# 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 |

<u>Ballasted track:</u>

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)<br>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<br>(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]<br>3.350m[2] |
| Floor height above head of rail | 940mm[1]<br>915mm[2] |
| Distance between bogie centres | 10.700m |
| Bogie axle spacing | 2.065m |
| Wheel diameter | 740mm[1]<br>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<br>Two motor bogies (one at each end)<br>Two powered axles per bogie (Axles 1,2,5,6 from the 'A' end)<br>Traction motors attached to the bogie frame<br>Motor drive is via a flexible drive to an axle hung gearbox<br>Two rubber scroll springs per wheel primary suspension<br>Two rubber air springs per bogie secondary suspension |
| Trailer bogie | Type P048E<br>One bogie central to the vehicle<br>Articulation between bogie & body units<br>Central circular floor area fixed to bogie<br>Two un-powered axles (Axles 3 & 4 from the 'A' end)<br>Two rubber scroll springs per wheel primary suspension<br>Two rubber air springs secondary suspension |

Vehicle weights: See Table 5.10.

**Table 5.10** Manchester Metrolink vehicle weights

| | |
|---|---|
| Tare weight | (Type T68) 48964kg<br>(Type T68 A) 49561kg |
| Weight of crush laden | (Type T68) 68017kg<br>(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<br>(Bochum single-ring resilient wheel) |
| Diameter | 740mm (new)<br>680mm (worn) |
| Tyre width | 127mm |
| Profile | MML-2 (modified British Rail P8)<br>(See Appendix 18 for details) |
| Re-profiling criteria | Maximum flange width wear = 2mm<br>Maximum flange height wear = 6.5mm<br>(As flange width is maintained hollow tread wear does not develop.) |
| Vehicle running distances between wheel re-profiling approximate) | (T68 units) 60000km<br>(T68A units) 34000km |
| Wheel discard criteria | Minimum 680mm diameter |
| Tyre material | BS5892 Part 4 Grade B6E<br>(UIC810-1 Grade B6E) |
| Wheelset back-to-back | 1362 +0/-2mm<br>(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<br>(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

