



## CHAPTER 2.

### THE CANTANKEROUS BUSINESS OF RAILWAY CURVES AND THEIR CANT \*

There is something romantic about little trains chugging around the sides of mountains where passengers can look out of the window and watch the engine. Now you see it, now you don't, but don't despair. There will be another curve in a minute. This is the sort of journey that heritage railways have turned to their advantage. There is Puffing Billy in the Victorian Dandenongs, the Pichi Richi Railway in South Australia, Tasmanian Wilderness Railway, and The Kuranda Tourist Railway in Queensland. They were planned and built by men of passion and when they had done their turn, there were more folk with passion and vision who gave them new purpose as tourism railways.

There are vertical curves and there are horizontal curves. You generally don't get one without the other. The content of this chapter relates mainly to horizontal curves. When we talk about vertical curves we are also talking about gradients. Trains do not like gradients.

The perfect railway is straight and flat. The train and the track are in harmony but the minute we introduce a curve, track and train are in conflict. It will be a point of friction at the wheel-rail interface which is the usual outcome but over time it produces wear of both rail and wheel flange. The wear is uneven which generates further uneven motion.

The train (or bogie) wants to go straight ahead. The track wants to turn the train.

The railway axle is rigid but the distance travelled by the wheel on the outside rail is more than the distance of the inside rail. When the train is on a curve the wheel on the outside rail is pulled backwards in a motion that could be regarded as a continuum of micro-skids. It is quite a battle for the rail to turn the train.

The *Indian Pacific* is raising some dust as it enters Broken Hill from Peterborough. Note that the cant at that point is minimal due to the high radius of the curve. This photograph was taken about the same location as the one on page 24, but the trains are going in opposite directions. 26 December 1972. Compare with the photograph on page 28. JLW.

Meanwhile the wheel at the other end of the axle is trying to catch up with the efforts at the other end with a micro skids in the opposite direction. The result is friction which is a battle by every axle of the train. That will be a lot of axles. The longer the axle (which is the same as saying a wider gauge), the worse the problem. And common sense will tell us that the sharper curve accentuates the loss of traction.

Railway curves bring many problems, but the end result is higher operating costs. The sad part is that, in most cases, those men of vision who built the curves were fired with the need to get the cheapest job possible. It was the people who followed them who had to wear the operating costs.

Curves in Australia are measured in units of radius. In earlier times the radius was measured in chains. The radius is measured from the mid-point between the rails. A chain was the length of a cricket pitch, and there were 80 chains to the mile (one chain was 66 feet. The metric equivalent is close to 20 metres). There is a different system in the US, where curves are measured in degrees of arc. When designing a curve the speed of the train needs to be considered. The faster the train on a curve the greater the problem. There are circular curves as distinct from transition curves. The circular curve is where a tangential straight line suddenly changes to the arc and can give the carriage and passengers quite a jolt. The transition curve is constructed to a parabolic formula that provides for a lesser curve at each end of the main curve.

\* The title of this chapter was composed by Des Smith. Cant is the tilting of the track on a curve where that curve is taken at speed. Cant is explained later in this chapter.

**A transition or parabolic curve.** Presently there are about 20 different transition curve concepts, each with its advocates. The mathematics are complex. It is not the intention of this book to venture into the mathematics of transition curves.

**Compensated gradients.** For the locomotive a curve means it needs to give more pull. Chances are that there is a gradient at the same time. Gradient is measured as say 1 in 50, which would represent a rise of 1 foot for a horizontal distance of 50 feet. It could be 1 metre rise for 50 metres of horizontal. It may also be expressed as a percentage. A gradient of 1 in 50 is 2%. A railway with a 'compensated gradient' is one where the gradient is eased at a curve. This means that the locomotive can maintain a steady amount of traction. A railway where there is no easing of gradient at a curve is called 'uncompensated' and the gradient number is adjusted downwards, so depending on a number of factors a 1 in 45 gradient could be equivalent to the amount of traction needed for a gradient of 1 in 41 or 1 in 42.

Conventional railways with ruling gradients steeper than 1 in 40 are undesirable because a large part of the tractive effort generated by the locomotive is consumed by the locomotive in pulling itself up the grade. Railways with gradients as steep as 1 in 30 encounter the additional problem of loss of traction or wheel slip. Wheel slip can occur with railways of less severe gradients when the rails are wet or invaded by millipedes. Application of sand onto the rail has been the traditional solution. Australia's steepest railway is the former Mount Lyell Railway in Tasmania where there is a short stretch of 1 in 12 track. That railway now operates as The Tasmanian Wilderness Railway and has a rack traction system.

**Slow boards.** Trains go slower around curves. Speed restrictions are the track engineer's friend. They do not come at substantial cost but do not win friends with the travelling public or the Traffic Department. As an example, in 1979 there were track problems on the Central Australia Railway which was destined for closure as soon as the new railway from Tarcoola to Alice Springs was completed. The level of maintenance had declined, and to add to the troubles, 1979 had been a particularly wet year, thus bringing its own difficulties. Australian National (Railways), the operator of *The Ghan*, had developed a very successful marketing campaign, 'Join the Old Ghan while you can'. Historically, *The Ghan* had made two return journeys each week. The deteriorating state of the old route required a speed limit of 40 kph over the whole route with even slower speeds on some sections. It was no longer possible to turn the train consist around and fit in the second journey.

**Centre of gravity and stability.** A curve pushes the centre of gravity of the rail vehicle away from the centre-line. This becomes an issue if there are other factors having a bearing on the centre of gravity. Examples are side-winds, double stacking of containers, uneven loading within the railway van or container, and cant (cant is super-elevation of the outside rail at a curve and is explained later in this chapter). A problem of recent times had been the double stacking of containers, and the suspicion that there have been occasions when loaded containers have been stacked on top of empties. When the centre of gravity falls outside the base the load is unstable and is destined to topple.

