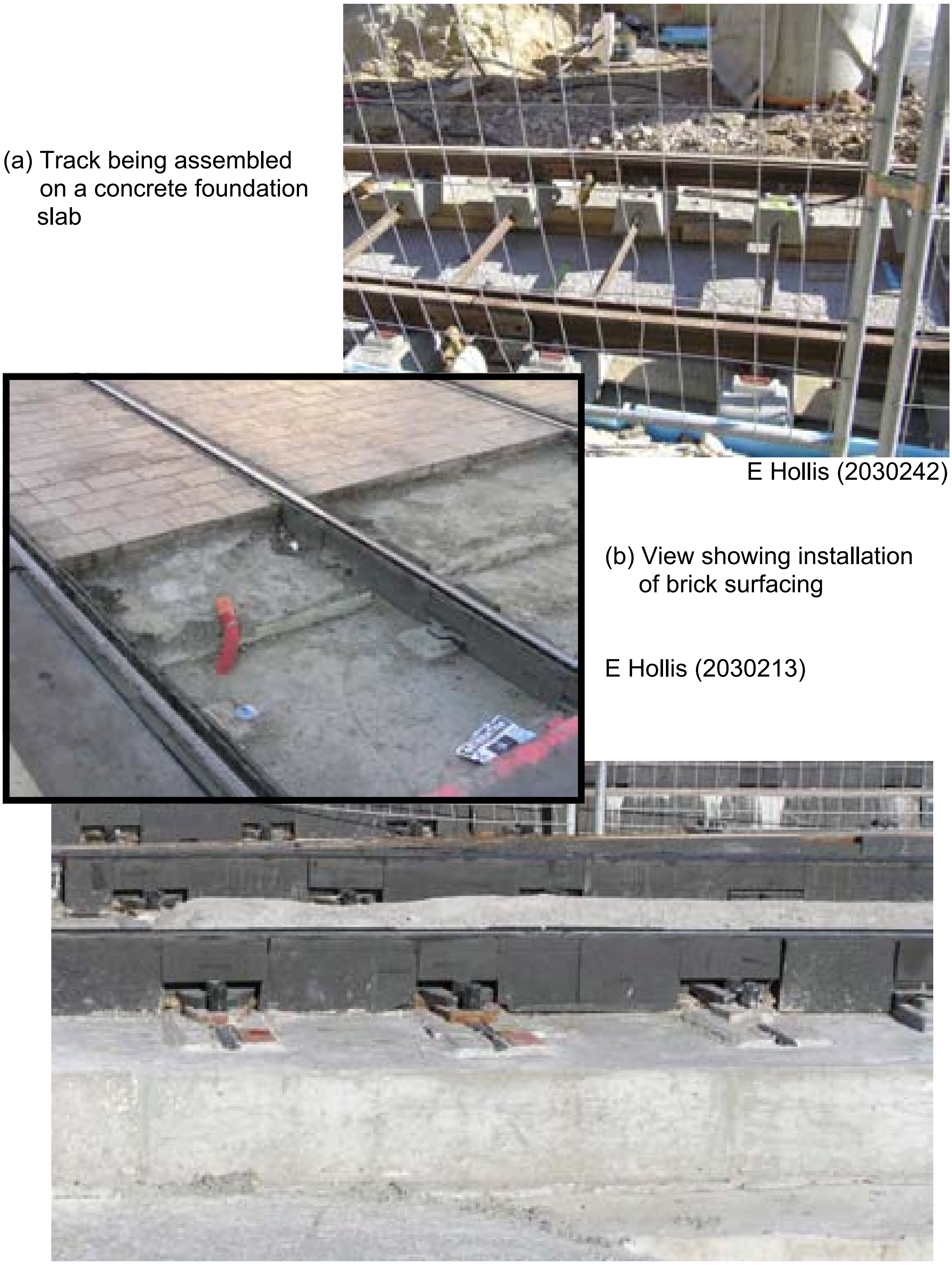
The form of wheel construction and tread profile is shown in Figure 11.24.

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

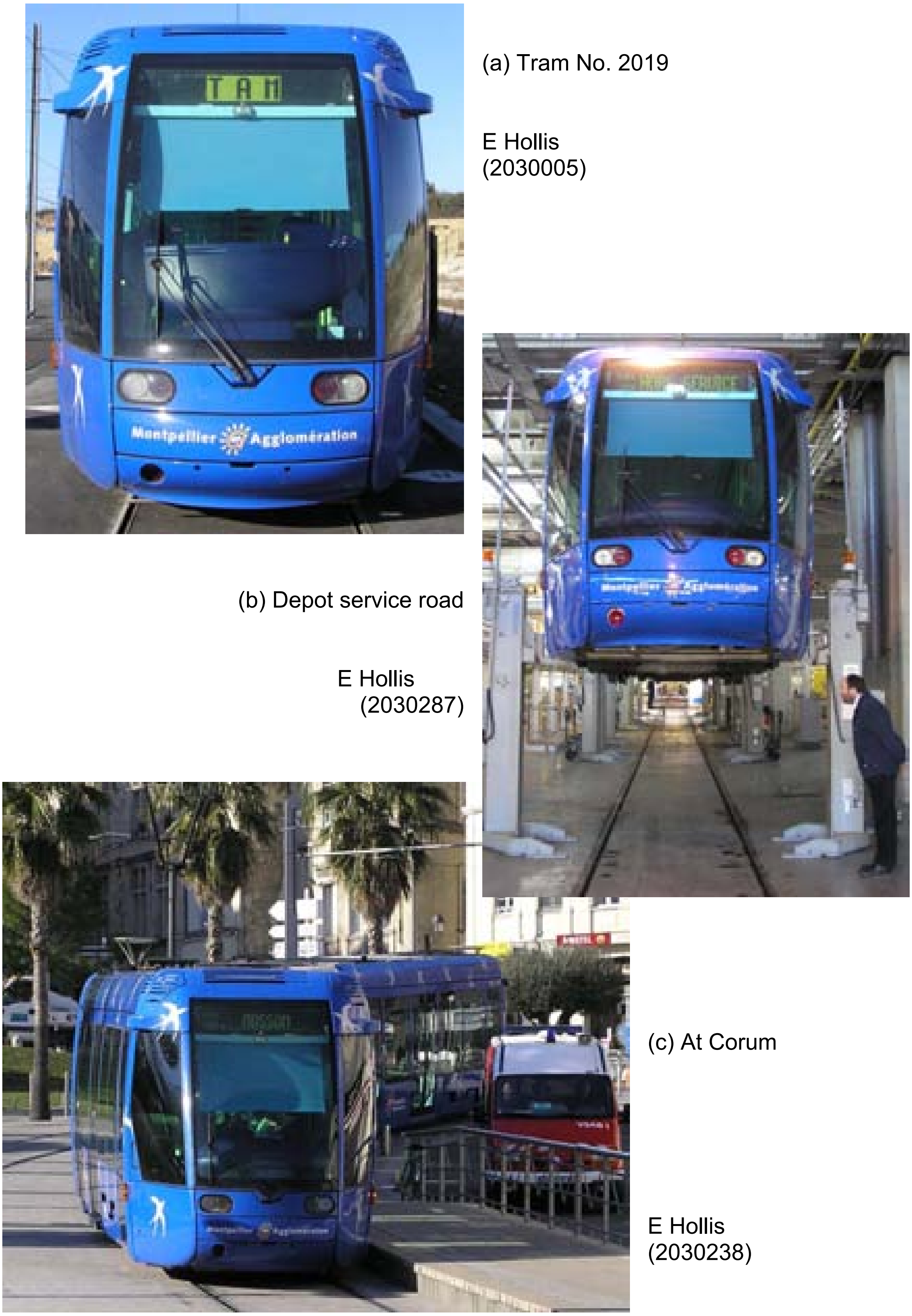
(c) Short truck mounted section, typical of two

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)

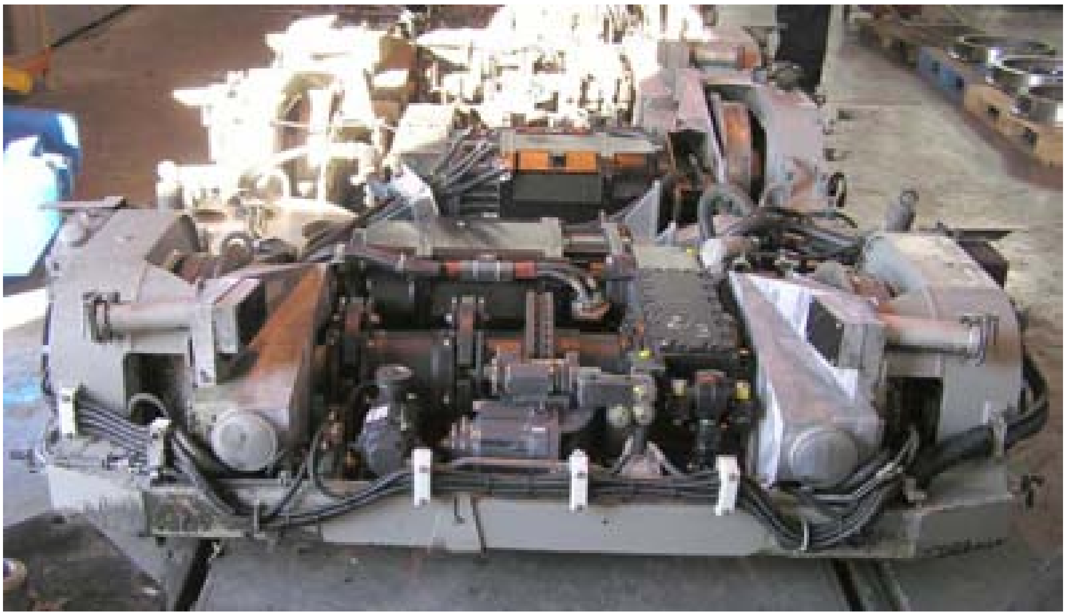
(b) Wheel tread profile

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

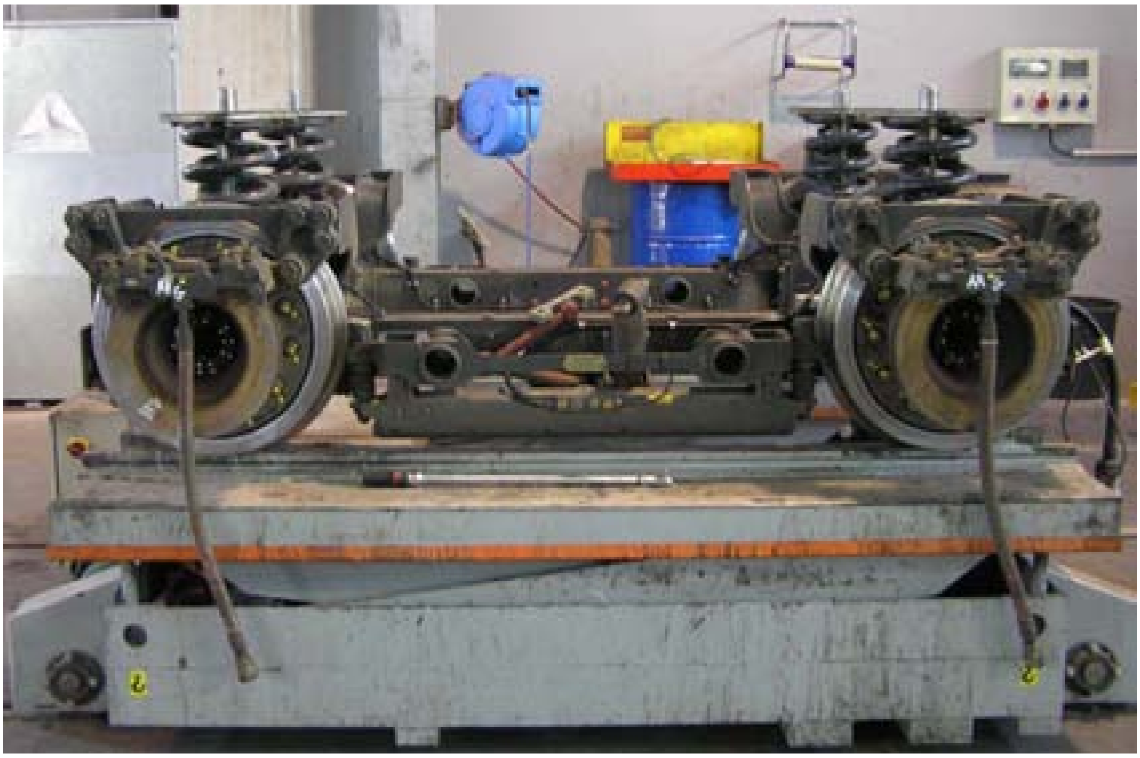
E Hollis (2030316)

(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.

