“Transactions speak louder than words”.
London Docklands Light Railway

The London Docklands Light Railway was officially opened by Her Majesty Queen Elizabeth II on July 10th, 1987.

The 12.1 kilometre railway serves the newly developed London Docklands built on the once derelict docks area to the East of the City of London. The system was designed to aid the development project, and has the capacity to carry up to 15,000 passengers on each route with trains at 7.5 minute intervals, and plans are already underway to extend the system.

The track is double tracked with the exception of two short sections. The elevated sections comprise fifty percent of the total length, which include a triangular junction with 40m radius turns, and gradients of up to 9%. Specially fabricated 65 metre spans, 8 metres above the water level have been constructed to cross three existing docks. Slab track with malleable iron fasteners is used on the elevated sections, with concrete sleepers on ballasted track at ground level, both using 80 E.F. continuously welded rail, fastened with PANDROL Brand type 'e' 1809 clips. The system uses 750V dc power supply through conductor rails.

Grant Lyon Eagle are the contractors for the trackwork and design of special turnouts and expansion switches on the Docklands Light Railway.
Singapore MRT Track Strives for Perfection

Construction of the 1.7km test track and sidings at Bishan Depot commenced in September 1986 and on the main line in March 1986. Work on Phase 1 and 1A, comprising 89km of track, including Bishan and Ulu Pandan Depots, was completed in June 1987, and Phase 2 tracklaying is due for completion by December 1988.

**Track Structure**

The design of the systemwide track work was undertaken by a Swiss consulting company, Electroconsult, in joint venture with Descon (Deutsche Eisenbahn Consulting GmbH) of West Germany. The track has a standard gauge of 439mm and utilises major components used by some of the world's major railway systems.

After evaluating various types of track structure, the following were selected:
- Ballasted track with timber sleepers on viaducts and in depots.
- Slab track with concrete sleepers set in concrete in tunnel sections.
- Floating slab track in tunnels passing near areas sensitive to noise and vibration.

The system consists of 190km of track, including the depots, of which 154km is ballasted track, 30km slab track and 6km of floating slab track. All tracks and turnouts in the system are continuously welded by the Thermit method.

An important aspect of the design and construction of the track was the requirement that maintenance costs should be minimised. For this reason, proven technology was used both for design of the track structure and the supply of track components.

**Design Philosophy of Track Support Systems**

By utilising fabricated track panels in tunnels at the installation stage, the track and component positions were fully adjustable to compensate for settling changes in place, which enabled the track to be built to very high standards.

The UIC 6B rail section is used throughout, with grade 90 for straight sections and curves of radius greater than 500 metres, and 110 for all smaller curves.

**a. Ballasted Track**

The selected track support types are as follows:

- **Ballasted Track**
  - Ballasted track has been chosen for the viaducts as well as at grade sections and in depots and stable yards. On the viaducts, the airborne noise emission plays a significant role and ballast will reduce the noise deflection by 3dB(A) at 5dB(A) when compared with slab track.
  - For sidings and depots, which are subject to differential settlement, ballasted track allows realignment and revisions to the track layout if required. It is also the most economical system.
  - The distinguishing feature of the MRT ballasted track is the use of guard rails inside every running rail on the viaduct sections. These have a dual purpose:
    - To act as a constraint to derailled trains.
    - To hold back running rails after the original rails are worn, when they will be interchanged.

- **b. Slab Track**

  For most tunnel sections slab track has been selected, as it is considered less maintenance intensive and provides optimum resistance against horizontal and vertical movements. Its reduced construction dimensions allow for a smaller tunnel diameter.

  The fixed slab track consists of 68m long prefabricated track panels with concrete sleepers at 700mm spacing. These are delivered to the tunnels by a gantry train propelled by diesel locomotives. The gantry train consists of two 6m long prefabricated track panels mounted on rail wheels which are connected to the tracks by the half-rail panels for ease of installation. After clamping the rails in place, temporary plate then the train can move forward to lay successive panels.

- **c. Floating Slab Track**

  The slab track design is based on the concept of an inertia mass as an additional vibration suppression. A single degree of freedom analysis for the vertical motion of the floating slab track (FST) is used. The mass is designed to exceed the weight of the train at all times (180 tonnes) and provides optimum resistance against horizontal and vertical movements. The reduced construction dimensions allow for a smaller tunnel diameter.