When looking at the pictures of the narrow gauge *Ghan* in its last few years, with old standard-gauge rolling stock rattling along on narrow-gauge bogies, we had cars (particularly dining cars) that seemed to have a high centre of gravity. The track had dips in places which begged the question of whether there had been lurching of the cars on curves.

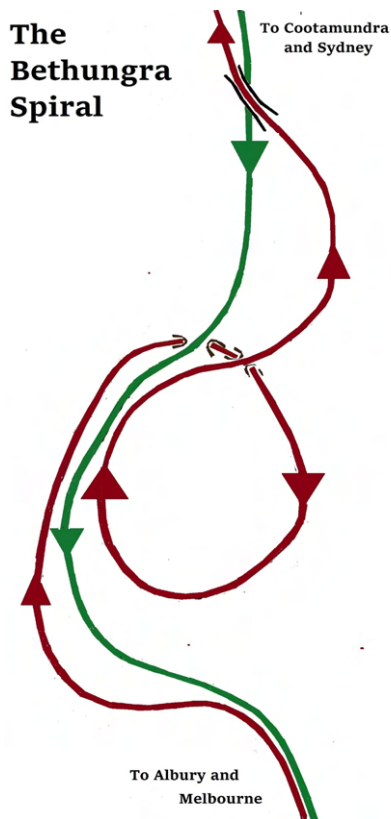
Des Smith wryly responded to that with the comment that while the Commonwealth Railways had been known as the 'Comical Railways', they took their task of running trains seriously. The dining cars, he added, were notoriously rough riding because all the weight (refrigeration and food preparation equipment) was at one end and the other end was hollow. Yet the bogies at each end of the cars were the same. There was also a problem with the standard-gauge bogies of the Wegmann carriages that had been built in Germany in 1951. These bogies had a vibration that resonated at exactly 60 mph, which also happened to be the track speed for the express.

**THE TASMANIAN WILDERNESS RAILWAY** is the new look of the former Mount Lyell Railway that was closed in 1962. It features rack traction which is shown as the toothed centre rail. The gradient of the rack section is 1 in 14 and there is one short section of 1 in 12. It is an exhilarating experience to travel this section and feel the pull. **JLW.**





**THE WILMINGTON LINE** in the mid-north of South Australia was a narrow-gauge line that was built with economies as shown in this picture, in that it followed the contour of the land. This wheat train was hauled by T class engines 240 and 245. The location was Yandiah. 1 December 1965. JLW.



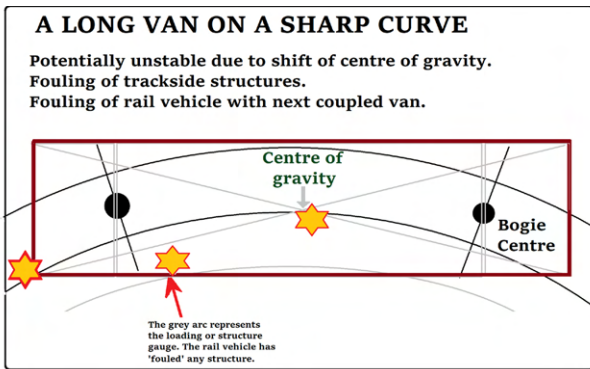
**THE BETHUNGRA SPIRAL** is the most famous in Australia. The other great spiral is the border loop where the standard gauge line from Sydney crosses the Queensland border.

**Deviations or redesign of the curve.** A solution to a problem curve is to 'ease the curve' or build a deviation. Redesign could involve converting a circular curve to a part transition curve. A transition curve has a lesser curve leading into the main curve. A deviation that sets out to 'ease a curve' will probably result in a shortening of the distance and that in turn will result in a steeper gradient. In practice, deviations generally involve the by-passing of several curves and may result in more curves (but sometimes less). The Bethungra Spiral near Cootamundra is the most spectacular. It originally had a gradient of 1 in 40 which required banking engines (push engines). In the 1940s the spiral was constructed resulting in a gradient of 1 in 60 for trains working upgrade towards Cootamundra and adding 2 km to the distance. The trains working downgrade use the old alignment. The Bethungra Spiral has been a hungry consumer of rails, made necessary by heavy wear.

**Truck length.** Dead weight is that part of a train that cannot be 'sold'. It includes the underframe, bogies and drawgear. It also includes the locomotives. The Commonwealth Railways achieved efficiencies by building long vans in the 1970s. There were '70 ft' covered vans and '85 ft' sheep vans. There is a lot of weight in a bogie and with these long vans achieved less tonnage of bogies being lugged back and forth across the Nullarbor. This allowed more loading that could be sold for revenue.

These long vehicles were consistent with the length of passenger cars, so there were no restrictions in operating these vans over the mainlines of New South Wales and Victoria. The Commonwealth Railways were blessed with plenty of open space, and were not burdened with tight curves. The shifting of the centre of gravity of a long rail vehicle on a curve is called 'overthrow'. There is a similar problem at the ends of long vehicles called 'end-throw'.

**Wind.** The significance of wind in relation to curves is if a train stops on a curve with a degree of cant. There is potential for other factors to push the centre of gravity to one side and one of them is wind.



**OVERTHROW AND ENDTHROW** of a long vehicle. It is particular problem in Queensland where there are many 5-chain curves.

It takes a strong wind to blow a train off its tracks but it has happened. Of all the railway disasters in the world, there would be few who would disagree that the story of the Tay Bridge disaster attracts a certain morbid fascination that places it near the top of the list.

It was the only railway disaster in England of which there were no survivors. Another fascinating feature is that there was no firm agreement about the chain of events that brought down the bridge that night.

One opinion is that the wind caused the train to derail when it was passing over the bridge and it was the derailed carriages crashing into the bridge girders that caused the collapse. Evidence was that it was a particularly violent storm that swept across the Firth of Tay on that night.

But there was one rail disaster where it was definitely the wind that blew the train off the tracks. That was in New Zealand on the Ramatuka incline in 1880.

