

Rail Irregularities and Their Effect on Track Maintenance

P. L. McMICHAEL

ABSTRACT

Research has shown that the free shape of rails determines the vertical geometry of railway tracks at wavelengths below 5 m. Tracks laid with rails of poor geometry require more maintenance and have a shorter life than tracks laid with good rail geometry. The major rail vertical geometry irregularities occur at welds. Methods of straightening welds and supporting the sleepers around those welds have been investigated. The best results are achieved with a closely controlled overlift of the weld, support of the sleepers by stone blowing, and a machining operation to smooth the running surface of the rail. A new generation of on-track maintenance machines has been designed by using the results of this research. It is anticipated that a significant reduction in track maintenance costs will result from the development of these machines.

Joints in railway track have always presented the railway engineer with a maintenance problem. The maintenance costs of bolted, fishplated joints have been greatly reduced by the replacement, wherever possible, of this type of joint with a weld to form continuous welded rail (CWR). However, the widespread introduction of CWR has not completely eliminated maintenance costs that can be directly attributed to the joints between rails. The reasons these maintenance costs arise and methods by which they can be reduced or possibly eliminated are discussed in this paper.

RAIL SHAPE AND TRACK GEOMETRY

Measurements of track geometry over a number of years, using British Rail's (BR's) high-speed track

recording car, have shown that railway track has an inherent vertical shape to which it returns after a maintenance tamping operation (Figure 1). Measurements have shown that this shape is remarkably persistent in track that is maintained by conventional tamping (Figure 2). It is this inherent shape and the time it takes for its roughness [expressed as its standard deviation (SD) about a mean line] to become unacceptable that determines the frequency of maintenance tamping required (Figure 3). Theoretical studies and practical observation (1) of the inherent shape of track have shown that if a Fourier analysis of the shape is carried out, splitting the track shape into its component wavelengths, faults with wavelengths of less than 5 m show a strong correlation with the free shape of the rail. As the wavelength increases, the correlation is reduced.

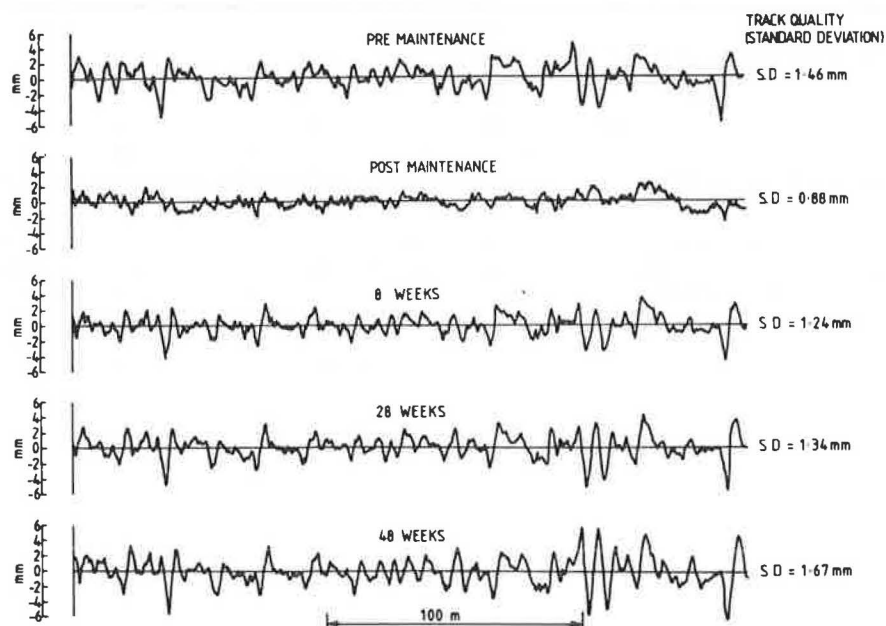


FIGURE 1 Track geometry after maintenance tamping.