  The fixed slab track consists of 68m long prefabricated track panels with concrete sleepers at 700mm spacing. These are delivered to the tunnels by a gantry train propelled by diesel locomotives. The gantry train consists of two 6m long prefabricated track panels mounted on rail wheels which are connected to the tracks by the half-rail panels for ease of installation. After clamping the rails in place, temporary plate then the train can move forward to lay successive panels.
and sleeper is placed individually using the same launching gantry as for the slab track panels on three elastomeric bearings. Rails are laid onto the sleepers which are then wedged to final line and level. Subsequently the void between sleeper and trough unit is filled with concrete.

Details of the Floating Slab Track System are:
- 20mm of non-shrink cement-bonded grout is placed underneath the bearings. The latter varies to allow for tolerances of the first stage invert concrete underneath.
- 69mm thick composite rubber/steel elastomeric bearings supporting the floating slab track units. Plan dimensions vary from 235mm to 360mm square depending on the trough unit size, and are staggered in order to provide a 3 point support for each unit.
- floating slab track units (toughs) approximately 450mm high, 690mm wide and approximately 3.5m in length to suit the respective tunnel dimension.
- prestressed concrete sleepers with roughened sides to improve bonding.
- in-fill concrete grade 35N/mm² with swelling additives for casting in of prestressed concrete sleepers in the FST Units.
- elastomeric joint packers to seal the gaps between the individual units as well as against the tunnel wall.
- track fastenings consisting of plastic pads, type 3993 M.I. shoulders and Pandrol clips.

Turnouts

Turnouts on the system have been standardized to 1:75, 1:9, 1:12 and 1:14.5, with swing noise crossings at emergency crossovers. Of particular note are two 1:14.5 SNC turnouts located under the Standard Chartered Bank building. These are located on a floating track bed consisting of an 80mm thick prefabricated fibre bridge below a heavily reinforced concrete slab (150mm thick) supporting the turnout. The thin concrete slab is used to distribute the loading evenly on the rubber bearings.

Fastening Systems

The "Pandrol" fastening system was proposed by the contractor and approved by the MRTC. Cast ductile iron baseplates for plainline and turnouts are used and incorporate an anti-slip device. The slab track fastening system incorporates 38mm diameter bolts cast into the concrete sleepers or concrete slab at turnouts. The baseplates are placed onto resilient pads. The resilient pad requires a low spring coefficient of 20.6 N/mm. A rail pad is inserted between the rail foot and the baseplate. Rails are insulated by placing a plastic shim between rail and baseplate.

The Floating Slab Track fastening has Pandrol shoulders cast into the concrete sleeper into which the clip is fastened.

Timber sleeper track incorporates cast spherical graphite iron baseplates, screw spikes and rail pads.

Third Rail

The 750Vdc power is supplied to trains by means of a bottom contact composite aluminium third rail with stainless steel wearing surface.

Depots

The main depot at Bishan is of unique construction, being partly located on a 1.5ha concrete deck supported above a canal flood plain by 17000 precast piles. 24km of track is placed on ballast on the deck, or within the concrete floor of the depot buildings. Other depots are located at Ulu Pandan (west) and Changi (east).

Operations

The third rail was energised early in April 1987, and the first train ran from Bishan Depot to Ang Mo Kio and Yio Chu Kang on 11th April and to Outram Park on 4th July. Test running from Yio Chu Kang to Toa Payoh commenced on 7th May; this section is due to be opened to public operation in December 1987 (6km) and the section to Outram Park (total 16km) a few weeks later.

Conclusion

Singapore Mass Rapid Transit Railway construction provides a unique blend of proven technology coupled with "state of the art" techniques and with these methods the Mass Rapid Transit System will become the most modern presently built.

When Phase 2 is completed in February 1990, the MRT will be able to carry nearly 900,000 passengers per day, with up to 30 trains per hour at peak periods.