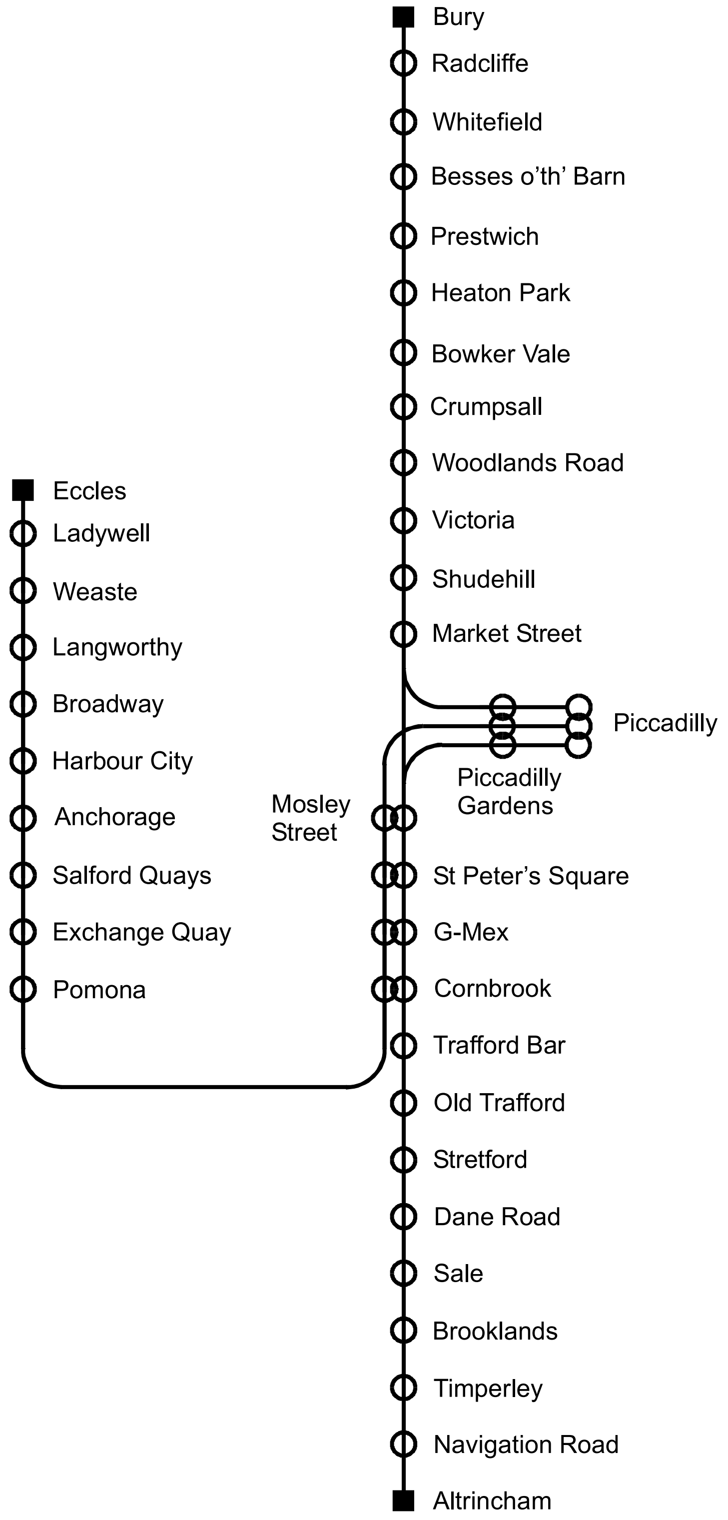


**Figure 5.1** Schematic route map of Manchester Metrolink

(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

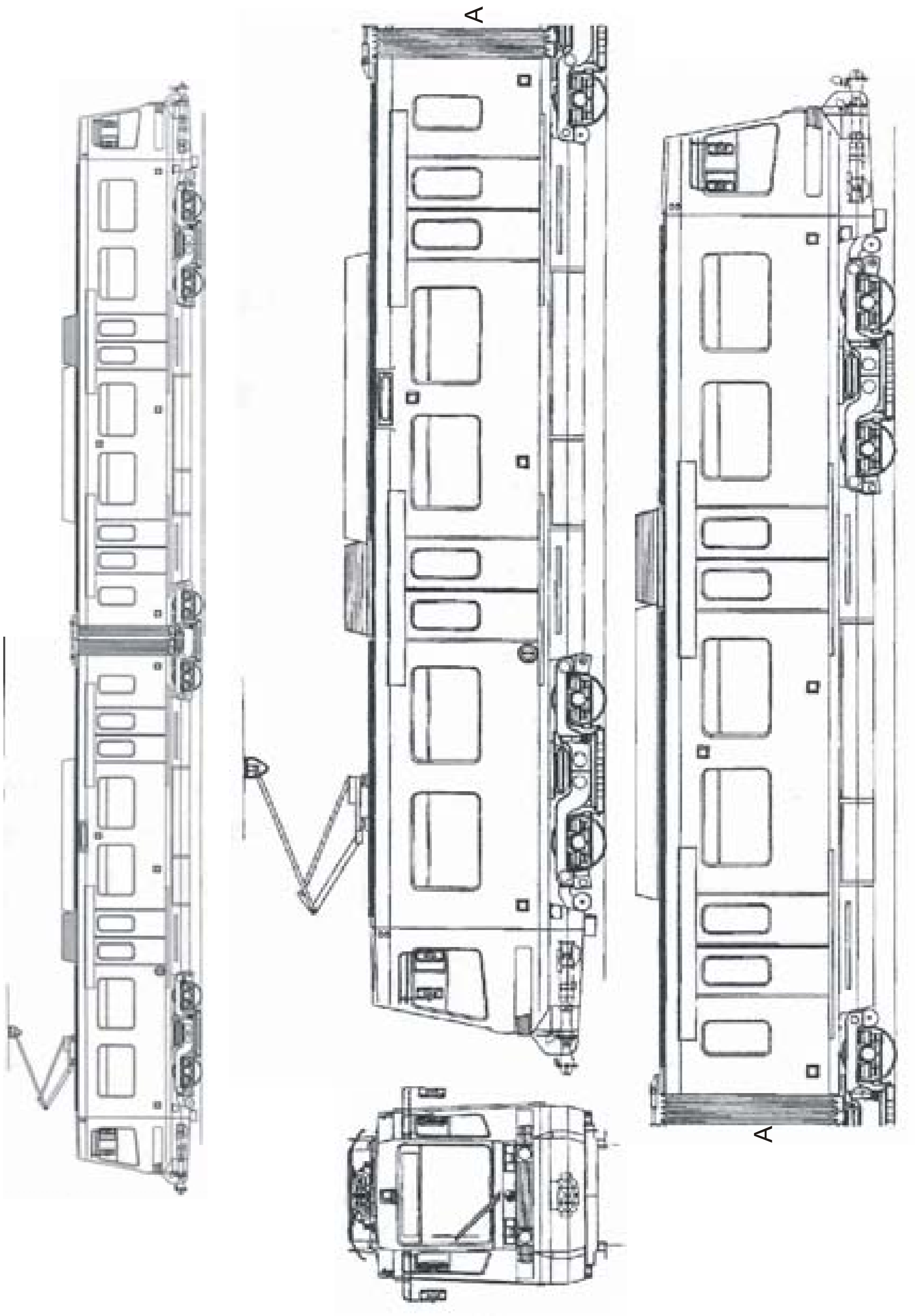


**Figure 5.12** Side and end views of typical Metrolink vehicles

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.

Ballasted track:

| | |
|---|---|
| Rail type | - Flat bottom BS 80A (see Appendix 10 for profile)<br>- 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<br>(At Swan Lane level crossing there is a short section with rail at 1 in 20) |
| Minimum track radius | 25m<br>40m (Depot) |
| Maximum track cant | Abs. max: 150mm<br>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<br>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)<br>Emergency crossovers 40m<br>Depot 25m |
| Switch rail type | Flexible[1,2] |
| Switch rail top planing | Overall length of planing = 2.5m<br>From 0.0m to 1.25m slope = 9.6mm/m<br>From 1.25m to 2.5m slope = 3.2mm/m |
| Crossing flangeway gap | 44mm |
| Check rail flangeway gap | 26mm<br>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<br>(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]<br>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<br>Two motor bogies (one each end)<br>Two powered axles per bogie<br>One 210kW motor per bogie<br>Motors mounted longitudinally<br>Rubber spring primary suspension<br>Air spring secondary suspension<br>See Figure 6.13 |
| Trailing truck | Four unpowered independent wheels<br>Wheels mounted on stub axles<br>Rubber spring primary suspension<br>Air spring secondary suspension<br>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)<br>620mm (worn) |
| Tyre width | 125mm |
| Profile | See Appendix 19 for original profile (DIN 34)<br>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<br>Maximum allowable flange height = 29.0mm<br>Maximum allowable diameter differences:<br>Motor bogie (same axle) = 1.0mm<br>Motor bogie (same bogie) = 2.0mm<br>Trailer bogie = 2.0mm<br>Maximum allowable ’hollow wear’ = 3.25mm<br>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<br>Now manual greasing of rail at selected sites |

## 6.5 OPERATIONS INFORMATION

Maximum line speed = 70km/h

Maximum acceleration = $1 m/s^2$

Maximum service braking rate = $1.2 m/s^2$

Maximum hazard braking rate = $3.6 m/s^2$

## 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.

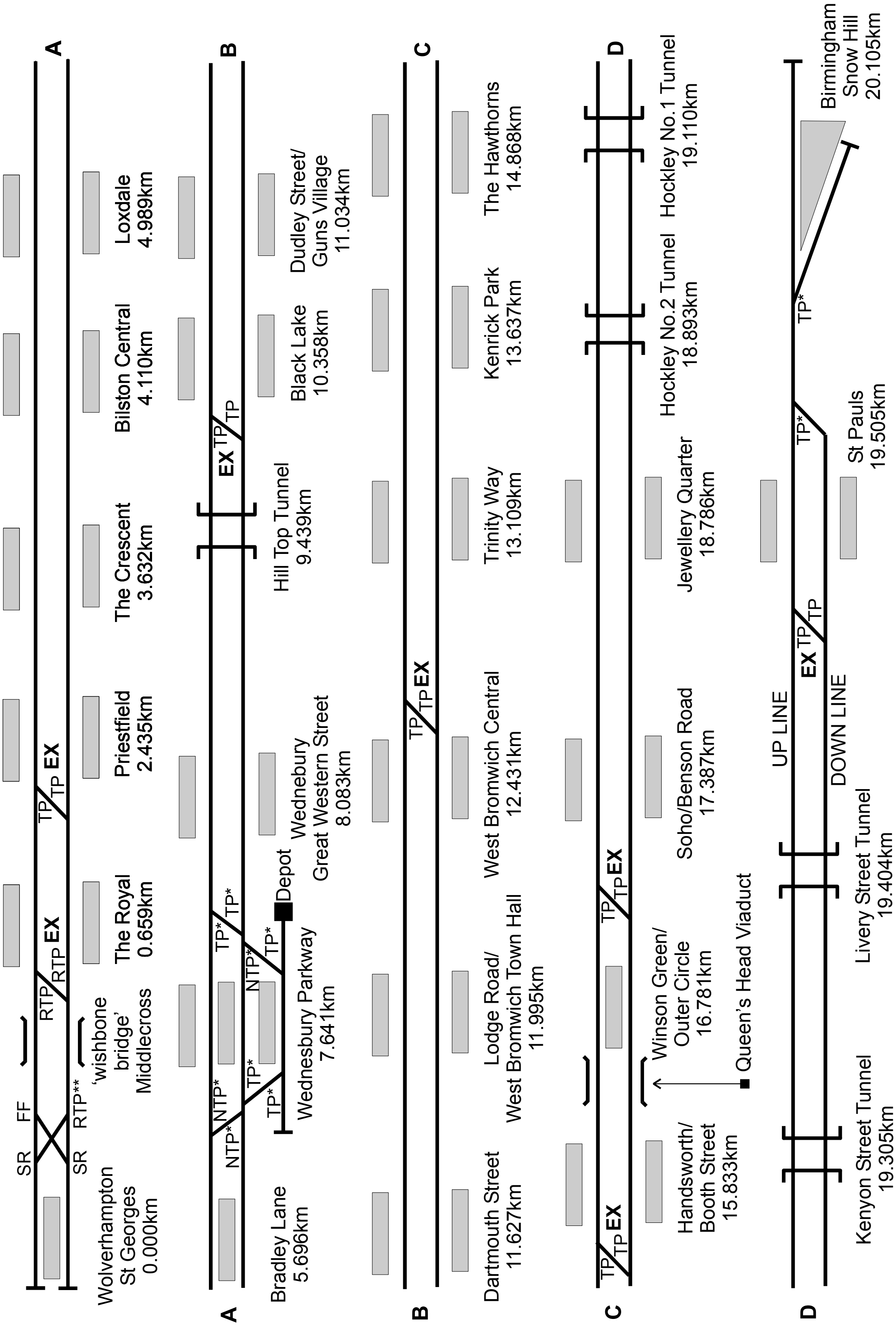
Rail corrugations:

