Understand the behavior of the 'Impermanent Way'

'Permanent Way' is used to describe railway track, but is in fact a very relative term. On the inception of railways in the 1830s, the railway was a 'permanent' way compared to the highways of the day, which were vulnerable to adverse weather conditions, but the surface always required routine maintenance. The continuously supported rail on a continuous concrete slab more closely approaches 'permanent' behavior than the more conventional sleeper or cross tie system, but still does not completely justify this description.

The 'impermanence' of railway tracks and the influences of the applied forces and the performance of its constituent components have been the subject of an extensive research and development program at Pandrol over the past five years. Railways are generally searching for better use of their assets, and the track, representing a major investment, is no exception. Heavier axle loads, faster trains and reduced manpower have generated a need to know in more detail exactly how the track behaves and how it can best be designed and maintained.

In previous issues of Track Report we have described our theoretical and practical investigations into the dynamic performance of track and the influence that the rail pad can have, particularly in association with concrete sleepers. In this issue we report on two other areas of research and update the results of our continuing programme of the measurement of track forces and behavior.

Our continuing programme of research is only possible with the co-operation and assistance of the railways on whose systems the work is undertaken. We are deeply indebted and grateful to those railways which are working with us to gain a better understanding of the 'impermanent way'.
EXTENDING THE LIFE OF TIMBER SLEEPERS

The life of a timber sleeper in track may be anything from 8 years to 40 or more with an average of some 25 years. Premature deterioration of these sleepers, which represent a major part of a railway's investment in track, incurs heavy cost penalties in replacement costs, labour costs and disruption to traffic. A new system available from Pandrol of preserving timber sleepers and extending their life offers the possibility of enormous cost savings to railways worldwide.

As a natural material, wood is vulnerable to deterioration from weathering, insect and fungal attack. Chemical preservation, for example, with a traditional material such as creosote, is effective in protecting the sapwood, while in many cases the heartwood remains virtually protected.

When the sleeper cracks or splits in service direct access by moisture to the heartwood occurs allowing fungal infections to be established in the untreated wood. Recent examination of failed sleepers removed from track in the UK and US has shown premature fungal decay of the heartwood to be a major reason for the failure.

A research programme, over several years, has studied the effects of an in-situ chemical impregnation of the heartwood with fused, water dissolvable borate rods. The results are described below.

*The new system has been developed under a research programme jointly funded by Pandrol, British Rail, UK Government Department of Trade and Industry and Bidco, the manufacturers of the fused, water dissolvable borate system.

New Maintenance Systems for Timber Slepered Track

Throughout the world, there has been the traditional method for sleepers of the railway industry. While concrete sleepers are widely and increasingly used, there remains more than 150 billion timber sleepers in track, many of which are being replaced periodically as they fail. It is also recognised that timber track replacement costs can be tens of thousands to several million dollars per mile including labour, equipment and disruption to traffic. The actual cost being governed by local conditions and economics. A substantial part of the cost is the uncertainty in sleeper maintenance programs, the somewhat random lifting of sleepers for damage assessment and premature failure are caused by fungal decay which increases the frequency of renewal programs.

Through the new techniques and technology now described, a new approach has been developed using an extensive research programme in the United Kingdom, the United States, Canada and Japan. The costs will be significantly reduced with minimal disturbance to track and traffic —

- the condition of a sleeper's heartwood can be determined electrically introducing a portable, one man operated 'integrity tester';

- an in-situ remedial wood preservation treatment to prevent premature fungal decay and extend the service life of sleepers by 25% at least; and

- an in-situ wood preservation system to reinforce critical sleepers, for example switch and crossing timber and mainline track sections.

Wood, Wood Biodeterioration and Sleeper Failure

Before discussing the various elements in the new maintenance system in more detail, it is worth briefly reviewing some aspects of wood and wood deterioration.

The technical performance of wood in the civil engineering industry relies on such properties as durability, flexibility, strength, stiffness, toughness, permeability and ease of processing. Not all of these properties will be of importance for any one end use and the order of importance will vary with the function the wood has to perform.

The important properties of wood in terms of the railway industry are durability and strength, and coupled with its natural resilience and damping of dynamic impacts, provides an excellent material for the industry.