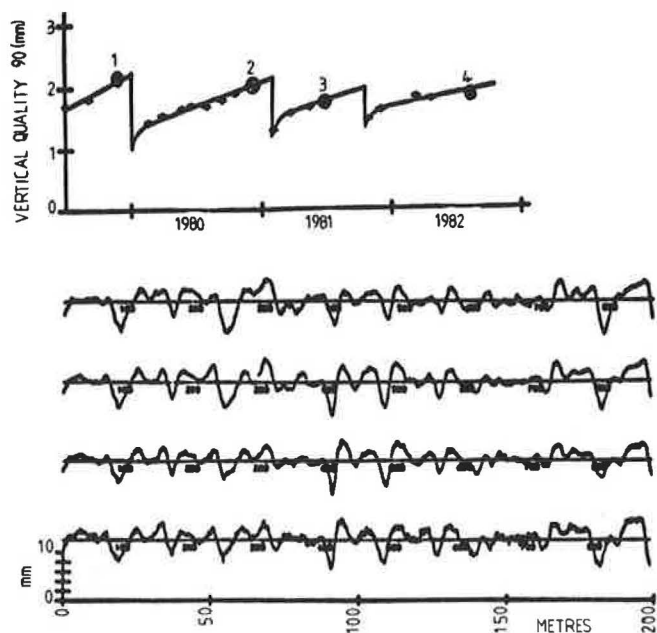


FIGURE 2 Recurrence of vertical profile.

Measurements of both free rail shape and track geometry have shown that the largest short wavelength irregularities occur at welds.

To illustrate the effect of weld shape on track geometry, an experiment was recently carried out on one of BR's tracks (2). In this experiment, the change in the longitudinal vertical profile of a 300-m length of CWR was measured before and after a pair of rails were moved 13.4 m along the track and rewelded into position. The rail was moved and clipped into position without moving any sleepers or modifying the ballast support conditions. The shape of the rail at each weld position before and after moving the rails was measured with a short (1.1-m) versine trolley and, as expected, the shape remained virtually identical over a 5-m length. A sample set of data for welds is shown in Figure 4. The measuring trolley is insensitive to wavelengths of over 5 m.

The geometric irregularity of the weld is determined at the welding depot and depends partly on the straightness of the rails and rail ends as supplied and partly on the effectiveness of the welding machine and press. The principal faults are dips, humps, and steps in the rail profile. The sequence of operations in rail welding depots is that the flash butt welding machine, the flash stripping machine, the straightening press, and the grinding

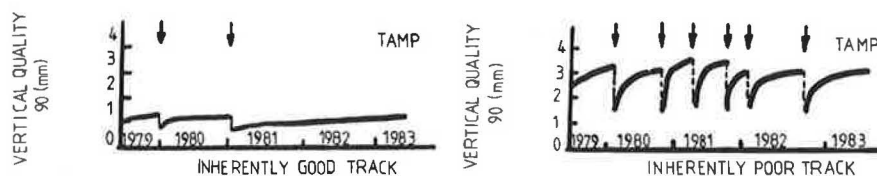


FIGURE 3 Frequency of track maintenance.

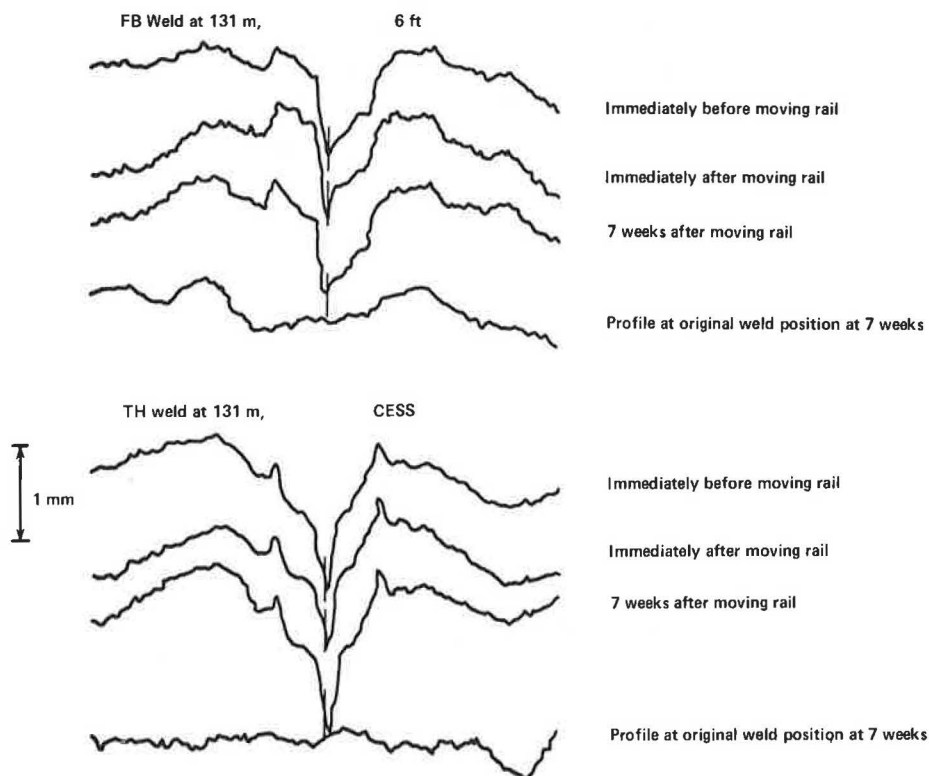


FIGURE 4 Unloaded 1.1-m versine measurements.

process are all located in a sequential line (Figure 5). Constraints of space within the depots lead to these units being one rail length (60 ft) apart. If the depot is producing a weld every 5 minutes, only 10 minutes are left for the weld to cool before reaching the press, at which time the rail is still hot.