Acknowledgements

Grateful acknowledgements are extended to Mr B Kraft of Cementon and Mr M Hudson of Henry Boot-Cameron and the MRTC for permission to use extracts of the paper "Track Selection, Design and Implementation" presented at the Singapore MRT Conference in April 1987.
Italy Develops Factory-Made Concrete Slab Track

Italian topography is such that railway realignment projects frequently involve major investment in tunnels and viaducts. Investment in the track itself is relatively small. Therefore an increase in this part of the investment can be justified if it will significantly reduce maintenance and thus increase the revenue-earning capability of the investment as a whole.

This philosophy has led to the development of a new type of ballastless track in Italy. Constructed in factory-made prestressed concrete slab units, 4.8m long, the new track can be laid at 200m per day. It is suitable for track speeds up to 300 kph and for axle loads up to 25 tonnes. Several layers of elasticity within the system provide running characteristics similar to those with conventional concrete sleeper track.

The photographs show the new track being laid in a 7.5km long doublet and realignment project north of Udine on the heavily used Villach to Venice freight route. The project will raise line speed from 80kph to 160kph. A similar 20km long project a little further north on the same route is at the design stage. Trial installations, with an additional polyurethane elastomer layer, have been made on the Milan and Genoa metros and a section will be installed in a tunnel under some of Catania's historic buildings early next year.

Dr Engineer Giancarlo Bonora has been consultant engineer throughout the project. His article describes the first development phase.

1. General

Within the framework of a general re-examination and re-organisation of the network, the Italian State Railways commissioned a development project with the aim of improving the current standard track which consists of prestressed monobloc concrete sleepers in a ballast bed.

There was a general need to improve track performance to permit higher maximum speeds and faster freight traffic.

Specific aims were to achieve:
- tighter construction tolerances;
- tighter operational tolerances;
- increased track stability under dynamic loads;
- reduced transmission of vibration.

The economic aim, whether directly or indirectly, was to reduce maintenance costs. The directly incurred costs of maintenance work in noisy or dusty environments, and especially in tunnels, are constantly rising. There was also a need to reduce costs incurred indirectly because of rerouting, delaying, or interrupting traffic for track maintenance operations. The latter problem is particularly relevant in Italy where traffic density on main lines is high and where few alternative routes are available due to the topography of the country.

Italian main lines carry all types of freight and passenger traffic so that the track must accept a wide range of speeds and axle loads.

The first stage of the project was a proposal made by Industria Prefabbricati Affari (IPF), a prestressed concrete manufacturer, in 1973. This paper describes the first stage.

A totally new track structure was designed for a very long maintenance-free life. The heart of the system is a factory-made prestressed concrete track unit. Figure 1 shows a typical section through the new track. In this case it is on an embankment.

The mass concrete base slab is omitted in tunnels and on bridges which themselves provide sufficiently rigid foundations for the prestressed units.

2. Factory-made Prestressed Concrete Track Units

Figure 1 and photographs A and B show the units. The 250 x 475cm prestressed concrete slab has a minimum thickness of 15cm.

The assembly has been designed to distribute wheel loads to the base slab and thence to the ground, supporting the track and providing sufficient stability and adequate elasticity. The design is based on the following load criteria:

- static axle load: 25t
- number of axles on any one prestressed track unit: 3
- bogie axle spacing: 2000mm
- coefficient of IP dynamic increase: 1.5
- for normal operating conditions
- for exceptional operating conditions
- accelerating and braking force: 8t
- lateral force per axle: 7.5t
- thermally induced force: 6t

A computer programme incorporating both static and dynamic parameters was used for the design analysis.

Figure 2 is a schematic of the entire system used for the computer programme and showing the elastic elements between rail and prestressed unit, prestressed unit and foundation slab and in the formation itself. Other parameters included in the structural design analysis were the characteristics of the UNI 60 rail and the resilient fastenings.

3. Rail Fastening Assembly

The design study includes a double elastic rail fastening assembly developed by the Italian State Railway. It is shown in Figure 3.

A schematic of the entire system used for the computer programme and showing the elastic elements between rail and prestressed unit, prestressed unit and foundation slab and in the formation itself. Other parameters included in the structural design analysis were the characteristics of the UNI 60 rail and the resilient fastenings.
A rolled steel C' base plate is supported by a 12mm thick 360 x 190mm base plate pad made of either hardened PGS or PGS-CQ or of King's Winter bonded cote. The base plate is bolted to the rail head using 16 M18 A10 Grade 8.8 iron shoulder. Class reinforced mullion irons provide electrical only from the point of view.

