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Longitudinal Forces in Track

When track components are designed both static and dynamic forces have to be considered in the vertical, lateral and longitudinal planes. Conventionally forces have been calculated from 'static' data and adjusted to allow for dynamic effect using an empirical multiplying factor—a typical live load impact factor common to structural design. With timber sleepered track which has high inherent damping this was probably an entirely satisfactory approach except in the case of longitudinal forces where rail creep in regions of large dynamic excitation, like joints or corrugated rail occurred. The advent of the concrete sleeper with its very low inherent damping and its propensity to resonate has highlighted the need to understand the dynamic forces and to adequately provide for them in design. As we have shown in previous articles on track forces at or near to a source of impact, the dynamic element of vertical force generating bending in concrete sleepers can be several times the quasi-static element and completely dominates the force spectrum.

In timber sleepered track, longitudinal forces cause rail creep but rarely cause the sleeper itself to move. In concrete sleepered track there is a greater tendency for sleepers to move with the ballast experiencing significantly greater excitation, the problem being worse where the general level of excitation is greatest as in sharp curves, on steep gradients, where the rail is corrugated and where very large tractive or breaking forces occur.

To study the problem, the Research & Development Department of Pandrol International has adapted their Dihronic Displacement Measuring Equipment (described in earlier editions of this journal) to measure longitudinal rail movement relative to a sleeper. Using this equipment it is possible to measure rail movement to very precise levels under and between each wheel of a train. The diagram shows typical results from a heavy haul coal train in a curve on a steep gradient. Each wheel generates some longitudinal movement which is largely elastically recovered but there is a small increment of net permanent displacement under each locomotive wheel which is gradually recovered during the passage of the wagons. This type of behaviour is quite different from the response to a conventional laboratory longitudinal restraint test when an increasing force is applied until total rail slip is achieved. Clearly the results from this test bear little relation to service conditions in this application and changes which result in 'better' laboratory figures may well not do so in practice.

We are accumulating data from a number of locations using different types of rail pads and with different rail fastenings from which it is hoped that we can develop a laboratory test that closely simulates actual track conditions. We will then be able to predict more accurately and compare component behaviour without the prior need for lengthy and expensive in-track testing.
Pandrol in Japan

by Mr S Ohi, Deputy Manager, Track Department, East Japan Railway Company

1. Introduction
East Japan Railway Company, since its privatization last year, has been continuing its efforts to introduce a new view of value. In particular, our division of track maintenance, naturally, has been trying to reduce the maintenance cost, considering it to be a most important subject.

There are a variety of rail fastening systems in the world, each of which represents in a sense their own country's history and culture. The features differ in each and the targets are different.

The rail fastening system now used in Japan consists of a flat spring bar and bolt. The adjustment of rail gauge can be done with metal parts called gauge blocks.

The feature of this fastening system is the ability to achieve a very delicate gauge adjustment in the accuracy of 1 millimetre, while it is difficult to obtain consistent clamping force.

Since the insulation is provided by the component called a plug, cast into the concrete, it is very difficult to maintain high clamping force. Eventually some of these plugs break after a few years service in track.

Meanwhile the Pandrol fastening system consists of few components and the installation of the clip is very easy (for the smaller Japanese workers in some sense not so easy) and stable and strong clamping force can be obtained. (2.5 times stronger than Japanese conventional type)

2. Outline of Trial Installation

<table>
<thead>
<tr>
<th>Name of Line</th>
<th>Length</th>
<th>NO. of Sleeper</th>
<th>PC System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapporo-Tokyo</td>
<td>2.100m</td>
<td>500,000</td>
<td>1.5 million tons per annum</td>
</tr>
</tbody>
</table>

3. Progress after Installation:

(1) Irregularity of track
According to the inspection record by high speed track inspection car, alignment of height is similar to conventional type due to short time after installation while the gauge is better than conventional type.

(2) Walking out of clip etc.
All the clips and insulators installed have been marked for checking of movement. So far (August 1986) the condition is good and no clip has walked out (moved).

(3) Damage of Parts
At the time of multiple tie tampering, where squeezing was made, a sleeper moved.
On that day 37 sleepers out of 756 sleeper were moved.

Because of the movement, 7 insulators were broken and pads had to be repositioned on the half of these sleepers.

We investigated the cause and found that since multiple tie tamper did not release the brake, therefore, sleepers were moved when the tool was positionned off centre.