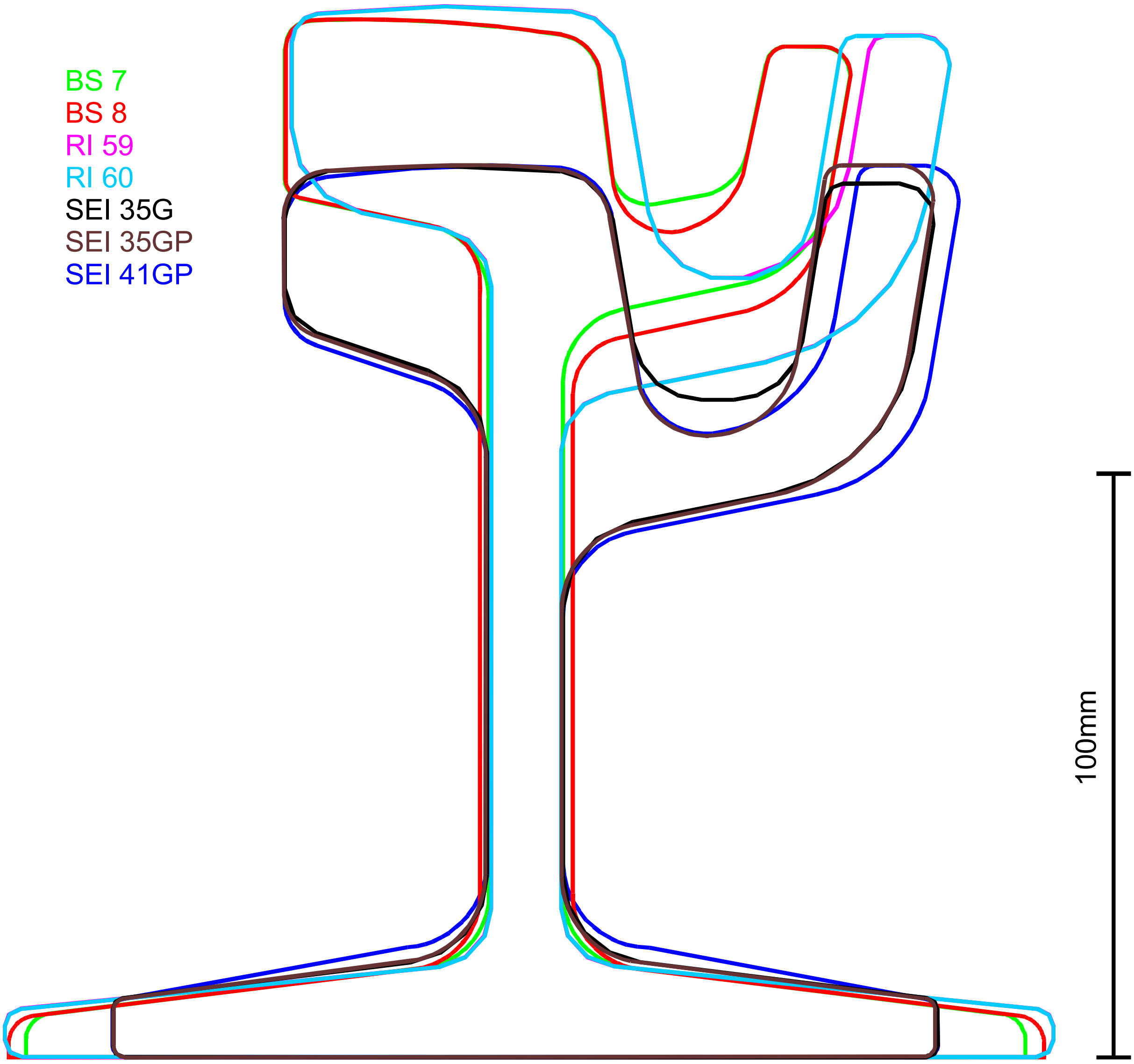
12.10 TABLE 12.10 SUMMARY OF WHEEL TREAD AND RAIL PROFILES

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]			

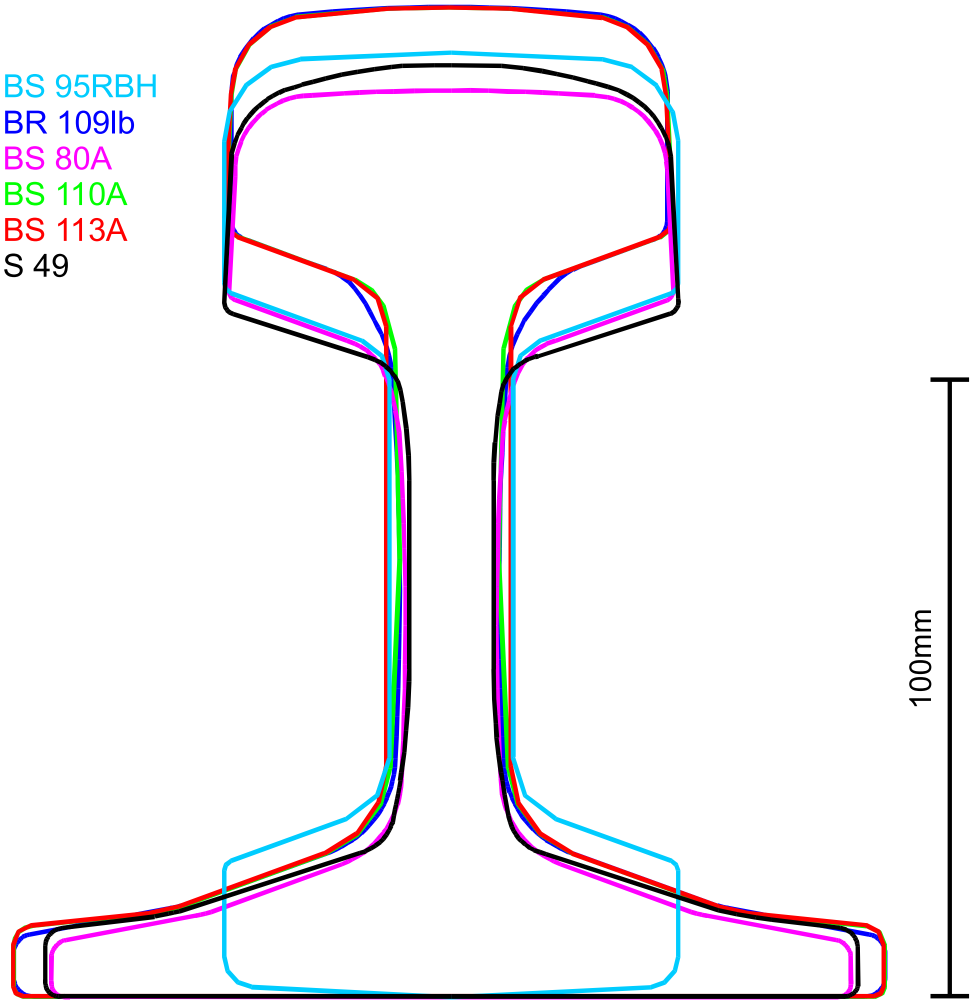
Notes:

[1] Used for very short lengths of track only

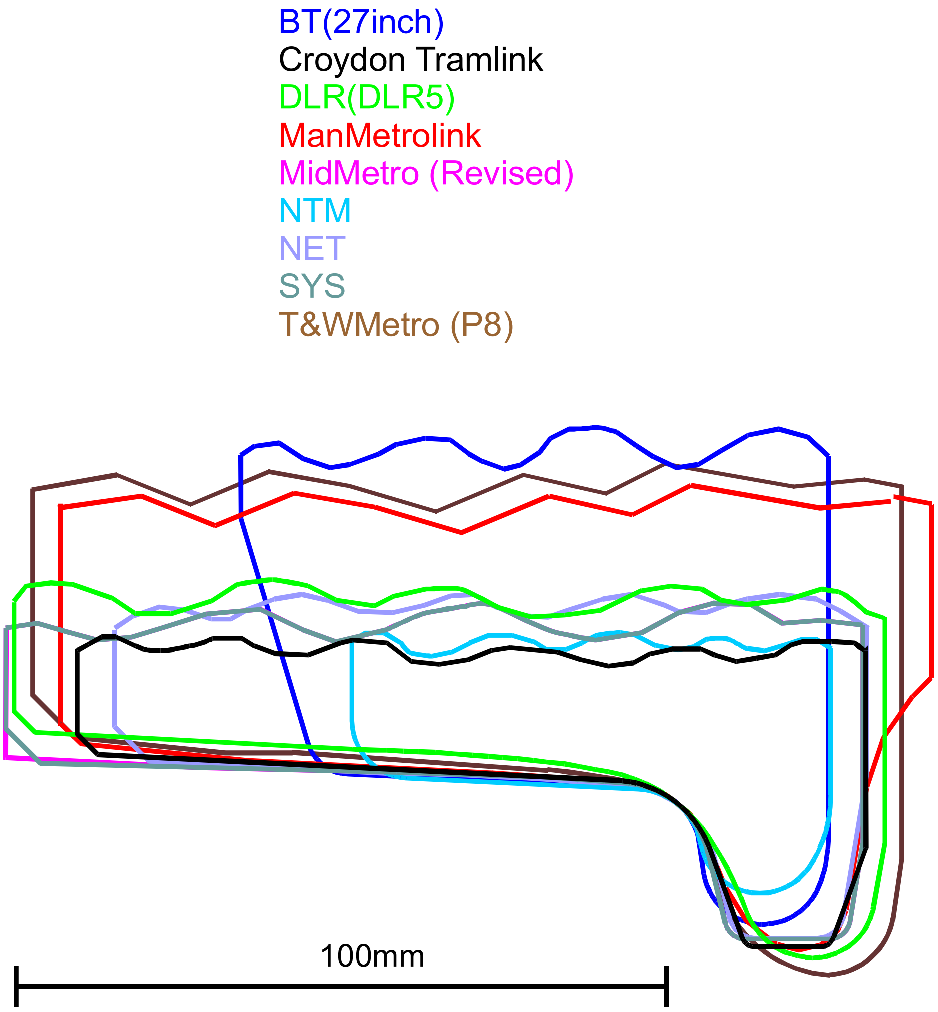
12.11 SUMMARY OF GROOVED RAIL PROFILES



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

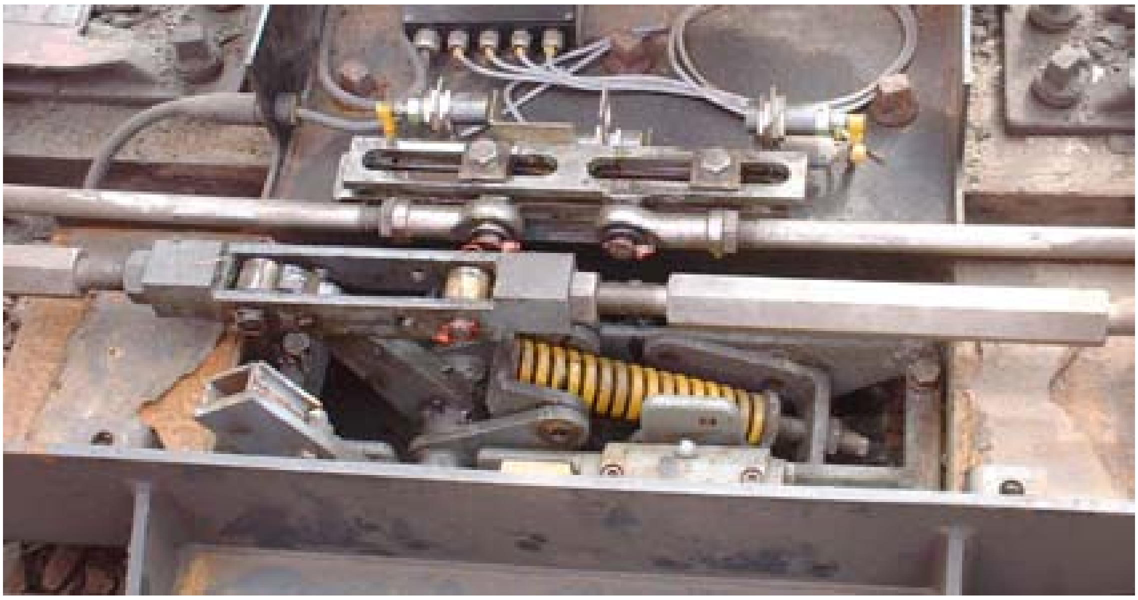
Figure 13.2 Example of an ‘in service’ wheel profile

A Steel

Figure 13.3 Road surface damage due to hollow wheel wear.