The second elastic layer is provided by a wood under rail pad 190mm thick, which is between rail and base plate. Rubber type PGS 20, PGS CQ or PGS L is used for the rail head. In each case, elastic ballast fastening type SK 3 hold the rail to the base plate.

The elasticity of the assembly is the sum of the elastic characteristics of the two elastic layers. The range stiffness will be the elastic layer loads between 14KN and 40KN, brand, dynamic case, frequency 50Hz, the following stiffness values are obtained for the assembly:
- static 3.28 x 10^6 N/m
- elastic 3.02 x 10^6 N/m
- calculation of 20 KN/m

Hence deflections of complete assembly for a height of 100KN are obtained.
- vertical 0.08 mm
- horizontal 100 x 0.008 = 0.8 mm

4. First stage experimental results

A prototype test trial was performed at Ghatkopar, on the Borong-Teresa line, and a high-speed train was also used. An instrumented test programme was carried out during August and September 2013. The following data was collected to examine the performance of the prestressed and non-prestressed rail with acoustic and longitudinal flanges generated. Numerous controlled passes by an RS locomotive type 58.4 were used. Photograph A, together with normal traffic on the line, were used in the analysis.

Locomotive passes were made in both directions at speeds from 80-100 km with incremental increases of 20km. Three tests were carried out at each increment and in each direction.
1. At a constant speed
2. Accelerating
3. Decelerating

The following parameters were measured:
- Relative displacement between rail and prestressed unit (RP)
- relative displacement between prestressed unit and foundation mass concrete (FPF)
- relative displacement between foundation mass concrete and datum (a massive block of concrete sunk into the terrain nearby, IFB)
- distortion of the prestressed unit
- distortion of the rails

Relative displacements between rail and prestressed unit were recorded for both rail sections: a displacement of the transverse axis and to the joint between the units. The arrangement is typical.

Measurements of relative longitudinal and horizontal displacements between rail and prestressed unit were recorded parallel to the transverse axis. More instruments were installed.

Instrumentation is shown at Photographs B and D.

Figure 5 is typical of the results. It shows the vertical displacement of the rail foot relative to the prestressed unit (RPS) during the passage of a train at a constant speed of 60km/h. These are the instruments shown in Figure 4.

Table 1 summarizes the peak values obtained by the same four vertical displacement transducers.

After a thorough analysis of the results, FSC approved the prototype design for further in-track trials at speeds up to 300km/h and under 25 tonne axle loads. 14km of the system are currently being installed on the Udine-Tarvisio line.

### Table 1

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**Author:** Dr Ing Giancarlo Boni, Consultant, MSC Company, Milan.

**Translated by:** Mrs H J Stewart and J D N Reiter
Pressed Steel Shoulders

The Use of Pressed Steel Shoulders in the Norwegian State Railways
Prestressed Monoblock Concrete Sleeper

Many railways are now actively considering Pressed Steel Shoulders in preference to shoulders of ductile iron for Pandrol rail fastening assemblies. Originally it was anticipated that the Pressed Steel Shoulders might be more susceptible to corrosion, but experience in track of a number of railways, including the Norwegian State Railways and Austrian Federal Railways, has proved these fears to be unfounded. In addition to being easier to manufacture than malleable iron shoulders, the pressed steel shoulder also has technical advantages, offering more resistance to tendon and pull-out forces, and being more resistant to loosening by vibration.

Pandrol work in close contact with the sleeper manufacturers in order to ensure that sleepers fitted with Pressed Steel Shoulders not only perform well in track, but are also easy to incorporate into the sleeper casting process.

Stein O. Lundgren
Permanent Way Design Engineer
Norwegian State Railways

The Pandrol Pressed Steel Shoulder was first developed in 1966 as a cost effective shoulder for the Pandrol concrete sleeper system being considered by the Norwegian State Railways. One of the main requirements was that it could be manufactured by a traditional Norwegian engineering company with cold pressing facilities.