The conventional type had not been broken by this movement. But since the clamping force of Pandrol type is so strong the insulators were broken.

We realigned the circuit of multiple tie tamper and had the brake released at the time of squeezing.

Therefore, no breakage has now been reported.

4. Conclusion
A half year has passed since the installation, and the Pandrol fastening system on concrete sleepers has been working well. From now on East Japan Railway Company plan to introduce Pandrol system gradually and also on wooden sleepers

We expect to reduce maintenance cost in total.
Panlogger Solves The Problem of In-Track Wooden Sleeper Analysis

by Dr. A. Brown, Beran Instruments Ltd

The condition of the sleeper is one of the key factors in ensuring the safety of the track. There are around 1.5 billion wooden sleepers installed in track around the world, 70 million of which are replaced each year. Due to the limitations of existing inspection techniques, a significant proportion of these are removed prematurely, and many sleepers with advanced decay are left in track. The conflicting factors of safety, and budgetary constraints force the track engineer continually to find a compromise position with regard to his maintenance policy.

Over the past few years, increased sophistication has been applied to the inspection of the rails and their mounting systems, but until now no fundamental improvements have been made in wooden sleeper analysis. The Panlogger system has now been developed which allows the inspection engineer to accurately determine the condition of wooden sleepers in his track, without the need either to extract them, or disrupt traffic. The information provided by the system allows the track engineer to better understand the condition of his track, and so make optimum use of the resources for sleeper renewal which he has at his disposal.

Determining Sleeper Condition

Until the introduction of Panlogger, the inspection engineer had a limited range of non-destructive testing techniques. These were based on an external visual examination of the sleepers, either in track, or after extraction.

By visually inspecting the sleeper while still in track, advanced decay on the underneath, or inside the sleeper is not seen. A sleeper may appear from the top surface to be in good condition, but underneath it may be a hollow shell, with the inside totally rotted away. Alternatively, sleepers which have experienced severe weathering on the top surface, and appear in poor condition may actually be quite sound internally. By using the visual inspection procedure, it has been shown that only around half of the sleepers that are removed from track may be correctly identified, and a similar number are left in track which should have been removed. This has major cost consequences.
Some track managers use a small sampling system to gauge the condition of a large section of track. A limited number of sleepers (often around 1%) are extracted, checked and recorded on all surfaces. The condition of the remaining sleepers in a track are then judged to be similar to those removed. Based on the condition of the sample extracted, the whole section of sleepers is then either left intact, or replaced entirely. Previous studies have shown that when all the surfaces of a sleeper are visible, the accuracy with which the internal condition may be determined rises to around 75%. However, this figure only applies to the sleepers actually inspected, and this type of statistical analysis often leads to a great many sleepers being left rotting in track, or prematurely replaced.

A third method in use is based on a rotational replacement programme, when sleepers are replaced at intervals based on their condition, with no regard for their age. These methods are based on subjective assessment of sleeper condition, with no real insight as to internal condition. Depending on the care taken by the inspection engineer, the percentage of sleepers identified correctly for renewal varies widely, but overall figures of 25 - 50% are not uncommon.

The Panlogger system uses a destructive technique which is quick and simple to use, and can determine the overall condition of the sleeper whilst still in track. The technique used by Panlogger is based on the simple principle of the tapping hammer, used for years for checking the wheels of rolling stock for cracks. When most metal objects are struck sharply, they emit a clear ringing sound, just like a bell. When cracks are present in the metal, the note produced is distorted.

The principle, although slightly modified, can also be applied to wooden sleepers. When freely suspended, they also ring when struck. However, when sleepers are in track, they are firmly connected to the rails and sub-ballast, which is of unknown composition. This causes a masking effect on their dynamic characteristics, making the analysis much more complex. Additionally, the rails may also start to vibrate, thus further complicating the result.

The Panlogger system includes a probe, which not only impairs the impact into the sleeper, but also monitors the responses. The analysis algorithms built into the Panlogger are then able to identify which facets of the response are due to the sleeper, and eliminate the masking effects of the ballast and rails. The numerical analysis which is required to perform this identification is well beyond the power of most desk top computers, but Panlogger contains an advanced high speed processor, which is able to perform this analysis in a fraction of a second.