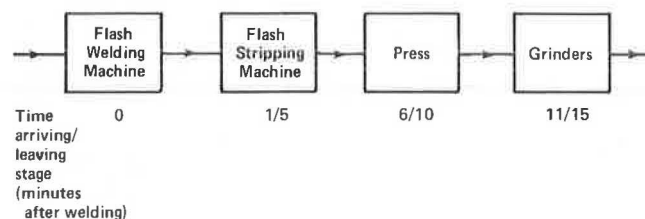


FIGURE 5 British Rail welding depot layout.

Differential cooling leads to the foot of the rail cooling first, causing an initial upward movement of the weld followed by a downward movement as the head cools. If the weld is pressed while hot, an allowance must be made for the movement that will occur after the press. In practice, this is difficult to control because weld temperature distribution varies from weld to weld. To overcome this problem, future welding depots on BR will incorporate a combination of forced air cooling and water spray cooling to ensure that the weld is cool before pressing and that movement following pressing is minimized. It is also likely that one of the control systems described later in this paper will be incorporated into the press. These steps will ensure that in the future, super-straight welds emerge from the welding depots. However, currently nearly two million welds exist on BR's network, produced in earlier depots.

If a rail weld is dipped, as a wheel passes over it the track will accelerate the unsprung mass of the axle upwards after it passes the point of maximum dip. This results in an increased dynamic load on the track, which will cause extra deflection of

the track components and ballast support at this position. The constant pounding of the ballast leads to extra settlement of the sleepers in the vicinity of the weld. A theoretical analysis of the effect of 125-mph traffic passing over a 5-milliradian rail dip shows the resulting track profile to be dipped over several sleepers to a maximum of 6 mm (Figure 6). The sleepers around the dip itself may become voided. The wear and attrition of the ballast can in some instances block the drainage pores between the stones and cause a wet or washy spot. This causes a pumping action leading to an abrasive slurry eroding the sleeper (Figure 7). Eventually, the only cure for this situation is to re-lay the track in this area with new components. It is thus imperative that (a) the rails are straight at the moment the track is installed and (b) wherever possible, dipped welds already existing in track (or dips in plain rail) are corrected as part of the maintenance process.

CORRECTION OF DIPPED WELDS

Several systems for straightening dipped welds are available. The most common method, and that used on BR, is three-point bending. In its simplest form, a rail straightener consists of a beam that rests on the running surface of the rail supported at two points, typically 1 m apart (Figure 8). A hook is located under the rail foot from the center of the beam, and this is loaded hydraulically to bend the rail. This type of rail straightener has the advantage of being inexpensive and simple, but it is crude in its operation and relies on the skill of its operator to achieve a satisfactory result. Before the lift can be applied, some excavation of the ballast is necessary to enable the hook to be located under the rail foot. This restricts the device to operation between sleepers.

British Rail's Research Centre at Derby has carried out a detailed study of the geometrical behavior of track after straightening with this basic equipment (3).

If the dip is merely straightened to leave the three points lying on a straight line, after the passage of a few weeks' traffic some of the rail dip will have returned and there will be only limited

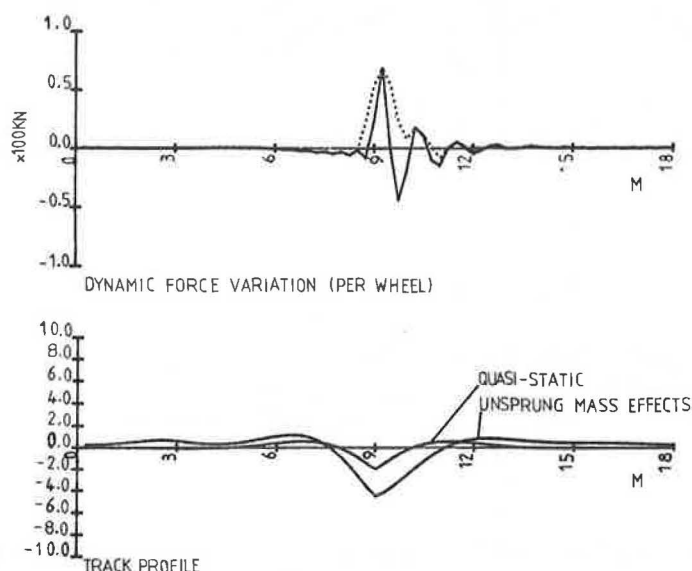


FIGURE 6 Track profile resulting from a 5-milliradian rail irregularity—unsprung mass effects at 125 mph.