Despite its many good features wood is subject to biodeterioration in a number of ways even though it may be chemically preserved initially to extend its durability. Biodegradation is often the result of preservative treatment processes for wood all suffer from the universal problem that the heartwood is difficult to treat. In many applications such as sleepers and transmission poles this has led to the heartwood becoming infested with fungal decay.

A significant change in the decay process is that different species of wood are more susceptible to different decay species. The decay process in the wood changes the surface of the wood and makes it more susceptible to further decay. The decay process also changes the physical and chemical properties of the wood, making it more susceptible to further decay.

Chemical treatment of wood is therefore an important factor in the preservation of wood. The chemical treatment is done to prevent fungal decay, and to extend the service life of sleepers by 25% at least.

Cross Section of Sleeper Showing Limited Creosote Penetration and Point Entry (v) of Infection Through Upper Surface Check.

Figure 1

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Track Inspection Procedures

Existing track inspection procedures for wooden sleepers rely on surface inspection by inspectors and computer systems. Assessment of the condition of the wood is based on its experience and/or the lifting of sleepers for positive identification of the problems.

The condition of sleepers in the railway industry can be identified using a new concept in timber testing. Sonic vibrations are created in the sleeper by impacting at various points with a rubber ended hammer. The assessment is made on the frequency of the waves and the amplitude of surface waves and internally transmitted vibrations in the first cycle of the wave modulations and the overall signal envelope. Where the density of the wood is uniform with little decay there is a distinct dissimilarity between the signals. If decay is present there is a distinct dissimilarity between the signals. (See Figures 2 and 3). The signal response has been calibrated to provide the operator with a visual monitor and/or a digital display to indicate the condition of the sleeper in terms of treatment or replacement. The integrity tester is readily portable battery.
In-Situ Remedial Wood Preservative Treatment

The remedial wood preservative treatment utilises the water present in and around the sleeper to distribute a water-diffusible chemical. Fungal infection may occur between the rail plates, where water entry is enhanced by the plate fitments. Infection will also occur through upper surface checks which allow water and fungal spores to penetrate into the untreated heartwood. (See figures 5 and 6.) By understanding the water relationships and distribution patterns in the sleepers, it was possible to determine the optimum positions to place the bore water-soluble borate rods (anhydrous disodium octaborate). These rods are hydrolysed and dissolved by the water regime in the sleeper to release a solution of borates, a highly effective and well-established wood preservative, which is then distributed in the water within the sleeper: remember it is water which is the primary condition for fungal decay and therefore the use of the rods provides an in-built preservative system which is regulated by the moisture content within the sleeper. The distribution of the preservative chemical is illustrated in figure 7. In the assessment, a dye reagent (red colouration) was used to identify the distribution of the borates from rod placements and the sections analysed were at furthest points from the sources of the preservative rod placement.

This assessment was made using the second configuration (see figure 6) where rods were placed centrally to protect the central core of the sleeper.

After the configuration of rods has been determined, in terms of moisture relationships, the application is simple and straightforward. Templates or set drilling patterns can be used to ensure accurate positioning of the rods. Holes are drilled vertically to a predetermined depth, rods are inserted and holes capped with a tight-fitting plastic cap. (See figures 8 and 9.)

Repair of Sleepers with Synthetic Resins

There are certain sections of wooden track which can be described as critical, for example switches and crossings, longitudinal bridge timbers. In many cases it is possible that selected sleepers in these sections may have experienced partial decay: the replacement of these sleepers is extremely costly especially if it is an unscheduled maintenance item. Two synthetic resin repair systems can be used to reinforce partially decayed sleepers which will restore strength to the sleeper. A low viscosity one part polyurethane resin can be used to impregnate wood and strengthen the sleeper where there are only limited voids. In sleepers where there is significant fungal decay and voids have been created, a two-part fast setting polyurethane resin can be applied to fill the cavities and restore strength and resilience to the sleeper.

Summary

The use of the solid borate rods which dissolve to provide a highly effective and diffusible preservative within the sleepers, can protect the untreated, vulnerable heartwood and extend the service life by a minimum of 5 years. Combined with the integrity testing, i.e. minimal look and ultrasound inspection procedures, and the synthetic repair system it will provide an extremely useful and cost-effective maintenance approach for the railway industry. In the United Kingdom, British Rail have calculated that the savings against present maintenance procedures will be about 68,000 per mile (NPV over 20 years).