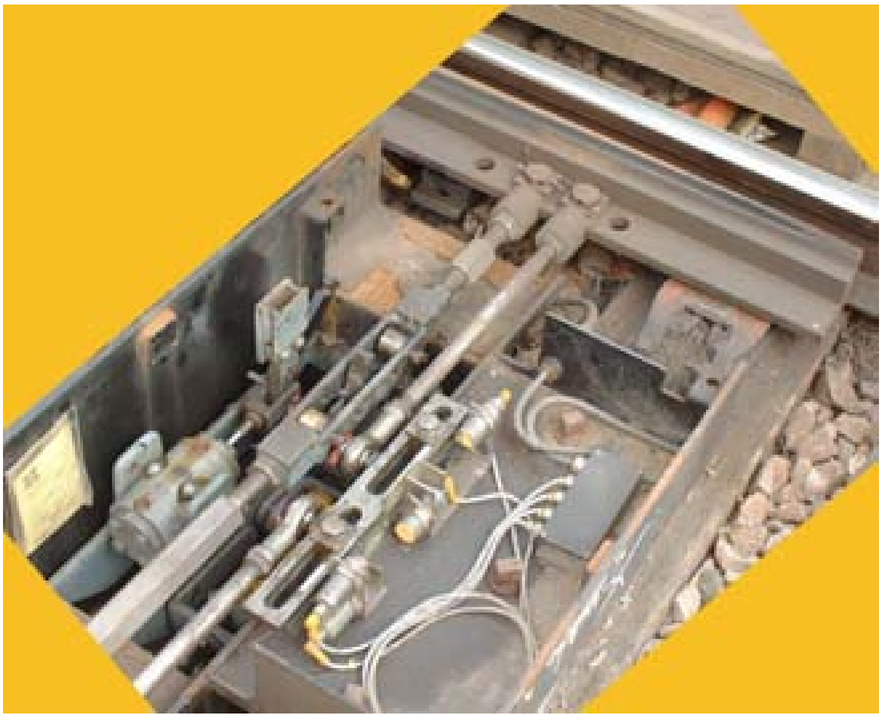
J Snowdon

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



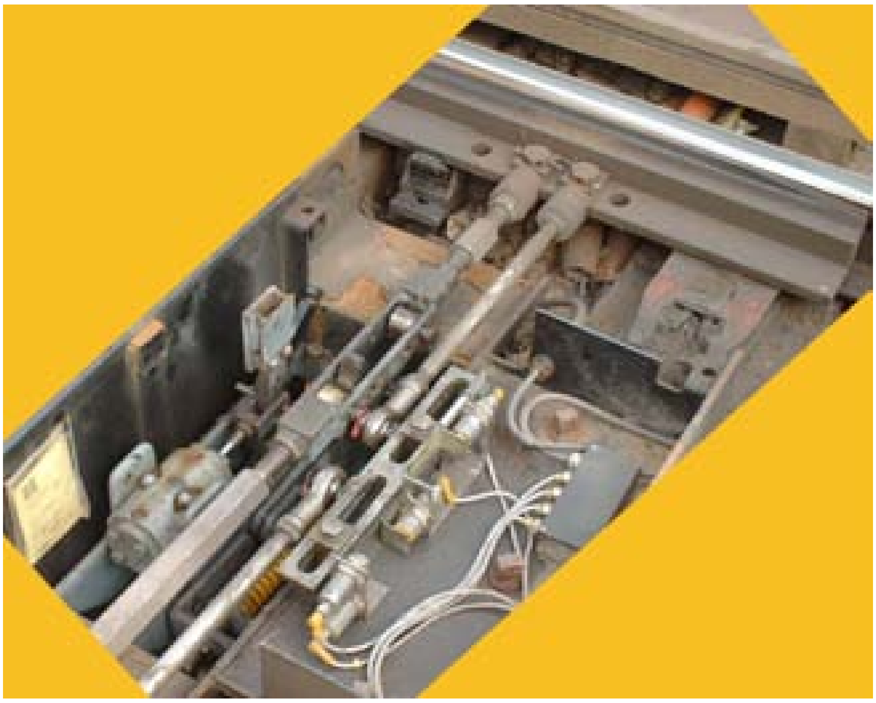
I Raxton

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

J Snowdon

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

J Snowdon

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

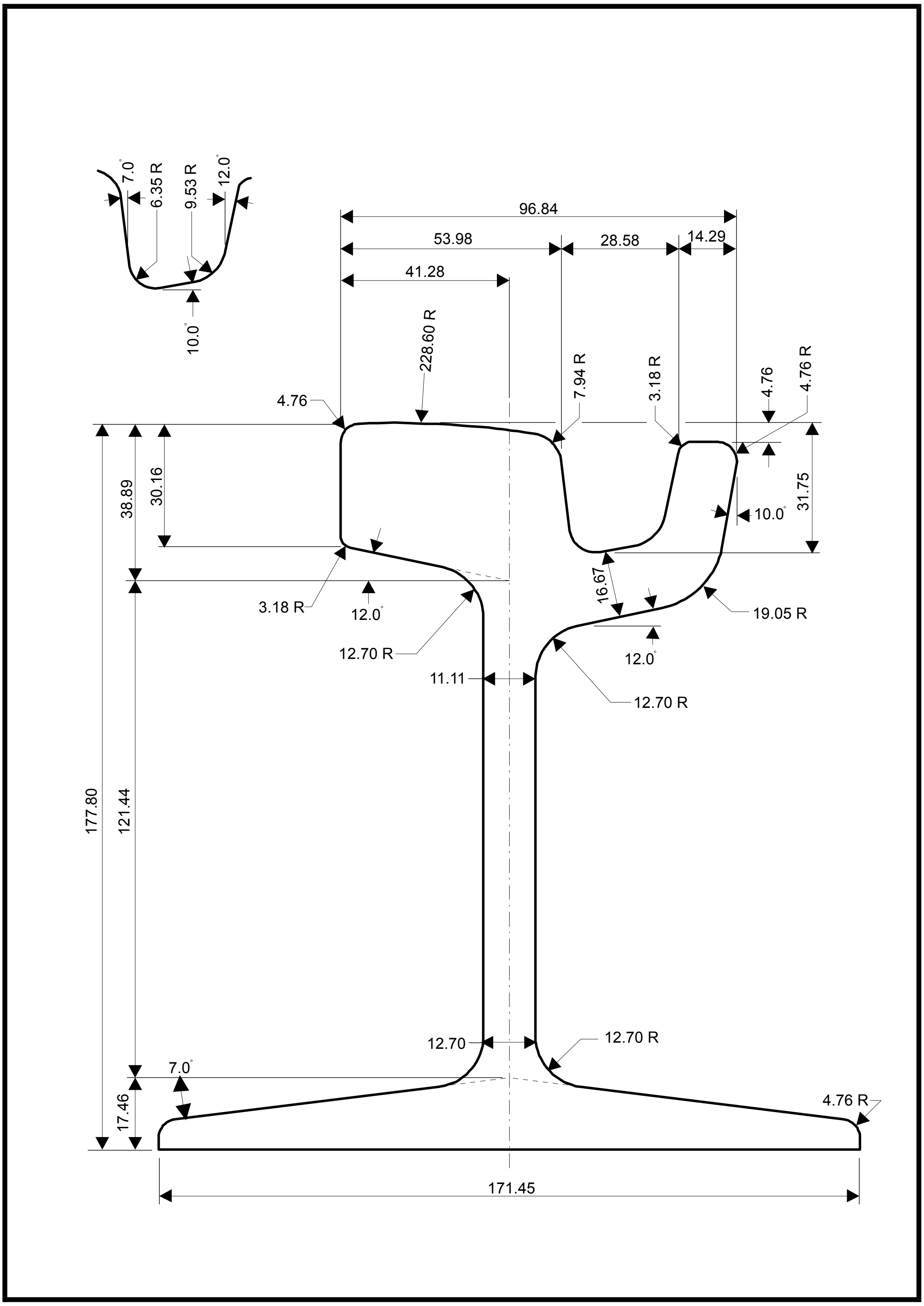
J Brown

Figure 13.9 Wheel marks following a derailment

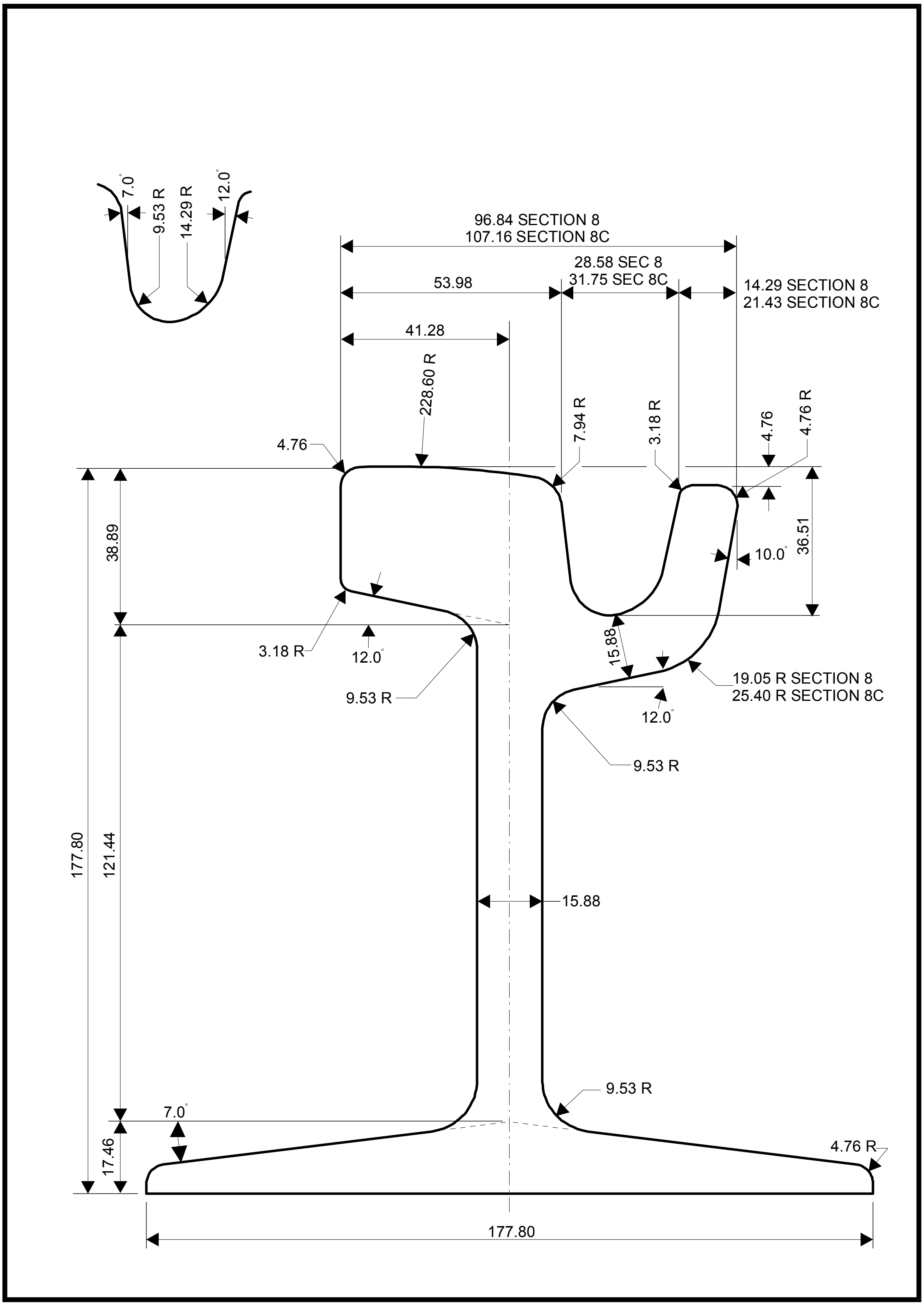
14 APPENDICES

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

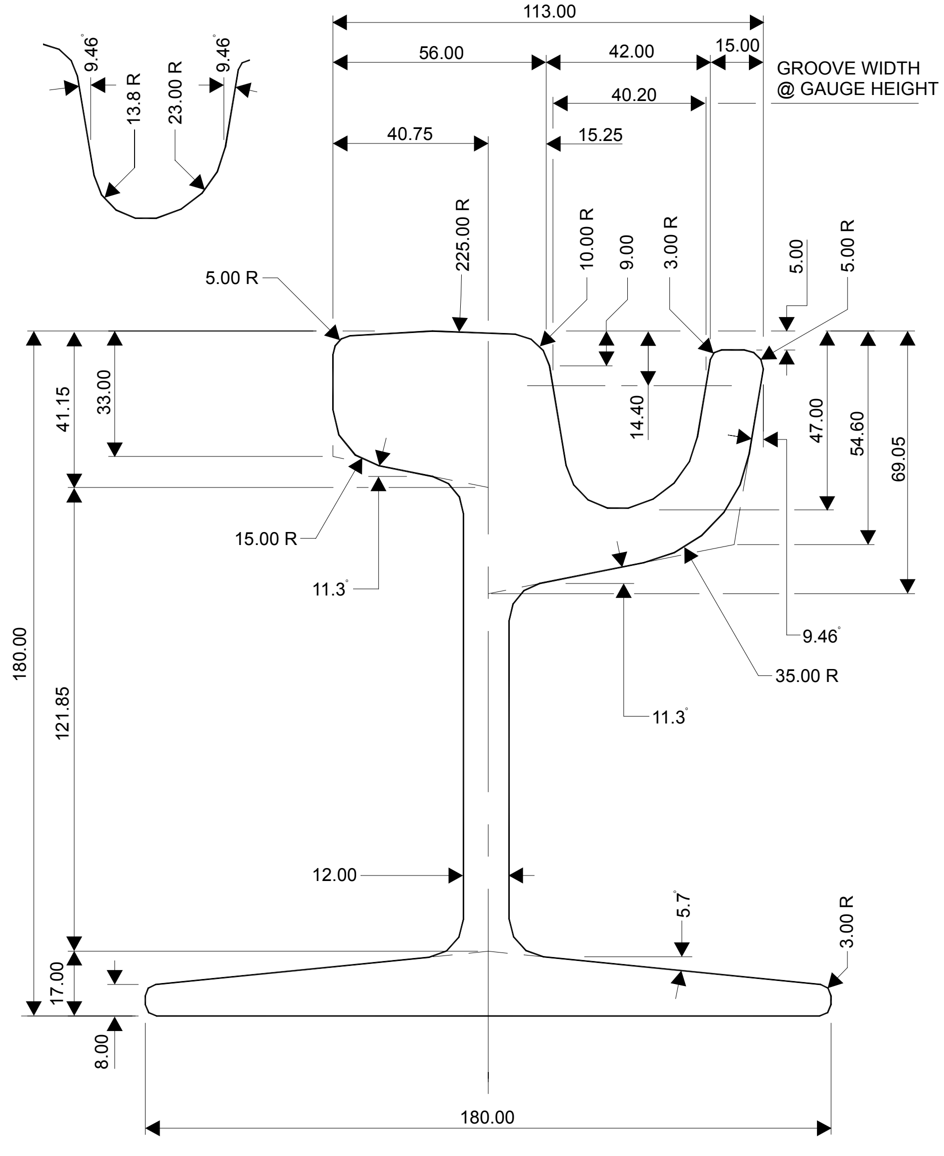
14.1 APPENDIX 1 BS SECTION NO. 7 GROOVED RAIL