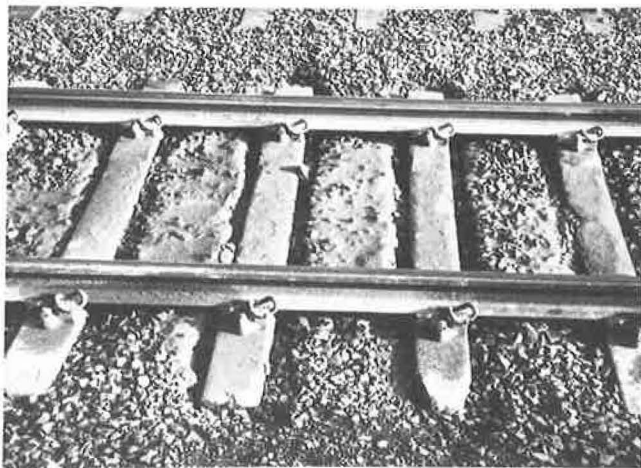


FIGURE 7 Washy spot in track adjacent to a weld.



FIGURE 8 Three-point rail straightener.

improvement in the loaded track geometry. A successful rail-straightening operation clearly needs to devote attention to the ballast support conditions and to the rebending phenomenon.

Rebending occurs because straightening by bending in one direction reduces the yield strength in the opposite direction (i.e., the traffic loading can more easily deform the rail). This reduction in yield strength is known as the Bauschinger effect and is due to the distribution of residual stresses in the rail. The static load of an axle would not, in itself, be enough to cause yield of the rail, but if a significant dynamic load exists because of local roughness in the running surface, the load can be high enough for the rail to yield. As the rail yields in the reverse direction, the yield strength increases and eventually its shape will stabilize. To a greater or lesser degree, this rebending of the rail always occurs, regardless of how the straightening is performed. If the rail is straightened and the sleepers on either side of the weld are squeeze tamped with no additional lift applied, there is again no lasting improvement to the loaded track profile (Figure 9).

An improved result is obtained if a maintenance lift of over 20 mm is applied with the tamping machine (Figure 10) because such a lift is large

enough for the tamper to push extra stone under the sleeper. However, even in this case some of the former dip persists in the loaded track profile 1 year after the maintenance.

The best results have been achieved by using the stone blowing technique (4) to support the straightened weld (Figure 11) together with a slight overbend of the rail to anticipate the reverse bending under traffic. By using this combination, a permanent improvement in the inherent track shape can be made.

Recent experiments have shown that, to reduce high-frequency impact loads at the weld, the amount of reverse bending can be more closely controlled if the rail surface is ground smooth within a few days of bending. The results of these tests indicate that a suitable rail-straightening system would consist of a machine to straighten the rails in a controlled manner, a machine to smooth the running profile of the rail, and a packing system capable of supporting the sleepers effectively over short and medium wavelengths.

NEW DEVELOPMENTS IN RAIL-STRAIGHTENING EQUIPMENT

The Austrian firm of Plasser and Theurer in conjunction with the Dutch Railways (N.S.) have developed a system known as STRAIT (STraightening of Rails by Automatic Iterative Techniques) (5). This is a system in which a conventional tamping machine incorporates a three-point rail-straightening device built into its track lifting equipment (Figure 12). The rail bending is done in exactly the same way as with a traditional rail straightener except that the displacement of the center of the rail, where the load is applied with respect to the two reaction points, is monitored by transducers.

A microprocessor using a Newton-Raphson iterative system is used to control the bending process. The rail is straightened in several load applications until a permanent hump of between 0.3 and 0.5 mm has been achieved over the 1.2-m span of the bending beam. While this bend is being achieved, the forces on the rail are such that the track within the wheelbase of the machine is lifted several millimeters. The sleepers surrounding the straightened part of the rail are then squeeze tamped by the machine before it moves forward to the next weld dip along the track. To complete the process, a second machine—a shuffle grinder (Figure 13)—is then used to smooth the surface and remove the slight hump left by the bending process. BR has recently purchased two of these systems, and early results indicate that a permanent improvement in the inherent track shape can be made. The output achieved is around 20 welds per hour.