The results presented by Panlogger have been validated in extensive destructive trials. Sleepers, after having been tested by the Panlogger, are extracted from track, cut into small sections, and carefully examined. An independent analyst then assesses each sleeper on a range of 1 to 6. A value of 1 is given for a sleeper which is in perfect condition, with no sign of deterioration. Defects in the internal structure of the sleeper will cause a higher number to be given, the higher numbers denoting extensive structural defects. A result of 6 indicates a sleeper which is totally failed, and no longer fit for service. This simple grading system has been built into the Panlogger Sleepers which give results in the middle of the range indicate that some decay is present, or incorrect, and the use of the Parallel TimberSaver™ preservative treatment at this stage will substantially increase the useful life of the sleeper.

Operation of the Panlogger
The Panlogger itself is housed in a leather carrying case, complete with shoulder strap. It is carried waist high, and is easily operated with either hand. It is battery powered, and will operate for a full working day before requiring recharge. The video camera is positioned at the front, with a wide angle lens to capture the condition of the sleeper. The video camera is connected to a high resolution monitor, which allows the operator to view the condition of the sleeper, and make a decision as to whether it is in service or needs to be replaced.

To test a sleeper, the Panlogger is placed on the sleeper, and whilst maintaining slight downward pressure on the probe handle, the Test button on the Panlogger is pressed. A series of images will be recorded by the Panlogger, and the test result will be displayed on the front panel display. The Panlogger is then moved on to the next sleeper.

Recoding of Information
The Panlogger is more than just a measuring instrument. It also contains extensive data recording facilities. The results from testing each sleeper are recorded internally. Additionally, a series of images is taken of the sleeper, and the tester is prompted to enter any additional information such as the date of testing, the condition of the sleeper, and any other relevant details. This information is then stored on a hard drive for future reference.

The Panlogger system is also equipped with a data management system which allows the data to be easily exported to a spreadsheet or database program. The data can then be analyzed, and trends identified. The Panlogger can also be used to create detailed reports, which can be printed or exported as a PDF file.

Analysis of Recorded Information
The analysis that is carried out on the recorded data may be geared to the particular needs of the railway operators. Each sleeper is given a numerical rating based on its condition. Sleepers that are in poor condition are marked for replacement, while those in good condition are left in place.

Summary
In order to maintain the quality of the track, detailed information concerning the sleepers is required. Until the introduction of Panlogger technology, the acquisition of this data was minimal or inaccurate. Now railway operators have the means to monitor the condition of their track, and determine the most effective maintenance approach for each particular track. Users of Timbersaver Panlogger will be able to determine those sleepers which require this additional treatment, in order to prolong their useful working life.

*Panlogger and Panoram TimberSaver are registered trademarks.
The Prestressed Concrete Tie in Peru

by Ing. Hector Gallegos

The first prestressed concrete tie to meet the needs of the Peruvian Central Railroad was designed in 1958 by the author of this article (who at that time was employed by a British firm, the Peruvian Corporation Ltd.). In 1965, 58 sample ties were manufactured and installed according to this design. They included a fastening system, imported from Great Britain, consisting of a threaded rubber insert, a nylon washer, a rubber pad, and the standard screw spike. Each tie weighed 223 kilograms. Since then they have been inspected on numerous occasions. The last official report stated that “…the section continues in an excellent state today, especially the alignment and surface…”

On the other hand, the proposed Pandrol fastening, already widely used in British railroads, was rejected because of its “high cost.” Instead, the insertion of wooden plugs in the ties was proposed by the railroad engineers: with the plugs being indirectly fastened using the plates and screeds, spikes used with the wooden ties. Accordingly, an investigation of different kinds of wood and plug shapes was launched, with static yield tests being performed to determine maximum load strength. Finally, a fastening was adopted and 5,000 ties manufactured and installed. The results were not satisfactory.

While the prestressed concrete elements behaved as expected, after a very short time, the failures in the fastening system were practically total. In any case, the project was still in an experimental stage and was accompanied by a growing shortage of suitable timber. The following year, 1972, a leading railroad engineer prepared a study for the Peruvian Corporation Ltd., recommending the following: a tie renovation programme should be launched immediately to retain the alignment, maintain the quality of the rails and the chemical analysis would tend to recommend two kinds of ties: prestressed concrete and pressure treated timber. In as much as the prestressed tie has a longer useful life compared to the pressure treated timber one, tests should be conducted to determine the feasibility of using the former in radial curves of less than 400 metres. The prestressed concrete tie should be fastened using Pandrol…; in the bottom’s recommendations, which were accurate, in regard to the definition of a railway structure policy could not foresee the growing demand in the supply of timber ties, the suppliers’ blatant and complete failure to comply with their commitments, and the spectacular increase in their cost. This occurred with great rapidity during the following years and revealed even more clearly the accuracy of the key point of that report: the prestressed concrete tie with a reliable fastening was essential for the existence of the railroad.