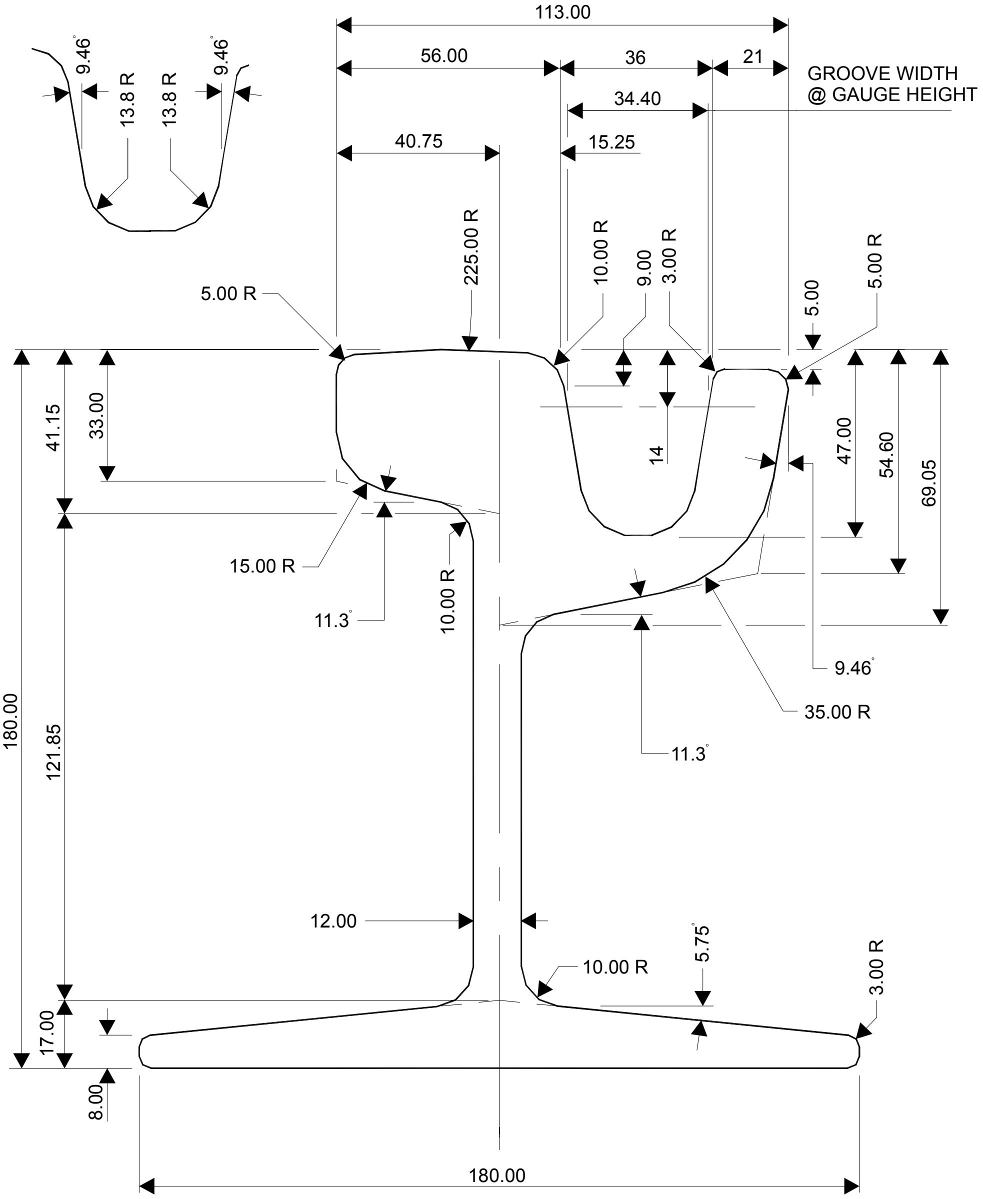
14.2 APPENDIX 2 BS SECTION NO. 8 & 8C GROOVED RAIL