One final point, with regard to environmental safety and health considerations, is that preservatives based on borates/boric acid present fewer problems than a wide range of currently used preservatives.
Concrete Sleepers under test in Canada

Over a three month period, strains were recorded under about 130 trains (some 39,000 axle passes) with different rail pads, different sleeper spacings, and different rail clips. Further measurements were made during the winter, with the ballast and sub-grade frozen, and following the spring thaw so that the new design would take into account the changes in the ballast support conditions. As well as measuring the strains due to the normal traffic on the line, detailed recordings were made of the track behaviour under known defective wheels. A number of wheel sets were selected with skid flats, built-up or shelled out treads, or "out-of-round" defects which, although measurable, were not bad enough for the wheels to be condemned under normal circumstances. Those wheels were fitted to a work train comprising loaded and unloaded 70 and 100 ton flat cars, and the train was driven over the test site at a range of speeds from walking pace, up to 125km/h. Many of the passes were repeated after changing from resilient, to conventional rail pads on the instrumented sleepers. Sleeper bending strains, rail web shear strains, and ground-borne vibrations were measured. The diagram shows a small sample of the results, indicating sleeper bending during a 100km/hr train pass with conventional rail pads in place. In this case, the most severe strains are due to an out-of-round wheel on a loaded car.

The Ryley test site is still being used for concrete sleeper evaluation. At the time of writing, the first examples of the new sleeper design have been installed on the site. Once again measurements are being made under normal traffic in order to confirm details of the design. Meanwhile, engineers at Pandrol, CXT and CNR are involved in more detailed evaluation of the work train test results, including theoretical modelling of the effects of wheel defects and development of "wheel flat detection" methods which would help to reduce the amount of damage which undetected defects may have on concrete sleeper track.
Throwing light on the track

The measurement of the exact movement of a rail relative to its base, either a sleeper or a slab has not previously been possible. The motion is complex and contains some very high frequency components. Furthermore the railway environment contains electrical and electromagnetic influences which adversely affect electrical measuring devices.

The Pandrol dicrotic system uses optical transducers coupled to an opto-electronic transceiver with optical fibres all of which are electrically and magnetically passive. Measurements across a wide frequency spectrum and to great accuracy result. These results provide a much greater insight into the dynamic behaviour of rail and the influence of the rail pad on the total track performance.

When applied to sections of track where problems are occurring, the cause of which is difficult to identify, use of this equipment could assist in providing railways with effective cost-saving solutions.

In order to improve the reliability of track components, and to keep up with the trend towards heavier and faster trains, and less labour intensive maintenance, it is becoming increasingly important to be able to predict component behaviour, and in particular component life, before any new design is introduced into large-scale service. In order to achieve that, we must have more and more confidence in laboratory and calculation methods in testing new designs, and those methods can only work if they can be checked against the performance of real components in real railway tracks. But measuring that performance, and making proper use of the test data present complex problems in themselves. In recent years the situation has been made very much easier in two respects: in the improvements in the capabilities of portable data recording equipment, and in the use of computers to sift through the data once it has been recorded. There remains however considerable difficulty in specifying the measuring devices themselves, which are able to take useful readings in the rather unkind working environment under the wheels of a passing train.

Almost all of the data which provides us with the basis for track design has been obtained by fixing foil resistance strain gauges onto the various components, and thus measuring the distortion of the components under traffic. These gauges work well on metal parts and with a few minor ‘fixes’ and ‘bumps’, but not on concrete, provided that they are suitably protected from the weather, and from electromagnetic interference. Unfortunately, they cannot give any direct measurement of the contact behaviour between components, and cannot be used on plastics and elastomers. These shortcomings have meant that many factors which influence component life, pad and insulator wear, for example, have remained something of a mystery. It was in order to tackle this problem that Pandrol enlisted the help of Cambridge Consultants Ltd (CCL) in 1984, to produce a device which would measure, directly, the relative movement of a rail and sleeper under traffic, and thus provide a basis for further development of the fastening system.

The device produced by CCL — The Dicrotic Displacement Measuring System — uses a non-contacting optical sensor as the basis for measuring rail movement.

