essentially of manganese steel body casting fitted into and between rolled rails and held together with bolts.

Solid Manganese Steel Frog--A frog consisting essentially of a single manganese steel casting.

Heel End of Frog--That end of a frog that is the farthest from the switch; or, the end that has both point rails or other running surfaces between the gage lines.

Toe End of Frog--That end of a frog that is nearer the switch; or, the end that has both gage lines between the wing rails or other running surfaces.

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Development Work on Switches and Crossings by British Rail

C. LOCKWOOD and P. J. THORNTON

ABSTRACT

To meet the increased demands imposed on switch and crossing installations by higher train speeds and higher axle loads, British Rail has a continuing program of development work. This program's purposes are to (a) provide junctions for higher speeds and (b) reduce track maintenance costs by improving track layout geometry and component design as well as materials and the support structure. Recent work in these areas includes design of high-speed junctions suitable for speeds up to 125 mph (200 km/hr), and studies of the paths of wheels through junctions, with particular emphasis on entry into switches. Computer simulations have been developed to predict wheel/rail forces. Measurements of actual forces by means of load-measuring wheelsets have confirmed predictions. Theoretical vertical wheel trajectories through a variety of crossings have been considered in detail, leading to proposals for changes in local railhead geometry to reduce impact forces. (Large vertical impact forces measured at crossings are illustrated.) Improved steels have been developed for use in crossings that can be welded into track, thereby eliminating troublesome bolted joints. Better support for switch and crossing work (in the form of prestressed concrete bearers) is being evaluated.

The railways in Britain link conurbations that, in many cases, are less than 40 km apart so railways have to compete with the motorway network with its speed limits of 113 km/hr. Some of the longer journeys are up to 650 km from end to end and have to compete for business travel with internal air routes. With these types of competition, it is important that the speed of passenger trains should not be unduly restricted at junctions, in order to maintain the highest average speed possible between station stops.

JUNCTIONS FOR HIGHER SPEEDS

Historically, the geometry of switches has been designed on the basis of a maximum-allowable cant deficiency at the switch tip. This was based on the amount of discomfort tolerable to passengers as assessed from running trials. The effective radius at the switch tip on a diverging route is calculated from the versine on a 12.2-m chord centered at the switch tip (1). The short-lived cant deficiency on that radius of curve must not exceed 125 mm (5 in.), and the sustained cant deficiency on the turnout curve is limited to 90 mm (3.5 in.).

These rules are still applied in British Rail (1). As speed requirements increased, switchblade geometry was gradually refined, and straight planing gave way in the 1950s to curved planing, which provides a narrower entry angle and improved travel from planed rail to full-switch rail (Figure 1). This was further improved in the late 1960s by making

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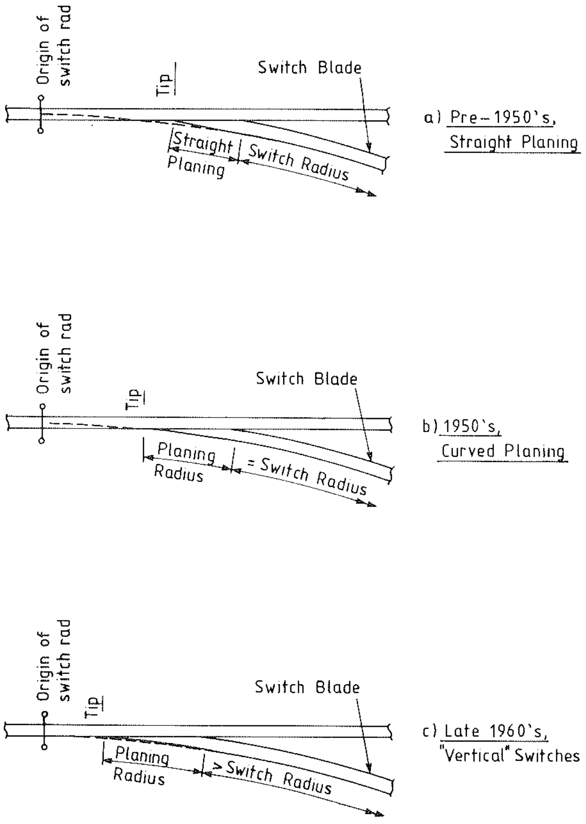


FIGURE 1 Development of British Rail switch design.

the switch curve tangential to the plain rail ahead of the switches, but with the switchblade planing at a slightly larger radius still intersecting the straight to maintain a sufficiently robust tip (Figure 1). The range of standard turnouts was rationalized to be in accordance with operating requirements. A further development at this stage was to make all rails of switch and crossing layouts vertical instead of inclined at 1 in 20 as most were hitherto. This led to a considerable reduction in the number of different baseplates required for this so-called "vertical" design.

All switch rails are flexible and have a fixed heel. Turnouts that incorporate such switches and that are suitable for speeds up to 70 mph (113 km/hr) are widely used (Figure 1 and Table 1). Crossovers incorporating these turnouts are subject to reduced speed limits, because of the rules for the rate of change of cant deficiency (maximum 80 mm/sec or 3.25 in./sec), to ensure passenger comfort (1). Use of spiral-transition turnout curves with flatter crossing angles and a portion of straight track between the two crossings enables the speed potential of the switches to be realized in crossover situations.