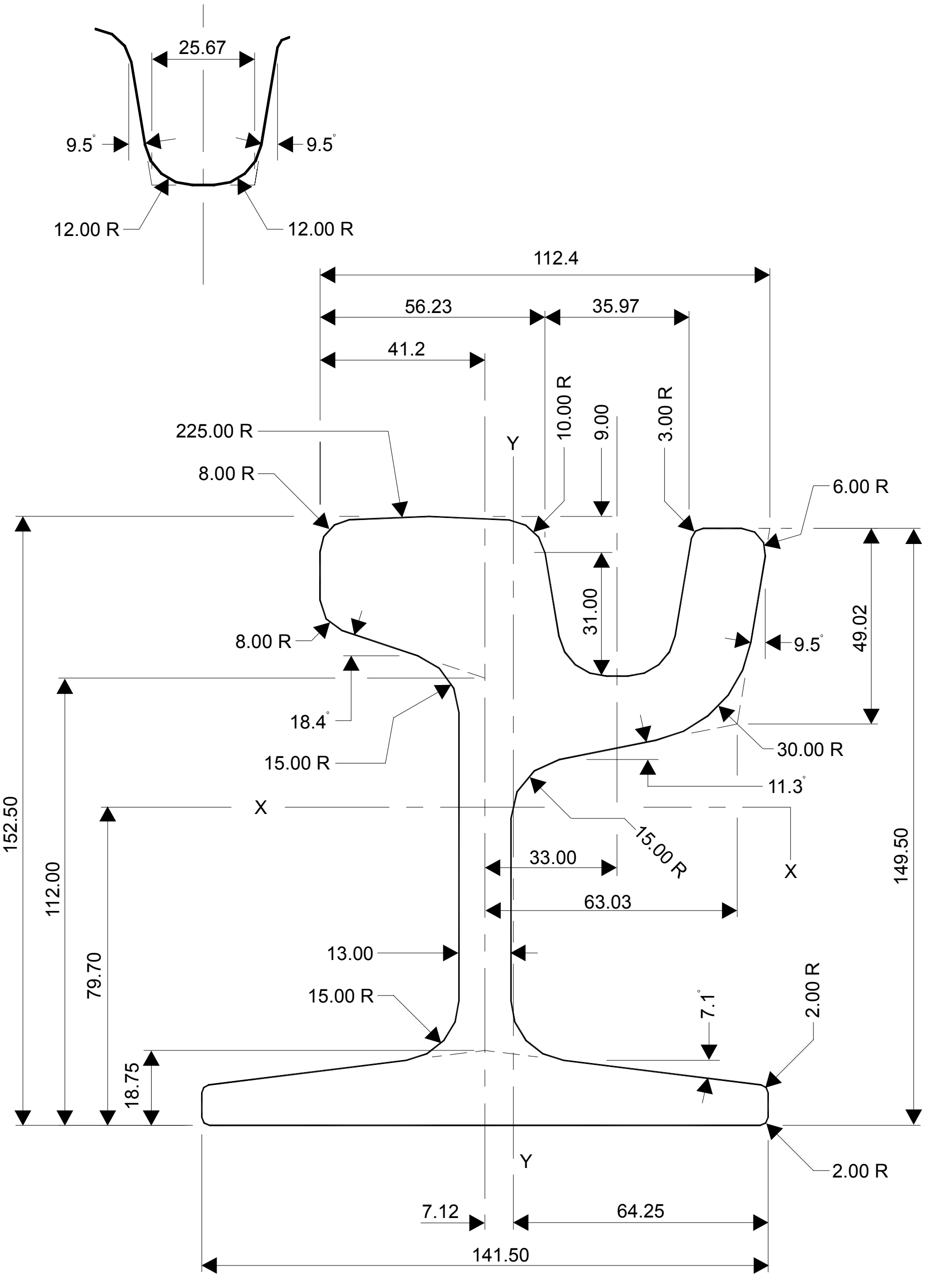
14.3 APPENDIX 3 RI 59 GROOVED RAIL



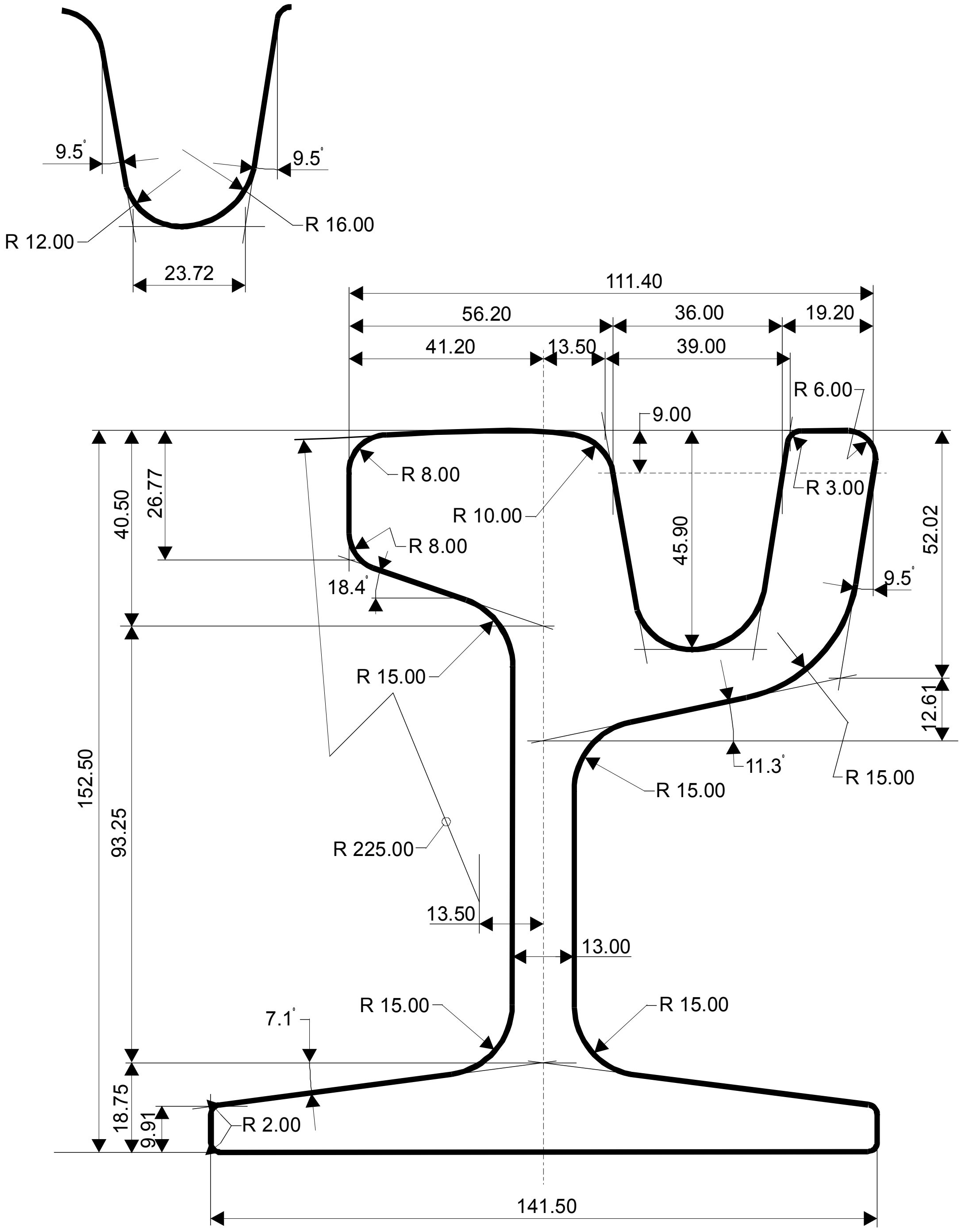
14.4 APPENDIX 4 RI 60 GROOVED RAIL



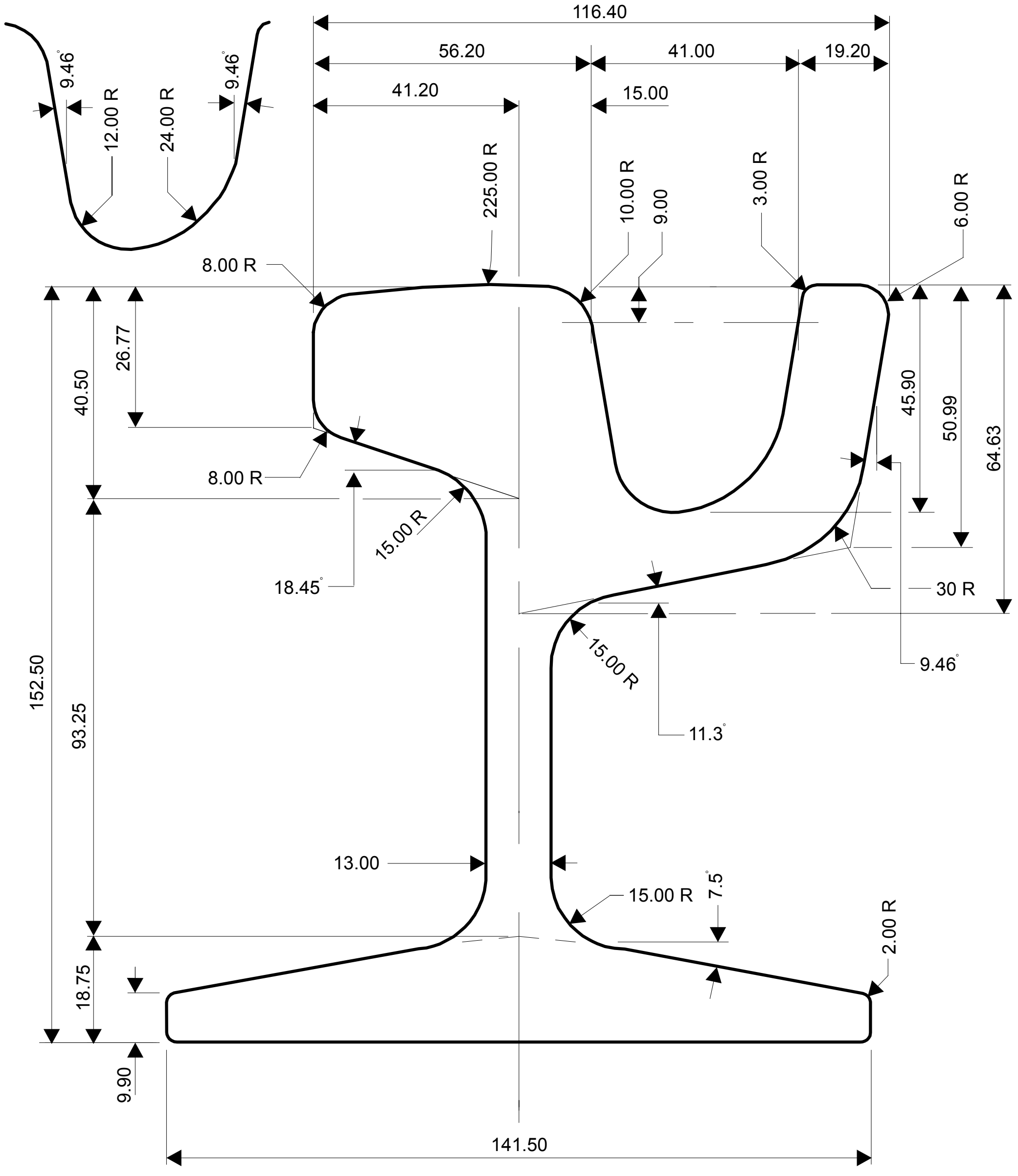
14.5 APPENDIX 5 SEI 35G GROOVED RAIL



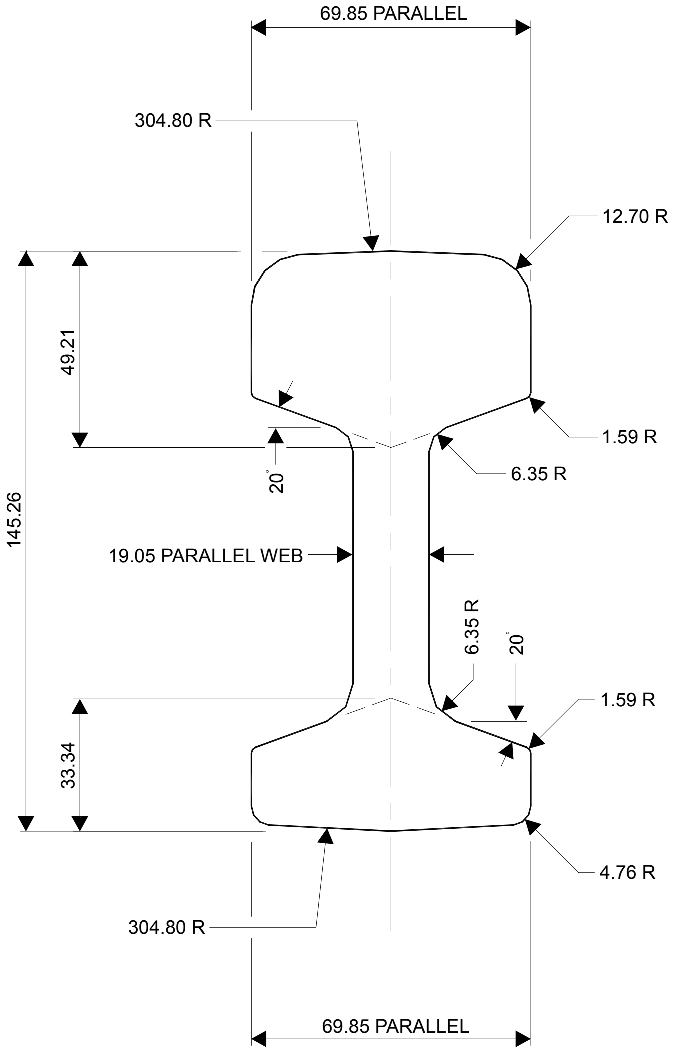
14.6 APPENDIX 6 SEI 35GP GROOVED RAIL



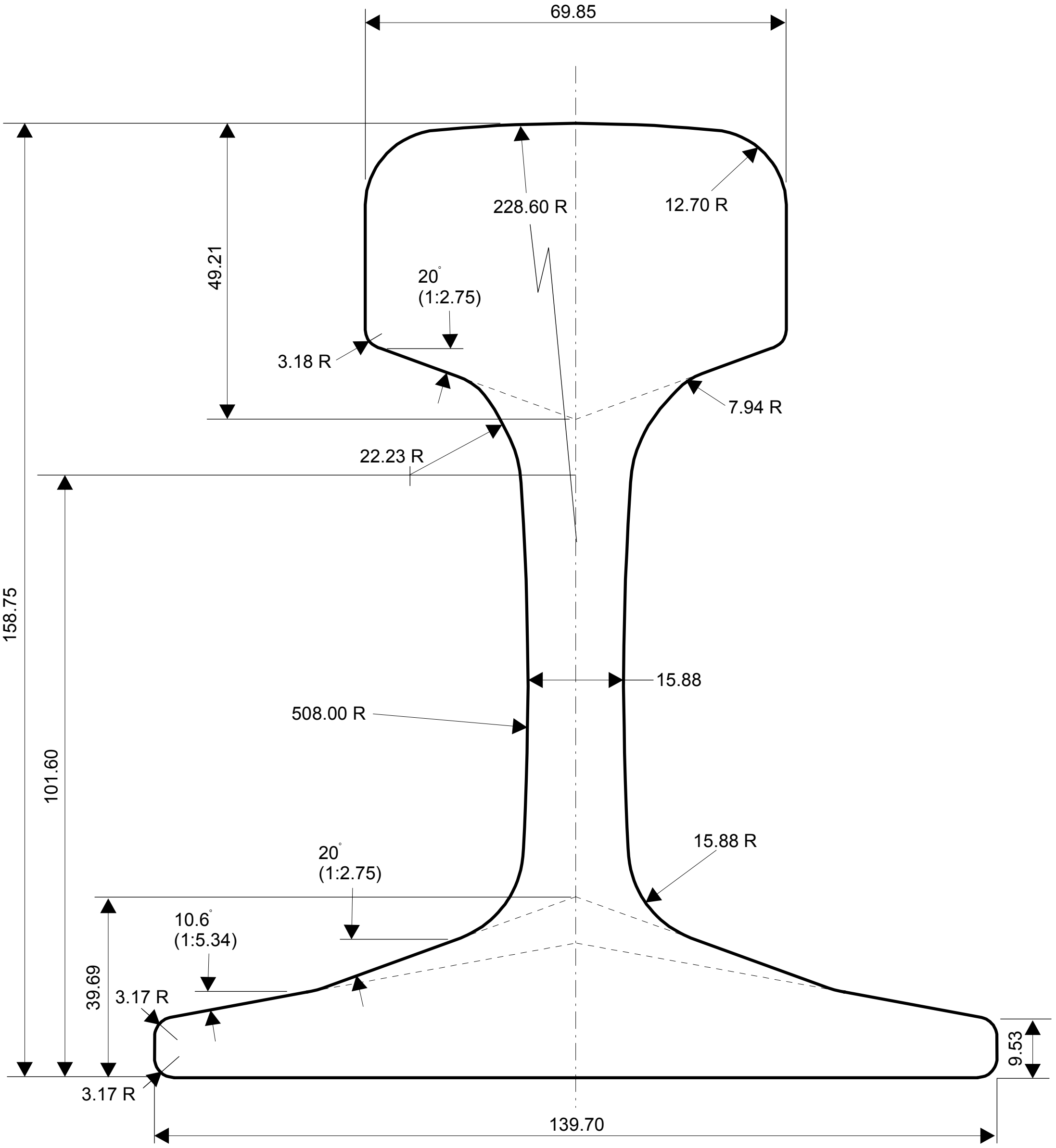
14.7 APPENDIX 7 SEI 41GP GROOVED RAIL