An alternative system is currently under development by the British firm of Permaquip in collaboration with the Research Department of BR. The system, known as RASTIC (RAil STraightening by Integrated Control), is also a machine-mounted system but is based on a small off-trackable machine weighing under 3 tonnes (Figure 14). The bending heads on this machine apply the load to the rail by gripping it under the railhead (Figure 15), which enables the bending operation to be unconstrained by the position of the sleepers. It also eliminates the need to excavate the ballast under the dipped rail. The bending is controlled by a microprocessor that monitors both the deflection of the rail and the load applied to it. The control algorithm calculates the elastic modulus of the track, detects the yield point of the rail, and predicts the permanent set that has been applied during the bend (Figure 16). This algorithm was developed from an instrumented three-point rail straightener.

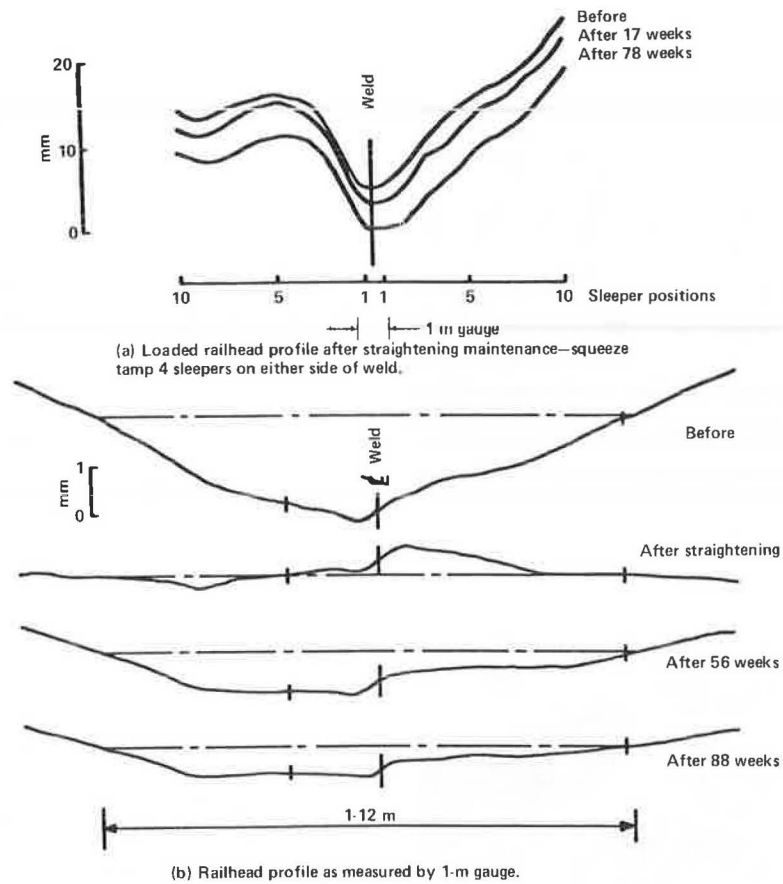


FIGURE 9 Rail and track profile after straightening and squeeze tamping.