In response to a recent operating requirement of 125 mph (200 km/hr) as the running speed on the East Coast Main Line of British Rail, switches suitable for this speed when laid "split" symmetrically [or for speeds of 90 mph (145 km/hr) out of straight] were designed and put into service in 1983 (Figure 2) (2,p.149).

A REAPPRAISAL OF SWITCH DESIGN

Requirements for higher speed through junctions have prompted British Rail to closely examine the way vehicles are affected by their passage through switches and crossings, aided by the greater knowledge of vehicle behavior that now exists. Large lateral wheel/rail forces are known to occur and theoretical assessment of switch designs by computer modeling is an important part of the current work, aimed at reducing those forces.

The Tangential Switch

This switch configuration has been proposed in the light of current knowledge of wheelset curving behavior with the aim of reducing the angle of attack of the wheel on the switchblade and, hence, the impact forces, while still adhering to the cant deficiency criteria.

On British Rail, there commonly is a 6-mm nominal clearance between the wheel flange and the rail on straight track. A wheelset running centrally approaches a set of switches in a straight line until one wheel flange contacts the diverging switch rail where this is approximately 6 mm thick, when all the flangeway clearance is used up. In the current, curved, planed switches, this contact is made at an angle of attack slightly larger than the planing angle at the tip of the switch (Figure 3).

To improve the situation, the switch (and turnout) curve would ideally continue forward to its tangent with the stock rail, but the resultant, extremely thin switch tip would be unsatisfactory. However, if the wheel does not normally contact the switch rail until the latter is 6-mm thick, then the switch rail in front of that point can be made straight, thus giving a finite angle at the tip of the switch and still providing the desired reduction in angle of attack. If a wheel is hugging the stock rail on the closed turnout switch side, the impact angle will be the same as for the 6-mm position, as will be the exit angle for the reverse direction of travel. The length of straight provided is short and will barely affect the running of a vehicle onto or off the switch curve. (Note: This design approach is shown in Figure 4 and is known as the tangential switch.)

TABLE 1 Current Range of Switch Types

Switch Type	Planing Length (m)	Planing Radius (m)	Switch and Turnout Radius (m)	Natural Angle (℄ measure)	Maximum Speed (km/hr)	Speed Restriction (mph)
AV	2 900	197	141	7	30	15
BV	3 500	231	184	8	35	20
CV	4 250	287	246	9.250	45	25
DV	5 200	367	332	10.750	50	30
EV	7 000	740	645	15	70	40
FV	8 550	1137	981	18.500	85	50
SGV	10 150	1399	1264	21	100	60
GV	11 600	1826	1650	24	115	70
HV	16 500	3188	3001	32.365	150	90

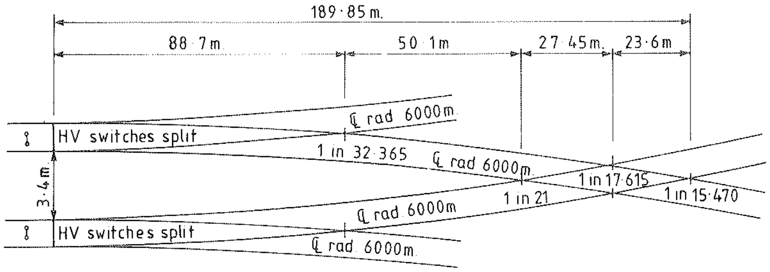


FIGURE 2 High speed junction for 125 mph (200 km/hr).

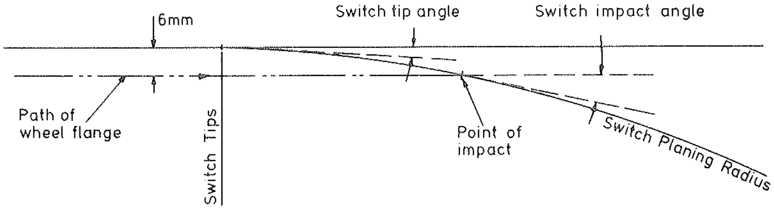


FIGURE 3 Switch tip angle and impact angle compared.

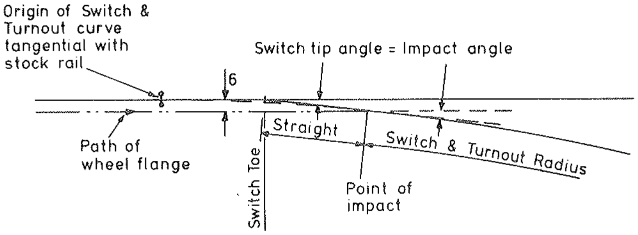
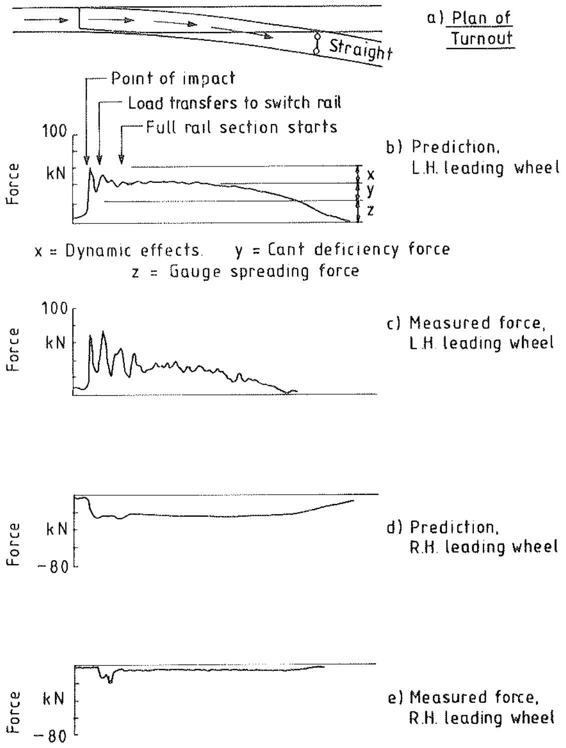


FIGURE 4 Design of tangential switch.