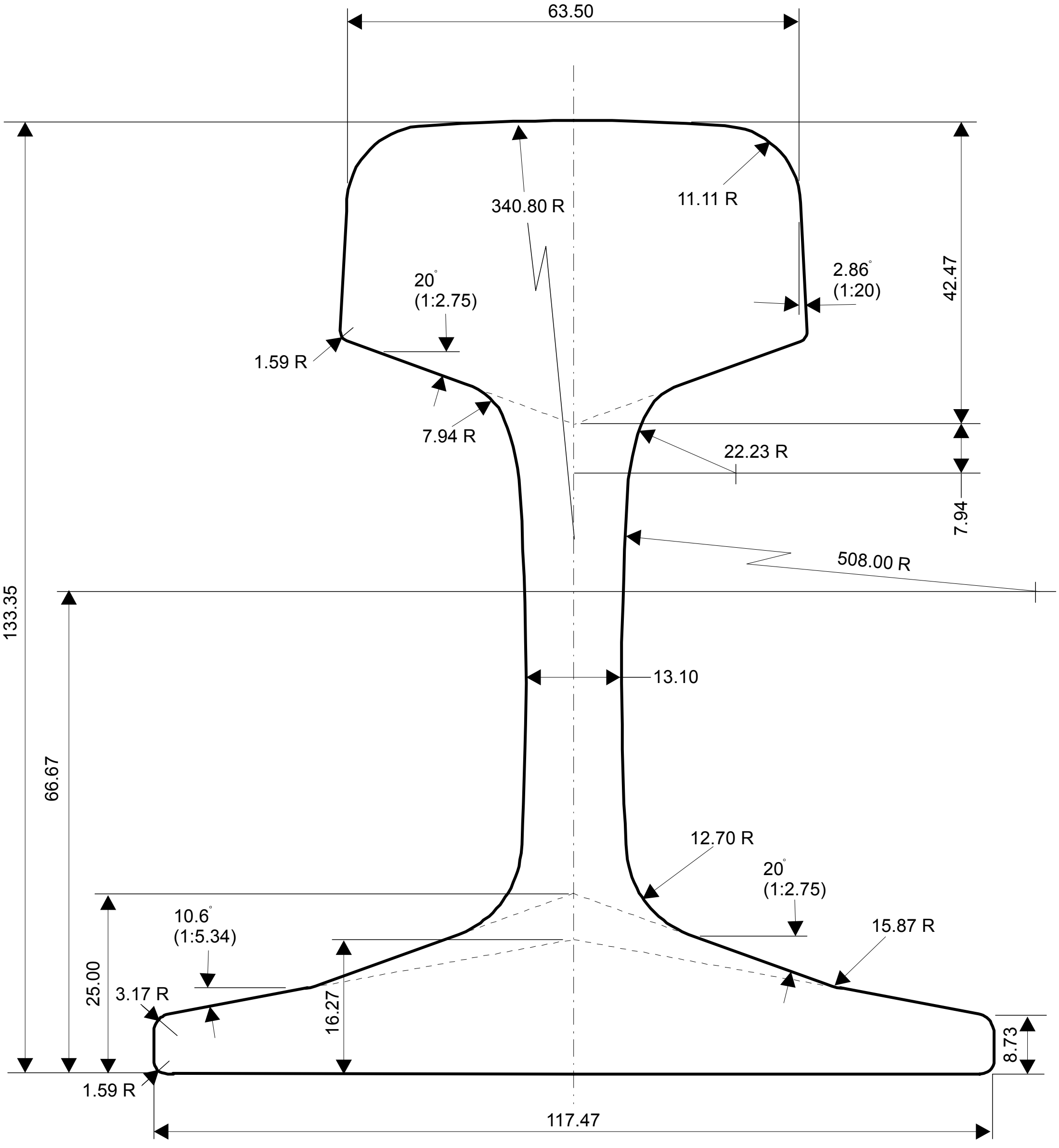
14.8 APPENDIX 8 BS 95RBH BULL HEAD RAIL



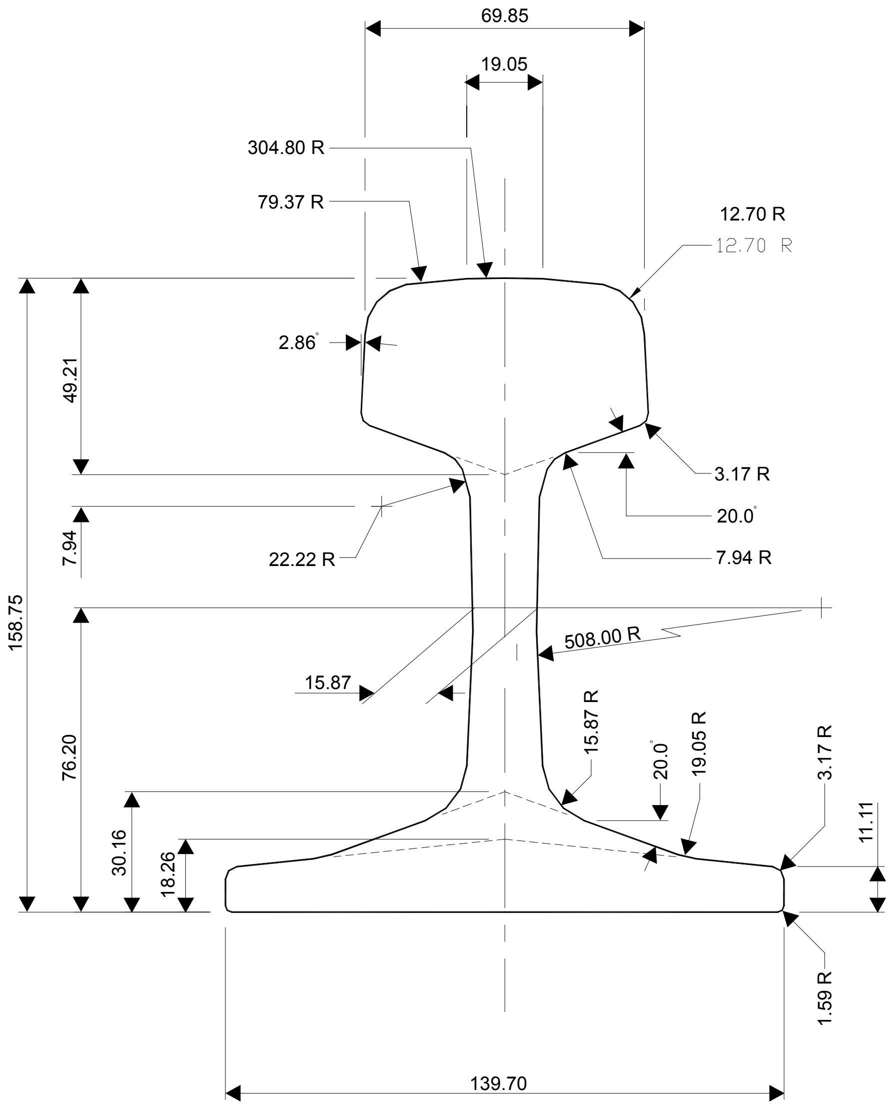
14.9 APPENDIX 9 BR STANDARD 109LB FLAT BOTTOM RAIL



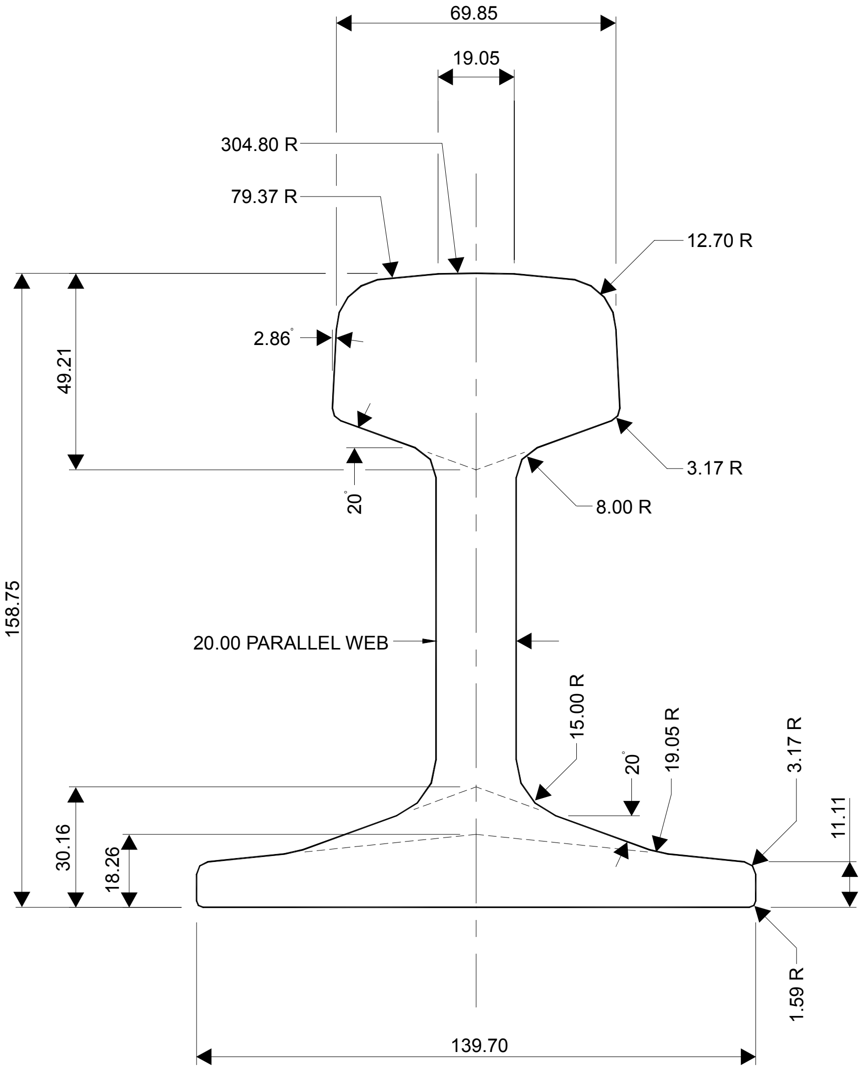
14.10 APPENDIX 10 BS 80A FLAT BOTTOM RAIL



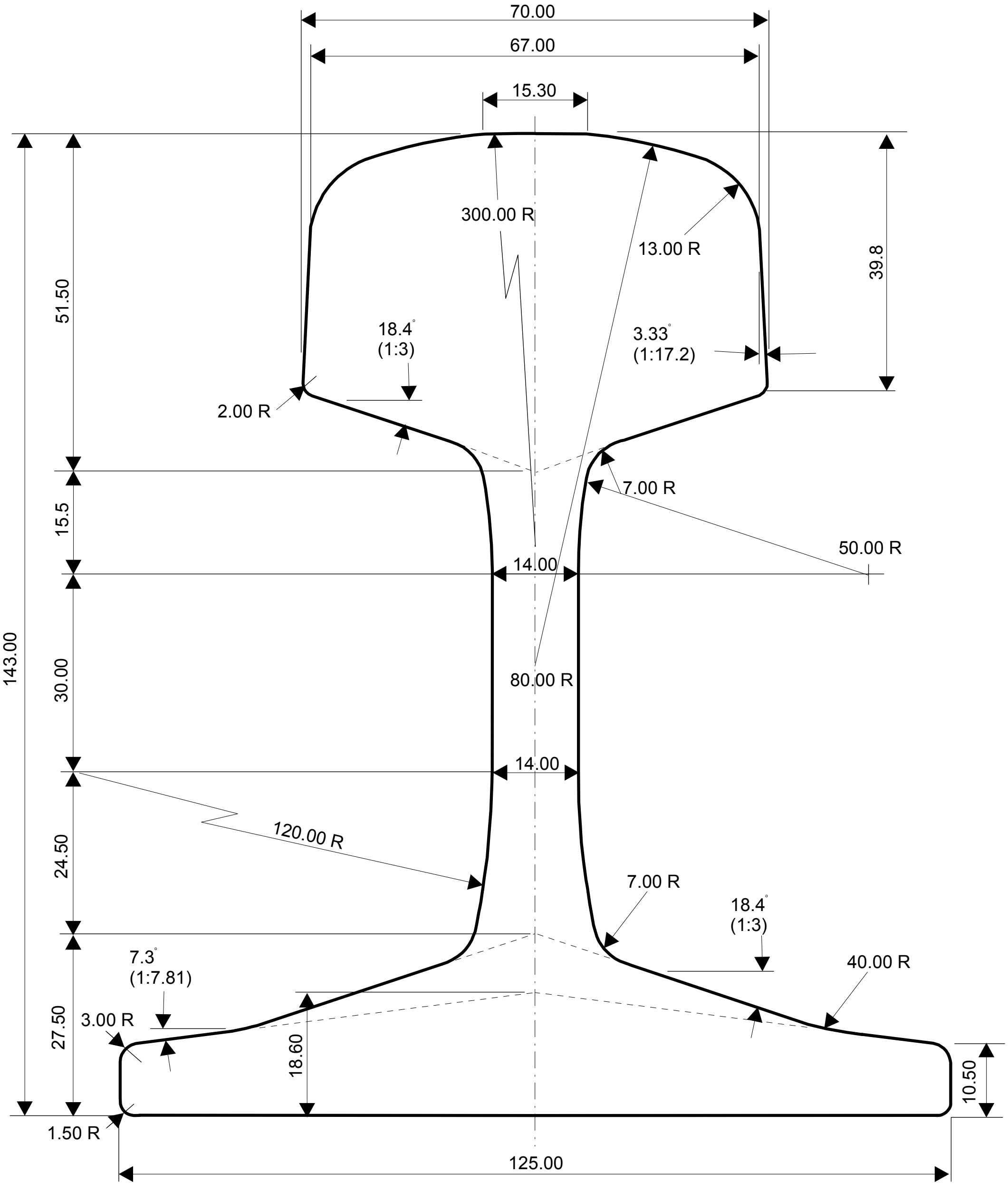
14.11 APPENDIX 11 BS 110A FLAT BOTTOM RAIL



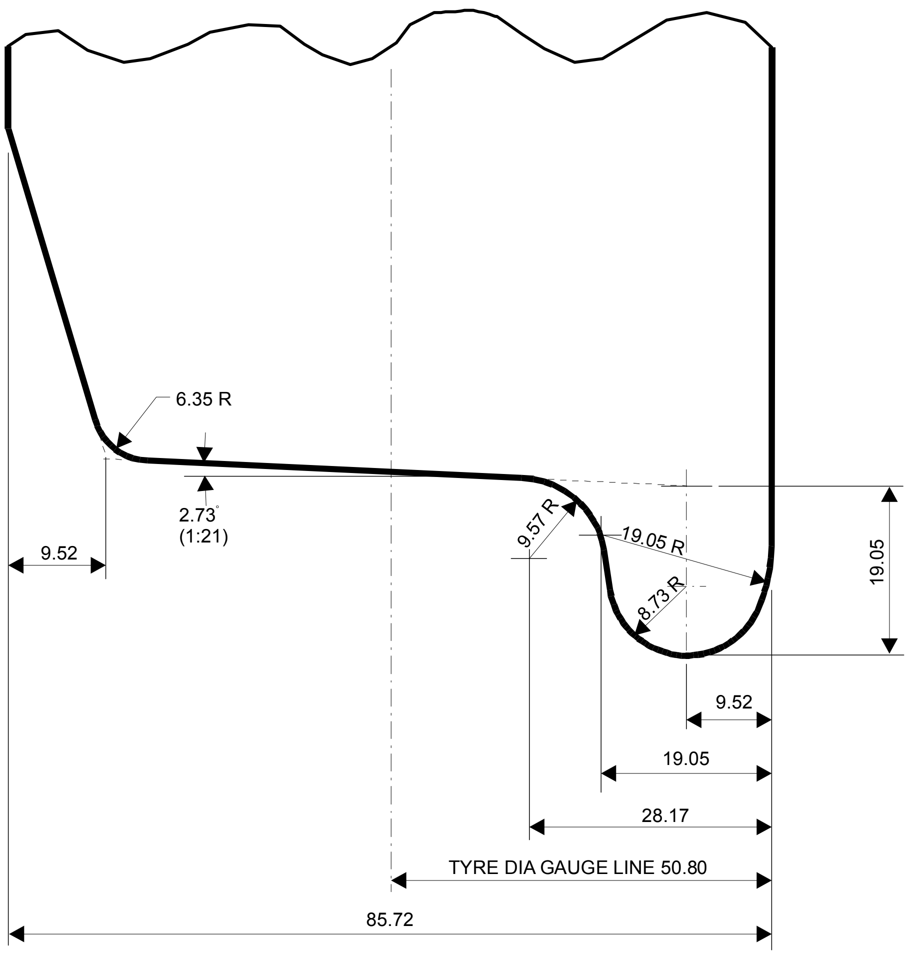
14.12 APPENDIX 12 BS 113A FLAT BOTTOM RAIL



