

Because data relative to parts already in service were not available, explosion hardening tests were performed to verify the soundness of the preceding affirmations. The results obtained on the A- and C-type steels are summarized in Table 3.

The extent to which the C material of the adapter will harden varies from 190 BHN for the solution heat-treated material to 265 BHN after three explosions. As expected, it thus presents a hardness that is intermediate between the hardened cross-frog and that of the rail.

Figure 7 schematically shows the hardness trend close to the two welds and along the adapter.

It must be noted that a special microscopic study showed that the hardening of the adapter must be traced back not so much to sliding planes, as occurs in austenitic manganese steel, but to the fragmentation of large austenite grains into smaller and more numerous ones.

## CONCLUSIONS

A new technology has been presented in this paper that permits the connection of the manganese frog to

the rail without mechanical discontinuities, and that overcomes limitations arising from other similar proposals. In addition, a series of successful results has been presented from tests performed at Breda Fucine Meridionali on flash-butt welds between experimental samples and between specimens of actual track materials.

The results obtained allow the authors to affirm that the proposed process is extremely reliable and has met all of the initial objectives. Other materials, also patented in Italy, are presently being tested at the authors' plant in Bari.

## REFERENCE

1. M. Bartoli. Welding Filler Metal (Materiale d'apporto nella saldatura). Il Gionale dell'Officina, No. 3, Milan, Italy, March 1985.

Publication of this paper sponsored by Committee on Railroad Track Structure System Design.

# Evolution of the Rail-Bound Manganese Frog

E. E. FRANK

## ABSTRACT

During the 19th century, the railroad frog was fabricated from standard carbon steel rail. During this period, there were many designs for the rigid frog from riveted plate frogs to the current AREA standard rigid frog. In the late 1800s, however, R.A. Hadfield of England developed "Hadfield Manganese Steel." The unusual properties of this manganese steel, as well as its toughness and ability to withstand severe impacts, made it most suitable for railroad service. The first manganese steel castings were made for street railway frogs. The success of manganese steel in the street railway castings led to its use in steam railway special work frogs, crossings, and switches. By the first decade of the 20th century, the rail-bound frog was introduced to the American railroads. Since then, the rail-bound manganese frog has progressed through many design improvements. Currently, there are new designs being developed to meet the needs of the heavy-haul railroad.

The rail-bound manganese frog evolved from the need to greatly improve the life of the rail-built frog, which was the standard frog used during the 19th century. During this period, the rail-built frog was manufactured from Bessemer steel in a variety of designs (i.e., riveted plate rigid frogs, clamp-type rigid frogs, bolted rigid frogs with cast iron

fillers, and, in later years, with rolled steel fillers).

## MANGANESE STEEL IN SPECIAL TRACKWORK

During this era, Bessemer rail-built frogs installed in severe locations would last on the average of 3 months. The industry recognized that the Bessemer rail-built frog was a high-maintenance, high-cost track component, and that a product having both

longer life and improved economics was required. At the present time, the rail-built frog is still being manufactured and installed in accordance with AREA recommended practice in yards and industry tracks where traffic is light.

In the late 1800s R.A. Hadfield of Sheffield, England, developed "Hadfield Manganese Steel." The unusual properties of this manganese steel, toughness, hardness, and ability to withstand severe impacts, made it most suitable for railroad service.

The Taylor Iron and Steel Company of High Bridge, New Jersey, in cooperation with Hadfield secured this new development for use in the United States. Hadfield manganese steel was first introduced in the 1890s for use in manufacturing car wheels.

It was not long, however, before it was realized that manganese steel was not suited for this application. When manganese wheels were used in railroad service, the wheel tread developed corrugations and excessive flow was experienced during the work-hardening period. Shortly thereafter, it was learned that manganese steel, which was a failure for steam railroad car wheels, was a great success for special trackwork over which the car wheels ran.

When the street railways supplanted the horse-drawn cars with electric cars, the heavier wheel loads proved to be quite destructive to frogs and crossings then in use. The necessity to improve the designs in the areas of greater wear in trackwork components became evident. It was apparent that the structures would have to be renewable, or durable, or both.