Des Smith recalls there was one occasion, and possibly two, in recent times, when high rail vehicles were blown over by strong winds. Des also commented that the northern rail on the track across the Nullarbor wore faster than the southern rail because the winds were from the south.

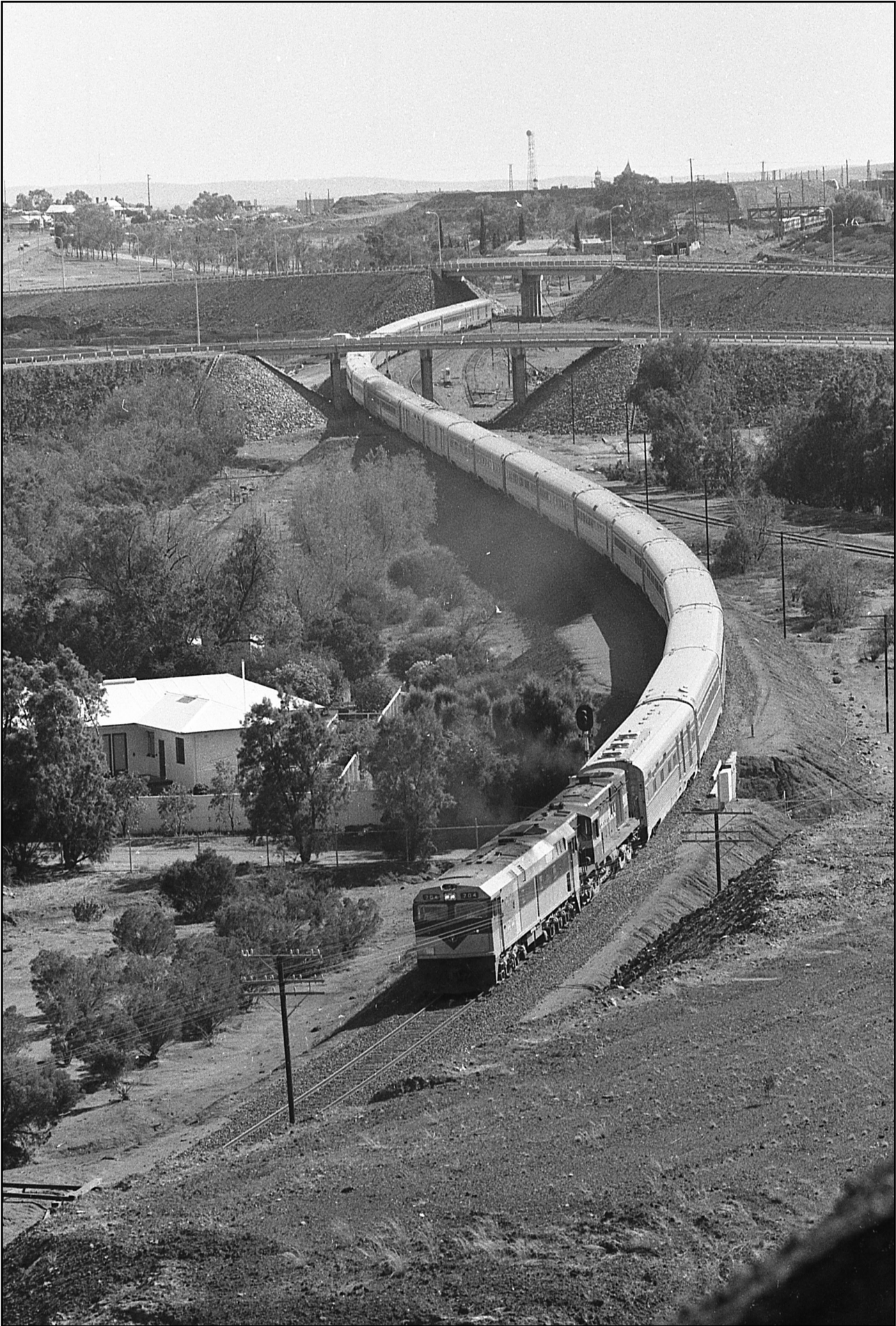


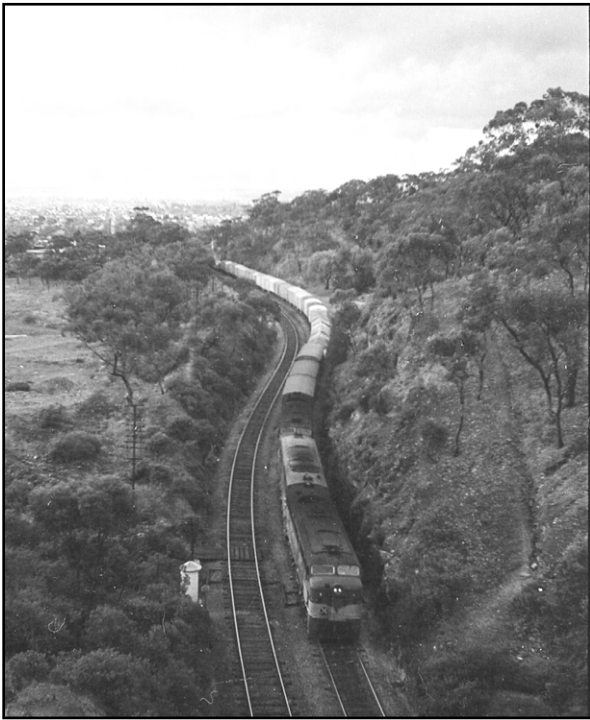
**ABOVE.** There is one thing that is working in favour of curves and that is the photography of trains is generally better than on the straight. The Australian Railway Historical Society did not have any trouble attracting numbers aboard its specials when they operated over lines with many curves and it was a feature to have photo stops along the way. This picture was at a photo stop just beyond Gawler North on the Barossa line on 26 March 1966. **JLW.**

**FULL PAGE.** A westbound double-consist *Indian Pacific* departing Broken Hill in 1972 The reverse curve was part of the construction of the Port Pirie to Broken Hill standardisation that had been done 3 years before this picture. The curve represents the up-to-date technology. The curves are transition curves separated by a good length of straight and whilst not obvious in this scene, a respectable degree of cant. January 1972. **JLW.**