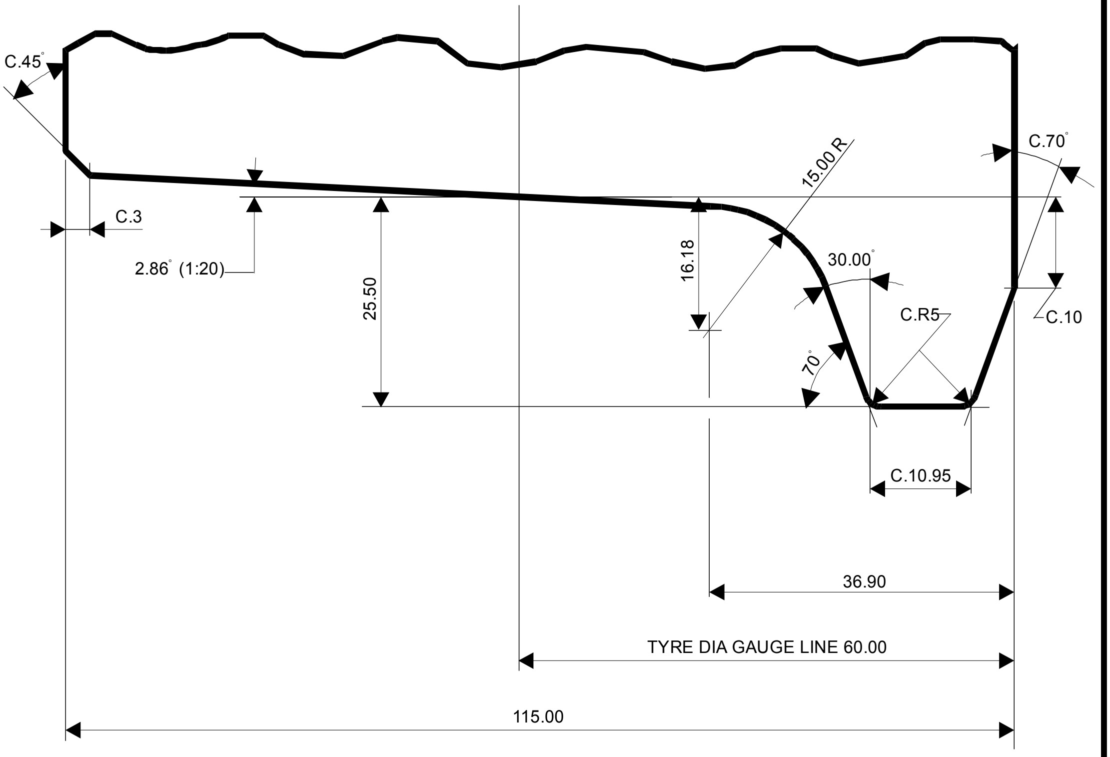
14.13 APPENDIX 13 S 49 FLAT BOTTOM RAIL



14.14 APPENDIX 14 BLACKPOOL TRANSPORT WHEEL TREAD PROFILE

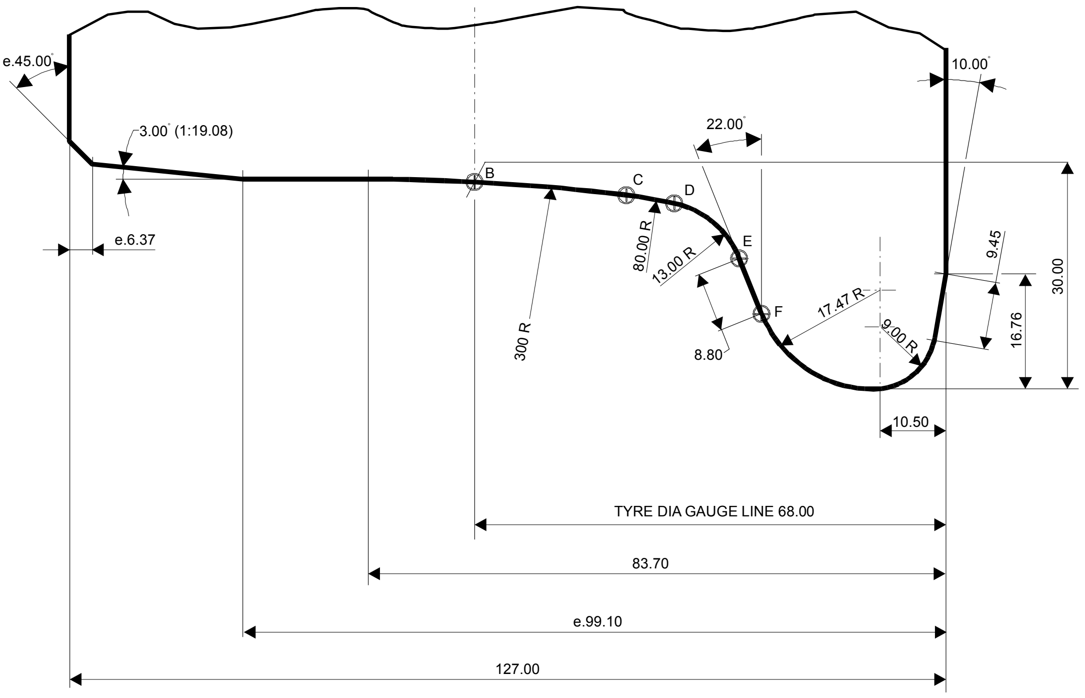


14.15 APPENDIX 15 CROYDON TRAMLINK WHEEL TREAD PROFILE



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

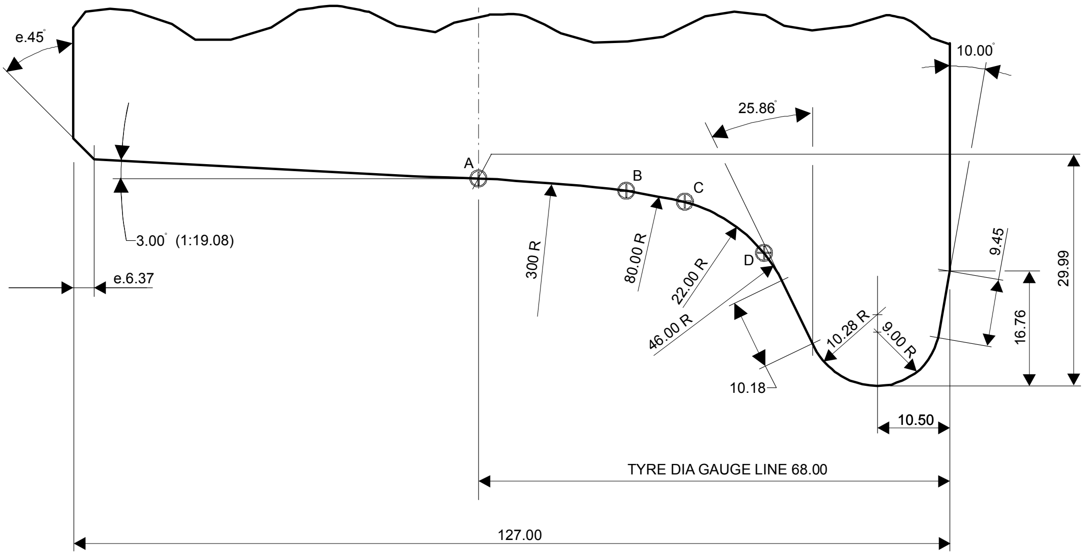
14.16 APPENDIX 16 DOCKLANDS LR WHEEL TREAD PROFILE DLR2



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

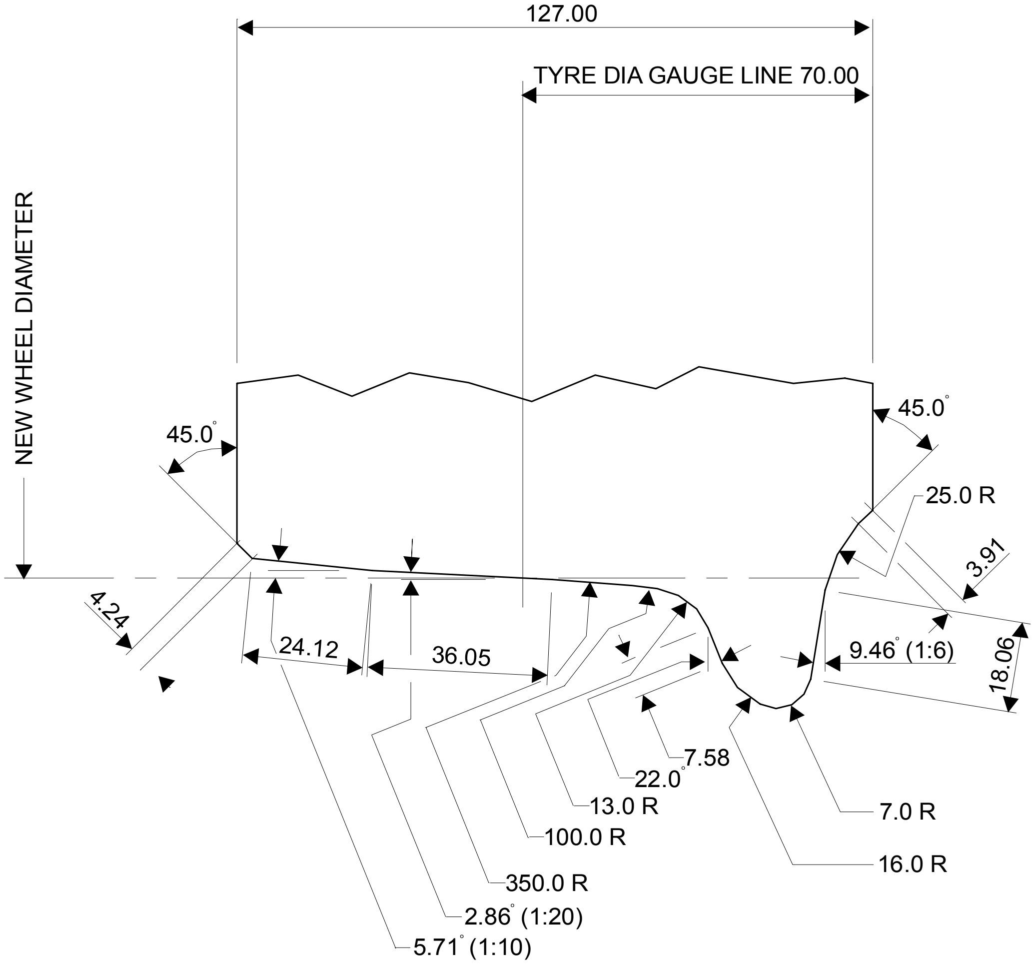
14.17 APPENDIX 17 DOCKLANDS LR WHEEL TREAD PROFILE DLR5



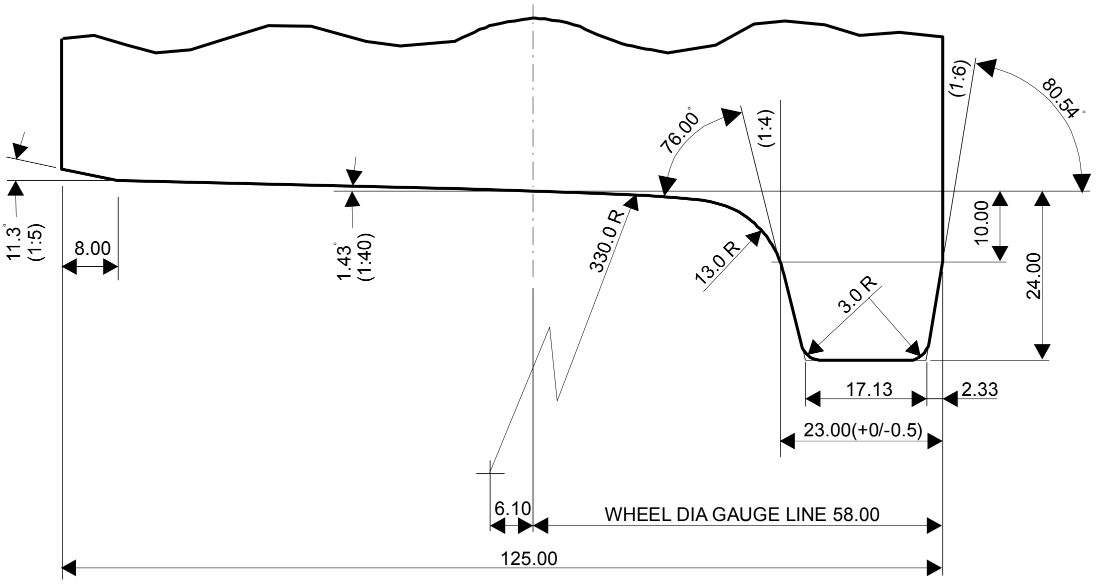
Note: 'e.' denotes an estimated dimension