NOTE — Vehicle in all cases is a diesel freight locomotive

FIGURE 5 Comparison of predicted and measured lateral forces in a turnout.

Lateral Forces

Although the calculation of cant deficiency at switch tips will give a reasonable indication of the lurch that will be experienced by a passenger, the study of the track forces applied by the wheels of vehicles gives a much more scientific approach to the assessment of likely wear and tear on the components. The Research Division of British Rail has studied the forces generated by a wheelset negotiating track alignment irregularities. The lateral force at the impact position on switches can be likened to that generated at such an irregularity. The levels of the forces experienced by conventionally designed switches have been predicted by a computer model and these have proved to be close to those recorded on track by load-measuring wheels fitted to a locomotive and to a freight vehicle (Figure 5). This information has been used to investigate the lateral impact force generated by the wheelset striking a diverging switch rail. Shown in Figure 6 are comparisons of predicted impact forces, which indicate that significant improvements can be made by adopting a tangential design, especially for facing-direction traffic. The horizontal forces would be the same in the facing and trailing directions for this design.

When compared with the current design of switches, the new tangential design can be expected to give a reduction of about 55 percent in the dynamic horizontal forces on a switch with a locomotive traveling through the turnout in a facing direction. In the trailing direction, the forces could be reduced by about 25 percent. The improvements would be achieved at the expense of an increase in planing length of about 12.5 percent.

Measurements of wear and monitoring of the integrity of components will show whether the increased cost of the tangential switch is outweighed by the increase in life expected as a result of the lower force levels.

VERTICAL WHEEL TRAJECTORIES THROUGH CROSSINGS

The discontinuity of the running surface at a crossing has always presented a challenge to the Permanent Way Engineer. Under traffic, large vertical impact

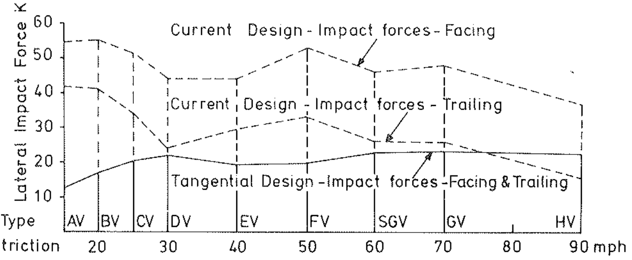


FIGURE 6 Predicted impact forces on switches (laterally unsprung mass of 2.39t).

forces can occur that can cause severe deformation and, perhaps, damage to the railhead, and can sometimes lead to fatigue failure. Rail fastenings and timbers are affected and accompanying deterioration of the track support hastens these processes. At higher speeds, the vertical trajectory of a coned wheel passing over a crossing is an important factor governing the magnitudes of the wheel/rail forces generated, which are similar in general shape to the irregularities presented by dipped joints or welds and by wheelflats (3), and a knowledge of this geometry is essential to the crossing designer. The problem of how to provide the best possible support for the wheel is compounded by the wide range of tire profiles likely to traverse the track--from a variety of brand new ones to those that are due for reprofiling--each one producing its own resultant wheel trajectory. Wear of the rails further complicates the issue.

The customary means of assessing the wheel's vertical path has been by the laborious drawing of wheel and rail profiles larger than full size and superimposing them on one another, for close spacings along the track. The wheel's height relative to a datum could then be scaled and plotted. This is a slow process and is probably a prime reason why the wheel/rail interaction at crossings has not been given as much attention as the materials from which the crossings are made.

However, the advent of powerful computerized drawing facilities has brought the possibility of carrying out such work much more quickly and accurately and has encouraged detailed assessment of trajectories. British Rail's Research Division has carried out some preliminary analysis work on existing crossing designs and will extend this to a consideration of modified designs. The effects of different tire profiles, new and worn, in different lateral positions can quickly be analyzed, once the basic crossing and tire data are filed. Such an assessment offers a quick means of comparing the likely results of modifications without the expense of service trials, and also of identifying undesirable features not otherwise apparent.

The working process is the same as for the manual method but the information provided is much more accurate than hitherto and professional-standard drawings are readily available. Having examined an existing crossing, the engineer can quickly test design changes and assess their benefits.

Theoretical Trajectories

The combination of tire coning and railhead geometry (the latter both vertical and horizontal) through the heart of a crossing leads to an irregular wheel path in the vertical plane, often of an undesirable shape and magnitude.