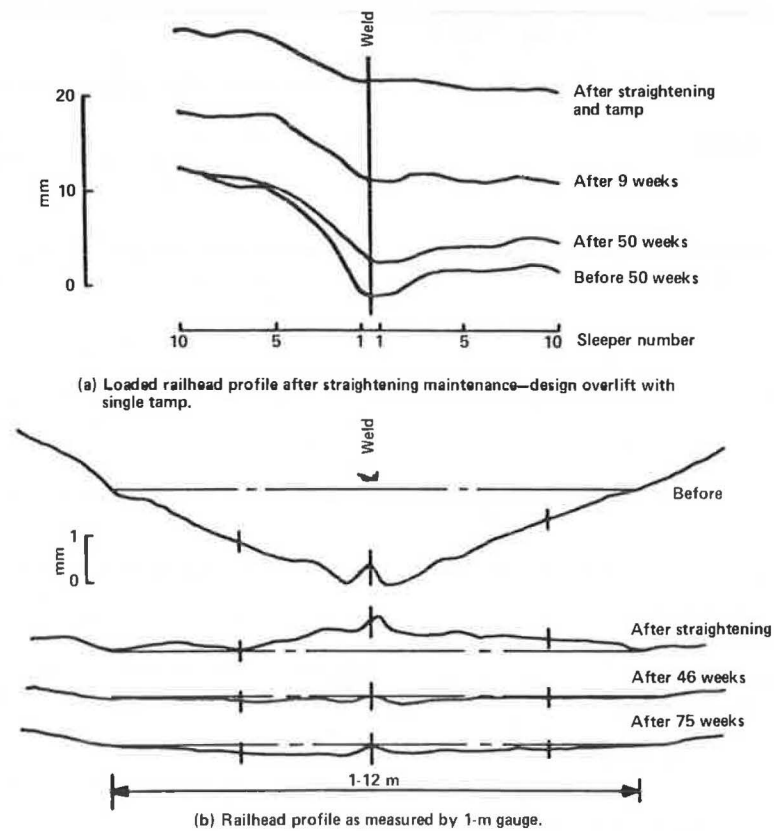


FIGURE 10 Rail and track profile after straightening and design overlift tamping.

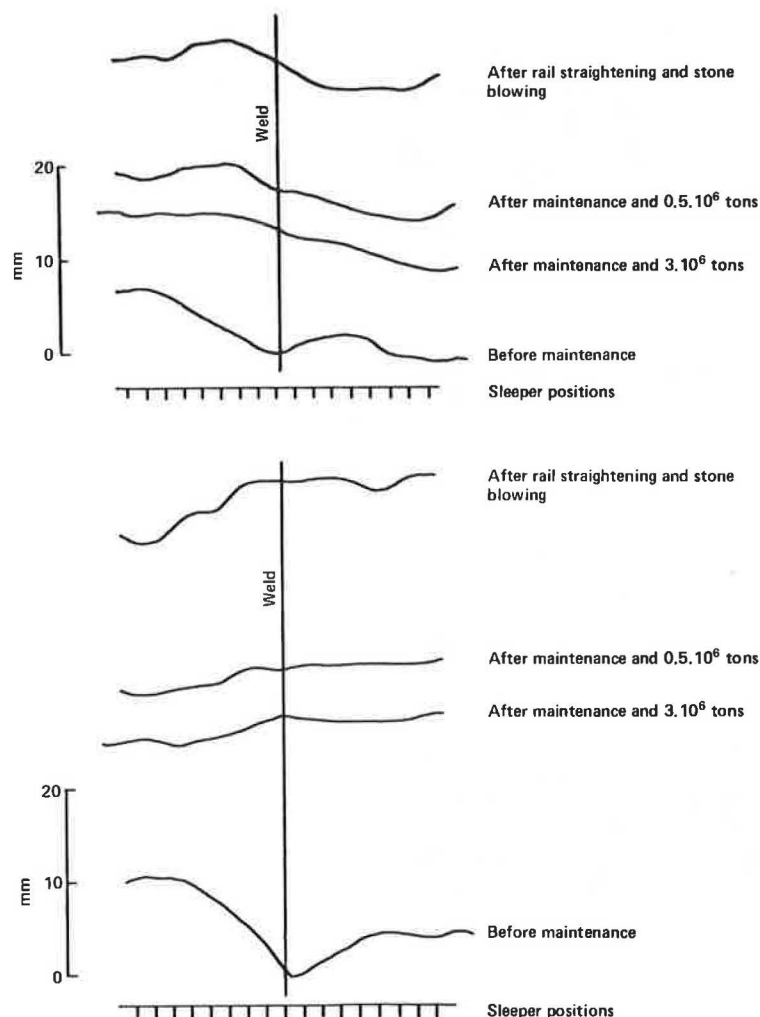


FIGURE 11 Loaded rail profiles of flash butt welds after rail straightening, stone blowing, and trafficking.

The equipment was used to gather load deflection data from a number of bends on differing tracks. Figure 17 shows a typical result obtained by using this equipment. The algorithm is capable of predicting the permanent set of the rail within a standard deviation of 0.2 mm over a 1.1-m span (Figure 18). The machine will therefore be capable of correcting a rail dip with a single lift of the rail, greatly enhancing the speed of the process.

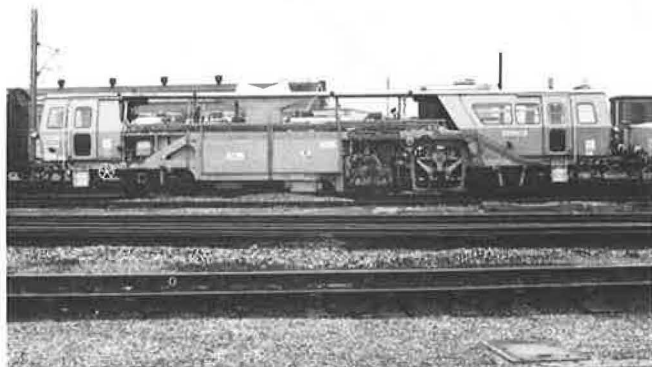


FIGURE 12 STRAIT, Plasser's three-point bending machine.