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

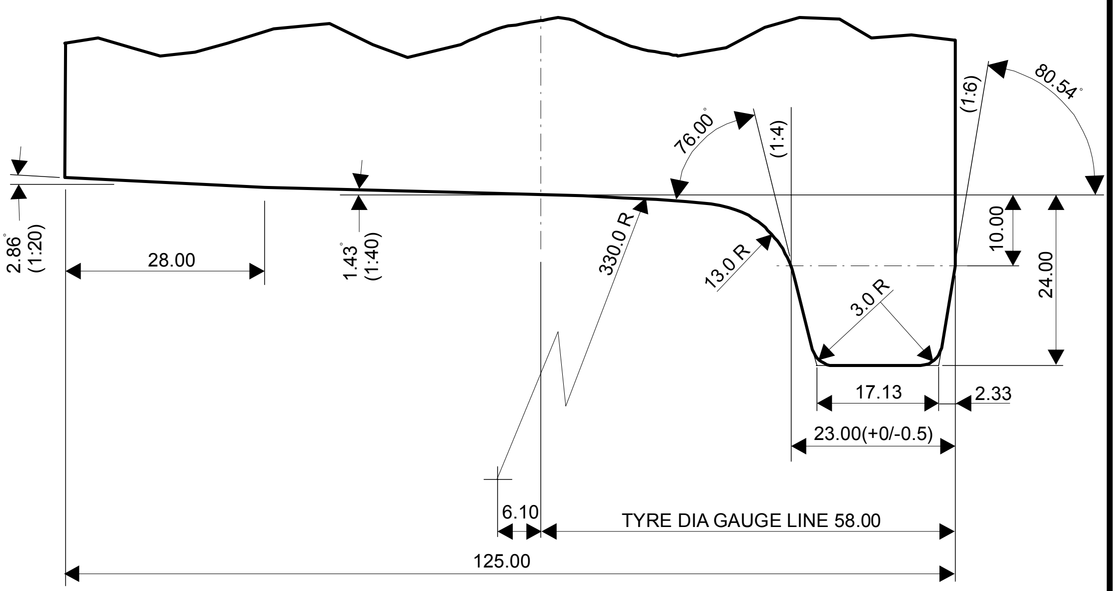
14.18 APPENDIX 18 MANCHESTER METROLINK WHEEL TREAD PROFILE



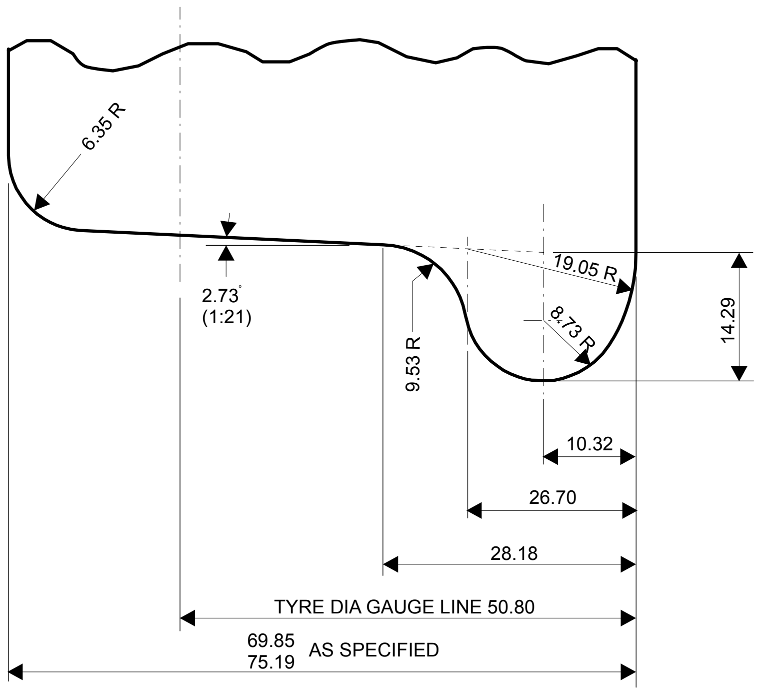
14.19 APPENDIX 19 MIDLAND METRO ORIGINAL WHEEL TREAD PROFILE



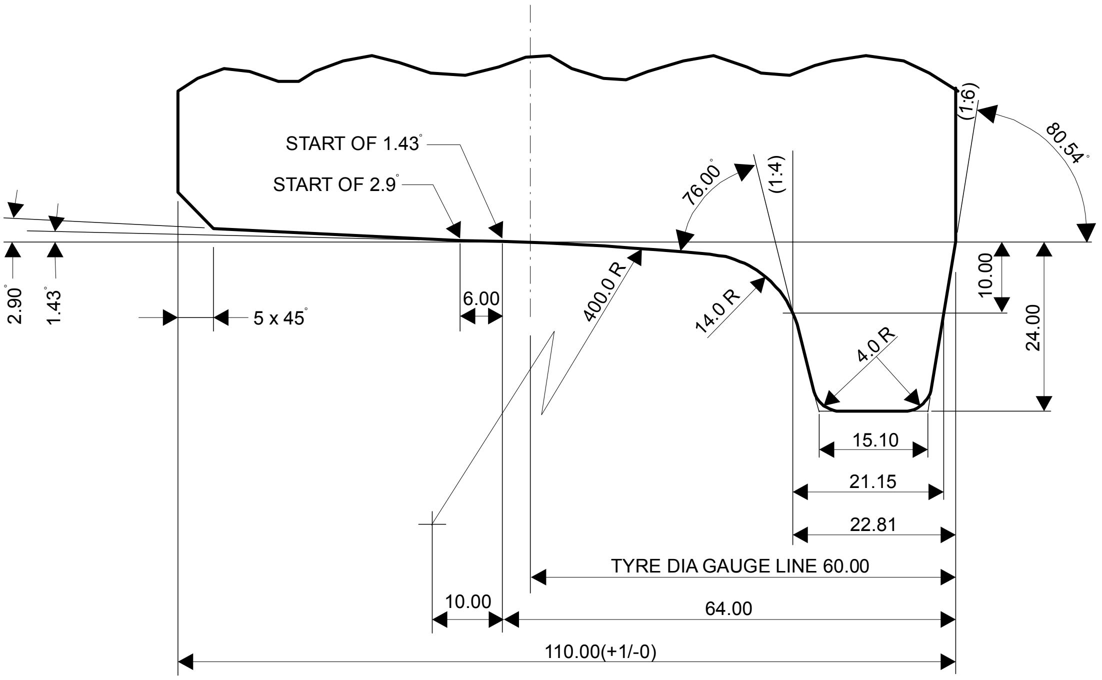
14.20 APPENDIX 20 MIDLAND METRO REVISED WHEEL TREAD PROFILE



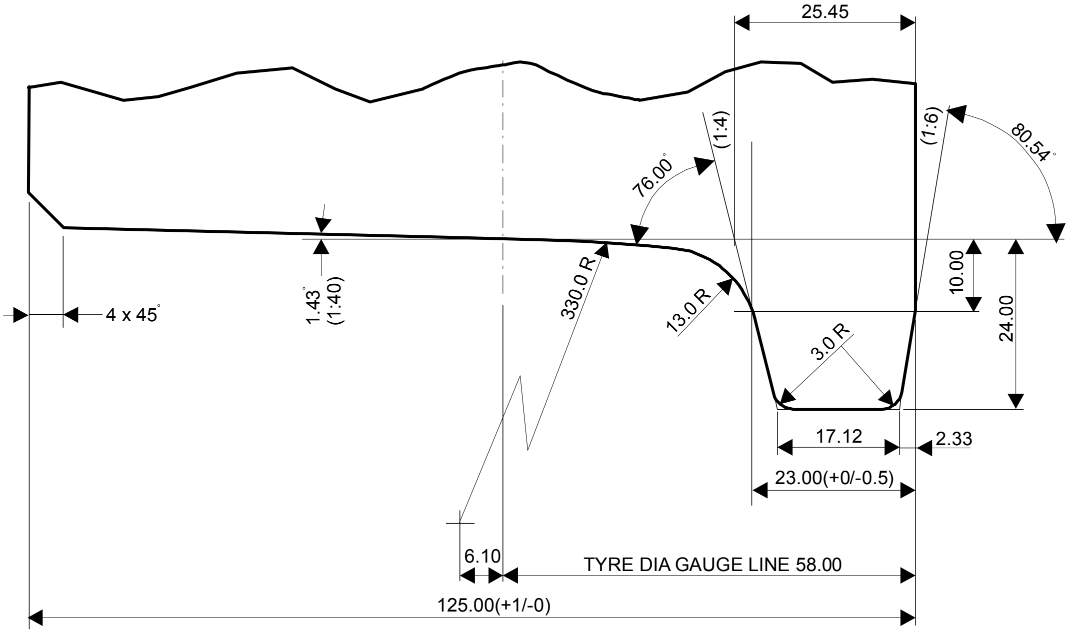
14.21 APPENDIX 21 NATIONAL TRAMWAY MUSEUM WHEEL TREAD PROFILE



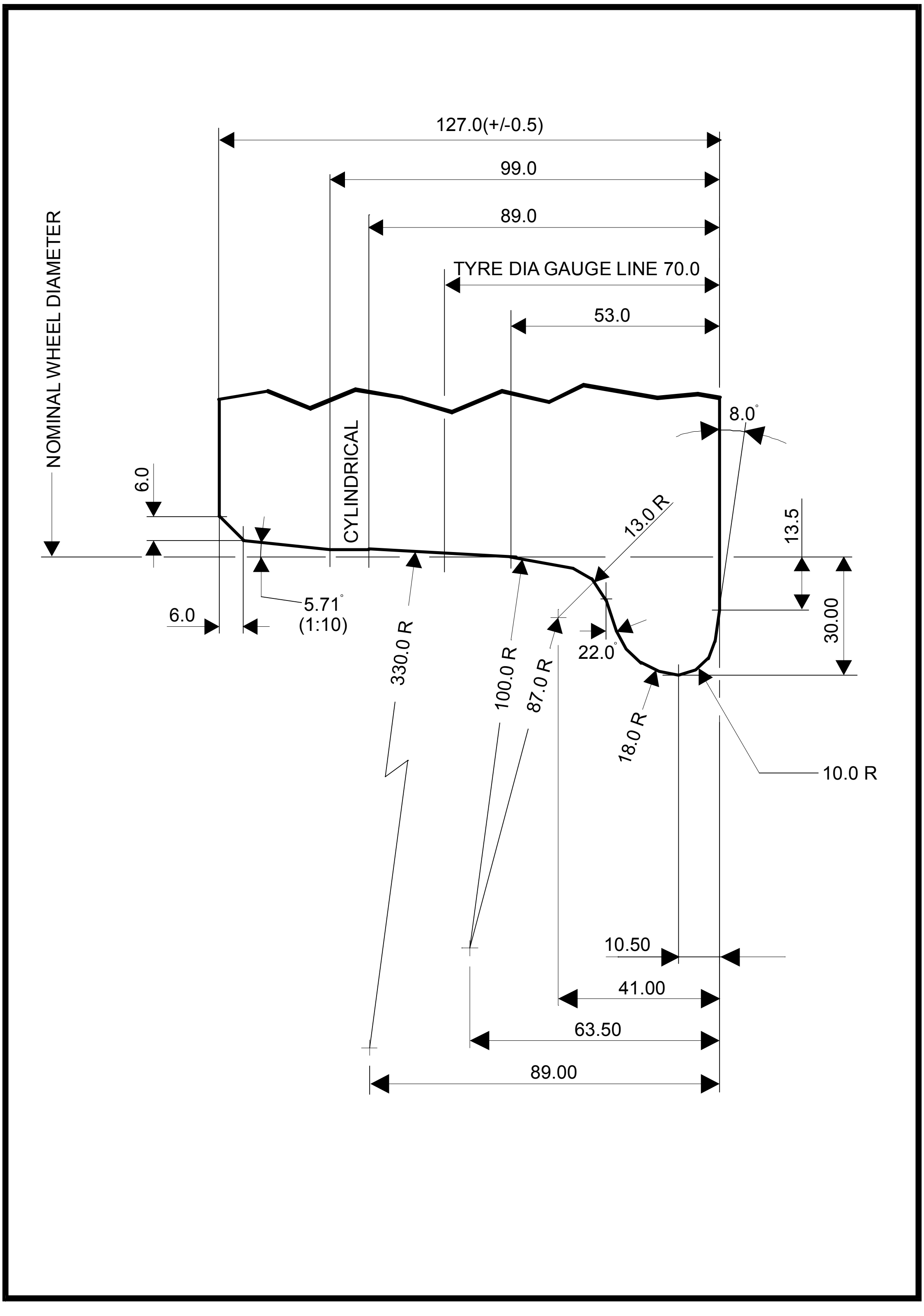
14.22 APPENDIX 22 NOTTINGHAM EXPRESS TRANSIT WHEEL TREAD PROFILE



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
LibeRTIN Light Rail Thematic Network	www.libertin.info
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POLYSAFE Level Crossing Systems Ltd	www.polysafe.co.uk
Rail Safety & Standards Board (Group Standards)	www.rgsonline.co.uk
REBS Zentralschmiertechnik GmbH	www.rebs.de
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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.

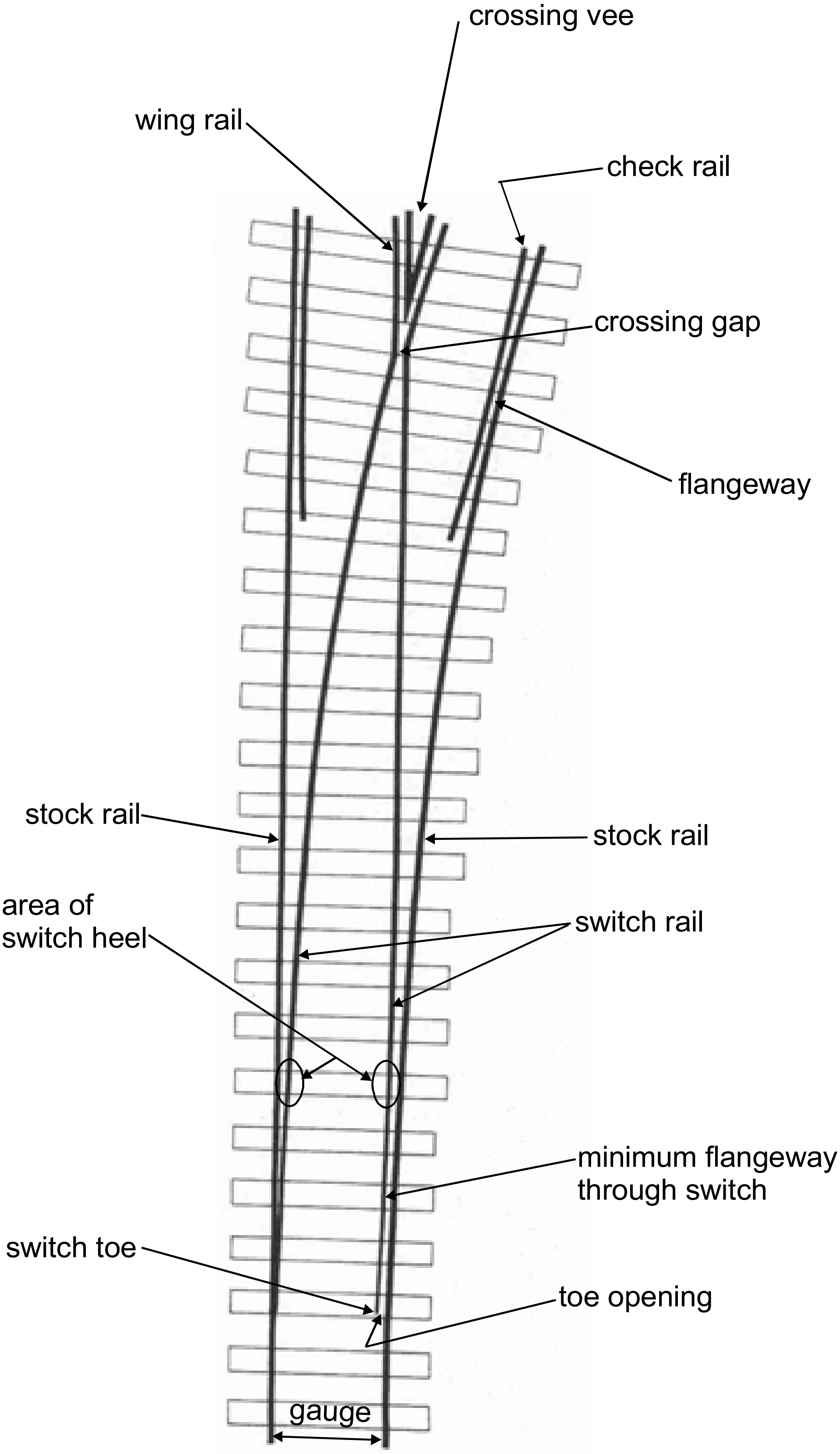

Figure 17.1 Turnout terminology