The wheel has, in effect, a series of ramps to negotiate and may even meet small steps. The results of a computer-aided analysis of a new, coned tire profile, type P.1 (Figure 7), traveling through a 1 in 9.25 angle common crossing fabricated from rolled rail are shown in Figure 8. This tire profile, which has a 1 in 20 tread coning, has been widely used by British Rail for many years, although other types of profile are becoming more numerous. This is shown superimposed on the nose area of the crossing in Figure 7. The three tire positions (A, B, and C) correspond to those of a centralized wheelset (B)

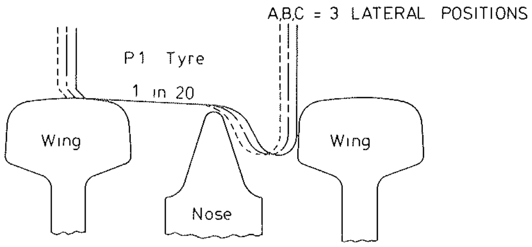


FIGURE 7 New P.1 tire at nose of rolled rail crossing.

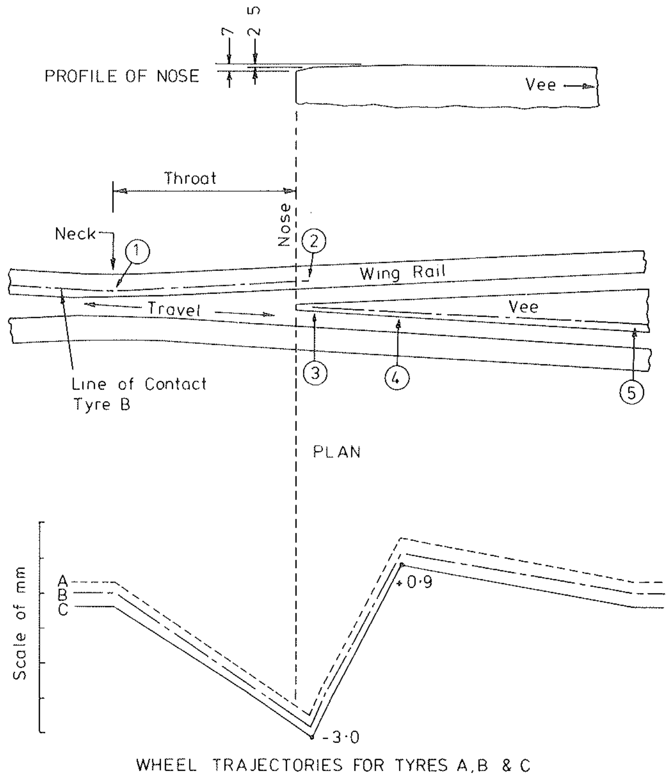


FIGURE 8 Vertical wheel trajectories for new P.1 tire/rolled rails.

and wheelsets near their two lateral extremes (A and C). The plan view in Figure 8 shows the running surfaces in the throat and nose areas of the crossing, irrelevant detail being omitted. The derived wheel/rail contact line for tire B is marked.

The path plotted in Figure 8 shows clearly that as the left-hand wing rail departs from the running direction along 1-2, a right-traveling (i.e., facing direction) wheel descends by some 3 mm until contact transfers to the vee at 3, behind the nose. The sloping shape here (Figure 8) presents an upward ramp to the wheel, 3-4, to a height of 1 mm above the general railhead level, from where the descent is made to the latter level at 5. A wheel traveling from right to left will follow the same path in reverse.

This case, although easy to visualize and capable of analysis by calculation, has been described in some detail as an introduction to more complex cases where the tire tread is worn and needs to be drawn accurately.

The ramped shape, 1-2, 3-4, is well known, but the rise above the railhead level to 4, due to the machined railhead shape locally, is not so obvious until analyzed in the manner described. The paths of a centralized wheelset and wheelsets near their two lateral extremes are almost identical (Figure 8). This will usually be the case for a new P.1 tire but will not be so for a worn example or for any other tire design whose profile is curved from new.

Figure 9 shows that a moderately worn tire will have a different path from a new one, running with the outer part of its tread on the wing rail and giving a less severe ramp angle at the bottom of its deviation from a level path. The path of a heavily worn P.1 tire is shown in Figure 10 and again is seen to be somewhat less severe than that of a brand new tire except at 1, where the abrupt step is worse for wheels traveling right to left (i.e., trailing direction).

The preceding discussion concerns a crossing that has rolled rails. The use of castings gives the designer more freedom in choice of running surface shape to improve the wheel's path. One such shape widely used by British Rail is shown in Figure 11. It has a 1-in-20 cross slope to match the P.1 tire, and the resultant wheel trajectories are shown in Figure 12 for new and Figure 13 for worn tires. Clearly, there is an improvement for these two over the rolled rail crossing; however, the heavily worn tire's path (Figure 14) does not compare so well, particularly in respect of transfer of contact from vee to wing at 1 in the trailing direction of travel. A slight modification to the outer part of the wing

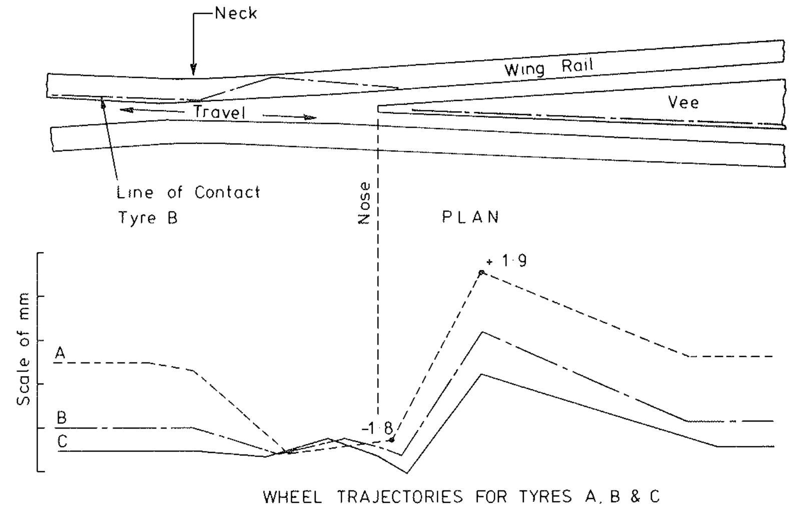


FIGURE 9 Vertical wheel trajectories for worn P.1 tire/rolled rails.