The manufacturers of special trackwork components worked on a solution to this problem. The solution seemed to be a replaceable manganese insert casting known at the time as "Hard Center Work." Designs for the application of a manganese insert casting were developed and a frog with a manganese steel center plate was manufactured and installed on the Atlantic Avenue Railroad in Brooklyn, New York, in 1894. The design furnished is shown in Figure 1. This design utilized lugs cast on the underside of the cast center plate for locking the insert in the frog body.

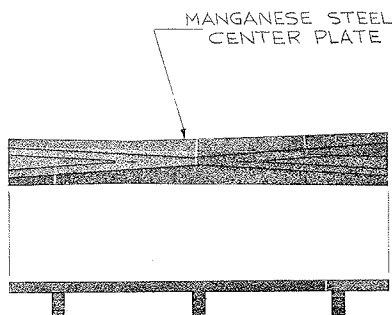


FIGURE 1 First manganese steel insert casting used in special trackwork—installed in 1894.

That year several installations were made on electric railways using manganese steel for various trackwork components. The expectations for the superiority of manganese steel for special trackwork castings were more than fulfilled by the results received from these test installations. Shortly thereafter, special trackwork components using manganese steel were developed for the electric railways (e.g., frogs, tongue switches, and mates) in both hard center designs and solid construction. The typical hard center frog design used by the

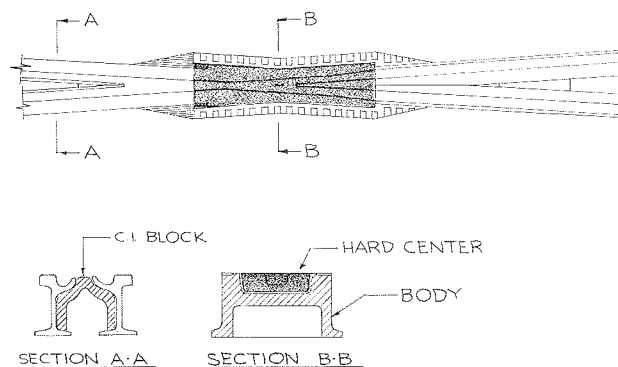


FIGURE 2 Typical manganese steel insert design frog used by electric railways throughout the United States and Canada.

electric railways throughout the United States and Canada during the 20th century is shown in Figure 2.

The first solid construction frog used by the electric railways is shown in Figure 3, and was furnished to the Delaware County Passenger Railway Company of Philadelphia, Pennsylvania, in 1895.

In 1899, the first manganese steel crossing was

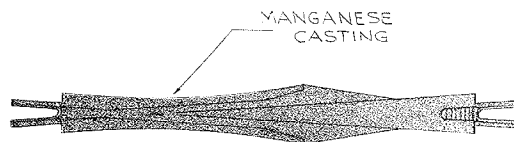


FIGURE 3 First solid manganese frog used in special trackwork—installed in 1895.

designed for the Union Traction Company of Philadelphia and is shown in Figure 4. The crossing was to be installed at a location where the electric street railway crossed a steam railway. The solid manganese steel rail of heavy box section was to be for the steam railway track and the Bessemer rail for the electric railway track.

During the same year, a solid manganese frog as shown in Figure 5 was designed for the Pennsylvania Railroad to be installed in Philadelphia. This was the first solid manganese frog installed on a steam railroad. The frog was installed in 1900 replacing a Bessemer rail-built frog. The Bessemer rail-built frog was lasting on an average of 3 months whereas the solid manganese frog that replaced it lasted 17 times as long. The solid manganese frog was removed from track once for regrinding to good surface. The frog was then replaced in track in the same location, and was finally removed after a total service life equal to the life of 25 Bessemer rail-built frogs. The results of this test installation's service life did not change the misgivings of the steam railroad engineers. The steam railroad engineers were concerned with the possible breakage of the casting in high-speed locations. To overcome this objection and the objection raised relative to the necessarily short length of the solid manganese frog, the rail-bound manganese frog was designed (Figure 6). The first rail-bound manganese frog was installed in the Baltimore Terminal on the Pennsylvania Railroad in 1900. After 2 years of successful service, the rail-bound manganese frog gained the confidence of the steam railroad engineers and its use in high speed service was established. During