**SUBSEQUENT PAGE.** In contrast to the Broken Hill picture is a reverse curve in the Adelaide Hills that was built in about 1878 which was well before the era of transition curves. There is little or no straight between the curves **JLW.**

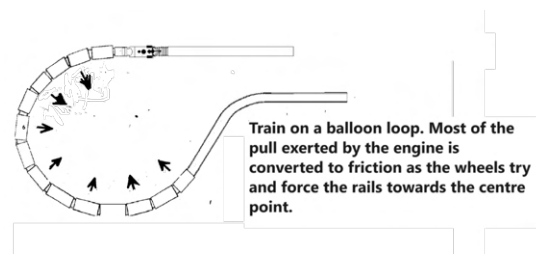
**LEFT.** The new and the old Tay bridges. The remains of the original bridge on the right, and the construction underway for the piers of new bridge on the left. Photograph from **RAILWAY WONDERS OF THE WORLD c1936.**





**Fouling of coupled vans.** When a train goes around a curve there is a tendency for the trucks or carriages to bunch up or foul. In 1887 the Intercolonial Express from Adelaide to Melbourne commenced. A look at the picture shows the boudoir (sleeping) cars could not be coupled, one to the other, because the end canopies would have fouled. There is the suspicion that the Gilbert Car Company in the USA had designed the cars based on American tracks which had more generous curves. We don't know if the South Australian Railways found out the hard way, that two of these cars wouldn't work on the 10 chain curves of the railway over Mount Lofty. The photograph below shows how the two boudoir cars were separated by an ordinary car. As a result, it was not possible to have a dining car on the Express because there was no through passage on the train for passengers to gain access. There were other reasons not to include a dining car in the consist of the express. A dining car generated no revenue. To include a dining car would require the dropping of a carriage and the consequent loss of revenue. There were also the costs associated with the crew of a dining car. But the Traffic Manager could point to those end-canopies as good reason not to have a dining car.

**THE INTERCOLONIAL EXPRESS** c1900. The Boudoir cars are towards the rear of the train and separated by a sitting car. **STATE LIBRARY OF SOUTH AUSTRALIA B-31232**



**Resistance resulting from curved track.** The diagram above shows a locomotive on straight and level track, which for the purpose of this exercise is on well-maintained track and the axles of the trucks have roller bearings and are well-maintained. Once started, and a steady rate of progress is achieved, there is little to impede the progress. But that train has now entered a balloon loop. The forward energy transmitted at the drawbar of the locomotive tender is pulling the first van that direction. But the forward pull at the coupling of trucks 1 and 2 is diminished and more so with each vehicle. There is quite a large force which is trying to push the inner rails on the balloon loop into the centre, and a large part of the original tractive effort has gone into the production of wheel squeal and friction.

**Locomotives.** The railway works on the principle of the locomotive driving wheels getting a good grip on the rails. The more driving wheels the better. But those wheels needed some weight to get the adhesion. The rails, therefore need to be strong enough to support that load. The conventional steam locomotive had a rigid boiler and underframe, which was not a good arrangement for negotiating curves. It had a tendency to derail on curves, with the result that there needed to be redesign of locomotives. There was also the problem that railways with lots of sharp curves generally had steep gradients. They needed power and grip.

Locomotive engineers were initially slow to respond to the wants of the proponents of narrow-gauge railways. The early narrow-gauge locomotives were mostly 4-coupled engines with a short frame and wheel-base. As longer 6-coupled and 8-coupled engines appeared on broad gauge there was a call for more powerful engines on the narrow-gauge lines. The railways that had to resort to sharp curves generally did so because it allowed them to ease gradients.

The engines, to work these sections, needed good power but they generally had smaller dimensions that would have limited the size of the steam generating components (such as firebox). Thus, we witnessed the early articulated locomotives such as Fairlie's double engines (see chapter 7).

Other innovations have been the rimless driving wheel and lateral motion devices. The R class locomotives of the South Australian Railways, which were later rebuilt as the Rx class, were the initial locomotives for the Hills Railway between Adelaide and Murray Bridge. They were a six-coupled engine which gave good traction to get the Melbourne Express over the 1 in 40 gradients. But there was no flange on the forward set of driving wheels. A similar arrangement was provided for the forward driving wheels of the wartime Australian Standard Garratt.

It was well into the 20<sup>th</sup> century that there was anything close to a solution, being a steam locomotive that had plenty of power and grip and was flexible. The Garratt. But by the time the biggest Garratts arrived in Australia, the diesel-electrics had started their march. New South Wales ordered a large fleet of the 60 class Garratts but the last of the orders were delayed. There were some delivered after the diesels, and were cut up having never entered service.

The drive bogies of the diesel-electric locomotives were an advantage on curves. But it was not plain sailing. Des Smith made the comment that when the first of the NSU diesel-electrics went through Pichi Richi Pass, he had to send the gang out to fix the curves where the bogies had pushed the rails out of gauge.

**Vertical curves.** These give rise to sags and summits. On page 14 is a gradient profile of the railway between Adelaide and Murray Bridge. The highest point on the railway is at Mount Lofty. There used to be a sign on the station letting everyone know that it was 1613 feet above sea level. That works out to be about 491 metres. We must be clear that the summit of the railway at Mount Lofty railway station is quite lower than the summit of Mount Lofty itself, which is 710 metres. Looking at that diagram shows there to be quite a sharp summit but if one goes to the Mount Lofty station it is easy to see the mainline at either end of the yard falling away. But where is the exact point of the summit?

If the ascending rails met at a sharp knife edge it would cause havoc to both train and track. That is where a vertical curve applies, and like the horizontal curves there are parabolic calculations. At the opposite extreme the same principle is applied when the railway enters a dip. This is referred to as a 'sag'. Des Smith has commented that the design criteria for a sag is twice as critical as a summit because of the tendency of the rolling stock to close up.