At the same time, the concrete element design was improved enhancing its efficiency. The design base chosen was the American Railway Engineering Association (AREA) code, to harmonize with traditional Peruvian practice. To comply with the AREA code and ensure design and manufacturing quality, the static tests were supplemented by the 3,000,000 cycle test of a random sample at the laboratories of the ASSA, with the tie being submitted to prescribed loads. The ASSA final report points out that “Prestressed concrete tie No. 37 submitted by Gallegos, Rios Casabonbe, Ucelli, Arango, Ingenieros Cíviles de Lima, Peru complies with AREA Bulletin 644 testing requirements for repeated loads on the rail bed.”

A short time later, ENFAI, a state-owned firm which since 1974 had been gradually assuming control over the railroads, imported the first consignment of Pandrol fastenings. Since then a number of ties have been installed in the Southern Railway. The longest section of 10 kilometres of continuous prestressed concrete ties is located at an altitude of 3,500 metres above sea level.

Finally, in the last two years after a second cyclic test, this time conducted in a university laboratory in Lima, the Southern Peru Copper Corporation, which owns a 100 kilometres railroad, has started using prestressed concrete ties with Pandrol fastenings and the new Lima Metro Authority (AITE) is also considering their use for the first 30 kilometres of line to be inaugurated by 1990.

(Hector Gallegos has specialized in concrete technology since 1975 and has designed concrete sleepers for SPCC and ENFAI in Peru. He is currently a partner in a firm of consulting engineers in Lima, Peru.)
Bridge Ties

In September 1984, CN installed twenty-two prototype concrete bridge ties on a 2.5t-long steel girder bridge located on its mainline Drummondville Subdivision between Montreal and Quebec City. The ties were 12t, 12" long, 12" deep, 10" wide at top, and 12" wide at bottom. Spacing was at 16.5". They were prestressed with thirty-two 53mm diameter indented wires to provide static moment capacity without cracking of ballast in positive loading and 2400 kips in negative loading. Design was based on AASHTO specifications. 

The 300 kips loading, and overall of 100,000 kips of total forces being carried by each tie. The PB40NL railfastening system consisted of PB61 clips, composite insulators, 4.5mm and 8.6mm EVA pads on the ties, and 9mm soft SBR pads on the other half. On the steel girder, half of the ties were supported on 1" hard SA-47 piles, and the other half were supported on 1" SAAHTO-600 pads. Rail tie pads and tie girder pads were located to provide four combinations of stiffness.

During the two weeks following installation, extensive tie strain and deflection measurements were taken under regular traffic (speeds 60mph freight, 80mph regular passenger, 85mph LRC passenger), and under a special work train containing a loaded ballast car with one noncondensable fluid flat wheelset. The first conclusion reached was that the tie end on the bridge (located over the bridge abutment) was picking up roughly 3 times more loading than the intermediate ties. This was attributed to the relatively abrupt change in track stiffness between the bridge and the roadway. The second conclusion reached was that track impact loading from wheels with tread defects causes high positive bending moments in the ties, and also raised them to go into reverse or upward-negative bending. Impact factors as high as 200% were recorded on the ties, and virtually no effect of regular loading were recorded on the steel bridge girders.

Extensive laboratory work at McGill University showed that the tie-girder pads had a major influence on quasi-static load distribution to ties, and that the rail tie pads needed to be modified to reduce the incidence of tie impact straining and that the end tie loadings had also been reduced. By May of 1985, the two end ties were fatigue cracked in positive bending and they were replaced with new tie pads. In the laboratory these two cracked ties were subjected to over 20 million fatigue loading cycles without failure. It was concluded that the new tie pads could be made smaller and cheaper but until then, the pads must perform yeoman duties.

Studded pads had reduced the incidence of tie impact straining and that the end tie loadings had also been reduced. It will take rigorous statistical data analysis to define optimum concrete bridge tie requirements. The structural deficiency of the tie, both in positive and negative bending, is dictated to a significant degree by the incidence and magnitude of wheel/rail impact loading and by the impact attenuation qualities of the rail/slab. Associated wheel loadings exceeding limits of 50-60 kips were to be adopted as cracks for wheel impacts in normal traffic. Moreover, if cracks be made smaller and cheaper but until then, the pads must perform yeoman duties.