A transceiver unit, beside the track, contains two light-emitting diodes (LEDs), one working at 730nm
(i.e. producing red light) and the other at 860nm (infra-red), which are pulsed alternately down a fibre optic cable. The main part of the sensor head is mounted on the sleeper. At one side of this sensor, a lens expands the light beam to about 4mm diameter. The beam passes through a shutter, which is attached to the rail foot, before reaching the return lens, which reduces its diameter to send it back to the transceiver via a second fibre optic cable. The shutter itself has two parts; one half will pass light at 730nm but not at 860nm. The other half passes the other colour. As the shutter moves across the beam (i.e. as the rail moves relative to the sleeper) the relative intensity of the two colours changes. The transceiver can detect the colour change, and by comparing the return beam with the output beam generates an electrical signal which can be recorded. By pulsing the LEDs at very high rates (typically ten thousand times per second) and by making the sensor heads very compact and rigid, the system can be made to measure even very small and very rapid movements – one hundredth of a millimetre movement for one thousandth of a second is still detectable.

Once the method of measurement had been established, further development work was necessary to make it possible to install the sensor on the track without disrupting the train services. The shutter must be positioned accurately in relation to the sensor head, and installation must be possible in adverse weather conditions.

These requirements were met by designing mounting plates which can be fixed to the sleeper and rail, using hot melt adhesive, then positions being determined by a simple jig which is clamped to the rail foot. Once the adhesive is set, the jig is removed and the shutter and sensor head bolted down onto the mounting plates. The lenses are permanently attached to the fibre optic cables, and are fitted to the sensor head using kinematic connectors.

During 1986, the system was used at several locations on British Rail, and on Canadian Pacific, Canadian National and Burlington Northern Railway tracks, to provide basic data on rail movement: February 1986: Waterbeach (BR Eastern Region) Tangent track; max speed 100km/hr; max axle wt. 25 tonnes
April 1986: Coppull (BR West Coast Main Line) Tangent track; max speed 175km/hr; max axle wt. 25 tonnes
May 1986: Woolmer Green (BR East Coast Main Line) 1st curve; max speed 200km/hr; max axle wt. 25 tonnes
June 1986: Albert Canyon (CPR Mountain Division) 6th curve; max speed 55km/hr; max axle wt. 30 tonnes
June 1986: Illecillewaet (CPR Mountain Division) 11th curve; max speed 40km/hr; max axle wt. 30 tonnes
October 1986: Ryley (CNR Wainwright Sub-Division) Tangent track; max speed 125km/hr; max axle wt. 30 tonnes
October 1986: Wendenower Canyon, Wyoming USA 4½ curve; max speed 60km/hr; max axle wt. 30 tonnes

The tests at Coppull included measurements on 10mm resilient rubber rail pads, and those at Woolmer Green, Illecillewaet, Ryley and Wendenower included 6.5mm TPE pads as well as conventional rail pads. At Albert Canyon, measurements were made on PACT slab track, as well as on concrete sleepers.

In order to compare results from the various locations on British Rail, particular note was made of track behaviour under ‘Class 47’ diesel-electric locomotives. These are the most numerous main line locomotives ever used in Britain, over five hundred examples having been put into service on freight and passenger operations on all BR regions. The diagram shows typical traces of vertical rail movement under Class 47’s at Waterbeach (with conventional 5mm rail pads), Woolmer Green (6.5mm studded TPE pads) and Coppull (10mm studded natural rubber pads), and gives a clear indication of the variation in behaviour. Although the total vertical movement is greater with the softer pad, all of the secondary components are reduced, most of them substantially. As the same resilient pads can reduce the dynamic bending strains in concrete sleepers, these results could have far reaching implications in terms of track component life.
IV.B.1. Fastening rails with ordinary clips. When, after the First World War, the various German State Railways amalgamated into the Reichsbahn, it was intended to introduce a uniform heavy type of track.