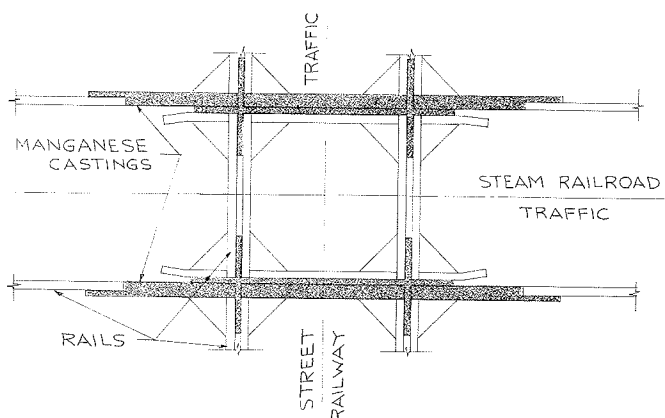


FIGURE 4 First manganese steel crossing installed in track (stream railway crossing electric railway)—installed in 1899.

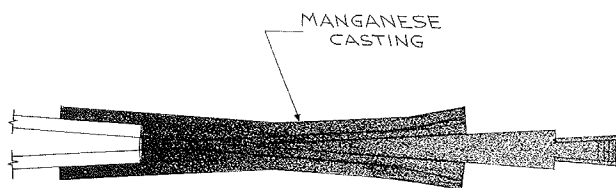


FIGURE 5 First solid manganese frog installed in steam railway track—installed in 1900.

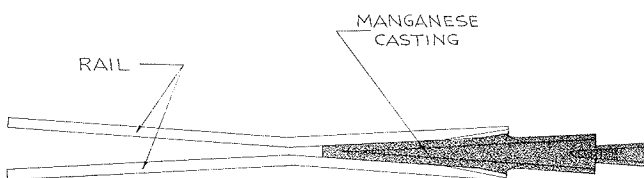


FIGURE 6 First rail-bound manganese steel frog—installed in 1900 on the Pennsylvania Railroad.

the period from 1900 to 1910, the use of manganese steel was extended to

- Solid manganese crossings,
- Rail-bound manganese crossings,
- Solid manganese guard rails,
- Manganese steel-faced guard rails,
- Rail-bound manganese spring frogs,
- Manganese steel-pointed split switches,
- Cast manganese steel rail, and
- Rolled manganese steel rail.

With the use of manganese steel in special trackwork having been firmly established and the economic benefits obtained in severe service widely recognized, the eastern railroads began extensive use of the unique metal for special trackwork components.

The Europeans were closely watching the results being obtained in the United States and when manganese steel was finally introduced in Europe for application to special trackwork, it was apparently received with less skepticism than in the United States.

#### DEVELOPMENT OF THE RAIL-BOUND MANGANESE FROG

After the successful service of the first rail-bound manganese frog installation at the Baltimore Terminal

in 1900, the railroad engineers gained confidence, and, in 1902, a rail-bound manganese frog was installed in high-speed service on the Pennsylvania Railroad. The success of this installation established the use of manganese steel in special trackwork. The eastern railroads recognized the economic benefits of manganese steel in special trackwork and began extensive use of this unique metal, commonly referred to as "the metal par excellence for the purpose."

During the succeeding years, there have been many attempts to develop a metal superior to manganese steel; however, to date, none has been found. From 1900 to the 1920s, there were many designs for special trackwork components developed and tested by the steam railroads, resulting in improved designs and service life to meet the demands of the ever-increasing wheel loads and higher speeds.

The first rail-bound manganese frog design shown in Figure 6 was introduced with modifications by the Pennsylvania Railroad in the 1940s. This design was successful but as the wheel loads increased, the short heel length created wear problems resulting in the heel joint becoming loose, thus increasing the need for maintenance. A new design rail-bound manganese frog was introduced by the Ramapo Iron Works in 1905, as shown in Figure 7. There were two basic variations to this design, one as shown in Figure 7 with extended fillers and the other design without extended fillers.