**Cant.** It is elevation of the outside rail on a curve. The amount of elevation is determined by the speed. Therefore a railway over which express passenger trains and slow goods trains operate, will have a cant that is correct for neither and wear on the rails and wheel flanges will be inevitable. The design of cant requires some mathematics, which is beyond the scope of this book. The main issues with cant are 'cant excess' and 'cant deficiency'.



**THE FLANGELESS FRONT DRIVING WHEEL** of the Rx class locomotive is shown in this photograph taken at Clare. **ROGER CURRIE.**

Cant equilibrium is the angle of cant for the nominated speed. Centrifugal force is the outward pulling when a train is on a curve.

**Des Smith reminds us that centrifugal force is proportional to the SQUARE of the speed.**

A passenger in a train that entered a curve without cant, would experience a sensation of rolling or being flung towards the outside rail. If seated on the side of the carriage that was in the direction of the curve, the passenger would be flung towards the aisle and may experience the sensation that the train was about to derail. Worse still, the centrifugal force could dislodge items from the luggage rack above.

**MOUNT LOFTY RAILWAY STATION.** They could have found more favourable routes for the railway but when it was first surveyed in the 1870s its purpose was to get the produce to market for the market gardeners of Mount Barker. Another important reason for building this line was that the well-to-do of Adelaide had their summer mansions at Mount Lofty. The railway was thus said to have been built for 'sanitary purposes'. **JLW.**



**DES SMITH'S 'CANTOMETER'** was a term of my own invention but Des was quick to correct me. It is not a meter, because it doesn't measure anything, and regarding its function it doesn't tell us about cant but is an indicator of unbalanced centrifugal force.

Des Smith is full of surprises. He is quite right when he comments that the rail fraternity (amateurs like myself) spend too much time watching (and photographing) locomotives and trains. He has taught me that it is track that is important. Actually, it was Des' old boss, Johnnie Walker, who was the source of that aphorism about track. Hardly an hour goes by with Des when Johnnie Walker doesn't score an accolade.

Des and I occasionally do field trips and Des is quick to point out mudholes, different rail fixtures and subtle oddities in track construction. We did a trip to Belair in the Adelaide Hills. Despite many years as a railway engineer, Des had travelled that line only rarely. We positioned ourselves on the side of the DMU\* and sat 'back to the engine' to get the best look at the remnants of the Eden Hills viaducts. Des placed his walking stick in front of him. As the Belair train traversed the Adelaide yard, there was a bit of a curve and Des' stick flew over to the window side. "Cant deficiency on a left curve!" he called out.

At Belair there was a wait of about 12 minutes as the driver changed ends, during which time a long freight with a couple of Pacific National locos, rumbled through on the standard-gauge track with dynamic brakes whining. About half way along the length of the train the rumbling and whining was overwhelmed by wheel squeal that was coming from one of the bogies as it passed through the station. It is time to talk about wheel squeal.

\*DMU Diesel Multiple Unit

**FOR THE INTERIM** we may call this Des Smith's 'cantometer.'



People and dogs squeal when they are in pain or otherwise unhappy. It is much the same with trains. This is a major problem for track engineers, especially if the wheels squeal at night and more so if there are dogs. And by day the people who live near the track, do some squealing as well. You don't hear wheel squeal on straight track. Wheel squeal on curves is something that is at the core of the relationship between the railway gauge and the degree of curvature of the track. The friction at the rail-wheel interface may generate wheel squeal which is a teller of wasted traction energy and a harbinger of the need for greater maintenance of track and rolling stock.

The lesson is that whilst it was usual to blame the track for many things, the fact that only one wheelset or one bogie of a long train was squealing indicates that suspicion should first fall on the rolling stock as the primary source of problem. Des was quick to point out that whatever the causes of wheel squeal may have been, it was a very loud and clear message that serious wear was happening to both wheel and rail.

He went on to talk about how curve wear affected the track gauge. A completely new wheel flange of the ANZR\* profile on a new Australian Standard rail has a clearance of 5/8 inch. But that new wheel on new rail is exceedingly rare. As soon as the wheel starts to turn, and to go around its first curve, wear begins. And that wear increases the clearance in the gauge allowing a greater level of attack between wheel flange in rail, so that they wear faster. If the process continues until both flange and rail are worn to their allowable limits, the free play in the gauge is approaching 2 inches (50 mm).

The point is that both extremes of fully new and fully worn are rare and the overwhelming majority of bogies on any train features part worn wheels on part worn rails. And there are no longer the big steam locos that need a measure of slack within the track gauge. That is why the Commonwealth Railways, when starting to lay welded rails on the Trans Australian Railway in the early 1960s, reduced the actual gauge to 4 ft 8 1/4 in, later to become 1430 mm.

When Des went to America a few years later he was gratified to find that some of the big US railroads were doing exactly the same thing (although their wheel flange profile was slightly different to the ANZR). At about the same time some of the European railways, including British Rail and the German Deutches Bundesbahn, reduced their nominal gauge from 1435 to 1432 mm, about 4 ft 8 3/8 in.

In the US they use the term 'superelevation'. *Trains* magazine, May 1, 2006 has an article by Robert S McGonigal, Grades and curves:

Since a train traversing a heavily superelevated curve at a relatively low speed tends to cause excessive wear on the low rail, many railroads reduced curve superelevation when their passenger trains disappeared. This practice has worked against the reinstatement or speeding up of passenger train

\*Australian and New Zealand Rail Standard.



**NOW THAT IS SERIOUS CANT.** It is the westbound *Indian Pacific* on the last curve leading into the station yard at Broken Hill. The New South Wales Government Railways seemed to favour a greater degree of cant. It is probable that this degree of cant was applied in consideration of the *Silver City Comet* introduced in the late 1930s. It was notorious for its speed, and more so its rough ride. 31 March 1972. JLW.