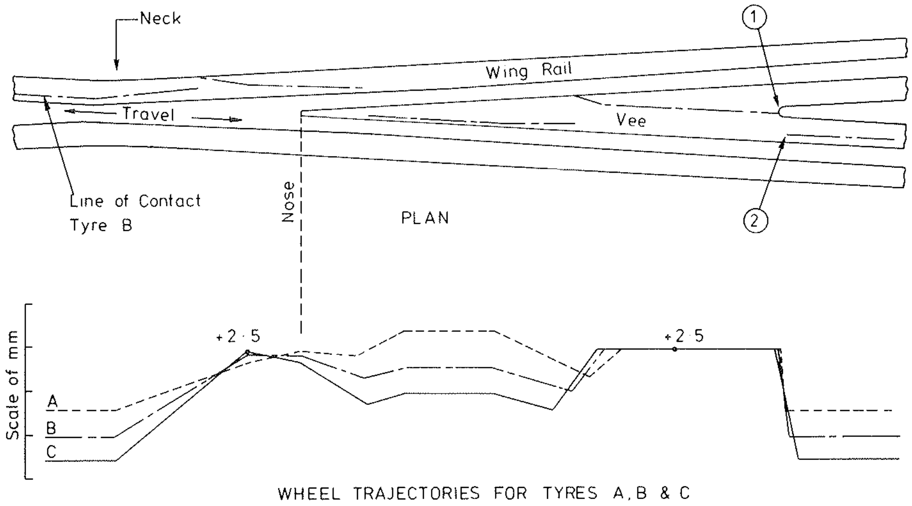


FIGURE 10 Vertical wheel trajectories for heavily worn P.1 tire/rolled rails.

rail surface could ease this, although it is difficult to satisfy the requirements for the smooth passage of all the possible tire shapes.

The irregular wheel paths discussed previously have been derived using as-designed railhead shapes, with no attempt made to relate them to real conditions in track. Wear of the running surfaces will lead to modification of the paths.

Battering of the rails will quickly smooth out small irregularities, which may not therefore be important. Larger, abrupt changes cannot be ignored, but may be amenable to redesign in the light of theoretical analysis. Generally, the wheels will act to smooth out the path and the use of designed rail shapes in analysis will tend to be pessimistic.

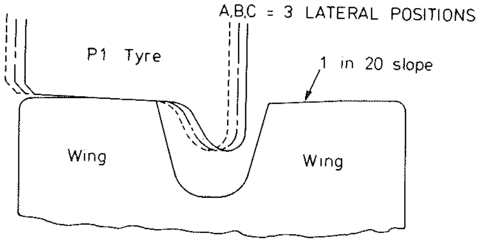


FIGURE 11 New P.1 tire at neck of cast crossing.

FORCES

As already noted, the wheel trajectories resemble those resulting from plain rail joint irregularities although the ramp angles to be negotiated in crossings can be more severe. Dynamic models used to predict wheel/rail forces for ramp irregularities in plain rails are well developed and have been validated experimentally. Extension of this work to crossings would be of great value to the designer.

The following table gives values of theoretical ramp angle for a new P.1 tire traversing a variety of crossings, compared with a severely dipped plain rail joint.

	Description	Trajectory (millirads)
1	Severely dipped plain rail joint	20
2	Part-welded common crossing	18
3	AMS cast crossing	13.5
4	Switch diamond crossing	19
5	Fixed obtuse crossing	16

Other tire/crossing combinations can give much larger angles, perhaps as much as double those quoted. The forces generated will depend on this geometry and on the effective mass and stiffness of the track structure and of the vehicles and can thus vary considerably in practice.

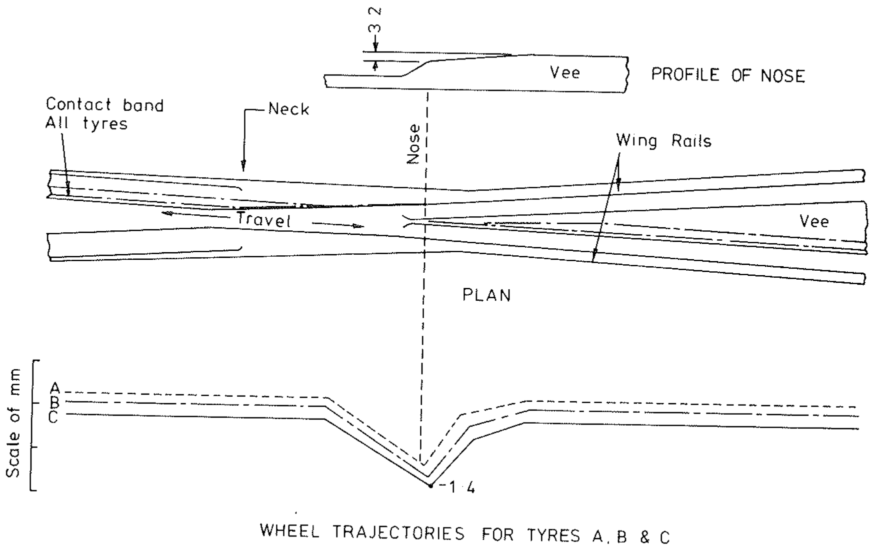


FIGURE 12 Vertical wheel trajectories for new P.1 tire/cast crossing.