The shape of the steel shoulder was modified slightly in 1969 but in general the basic profile and production techniques have remained unchanged. The shoulders are manufactured from standard flat rolled section 122 x 150 mm delivered in lengths of 4000 mm - material quality KST 37 2.

The production is split into two basic operations:
1. Blanking - see figure A
2. Cold Forming to required profile - see figure B

Currently the Norwegian State Railways have in service some 9.9 million Pandrol concrete sleepers which have required 15.6 million pressed steel shoulders. They operate 4.268km of 1435mm gauge track which extend northwards beyond the Arctic Circle. The maximum axle load is 20 tonnes and maximum speeds of the passenger trains are 120kph.

Whilst the short Norwegian summer can be pleasant with temperatures occasionally hitting 40 Degrees Centigrade, the biggest problem is the harsh winter when temperatures can drop below -40 Degrees Centigrade, creating difficulties for both the Operations and Track Maintenance Departments.

With high annual rainfall and many locations near the coastal area, corrosion has been a feature which the Norwegian State Railways had to consider seriously.

Over twenty years of continued service has indicated that corrosion of shoulders has not been a serious factor. In practice the exposed head of the shoulder becomes covered in oil, grease, brake block dust and other trackside debris soon after installation, forming a barrier against prolonged corrosion. It is however the policy of the Norwegian State Railway to apply an anti-corrosive coating to the shoulder prior to sleeper production, for use in selected areas i.e. tunnels and notably wet areas such as docksides.

Part of the acceptance requirements for the concrete sleeper assembly was a series of static and dynamic load tests carried out on behalf of the Norwegian State Railways by the Technical University of Trondheim, Norway. The major test was a dynamic load test on the full concrete sleeper assembly. A load was applied to the 549 rail head alternating between 3 and 30Mpa for a maximum duration of one hundred million cycles without any indications of component failure or shoulder loosening.

Shoulder pre-load tests have also been carried out within the laboratory of a concrete sleeper manufacturer - Strangbottøg AB, Sweden. The pressed steel shoulders were subjected to a load in excess of 10Mpa without any indication of movement of the shoulder or cracking of the concrete.

Future developments of the pressed steel shoulder are concerned with investigating the possibilities of providing a more economical steel cross-section without reduction in the overall performance of the fastening assembly.
Resilient Pads For Twin-Block Sleepers

There are two types of concrete sleeper widely used on ballasted track — monobloc sleepers, which consist of a single beam of pre-stressed concrete, supporting both rails, and twin-block sleepers which comprise of two blocks of reinforced concrete, one under each rail, connected by a tie bar which is usually made from a simple rolled steel section. "Pandrol" fastenings may be used on either design, but until recently most of Pandrol's rail pad development work has been based on extensive theoretical and experimental work on pre-stressed monobloc sleepers. The balance has been redressed by a series of laboratory and in-track tests carried out in close co-operation with the Belgian State Railway, S.N.C.B.

A small number of twin-block sleepers were produced with a modified rail seat area which made it possible to install pads up to 10mm thick with standard "Pandrol" type 'e' 1813) and insulators (glass-reinforced nylon). One of the sleepers was strain gauged, and drop-weight and static bend tests were carried out using procedures developed for monobloc sleepers. These highlighted a major difference in behaviour under impact loading. With a monobloc sleeper an impact at the rail seat position results in vibration of the entire sleeper in several modes, some of which result in several cycles of strain being observed at the rail seat. With the twin block sleeper the behaviour is as shown in the diagram - i.e., the initial impact still results in local peak strains in the concrete, but the continuing vibration is entirely due to bending of the tie bar, with the concrete strains returning almost immediately to zero. As the energy is transferred, relatively high strain values may be observed at the connection of the tie bar and the concrete.

During the laboratory tests, strains were measured at six locations on the concrete and six on the tie bar. As a result of the tests, two positions were selected (one on the concrete and one on the tie bar) for tests in track. Five sleepers were strain gauged and prepared for installation in the S.N.C.B. main line between the city of Antwerp and the Dutch border. This line carries mainly passenger trains, including the "Benelux-Trein" which operates an hourly service between Brussels and Amsterdam using 125km/hr push-pull train sets.