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

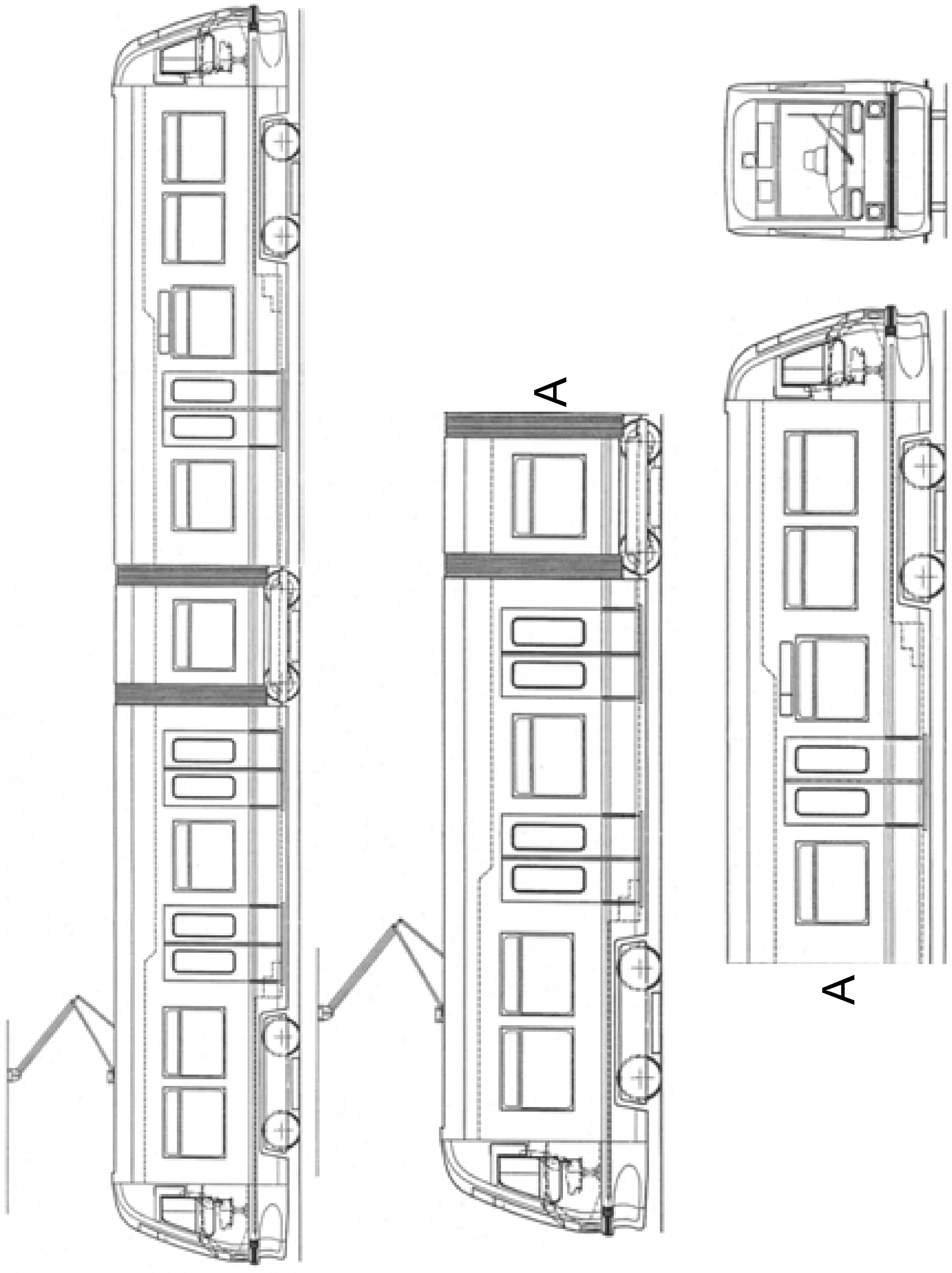


**Figure 6.11** Firema Trasporti S.p.A. T69 tram

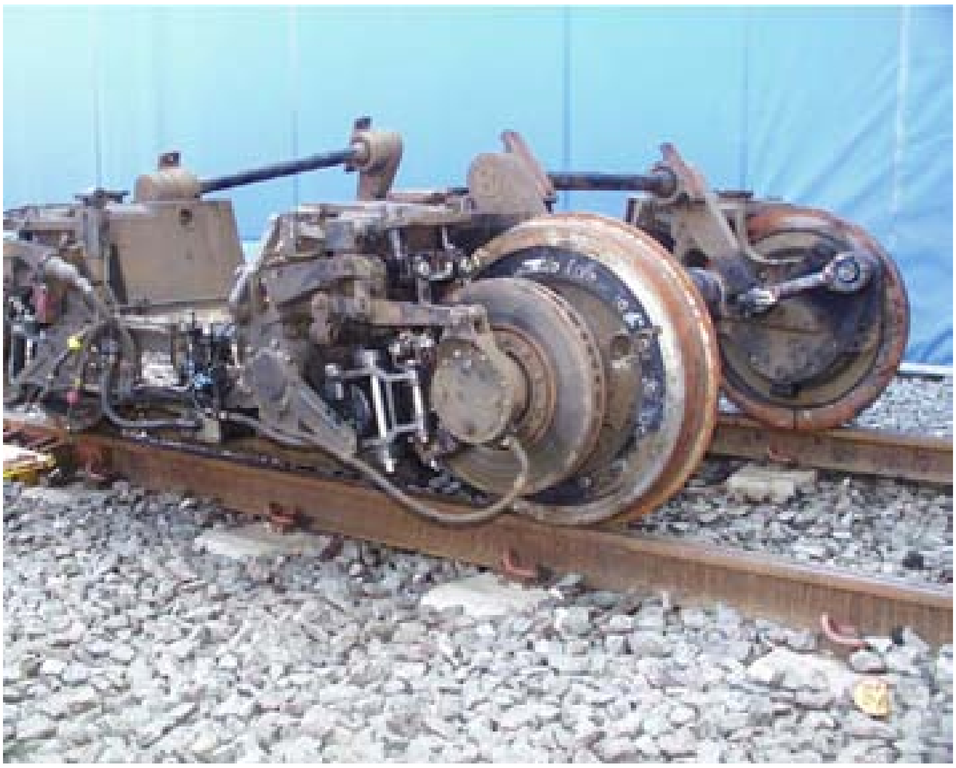
HSE0305-28/13

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

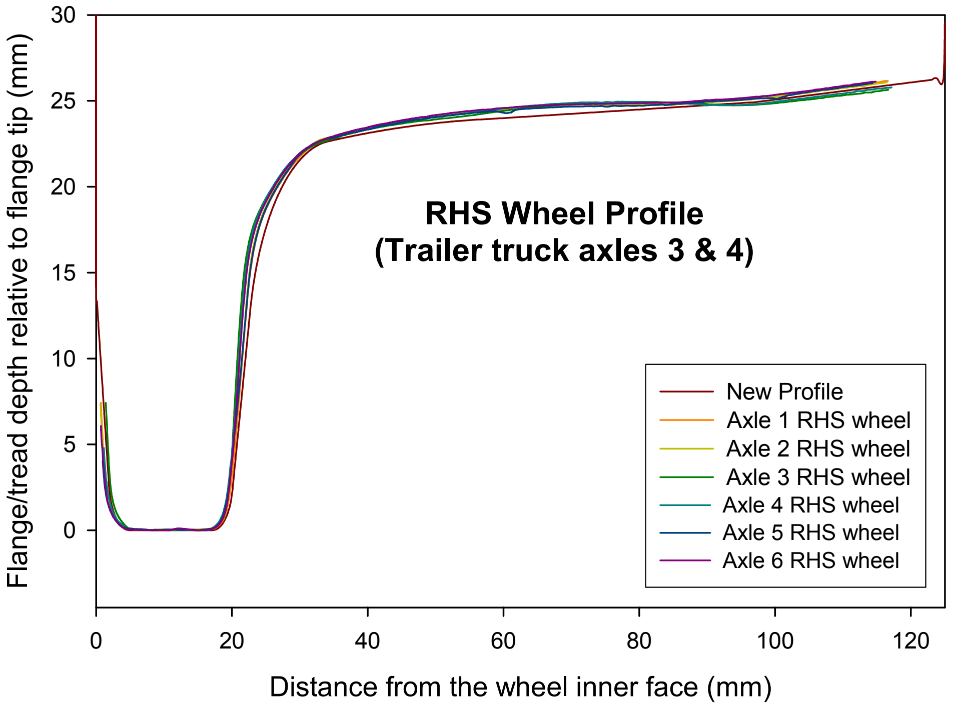
J Brown

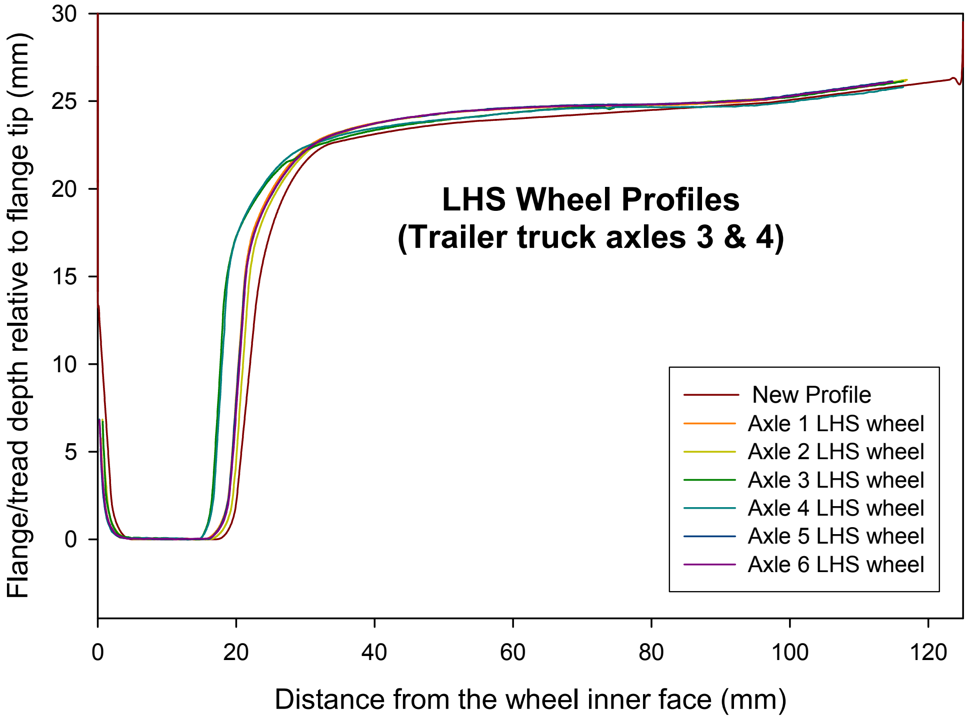
(a) New wheel profile

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)

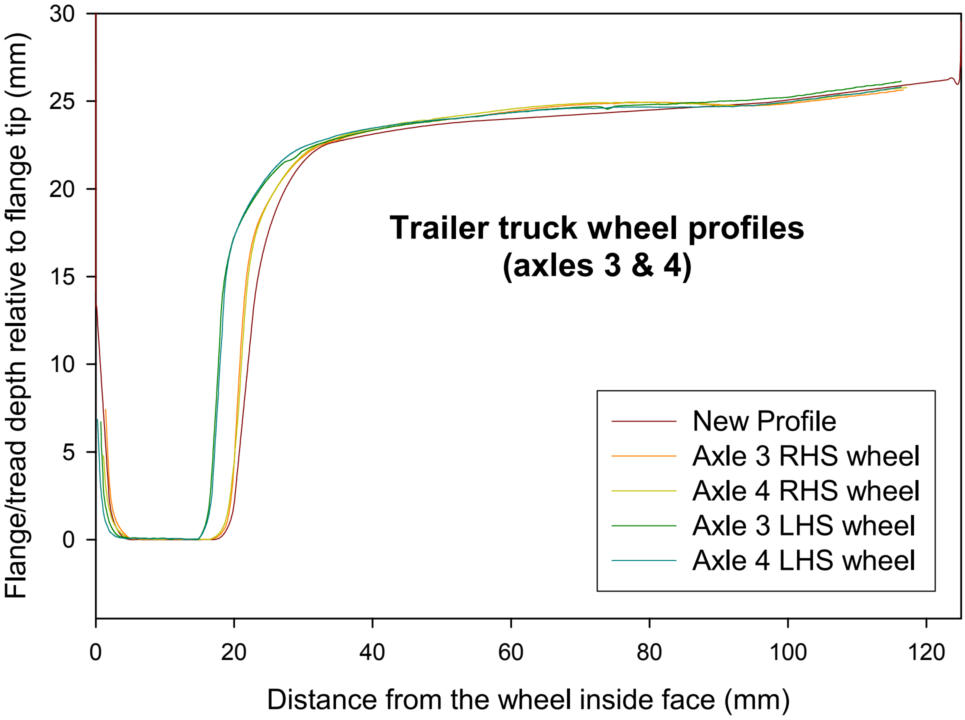


**Figure 6.17** Comparison of wheel profiles associated with independent 'notional wheelsets' from the trailing bogie of Tram 8 (07.07.04)

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<br>Passenger request stop |
| Bandstand | Compulsory stop<br>Passenger request stop |
| Stephenson Place | Compulsory stop<br>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<br>- 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.