**Turnout Ties**

In July 1984, CN made its first concrete turnout tie installation at Kiskiss, British Columbia. This was followed in the fall of 1986 with the installation of another turnout and a cross-over (essentially two turnouts) on the Yale Subdivision just east of Vancouver. The turnouts were all welded No. 20 laterals, made up in 116lb chrome rail, with curved Samson switch points and internally glued explosive hardened RBM frogs. Plates in the frog and switch areas were secured with fasteners screwed into nylon inserts cast in the ties. Solid EVA pads of 9mm thickness were used between the specialty plates and ties, while standard cast-in-place shoulders and 5mm thick EVA pads were used elsewhere. Rails on the first turnout were secured with PB40NL, PB61 clips, while e-2000 clips were used on the other installations.

CN Research recorded tie strains on all of the turnouts and concluded that concrete tie design was close to optimum. The static loading strengths were 390 kips in positive bending and 290 kips in negative bending. It was found that the impact loading from wheel/rail impact loading exceeded limits of 50-60 kips were to be adopted as cracks for wheel impacts in normal traffic. Moreover, if cracks be made smaller and cheaper but until then, the pads must perform yeoman duties.

Summary

Concrete ties are resistant to rot and their inherent mass can provide excellent track stability. It is the rail fastening system, however, which must provide rail stability and also must protect both the rails and ties from the effects of impact loading generated by wheel/rail impacts. If the fastening system is too stiff, both the rails and ties will suffer, but if the system is too soft, track gauge and rail alignment may not be properly maintained and the rails and pads are likely to fail prematurely. The elastic rail clips and the rail tie pads have been engineered as a unit to provide both resiliency and stability while at the same time enduring the rigors of wear and fatigue. CN is closely monitoring all aspects of bridge and turnout tie performance in order to be prepared for traffic demands of the future.
In part this was demonstrated experimentally using frequency analysis of signals from axelbox accelerometers on a test train containing an instrumented coach and a locomotive (Fig. 4). This train was driven over uniform corrugation at a variety of speeds. Near the speed of 40km/h, to which the majority of freight traffic is limited, there was a particularly high response from the locomotive (Fig. 2a) whereas there was no similarly high response from the test coach (Fig. 2b). It is reasonable to conclude that the high response from the locomotive (Fig. 2a) is due to excitation of resonance of the locomotive which has a high unsprung mass and correspondingly gives rise to high dynamic loads on the track at this speed. It has also been caused by excitation of the resonance. Other experiments were carried out to demonstrate that these high accelerations were not excited by sleeper spacing.

Resonance is excited initially by bad welds. The railhead profile at one site, measured using a small, self-propelled instrument developed at Cambridge University, is shown in (Fig. 5a). The welds, at a spacing of about 13m, are clearly as is the corrugation propagating from them. The corresponding acceleration on the axlebox of the locomotive, with high accelerations at the welds, is shown in (Fig. 5b).

For AN’s 47kg/m rail the corresponding dynamic loads are insufficient to cripple the rail and rolling yet do not cause gross plastic flow. The most plausible explanation of this is that the yield strength of the somewhat killed rail steel is relatively low yet its capacity for work hardening is high. Accordingly the rail could yield in bending under loads which are insufficient to yield the work hardened layer at the running surface. The more recently-fully killed rail steel has a substantially higher yield strength.

The most attractive and economical treatment required specification of allowable limiting vertical loads which would allow continued use of the existing 47kg/m rail. For AN’s conditions an appropriate limiting static plus low frequency dynamic loading force (often known as the “P2 force”) was found to be 200kN per wheel. Corresponding limits have been set on allowable track irregularities of 1.3 millimeters at a weld (3.25mm under a 1m straight edge) and the amplitude of corrugation from peak to trough. The track will progressively be improved to these standards by a combination of grinding, removal of excessively corrugated rail, and straightening of welds so that the corrugation will correspondingly be reduced to the specified level both by these means and by attention to the dynamic characteristics of future vehicles.