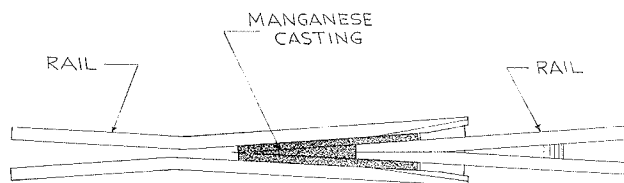


FIGURE 7 Typical rail-bound manganese frog introduced in 1905 and used extensively by steam railroads.

The frog design in Figure 7 was used extensively in the new Grand Central Terminal, which was being constructed from 1906 to 1911. Other eastern railroads made extensive use of this newly designed rail-bound manganese frog. A modification of the design shown in Figure 7 is still in use today and is shown in Figure 8. (Note: the frog shown in Figure 8 has manganese wings that were introduced about

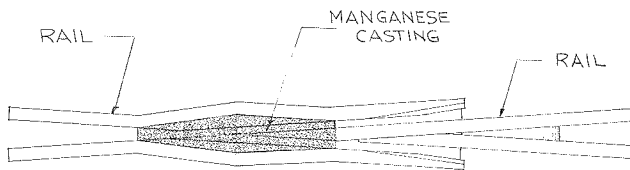


FIGURE 8 Frog design currently in use based on the design in Figure 7.

1915.) As the wheel load increased, the false flange (in wheel terms hollow tread) developed, causing crushing and wear on the receiving guard line or gage line in the area where the false flange traverses the flangeway.

To overcome this problem, in 1915 manganese wings were added to the basic design to provide a wearing surface in this area. The manganese provided a surface that work hardened, thus reducing wear and maintenance. This modified design as shown in Figure 9 has the manganese wings fitted to a milled recess in the wing rail. To improve the heel-rail connection, a heel extension was added to provide a means of attaching the heel rails to the manganese insert casting. The manganese recess at the toe end provided a continuous line on the gage line, which was desirable, but as wear occurred, the manganese flowed resulting in chipping and, in some instances, breakage of the manganese guard. During this same period, integrally cast manganese wear surfaces were added to the rail-bound manganese center frog casting at the bend in the guard rail as shown in Figure 10. This wear strip was discontinued in the second decade of the century as new designs became available. By the mid-1920s, the rail-bound manganese frog design shown in Figure 11 was developed and became the AREA

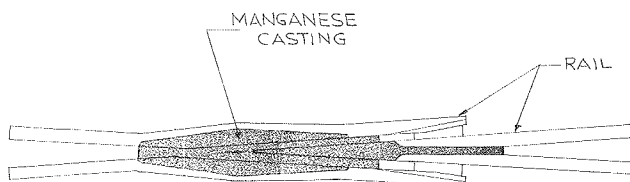


FIGURE 9 Improved frog design introduced in 1915.

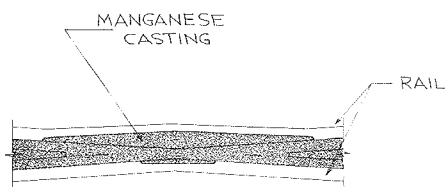


FIGURE 10 Application of integrally cast manganese wear surfaces to special trackwork components.

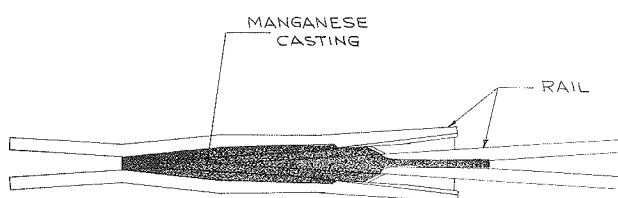


FIGURE 11 AREA rail-bound manganese frog design introduced in the 1920s.

standard rail-bound manganese frog referred to as the AREA 600 design.