Des Smith on cant equilibrium:

Do we apply the equilibrium cant for the highest track speed? Absolutely not. We make a compromise, allowing the higher speed trains to run with a cant deficiency and hopefully keep the lowest speed trains with close to equilibrium cant. Cant deficiency, within limits, is a good thing while cant excess isn't. Cant deficiency causes more of the weight to be carried by the outer rail which is the one that steers the train wheels around the curve. So it is better to stabilise that outer rail with more of the weight.

**The Tilt Train.** Tilt trains (and radial steering) work on the principle that the passenger compartment is separate from the bogie and tilts as the train goes around a curve, thereby allowing faster speed. They have found favour in Europe. Their operation is dependent on transition curves, and there is some suggestion that they work better on some types of transition curve than others.

**Radial steering.** When a tilt-train tilts, it does so to give the passengers a more comfortable ride but it doesn't otherwise solve the curve problem. It is the radial steering bogies that allow the tilt-train to zip around curves. It is a high-tech solution and a costly one. A sensor in the bogie will identify the start of a curve, which then activates a hydraulic mechanism that steers the bogie into the curve. It has some limitations. The tilt-trains cannot zip over curved bridges, and tunnels. Its cost and maintenance requirements make it suitable for only a few routes where there is an intensity of sharp curves for most of the distance.

To use an example, people talk about introducing a tilt train to replace the present *Overland* that operates a rather slow service between Melbourne and Adelaide. The section between Adelaide and Murray Bridge includes many 10 chain and 12 chain curves. The journey time for this section is about two hours. A tilt-train would allow faster travel and probably shave 30 minutes off the timetable. But nowhere else between Murray Bridge and Melbourne is there an intensity of curves that would justify the expenditure.

There has been a trial of a tilt train in Australia in 1995 when a unit from Sweden toured New South Wales.

It performed well and was well received by the public but fell foul of a change of government policy. In Queensland tilt trains operate from Brisbane to Cairns.

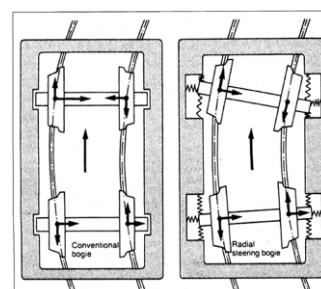
I have had much correspondence and spent many hours with Des Smith and accumulated many notes and comments. I confess that some of it is outside my field of expertise but I have condensed it to the following, which I hope has retained the important content.

Des Smith on the tilt train. I asked Des for comment, recognising that the tilt train was something belonging to an era after his retirement.

Maybe they have cars with a lower centre of gravity. That would enable them to tolerate a higher safe speed... The sharper the curve radius the greater would be the benefit of self steering, but again it is the lowering of the centre of gravity that would increase the maximum safe speed. Derailments caused by wheel climb over the outer rail are far more likely at low speed when there is less weight on the outer rail...

The tilt is for comfort and does not affect the safe speed limit on curves. That can only be done by lowering the centre of gravity. At 8° maximum it corresponds to 8 inches of cant on standard gauge. On the 10-chain curves in the Adelaide Hills this is equilibrium for nearly 70 kph and perhaps tolerable without much discomfort at up to 80 kph. ARTC allow no more than 60 kph on these curves.

**RADIAL STEERING.** The bogie on the left is the conventional bogie. The one on the right has radial steering. Diagram from ROA magazine (Railways of Australia).



## DES SMITH'S LESSONS ABOUT CURVES

### ON TRANSITION CURVES AND CANT

There are innumerable types of curves; a straight line is a curve of infinite radius (so I guess a dot is a curve of zero radius). A circular curve is one of fixed radius and therefore constant curvature. As well as a circular curve there are those of varying curvature such as parabolic and hyperbolic curves, sine curves etc. etc.

A transition curve, as used on railways and highways is one that has zero curvature where it begins at the end of a straight and progressively increases in curvature until it has the same curvature as the circular curve which it joins.

Railway and highway curves differ - on a railway there is usually a long circular arc with comparatively short transition curves at each end, whereas a highway generally has long transition curves and shorter circular arcs. Another point of difference is that trains have to follow a fixed path defined by the rails, whereas road vehicles are free to choose their own path.

The perfectly correct transition curve is a complex mathematical beast called a clothoid. There are several simpler alternatives that are close to it in practice including the cubic spiral, cubic parabola and lemniscate. We used the cubic parabola; it is mathematically simple and near enough, and rail vehicles have a further transitioning effect because of their bogie spacing, so trains can't tell the difference.

Transition curves need to be long enough so the cant is not applied too quickly. Too short will still cause lurching. This could be a problem with a tilt train on sharp curves with short transition curves.

#### Concerning cant deficiency and cant excess.

Cant excess causes lesser weight to be carried by the inner (low) rail. I remember it causing big problems on the North Australia Railway in the late 1960s when CR started running heavy iron ore trains, on the old light track having small 41 lb rails on lightweight steel sleepers. There was too much cant on curves and many derailments resulted from the extra weight on the low rail causing it to punch through the thin steel of the rails..

#### I asked Des if the cant calculations for passenger lines were different for freight-only lines.

He replied that cant is an impartial animal which doesn't discriminate between payloads. Speed is the key. So the design of the railway such as the Inland Rail should put its curves appropriate to train speeds, regardless of what they were carrying. He did say that on the Marree line, the degree of cant was reduced when the passenger trains on that line ceased but he pointed out that the coal trains were much slower.

### ON MUSICAL CURVES.

The Trans-Australian Railway is noted for its long straight, but at the east end of that it dives into a near continuous series of more than 170 curves in the next 150 km winding through (and up and down) the sand dunes of the Great Victoria Desert. As with most curves of that era they were plain circular curves without transitions. Transition curves were put in later by "string-lining" which had the effect of sharpening the curvature at their ends and retaining the original flatter radius at the centre. I called them "musical curves" because of those sharps and flats. Theoretically the cant should have varied around each curve in synch with the local curvature. That wasn't practical but the curves were tolerable, improved by the smoothing effect of more "stringlining". But they were not quite as good where there had been a common tangent point and no intervening straight, so that the transition curves would theoretically overlap by half their length. There the musical genre of the transition curves went a little towards Rock & Roll. They too were kept tolerable by string-lining and later by automatic track curve lining machines using the 2-chord principle. Eventually they were resurveyed and corrected when changing to concrete sleepers in the 1970s.