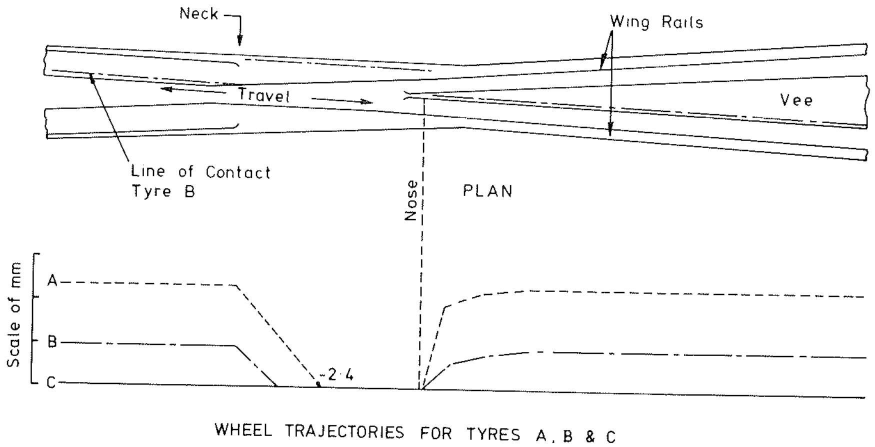


FIGURE 13 Vertical wheel trajectories for worn P.1 tire/cast crossing.

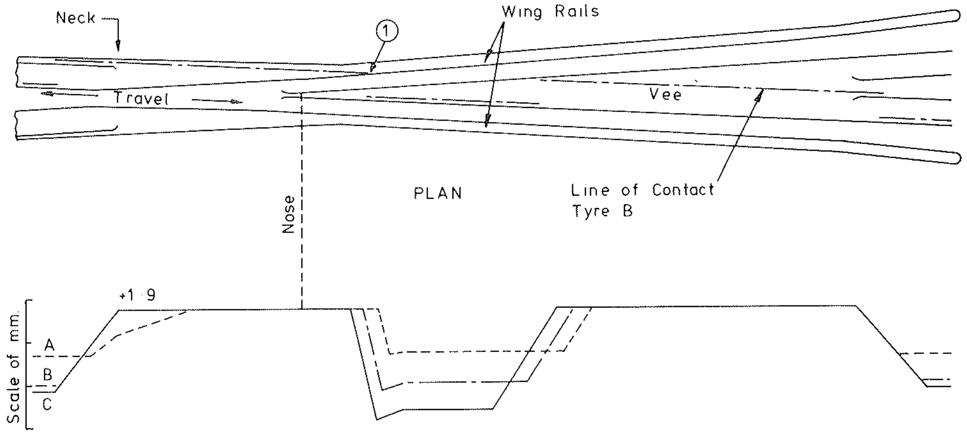


FIGURE 14 Vertical wheel trajectories for heavily worn P.1 tire/cast crossing.

Figure 15 shows examples of forces recorded at crossings, with plain rail joint responses for comparison. The forces are large and wheel trajectory analysis should play an important part in reducing them, thus prolonging crossing life and reducing maintenance costs.

IMPROVED MATERIALS FOR CROSSINGS

British Rail has evaluated new materials for crossings, seeking higher strength steels and harder welding consumables for the part-welded type of crossing, and an alloy steel for cast crossings, which combines good casting properties with good weldability and mechanical properties. Improved materials for use in part-welded crossings of the type shown in Figure 16 have been developed by British Rail in collaboration with T.W. Ward Ltd. (railway engineers).

Commercially available grades of rail steel and welding consumables have been subjected to laboratory assessment and selected combinations used in service trials. That using 90 kg/mm² ultimate tensile strength (UTS) pearlitic steel rail with A33 welding wire has been adopted as standard. This combination gives a high resistance to deformation, can be welded into track, and can be weld-repaired in situ.

A considerable drawback to austenitic manganese steel (AMS) is the difficulty of welding it into track. At present, there is no economically attractive alternative to troublesome bolted joints. To avoid the problem, a bainitic alloy steel has been developed as an alternative to AMS, which not only has excellent casting and mechanical properties, but is readily weldable to pearlitic steels. Collaborative work with Edgar Allen Engineering Ltd. had led to trials of cast center crossings (Figure 17) and performance so far is encouraging.

CONCRETE BEARERS FOR SWITCHES AND CROSSINGS

The support for British Rail's switches and crossings has received much less investigative attention than that for plain track. High-speed main routes are now largely equipped with plain rails on prestressed concrete sleepers employing spring rail fastening clips and rail pads, but owing to the variety of rail-fastening positions in switch and crossing layouts, timber bearers have continued to be used for these with gray cast-iron baseplates and spring rail fastening clips.