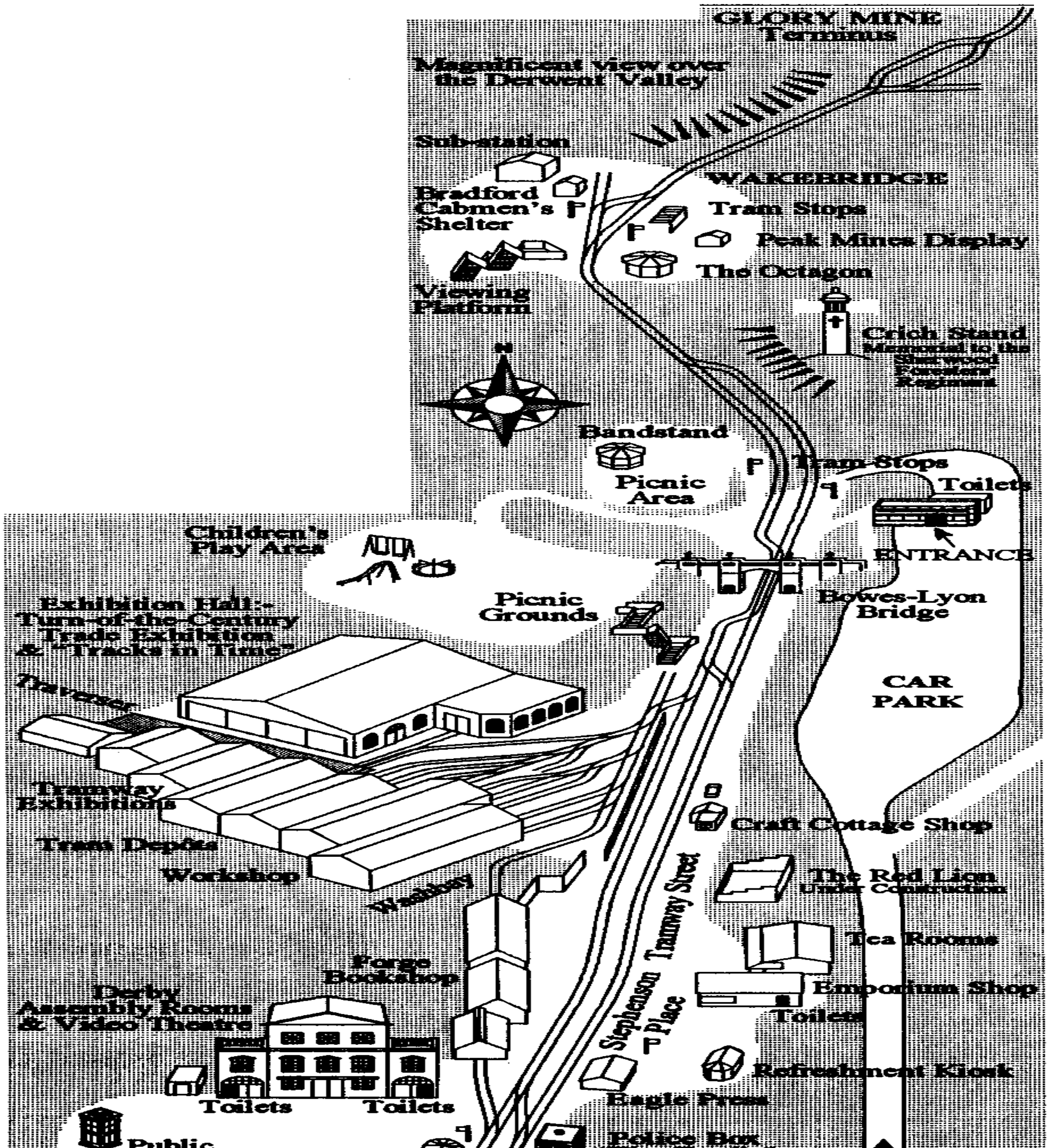
## 7.7 FIGURES

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

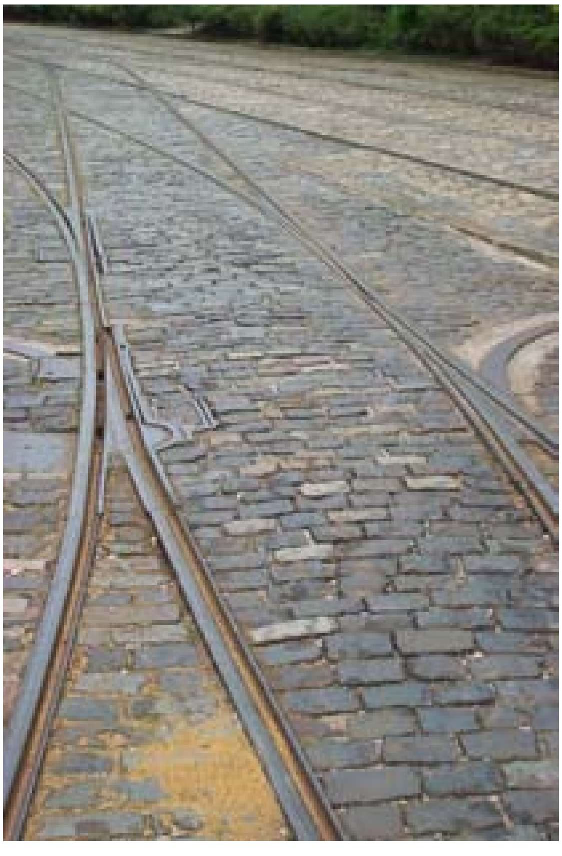


The Tramway Museum Society

**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

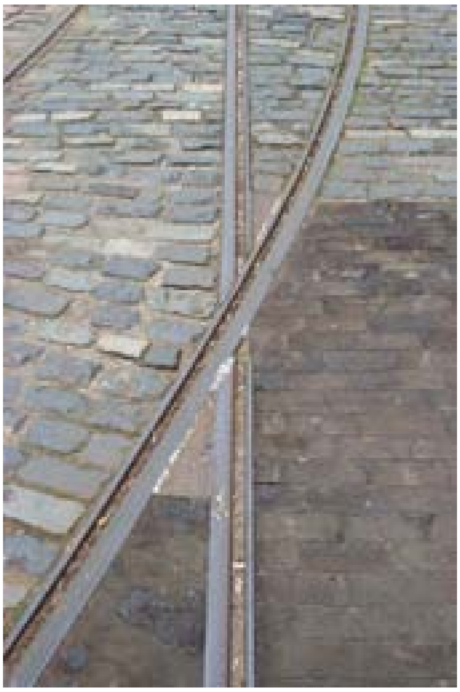
**Figure 7.5** A pair of grooved bladed turnout castings with dummy mates at The National Tramway Museum

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

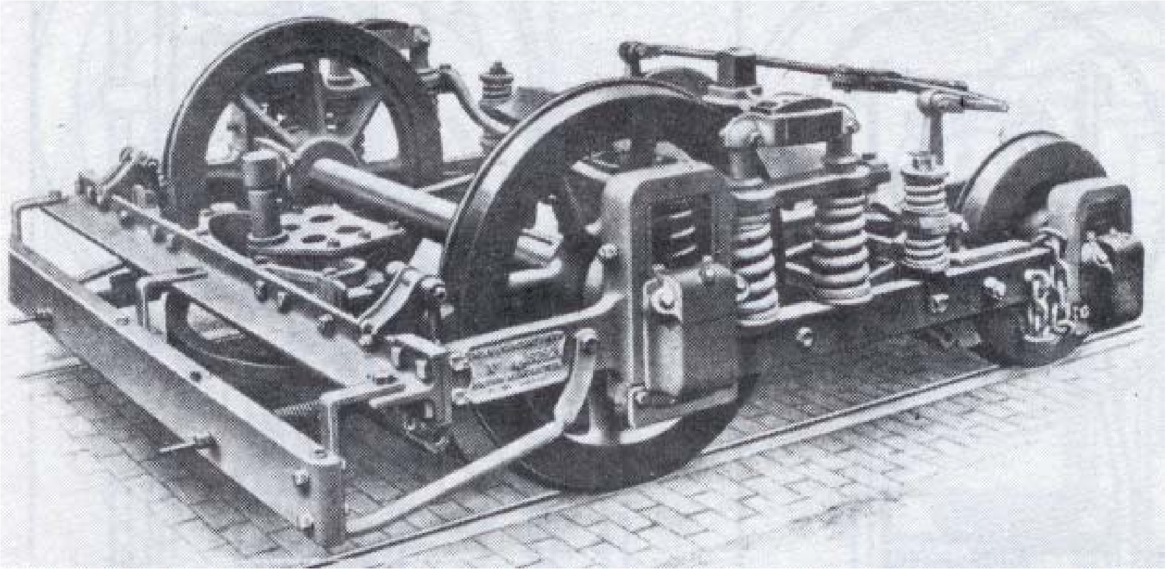
**Figure 7.8** A ‘bump over’ crossing at The National Tramway Museum

The Tramway Museum Society

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

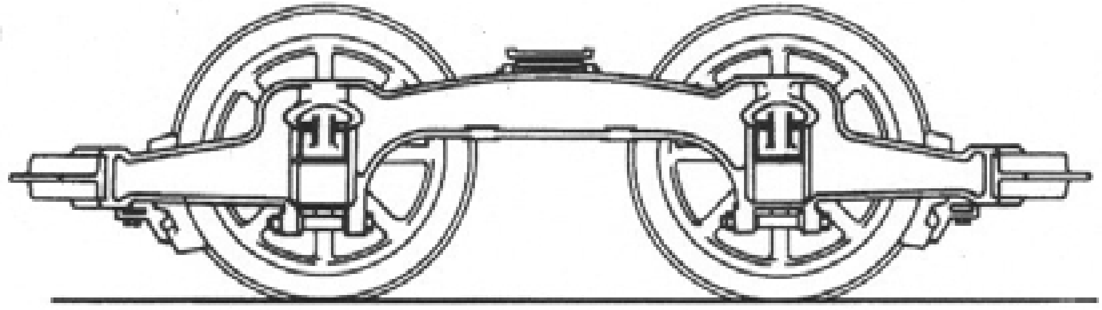
The Tramway Museum Society

**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)<br>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<br>(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<br>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<br>One truck each end<br>Four independent wheels per truck<br>Each wheel powered by own asynchronous traction motor<br>Integral dive and wheel hubs<br>Coil spring primary and secondary suspension<br>Sanding system |
| Trailer truck | One centre truck<br>Four independent wheels per truck<br>Coil spring primary and secondary suspension<br>Flange lubrication |

<u>Vehicle weights:</u> See Table 8.13.