FIGURE 13 Plasser's shuffle grinder.

In operation, the machine is positioned over the dipped weld. The rail-straightening beam is lowered and moved fore-and-aft until the point of maximum dip is located. The jaws clamp the rail head and the straightening process is carried out. After completion of the bend, the beam is raised from the track.



FIGURE 14 RASTIC's rail-bending machine.

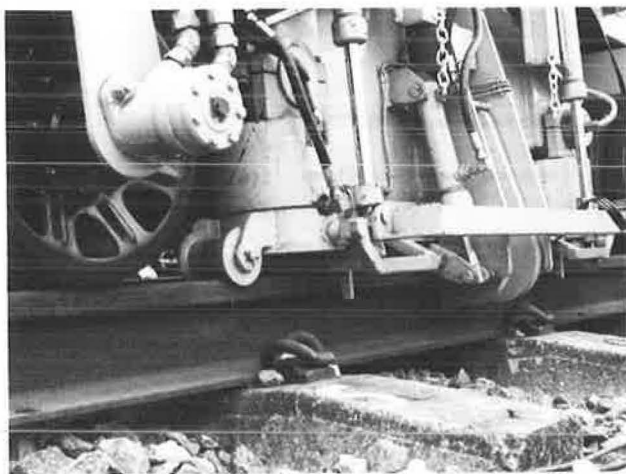


FIGURE 15 Three-point bending head of RASTIC machine.

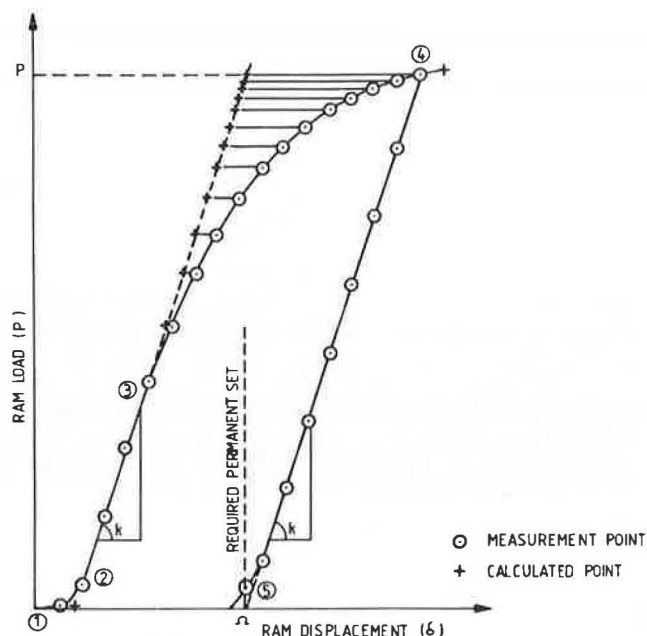


FIGURE 16 Determination of load-permanent rail displacement relationship.

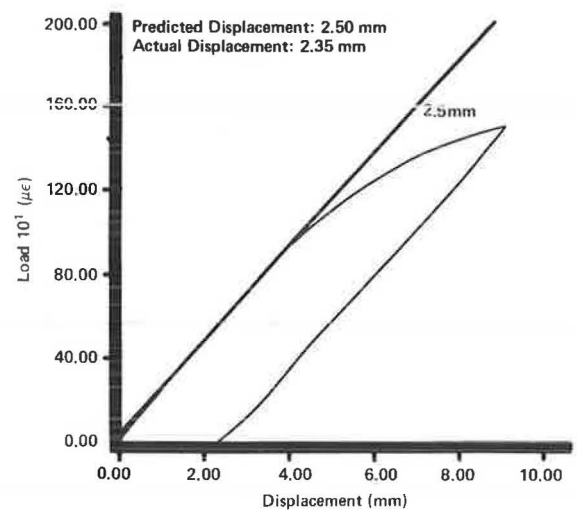


FIGURE 17 Typical result from using instrumented rail straightener.

The process is repeated, if required, on the adjacent weld and the vehicle is then ready to move forward to the next dipped weld. This sequence of operation is totally automatic and is controlled by the microprocessor. A complete bending cycle takes under 20 seconds.