This design was in universal use until 1946 when the current AREA 621-design rail-bound manganese frog shown in Figure 12 was introduced. As the wheel loads increased, it became evident that a heavier frog was required. The main deficiency in the 600-design rail-bound manganese frog was the weak section where the heel extension connected to the body of the frog, resulting in breakage at this location. The new AREA 621-design frog had heavier walls and the section where the heel extension connects to the body of the frog was improved; in addition, the notch in the wing rail was eliminated. To (a) improve the 621-design rail-bound frog and (b) reduce maintenance, the depressed heel shown in Figure 13 was adopted in 1971. The depressed heel permits the wheel

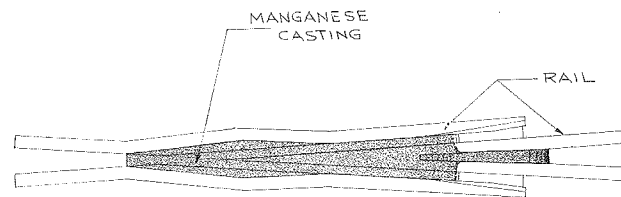


FIGURE 12 AREA rail-bound manganese frog design introduced in 1947.

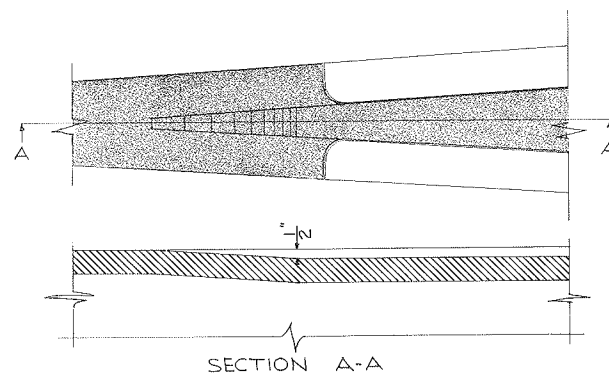


FIGURE 13 Depressed heel for AREA 616- and 621-design rail-bound manganese frogs introduced in 1971.

load to be carried by the wheel tread on the heel rail and manganese insert, gradually transferring the wheel load from the wheel tread to the false flange when the false flange engages the ramp that is located inside the body of the casting where there is a stronger section. The normal plastic flow and resulting chipping experienced by the original AREA 621-design rail-bound manganese frog required grinding in the heel extension area to control the metal flow and eliminate chipping. The depressed heel has since been adopted as a standard by the AREA for the 621-design (heavy-wall) and the 616-design (medium-wall) rail-bound manganese frogs.

During this same period, the integral base-design frog was introduced using the same design criteria as the AREA 600- and 621-design rail-bound manganese frogs except with the sections as shown in Figure 14. This frog design has been used with success in heavy-haul locations.

During the last decade, the number of heavy-haul lines and unit trains consisting of 100-ton cars has greatly increased. This increase in high-tonnage cars has developed the need for an improved rail-bound manganese frog.

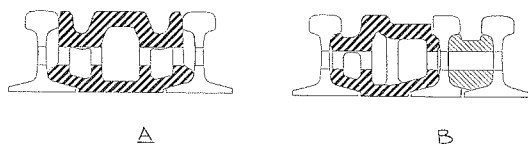


FIGURE 14 Sections for integral base design frogs.

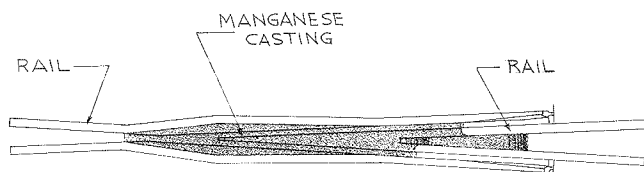


FIGURE 15 Improved rail-bound manganese frog designed for heavy-haul railroads introduced in 1980.

In 1980, a new design rail-bound manganese frog was introduced to meet these demands. This new design rail-bound manganese frog is shown in Figure 15 and typical sections are shown in Figure 14.

To overcome the failure of the heel extension on the current rail-bound manganese frogs, the new design has the joints where the heel rails connect to the manganese casting staggered rather than opposite as the existing design requires. The staggered joints provide improved sections in the heel area that are stronger than the existing design. In addition, the casting section is improved.