Once the test sleepers had been in track for about one month, strain recording equipment was connected up and at the same time the Pandrol Deroo Displacement Measuring System was installed on one of the sleepers, close to a thermite welded joint. Meanwhile S.N.C.B. engineers attached strain gauges to the rail web, so that sleeper and rail bending strains, and fastener deflections, could be all measured simultaneously, under passing trains. Over a two week period, measurements were made with five different types of rail pads in place. These included Pandrol's 10mm thick studded natural rubber pad, which is now being supplied to British Rail for use on monobloc sleepers.

Analysis of the results of both laboratory and in-track tests indicates that impact loads due to imperfect wheel and rail surfaces can generate high dynamic strains, but that the current S.N.C.B. track design is perfectly adequate for the traffic conditions which exist today. However, high speed passenger and freight services are being introduced on an expanding network throughout Europe, and this will inevitably lead to higher dynamic forces in the track. The tests demonstrated that, by incorporating more resilient rail pads, sleeper strain levels (including those at the concrete/tie bar connection) can be reduced substantially while fastener deflections remain well within the design limits of existing components.

Pandrol's association with S.N.C.B. continues, and other aspects of twin-block sleeper behaviour are likely to be the subjects of future work. In particular, we are interested in monitoring the long term behaviour of resilient rail pads in track of this kind, and in the performance of twin-block sleepers on sharply curved track. All of these tests, together with continuing tests on monobloc sleepers, are providing Pandrol with a firm foundation on which to base its product support and future development programmes.
An Introduction to RMS-2

The Sparo RMS-2 rail maintenance unit introduced in August 1986, is an enhanced version of the RMS-1 unit. It is completely computer or micro-processor controlled in the functions of grinding head angular position, which determines the pattern being ground on each rail, grinding head load control, long wave leveling effect and traction control. It is possible to program 99 distinct patterns for each rail.

The unit consists of 12 separate cars or equipment sets: five grinding cars, one accommodation (or bunk) car, four combined fire protection and diesel fuel cars and two power and traction units (which supply both traction power and grinding power). The five grinding cars have each mounted 24 grinding (profiling) heads of 20 horsepower each arranged in pairs for a total of 120 heads. Each car has a micro-processor slave control switch which directs on the command of a master controller, all the operations of the grinding heads on that car – unlocking and lowering to the rail starting the grinding motors, arranging the grinding heads (by hydraulic control) to the desired angular position for various grinding patterns, controlling each individual grinding head pressure, initiating and stopping the grinding action, monitoring the state of each grinding head, clearing for obstacles such as road crossings, switches, etc. and then performing the reverse of the initiation process - turning off the grinding heads and lifting the grinding apparatus into the transport position. The control centre for the unit is in the centre of the five grinding cars. This is also a monitoring station occupied by the master operator and observes the status of each car displayed on individual CRT’s and takes corrective action as necessary (such as changing individual grinding head position (pattern), motor load changes and so on).

The initialization units for the grinding operation are at the control stations of each power, control and traction unit. The control operator at either end of the unit takes control when the unit is moving in that (forward) direction. He controls the speed of the unit, utilizing the automatic speedometer speed control to make changes in the grinding speed which has a range of 1.5 MPH to 6.0 MPH. Similarly the unit can be controlled for travel (or transit) from either end. The unit can be operated in the transit mode at track speed up to 30 MPH.

The unit has a unique arrangement of power and traction with a total engine horsepower of 4000. The two units in the consist...
guarantee against any tie up of main line because of traction failure difficulties. (The traction control system is micro-processor controlled with overspeed and deadman controls integral to the operation, with an additional manual override included). The unit has an on board fuel supply of approximately 14,000 US gallons.

The fire water capacity of the unit is 44,000 US gallons. The fire protection system consists of a dual pump right of way spray system and a dual head water monitor (water cannon) system to reach more distant fires.

RMS-2 with its expanded capability for patterns, which include the angular grinding head position and capability of 0° to 90°, high degree of mobility along with the logistical support of fuel and potable water supply which allow longer periods of tie up before resupply, clearly make it the most advanced rail maintenance unit in the market.