**Table 8.13** NET vehicle weights

| | |
|---|---|
| Tare weight | 39300kg |
| Weight of crush laden | 59875kg |

<u>Wheel details:</u> 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)<br>580mm (worn) |
| Tyre width | 110(+1/-0)mm |
| Profile | See Appendix 22<br>(Flange width to be maintained within 18 – 24mm) |
| Re-profiling criteria | Awaiting operating experience |
| Wheel discard criteria | Minimum 580mm diameter<br>(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

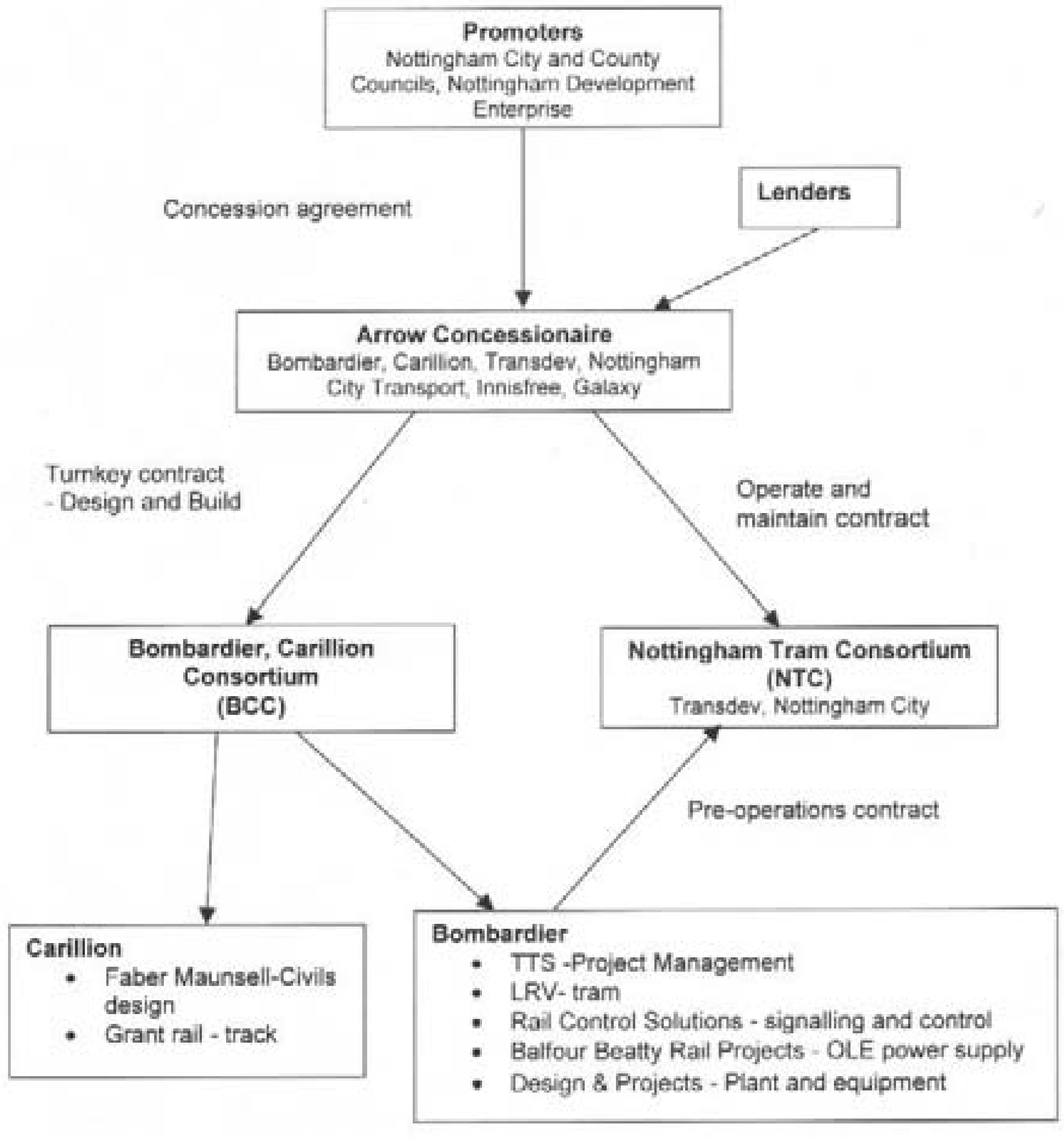


**Figure 8.1** Contract structure of Nottingham Express Transit (NET)

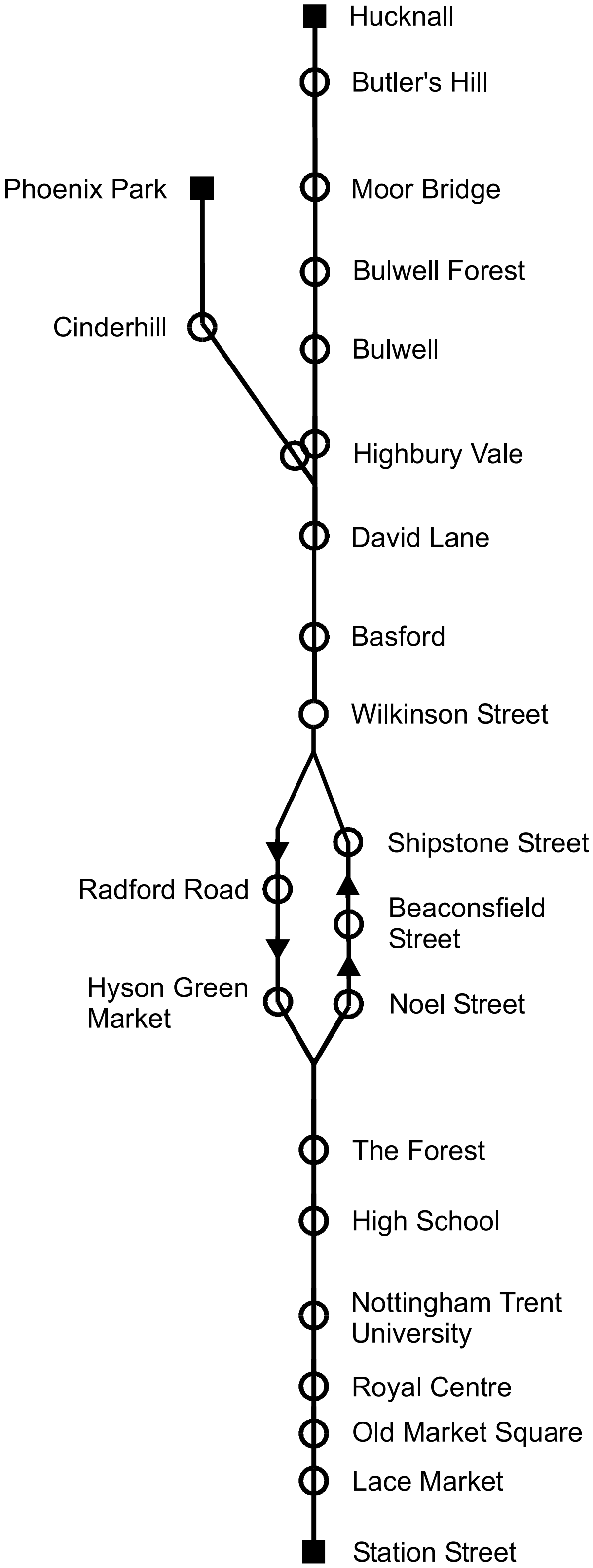


**Figure 8.2** Schematic route map of Nottingham Express Transit (NET)

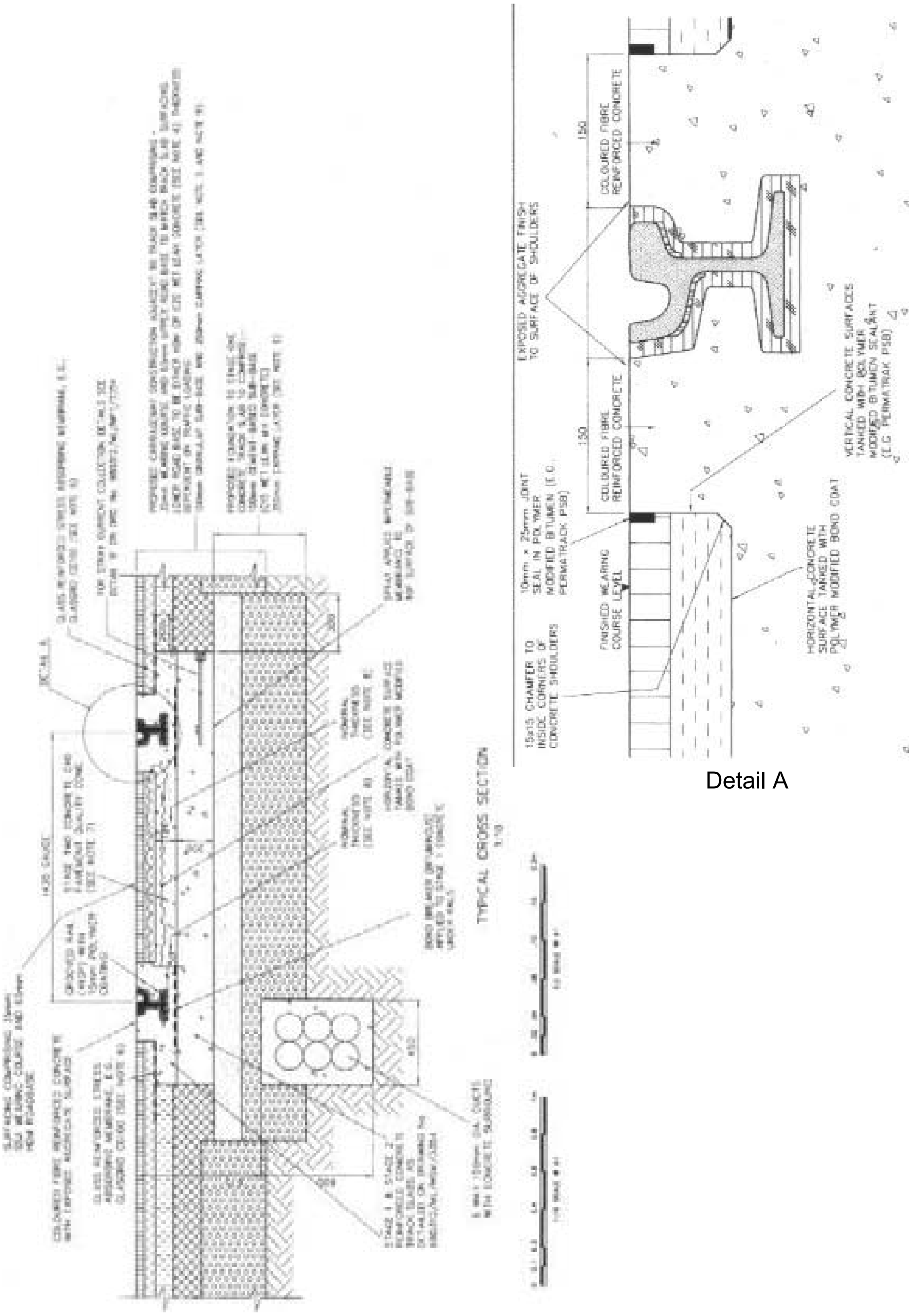


**Figure 8.3(a)** Drawing showing a typical cross section through on street in traffic NET trackform (by courtesy of Carillion)

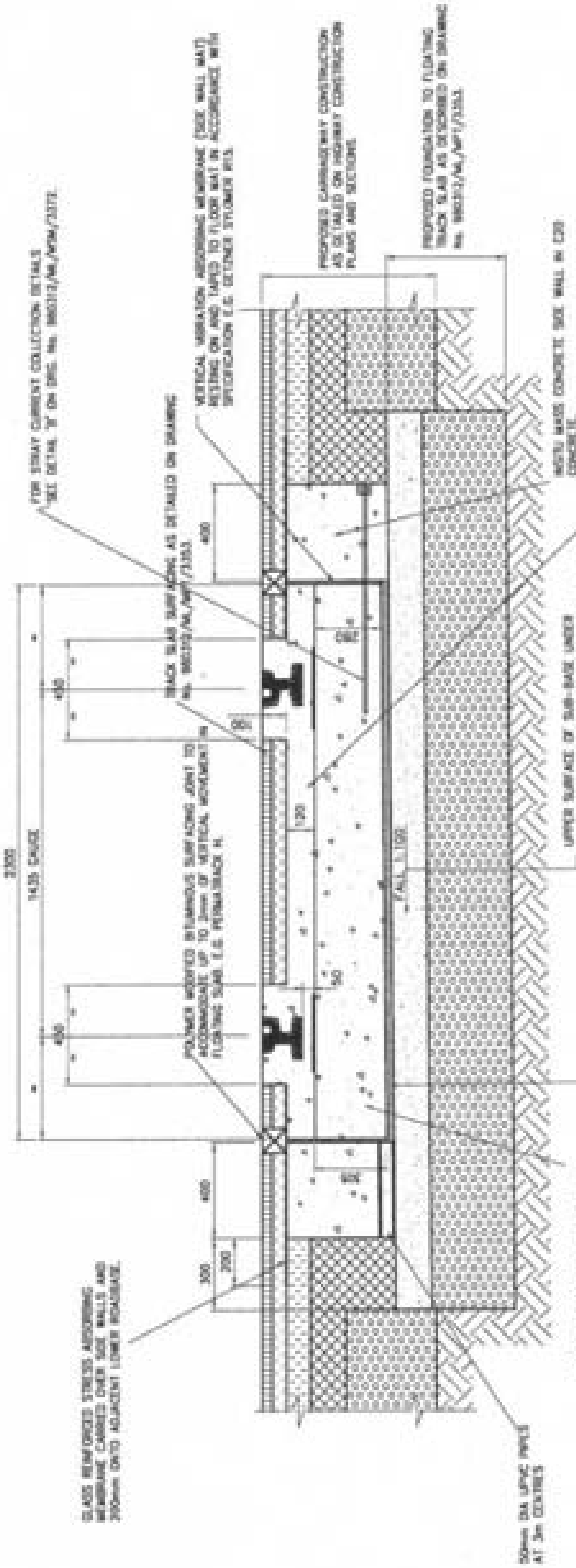
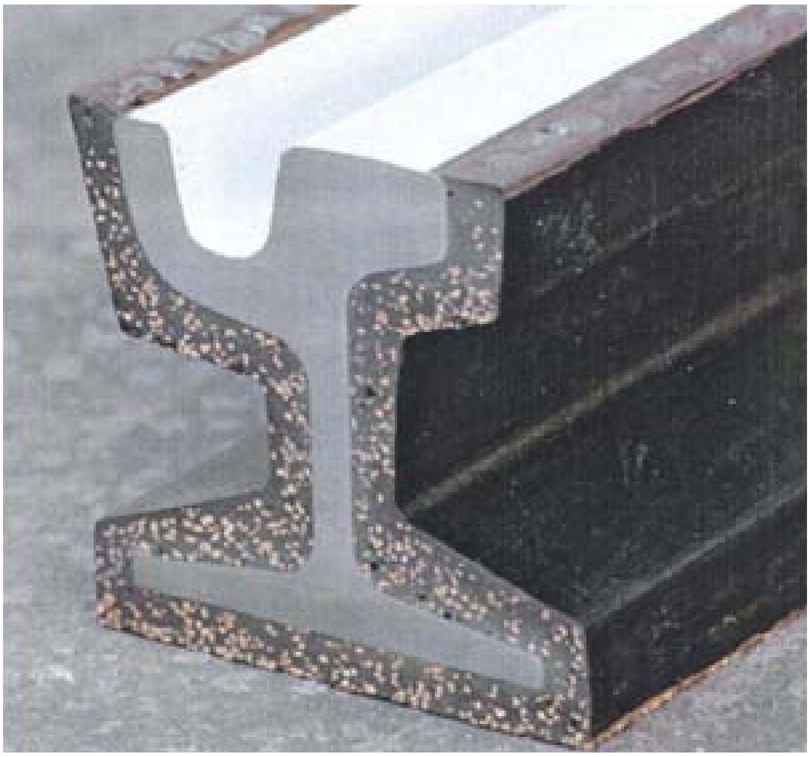