#### MANGANESE IN EUROPE

After the use of manganese steel for special trackwork was firmly established in the United States, it was introduced in Europe with great success. The results obtained in the United States with manganese steel in the application of special trackwork had been closely monitored by the Europeans. The Europeans began using solid manganese frogs and crossings and experienced the same results as the U.S. railroads--longer life and economic returns.

It was reported that one installation on the Central London Line at the British Museum Station was in use 14 to 15 years handling approximately 700 million gross tons (MGT) of traffic whereas the rail-built crossings previously had a life of 6 to 8 weeks.

The Europeans still use solid manganese construction and, to date, have not used rail-bound manganese construction. A typical frog currently in use in Europe is shown in Figure 16.

#### CURRENT NEW FROG DEVELOPMENTS

The preponderance of 100-ton cars and unit trains in the last decade has developed the need for frogs that will withstand the impacts delivered as the

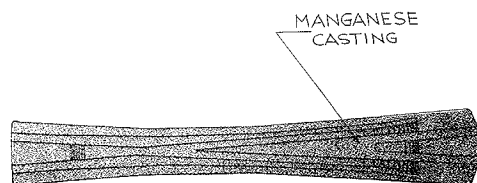


FIGURE 16 Typical European Monobloc frog.

wheels cross over the flangeway from the point to the guard (or wing) surface or conversely from the guard to the point. Currently, frogs have the receiving guard line or gage line crushed by the false flange, which requires maintenance.

To improve the dynamics of the turnout, the welded/epoxy-bonded turnout was designed and tested in 1972 on the Penn Central Railroad. The tests proved successful, and, with the elimination of bolted joints, switch heel joints, and short frog arms, the dynamics of the turnout were greatly improved. The long switch-point rail and long frog arms permitted the natural track wave to propagate through the switch and frog providing a smoother ride. The welded turnout also included long guard rails with the guard rail flare opposite the frog flare. This greatly reduced the lateral movement of the frog, which reduced stresses in the casting and frog bolts.

In 1984, a spring frog for welded or epoxy-bonded turnouts was introduced and tested on Amtrak in the Northeast Corridor. The tests have been successful in providing a continuous surface for the wheel tread to traverse. The long frog arms dampen the vertical movement of the spring wing and provide additional force biasing the spring force. It is to be noted that a spring frog should only be used in a location where 80 percent or more of the traffic is on the main line and 20 percent or less is for the turnout run. Further improvements are being sought and a new generation of frogs is being developed, specifically, movable wing and point frogs. These designs provide a continuous surface for the wheel tread to traverse thus eliminating the impact delivered by the wheel crossing a flangeway. These frogs are still in the testing stage and results are to be evaluated. The main drawback, however, is economic because an extra machine is required for the frog and more circuitry is necessary to have the switch and frog thrown in correspondence.

#### CONCLUSION

Today, manganese steel in special trackwork is extensively used throughout the world and still remains "the metal par excellence for the purpose" and, since its introduction, nothing has been found superior to it.

#### GLOSSARY

Crossing (track)--A structure used where one track crosses another at grade, and consisting of four connected frogs.

Electric Railway (track)--A track whereon is to be operated rolling stock, the wheels of which have smaller flanges or narrower treads (or both) than those of AAR standard wheels, the motive power being immaterial (according to AREA Portfolio of Trackwork Plans).

Frog--A track structure used at the intersection of two running rails to provide support for wheels and passageways for their flanges, thus permitting wheels on either rail to cross the other.

Joint, Rail (manganese)--A fastening designed to unite the abutting ends of a manganese casting and rail.

Special Trackwork--All rails, track structure, and fittings, other than plain unguarded track that is neither curved nor fabricated before laying.

Bolted Rigid Frog--A frog built essentially of rolled rails with fillers between the rails, and held together with bolts.

Rail-bound Manganese Steel Frog--A frog consisting

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.

---

Publication of this paper sponsored by Committee on Railroad Track Structure System Design.

## 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 pre-stressed 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

---

C. Lockwood, British Railways Board, Civil Engineering Department, Departure Side Offices, Paddington Station, London W2 1FT, England. P.J. Thornton, British Railways Board, Research Division, Railway Technical Centre, London Road, Derby DE2 8UP, England.