#### SOME MORE DES-ISMS

Interesting point is that people see the fancy new train or big loco, and not really notice the track underneath. You can't take a track fault or weakness to the workshop to repair it, as my old boss, Johnnie Walker (you will note my huge\* respect for him) said when we were rebuilding the Trans-Australian Railway "you can buy a new train in a year or less but it can take a lot of years to upgrade 1,000 miles of track, under traffic, to run on it."

\*Actually the original text was 'you will note my hugs'. I have corrected the spelling but suspect there was an element of the unconscious behind it (JLW).

I am reminded of past auctions on loading gauge and axle load...there are other incremental changes where there has to be a cut-off line somewhere and it is hard to judge when it is reached. Judge is the word because all these are areas where railway engineering is not an exact science... there is scope for art as well as science.. that's what makes railway engineering interesting and enjoyable. And it is possibly why there are many armchair experts who have all the answers.

#### A couple of other random comments regarding points in the text.

William T Doyne has said that a 5-chain curve on narrow gauge is, near enough, equivalent to one of 7 chains on standard gauge. Des Agrees.

Des has commented on Harding's mention. It seems to me, that Eric Harding (who was not an engineer) was trying to contrast, rather than compare, little trains of narrow gauge creeping around 5 chain curves at 15 mph, with broad gauge monsters that needed curves of 15 chains or more to be able to 'rush headlong' at 40 mph. If so, he roughly got it right.



## Eric Harding and his

### *UNIFORM RAILWAY GAUGE*

My copy of Eric Harding's book had lost its dust jacket before it came into my possession. Des Smith has a copy of the book that was given to him soon after it had been published. It still has its dust jacket although in somewhat tattered condition, which suggests that the contents have been well studied.

The dust jacket provides some biographical detail about Eric Harding which is additional to what can be gleaned from the contents of the book..

Harding has dedicated the book to the memory of Norris G Bell, former Engineer-in-Chief and first Commissioner of the Commonwealth Railways, whom he describes as one of the three great Australian railway administrators of the 20th century. He identifies the other two as being Edward Eddy, former Chief Commissioner of the New South Wales Government Railways and Harold Clapp, of the Victorian Railways. The pedant will point out that Eddy died in 1897 and should not be in that list. But Eddy was a man well in advance of his time so I have no quarrel over his inclusion. One could contemplate the inclusion of the South Australian Chief Commissioner of the 1920s, W A Webb, but South Australia, more so its Government than its Commissioner, gave the Commonwealth Railways nothing but trouble.

Eric Harding had commenced his railway career with the New South Wales Government Railways but joined the Commonwealth during the time that the Trans Australian Railway was being constructed. He held an administrative position. One of his early roles was the compilation of a set of rules and General Appendix for the Commonwealth Railways. He became Assistant Secretary of the Department.

**COONAMIA** is a 'suburb' of Port Pirie. It is promoted by the train crews on the *Ghan* as the only place on the journey where passengers can see the locomotives from the train. This loop line was built in 1978 and before that, all trains had to go into Port Pirie and have the engine change ends. Des Smith had been involved in the planning of this by-pass route and had recommended an 8 km section of new track that would have allowed the trains to proceed at full track speed. He said that the 'bean counters' of Australian National Railways won the day. **JLW.**

**BELOW:** The railway through Pichi Richi Pass was a near continuous collection of alternating curves. The leading engine in this picture was NM34 of the Commonwealth Railways on its last day in service. The train was an ARHS special on 8 October 1967. NM34 was on its way to the Railway Museum. **JLW.**



## LESSONS FROM HISTORY

It is time to consult the great railway engineers of Australia. They pushed the railways over the ranges in the 1860s and 1870s. John Whitton in New South Wales, Thomas Higinbotham in Victoria and Henry C Mais in South Australia. I have not included Abraham Fitzgibbon in Queensland. I suspect there may be some who question the latter's exclusion. As this story unfolds it will become clear why I have not included Fitzgibbon.

This threesome has left us with very clear examples of the limits of what was possible regarding gradients and curves on railways built to the gauges relevant to their situation. They were all subjected to the opinions of members of Parliament, who would want them to believe that the Parliaments had superior knowledge. And there was the press and public too.

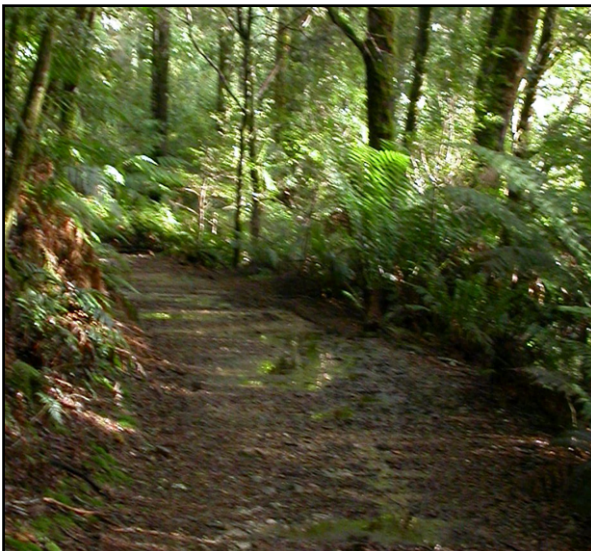
They have defined these limits but we cannot know the extent that, in setting these limits that they had considered the limitation imposed by the steam locomotive. Could they have gone to a sharper curve if they had electric traction?

Whitton built the railway across the Blue Mountains with 8 chain curves and a gradient of 1 in 33.