**Figure 8.3(b)** Drawing showing a typical cross section through NET on street track slab that incorporates vibration absorbing mat (by courtesy of Carillion)



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)

FES0409-02/07

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

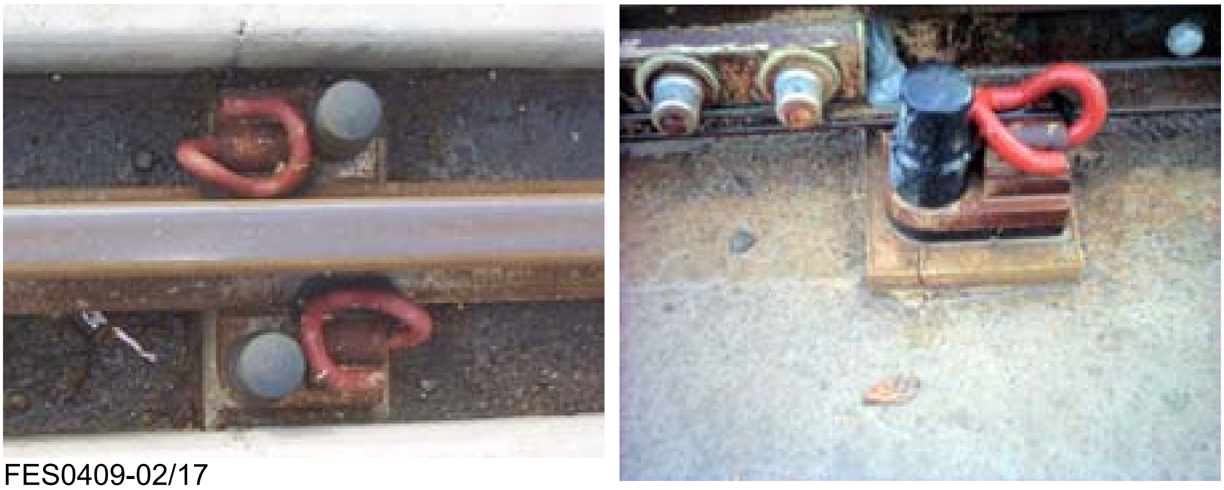
J Brown

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

**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)

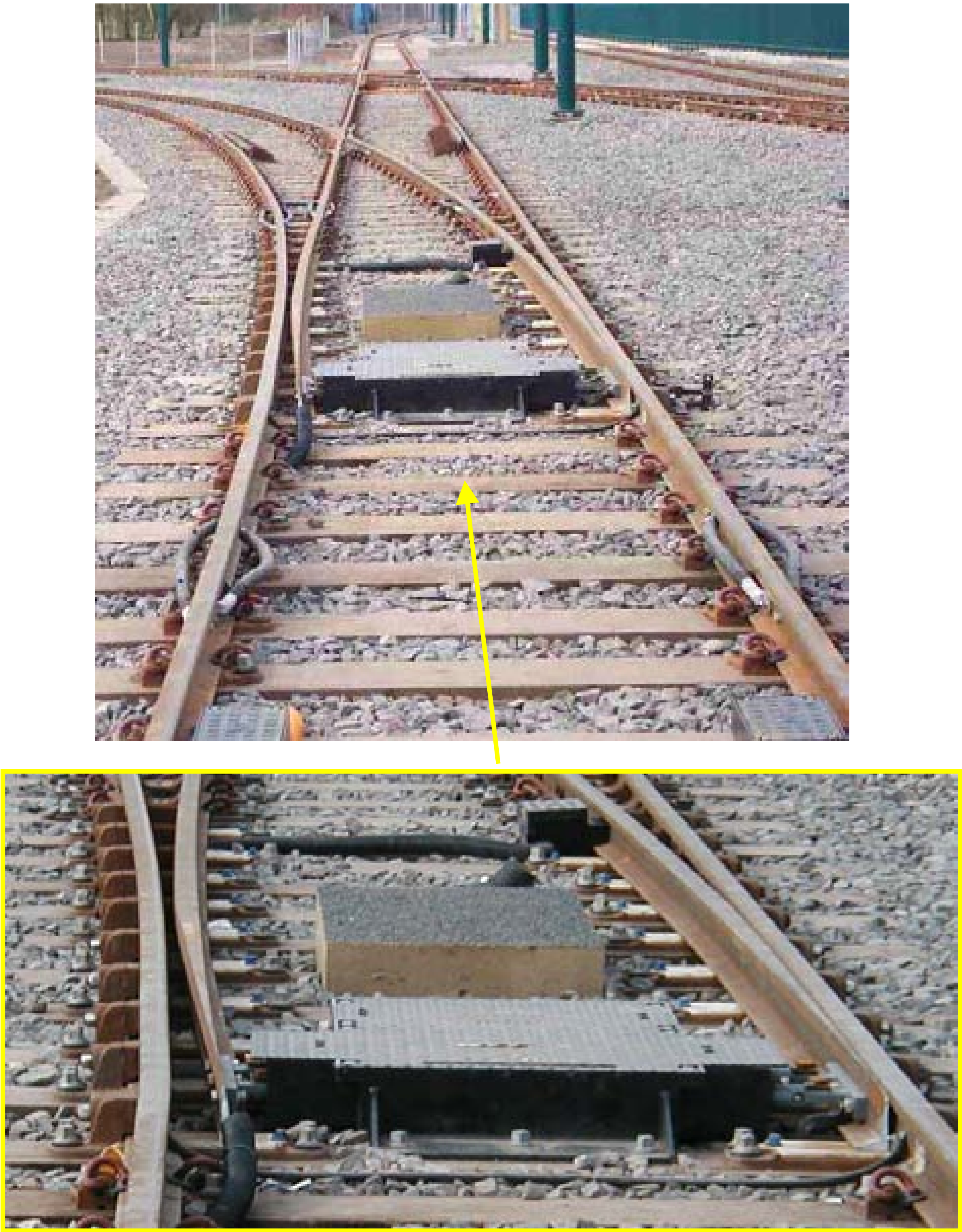
J Brown

(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

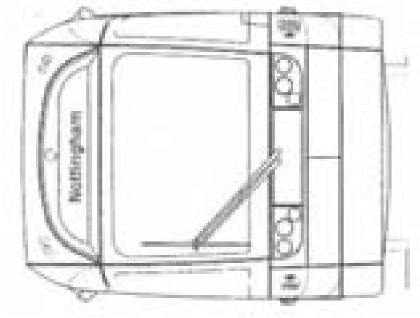
**Figure 8.21** Turnout crossing nose of at Station Street, NET (08.04.03)

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



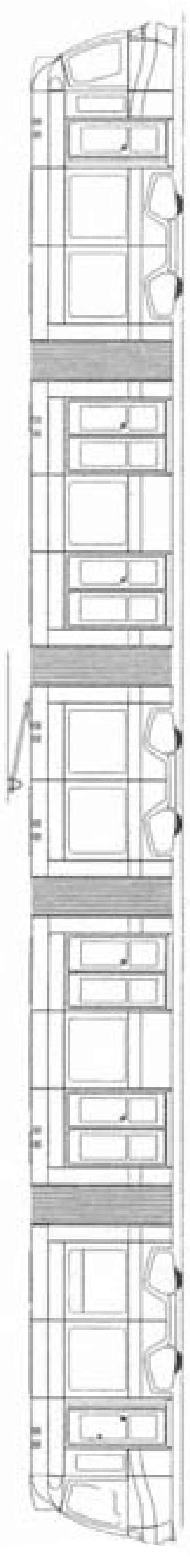


**Figure 8.24** The NET Incentro tram

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

FES0409-02/41

(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)