Softwood bearers were used for many years, but their service life was insufficient and Jarrah hardwood has been used in recent years. When the rails of older types of switch and crossing assemblies needed replacement, there was often little life left in the softwood, but improved designs of steelwork were found to outlast the bearers. Hardwood has helped to restore the balance but the need to im-

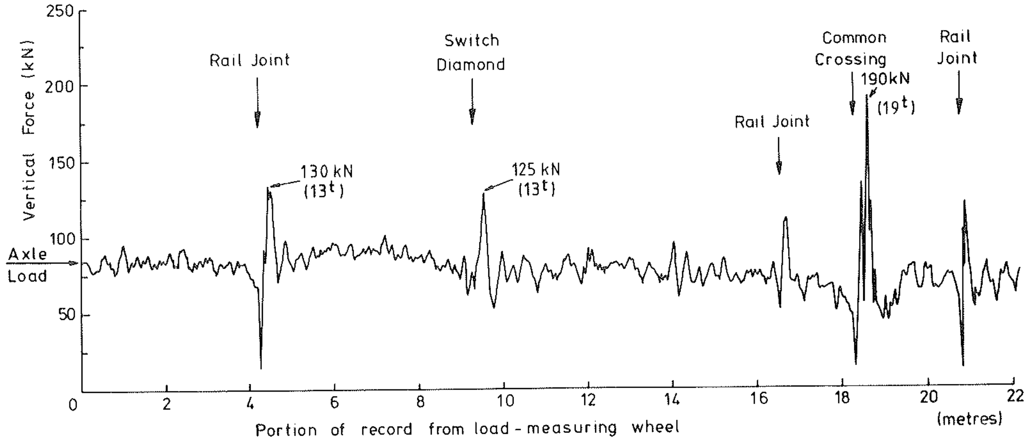


FIGURE 15 Comparison of wheel/rail forces measured at track irregularities.

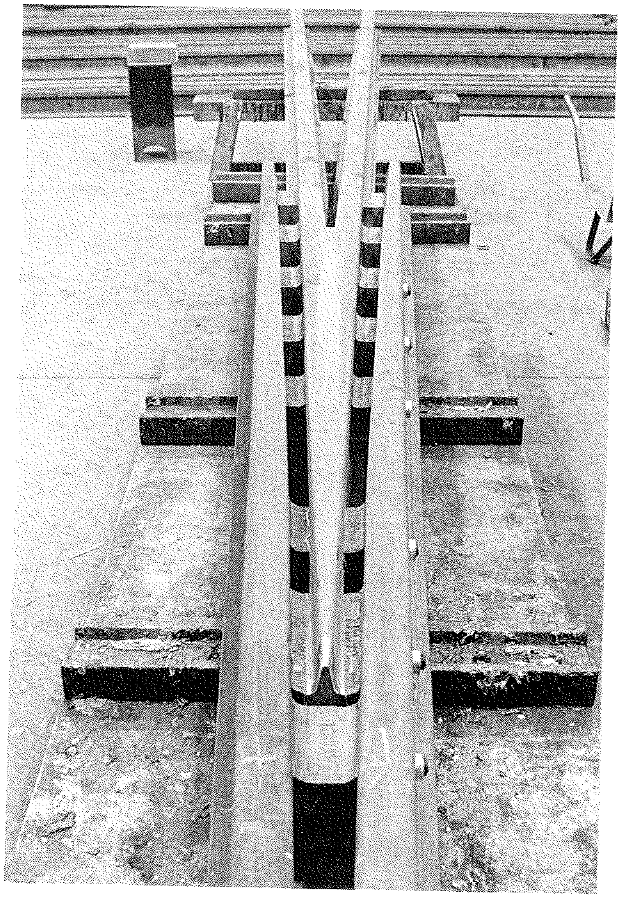


FIGURE 16 Part-welded crossing in BS.11 grade steel (90 kg/mm^2).

prove the retention of track geometry, and reduce maintenance costs and reliance on imported timber, has resulted in the development of prestressed concrete bearers. This is seen as a logical move to follow plain track practice, and concrete bearers are expected to last at least twice as long as the steelwork and result in more economic renewal cycles.

A few trial layouts had been laid as early as 1967 (one turnout) and 1972-1973 (six turnouts), in minor lines. They took advantage of the then new "vertical" switch and crossing designs, which required baseplates only for the switch slides. The concrete bearers were laid out as timber ones would be, with the steelwork laid on top as a template, enabling holes for the malleable iron spring clip housings (Figure 18) to be drilled in the concrete. A resin adhesive was used to glue in the housings. Stud bolts were resin-bonded into the concrete for holding down fabricated steel slide baseplates.

The service performance of these layouts encouraged installation of three further ones in 1981, incorporating improvements. Earlier problems with bowing of the longer bearers due to uneven drying shrinkage leading to track cross-level errors were overcome by casting them on their sides so that any bowing took place in plan. Standard gray cast-iron switch slide baseplates were adopted, and the bearers here are correspondingly shallower to maintain uniform construction depth. In these three installations, the holes for spring clip housings were percussion drilled, either as described previously or using jigs for location. The latter proved to be the more expensive. Also, cost studies showed that if the labor costs associated with the fixing of rail clip housings could be reduced by casting them in, then concrete bearers could be competitive in cost with hardwood.