In order to do this, attempts were made to find a type with independent fastenings (IV), in which all the rail fastening units would lie above the baseplate, so that it was not pierced at any point and the whole surface could rest on the sleeper. The type developed by Dölle of Dresden, (Fig. 8) satisfied all requirements and had been employed since 1926 as the standard track, under the name of K-track or ribbed plate track usually known abroad as “Gre-track”. It proved to be extremely efficient. Apart from the advantages of independent fastening, the ribbed plate track also has the following advantages: Great rigidity, low maintenance costs, long life of sleepers and good compressibility, and hence compensation for slight errors in height during track laying because packing pieces (3 to 9 mm) can be inserted between the rail foot and baseplate (see page 28). The comparatively high price is well justified by the advantages of this track. The disadvantage, however, has practically no importance as K-track is not usually laid in lines with curves of such radii as to necessitate gauge widening. The baseplate is fastened down by means of 4 coach screws. In Belgium, only 2 screws per seating are used, and these screws are 10 mm thick. In this way, the baseplate being securely fastened to the sleeper, double spring washers and the hooked screws, and rail pads of compressed V-shaped wood between the rails and baseplate are part of the K-track. The pad is cut to a thickness of 5 mm. It has thereafter impregnated and compressed to a thickness of 5 mm. It has considerable delays the cutting of the plate into the wood and so prolongs the life of the sleepers.

(c) Direct fastening by coach screws and spring washers (K-track), Sec. 1:8

The K baseplate has been used extensively on railways throughout the world, particularly in Europe and the Middle East, but is gradually being replaced by more modern designs involving less maintenance. Conscious of the periodic oiling and re-tightening required by the K system, Pandrol has developed an adaptation of the K plate to take the Pandrol resilient track fastening. The system offered by Pandrol consists of a small malleable iron shoulder which can be fitted onto the baseplate in situ under traffic, simply by taking out the existing K bolt, and inserting the Pandrol shoulder. The Pandrol clip can then be installed in the usual way.

1. Remove nut and spring washers from field side.
2. Where spring washers are used with the screweyes, it may be necessary, with certain widths of plate to remove the Screweyes and spring washers on the right hand side as you face the rail, and reapply the Screweyes without the spring washers.
3. Slide the Pandrol shoulder into the dowel slot.
4. Position the Pandrol’s 2000 series clip and pull smoothly to refusal with a Pansad.
5. Repeat the procedure for gauge side.
NEW

RESILIENT RAIL PADS

Ever since "Track Report" first appeared, we have been reporting on a programme of development of resilient rail pads for use on pre-stressed concrete sleepers. Mathematical modelling (Autumn 1982 issue) suggested the sort of properties that were desirable in a pad, and led to an appreciation of the need not only for proper material selection, but also for careful design of the pad thickness and surface shaping (Summer 1983).

Pandrol adopted the "Battelle" type impact test rig to evaluate candidate pad types (Summer 1984) and confirmed the results by means of detailed measurements of performance in track (Summer 1985).

As a direct result of this programme, Pandrol now supplies resilient rail pads in significant numbers to British Rail. These pads are produced from a natural rubber compound, are 10mm thick and have a studded surface design. The stiffness of the pad, and its ability to attenuate dynamic forces, can be controlled by changing the size, shape and number of studs, or by using different rubber compounds.

Where the thickness of the pad is limited — for example, where it must fit into an existing sleeper design — harder materials must be used if the surface shaping is not to be 'squeezed flat' as soon as some load is applied. For such applications encouraging results have been obtained by using high quality thermoplastic elastomer (TPE) in place of natural rubber. As a result, GO-Transit in Toronto have ordered over 80,000 6.5mm thick pads made from such an elastomer.

Research and development work is also continuing on several aspects of rail pads — some of the first production standard pads are being monitored in track to look for even the slightest signs of deterioration. The Ditchko Displacement Measuring System is an invaluable tool for this work as, by returning to the same location periodically, any tendency for the pad to stiffen up as it ages may be measured. Other pads are being removed from track at 6-12 month intervals for inspection. This inspection is usually extended to include other fastening components working with the resilient pad — e.g. clips and insulators — to monitor their performance.

In some cases, the pad's capabilities are deliberately restricted to limit the movement of these other components and thus avoid wear and fatigue problems. By designing the entire assembly in the knowledge that a very resilient pad is available such restrictions may be lifted. At the same time, our understanding of resilient pad behaviour may enable us to advise some railways to continue their use of non-resilient pads, or to select track and traffic conditions where particular pad designs are most appropriate.

High Frequency Resonance Rig — Rails pads under test are sandwiched between rigid card frames. By measuring the resonance behaviour of the rig, it is possible to calculate the characteristics of the pad using the frequencies of several hundred cycles per second.

0.2cm thick natural rubber pad (above) and 6.5mm thick TPE resin pad (below).