The envisaged output of the machine is over 80 welds per hour, resulting in a working rate of 800 m/hr. At this speed, the machine will be capable of running ahead of a tamping machine that is used in a

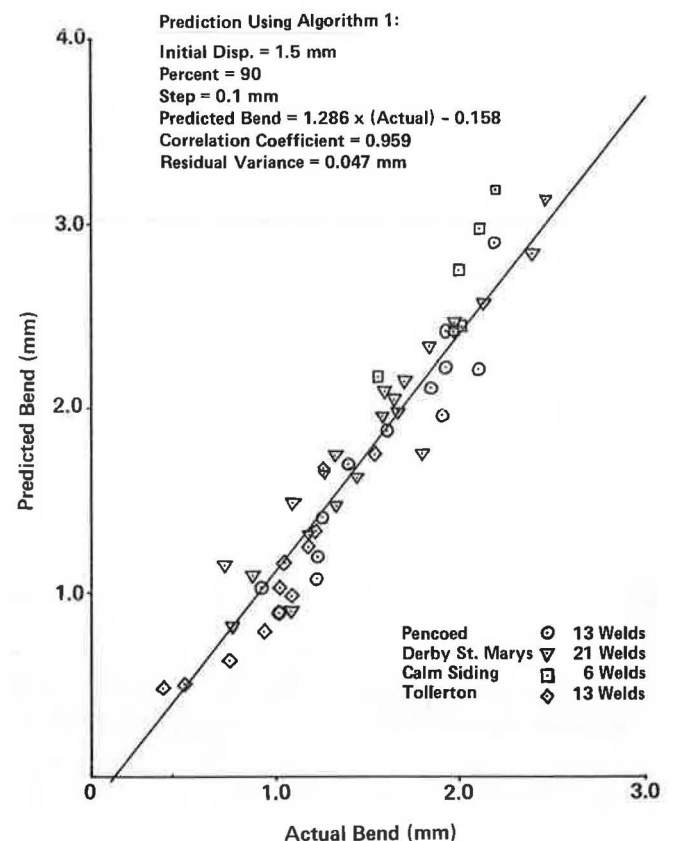


FIGURE 18 Actual versus predicted bend relationship.

normal maintenance operation or ahead of BR's new stone blowing machine. Therefore, it is not necessary to carry out a special packing operation with the straightening operation.

To reduce the high-frequency impacts and to control the reverse bending it will be necessary to smooth the surface of the rail. Conventional grinding machines are too slow to be compatible with the rest of the system, and an in-track rail milling machine (SUPERLEV) is being developed for use in conjunction with RASTIC. This machine is similar to the rail straightener and is also based on an off-trackable concept (Figure 19). The milling heads are arranged to produce a profiled cut of the humped rail. Laboratory trials have shown that an excellent finish of the running rail surface can be obtained by using this technique.

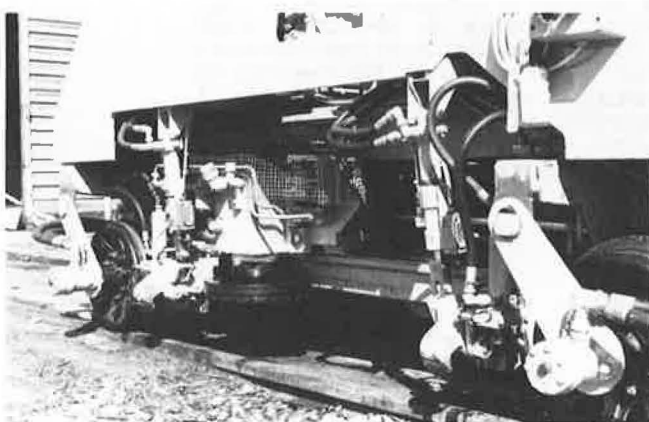


FIGURE 19 SUPERLEV milling machine.

If this system is used selectively on sections of track known to have poor weld geometry, the inherent shape of those sections will be improved. Consequently, less-frequent tamping will be required. Estimates indicate that elimination of all of the dipped welds in BR's track could lead to a considerable saving per annum.

SUMMARY

Vertical rail geometry has a strong influence on the inherent shape of railway track. The major irregularities in rail shape occur at welds. These should ideally be corrected at the welding depots before the rails are allowed to be made into track. Various machines are available or under development for the correction of dipped welds in track. To achieve a durable improvement in track geometry, a straightening system requires close control of the permanent set applied to the rail and an effective packing system to support the sleepers around the straightened weld. The best results are achieved with a machining operation to smooth the running surface of the straightened rail. It is anticipated that the introduction of a new generation of rail-straightening systems will produce significant savings in track maintenance costs.

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