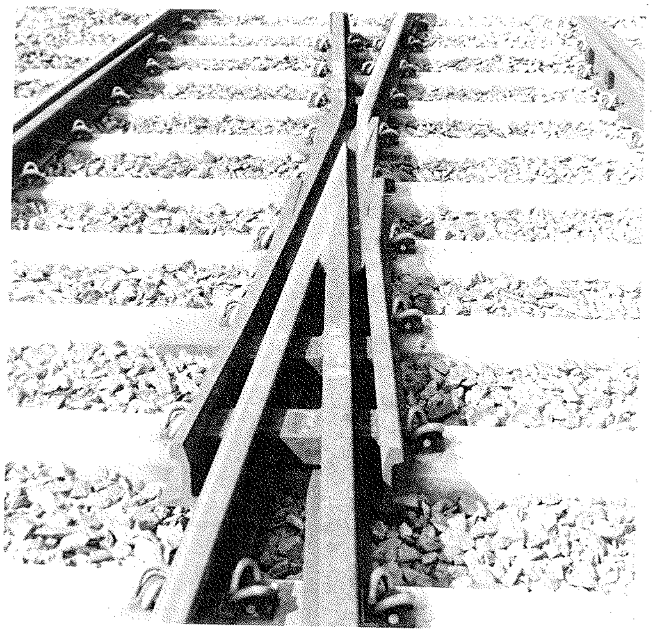


FIGURE 17 Bainitic cast center crossing with welded-on legs.

The position and angle for each housing were calculated by computer and the housings cast in during manufacturer of the bearers. Despite the large number of individual mold plates required, this method is now established and a range of standard turnouts and crossovers is available. Replacement bearers, if required, can be supplied quickly. Bearers up to 6 m long for plain rails and crossings with standard concrete sleeper-type clip housings, rail pads, and insulators have proved reliable (Figure 18).

Following the development work, carried out in collaboration with Dow-Mac Concrete Ltd. and Costain Concrete Ltd., some 30 turnouts and crossovers with a variety of switch and crossing combinations have been installed to date, with rail clip housings cast directly into the concrete. A further refinement has been the casting in of the plastic plugs for the slide baseplate screws (Figure 19).

Early problems with splitting of a few shallow bearers under switches were overcome by providing adequate drainage of the plastic plug to obviate freezing of entrapped water, and by redesigning of the screw and plug assembly to make sure that high tensile stresses were not generated in the concrete on insertion of the screws.

As with any railway track, it is considered essential to provide an adequate depth of clean, level, and well-compacted ballast for the satisfactory performance of concrete bearers. The layouts installed so far, in lines with speeds up to 90 mph, have behaved well. Geometry has been maintained well and reduced maintenance attention has been required compared with timbered layouts.

CONCLUSIONS

1. British Rail's track engineers have responded to demands for shorter journey times by designing and installing junctions for progressively higher speeds. A recent one on a major route diversion allows for a 125-mph (200-km/hr) running speed, and has proved satisfactory in service.

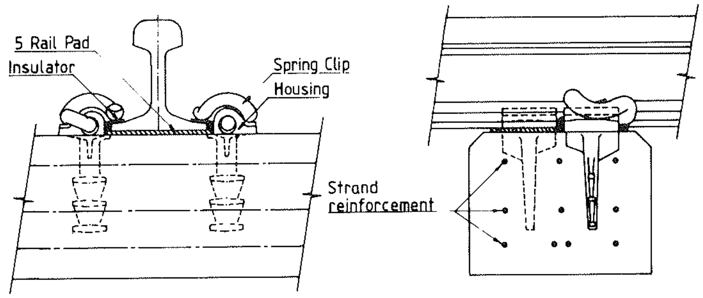


FIGURE 18 Deep concrete bearer with spring clips.

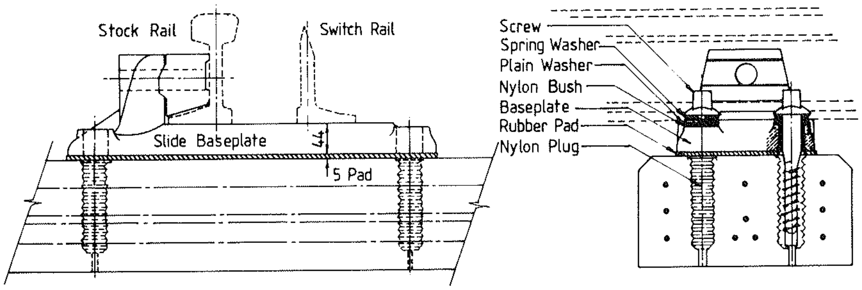


FIGURE 19 Shallow depth bearer with slide baseplates.

2. Computer models of wheel/rail interaction at switches have been validated by site running tests and used to examine design proposals. Significant reductions of lateral impact forces are considered possible with attendant economies in maintenance and component renewal costs. Crossing forces, too, have been measured by instrumented wheelsets, and computer models of wheel/rail interaction are being developed.

3. Careful choice of crossing geometry could make a significant reduction in forces causing batter. Computer-aided drawing facilities have enabled modified railhead shapes to be assessed and it has been shown that vertical ramp angles to be negotiated by wheels at crossings can be more severe than those at plain rail joints.

4. Work on improved materials has led to the adoption of a higher strength steel for part-welded crossings and evaluation of a weldable alloy steel for castings is well advanced. Substantial economies are anticipated from using these materials.

5. Increasingly, switches and crossings are being supported on concrete bearers and maintenance periods have been extended.

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