An instrumentation system was developed for AN with the twin purposes of measuring railhead profile and for general data analysis from experiments in track and on trains. This equipment is based on the proven method of analysis of axlebox accelerations, but using a Compaq portable microcomputer (or indeed any IBM PC compatible microcomputer) for data analysis to give a relatively inexpensive and portable system. To this end the author has been drawn upon expertise of Thoroughbred Digital Systems Ltd., who supplied the signal processing boards and appropriate software, and Cambridge Control Ltd., who wrote the software for analysis of railhead profiles from axlebox accelerometers. Data is analysed in real time as the train runs along the track at about 40km/h and can be played back as appropriate to a computer. This computer can then be used to measure track irregularities and immediately determine whether the track is fit to continue.

(During the period when the project described here started Dr. Grasse was working on an assignment for Pajudal International Ltd to Pajudal Australia Pty. Ltd. He saw the work as an independent consultant, engaged primarily on railway projects.)
The Pandrol Gauge-Lock – Designed for Developing Countries

Whilst visiting railway engineers throughout the world, in particular in Africa and South America, Pandrol representatives have repeatedly been asked for a PANDROL fastening, for use on timber sleepers, that did not require a baseplate. The engineers were looking for an alternative to both the rigid and elastic spike-type fastenings. In order to meet their request, we needed to find a method of securing our resilient type of clip more directly to a sleeper.

In the Group Laboratory at Worksop, work commenced on adapting the PANDROL Brand Type ‘e’ clip for installation into timber sleepers without using baseplates or shoulders. This meant the clips had to be designed to be held securely in place by a single screwspike.

In addition, in order to meet the needs of these railways, the fastening had to be low in cost, simple to install and requiring little maintenance.

The result was the Gauge-Lock. It not only met the initial requirements, but has a number of other advantages as well.

**Technical Details of Gauge-Lock**
- Holds rail to sleeper, whilst at the same time retaining gauge.
- Provides a good retention face (10mm). This retention face resists sleeper skewing.
- Provides an adequate toe load.
- Manufactured with the same type of recieved and from the same high quality spring steel as other PANDROL Rail Clips.
- Subjected to the same extensive testing as all Pandrol products.
- If used on softwood, an inexpensive flat metal plate can be put beneath the rail to limit indentation of the sleeper surface e.g. a gang rail.

**Economics of Gauge-Lock**
- Baseplateless on hardwood sleepers (the sleeper can be added where required to give rail inclination).
- Only 4 components (2 clips and 2 screws) per rail seat assembly.
- Simple to install.
- Applicable to both old and new sleepers.
- On old sleepers, the Gauge-Lock can be installed on sleepers without removing them from track.
- New sleepers can be delivered to site with the Gauge-Lock in place, partly fastened to the sleeper.
- Virtually maintenance free.
- Can be re-used as many times as required.
In addition, where existing rigid fastenings are subject to creep, it has been found that by fitting Gauge-Lock on every other sleeper the problem has been solved.

Initially supplied in two sizes, in 12.7mm round bar spring steel for use up to 80lb rail, and 14mm round bar spring steel for use up to 100lb rail, the new Gauge-Lock has received an enthusiastic welcome.

Trial lengths have already been installed in track in Bolivia, Chile, Cuba, Ghana, Paraguay and Uruguay, and will shortly be put into track in Kenya, Tanzania and Peru. All trial lengths have been installed in problem areas.

Pandrol have also been pleasantly surprised that certain developed countries, including the UK and Japan, are considering using Gauge-Lock on their more lightly used lines.

At the time of publication the new Gauge-Lock has been performing satisfactorily in track trials for over 6 months.

Pandrol's on-track testing activities have increased over recent years to the extent that it is impossible to describe all of the work in detail in 'Track Report'. These examples show just a few of the locations where work has been carried out.

1. Canadian National Railway in Alberta, including trials of sub-zero temperatures to investigate the effects of frozen ballast and mixed-grade*.
2. West Coast Light Railway in London, to investigate track performance under very high-speed 190km track designs.
3. New Zealand railways to evaluate new types of rail pads under increased and mixed rail.
4. Finnish State Railways (VR) on their main Helsinki–Lappeenranta line to evaluate resilient rail pads under mixed traffic on post-factored concrete sleepers.
5. Union Pacific Railroad in Oregon, USA, to study the behaviour of Pandrol track – evaluative sleepers under heavy freight trains*.
6. Locations in UK and France to provide data for the design of track for high-speed passenger trains.*

*These tests were part of a joint test programme involving Pandrol International and concrete sleeper manufacturers.