Henry Mais can be forgiven for his sharp curves on the route over Mount Lofty. Having been given the task of finding a 1 in 30 gradient to Mount Barker, and having given up after he found that a three-mile tunnel under Mount Lofty wasn't going to work, Premier Thomas Playford\* gave him eight weeks to find another way. His curves were 10 chains. He built the line through Pichi Richi Pass with 5 chain curves and a gradient of 1 in 60. Regarding Thomas Higinbotham, it is harder to pin down any practice regarding curves. The North-east railway to Wodonga was Higinbotham's one mainline.

\*He was the grandfather of Sir Thomas Playford, SA Premier from 1938 to 1965.

**THE TRAIL TO MONTEZUMA FALLS.** The former North-East Dundas Tramway was a 2 ft 0 in gauge line with the sharpest curves in Australia. It was closed in 1932. The corrugations left by the sleepers are still visible. **JLW**



He had the good fortune of finding a low point in the Great Dividing Range at Kilmore and was hence saved from the need for sharp curves.

Concurrent with the construction of the Hills railway, Mais also had responsibility for the planning and construction of the railway from Port Augusta to Government Gums. Again, there was confusion within the Parliament why they wanted it built and where it would go.

Whitton and Higinbotham came under pressure to support the construction of light railways of narrow gauge but both stood their ground, and the evidence is that the two were mutually supportive.

Mention is made of the Ipswich to Grandchester Railway in Queensland. It was built to a gauge of 3 ft 6 in with curves of 5 chains. It was claimed at the time that a railway built to the standard gauge would have required curves of 8 chain radius which would involve earthworks costing about two or three times as much as a 3 ft 6 in railway with curves of 5 chains. In a later statement, Mr William T Doyne, railway contractor and consultant, sometimes referred to as the 'Jupiter of railway contractors', estimated that the 5 chain curve on a railway of 3 ft 6 in was comparable to a curve of 6 3/4 chains on a standard gauge railway.

The relationship between Fitzgibbon and Doyne will be examined (Chapter 4). Fitzgibbon claimed to have been the one who planned the Dun Mountain narrow gauge horse tramway in New Zealand. It was Doyne who designed and built that line. Fitzgibbon was his assistant but wasn't clear about the gauge of the tramway. His initial report was unsure if the gauge was 3 ft or 3 ft 6 in.

To put this in summary, there is no precise science that defines the extreme limit of sharpness of curve for a given railway gauge. As a railway descends into single digit figures for radius (measured in chains), problems progressively arise and begin to compound each other.

For the sharpest curve on an Australian mainline there was the North-East Dundas Tramway in Tasmania's West Coast. It had a gauge of 2 ft 0 in and there were curves of 1 1/2 chains. The North-East Dundas Tramway had been built by the Tasmanian Government Railways to service the silver mines of the Zeehan region. It was opened in 1896 and closed in 1932. It now functions as the walking trail to the Montezuma Falls.

More than a century after the colonies of New South Wales on the one hand, and Victoria and South Australia on the other, went their separate ways, Eric Harding (p 31 of his book) wrote:

Little trains of 3 ft 6 in gauge could creep around curves of 5 chain radius, whereas the broad gauge monsters required fifteen chains or more.

But here, 'creep' is the important word. Those railways with 5-chain curves were very slow railways. Regarding the monsters that required 15-chain curves, I shall amend that to 12 chains, but they still had to take it slowly.



**THREE ENGINES - THREE GAUGES.** Port Pirie, 14 August 1968. Narrow-gauge T 44, Commonwealth Railways GM27 and broad-gauge 509. JLW.

It is time to consider the early railways. We will look at three very different railways.

The Liverpool and Manchester Railway opened in 1830 and was synonymous with George Stephenson and his *Rocket*. The alignment was nearly straight. This railway was soon followed by the London and Birmingham Railway, which was also designed by the Stephensons. The extensive Tring cutting on the London to Birmingham Railway was to eliminate troublesome gradients and curves.

Brunel's Great Western Railway from Paddington to Bristol. The first section was opened in 1838. Brunel forged a route, as close as possible to a straight line by building enormous masonry viaducts across valleys, great cuttings, and tunnels that challenged and exceeded previous engineering achievements. It came at great cost, but it served a population that was willing to pay for the luxury of fast travel.

The Ffestiniog railway in Wales. Was a gravitational tramway built in 1832 to transport slate to Portmadoc. Horses were used to haul coal and sundries in the uphill direction. Locomotives were used from 1863 and passengers were carried from 1865.

The Ffestiniog Railway had a gauge of 1 ft 11½ in. We may speculate on the origin of that gauge but it was probably based on an estimate of the loads to be shifted and they weren't in a hurry.

These railways were built at a time well before there was any serious debate about gauge. It was each according to their need.

George Stephenson simply went with the same gauge that had served the Killingworth Colliery.

Brunel had determined that a wider gauge provided stability, which in turn would give a more comfortable ride and thus a safer and faster journey. His '7 ft' \* gauge would allow the carriages to be inside the wheel base, hence ensuring that the centre of gravity was well contained.

\* The gauge was 7 ft 0¼ in but was generally called '7 ft.'

When we look back at Brunel's 7 ft gauge it came at great cost. But the trains could travel at great speed. But there were only about 100 miles between Paddington and Bristol. There was a density of population that was prepared to pay.

In August 1838 Brunel submitted to the Board of the Great Western Railway his reasoning in support of a wider gauge. He had worked out that there was no science that could determine the precise gauge of any railway.

The gauge that is adapted to one is not well adapted to the other unless, indeed, some mysterious cause exists that hasn't ever been explained for the empirical law which would fix the gauge under all circumstances.

**A RAIL LUBRICATOR** in the Adelaide Hills, near the site of the former Heathfield station. Note the crud, which is a mixture of grease and metal filings, on the side of the rail. The placement of the lubricant is critical to the operation. Ideally the lubricant should be on the wheel flange. If it gets on the rail head it will cause loss of traction. JLW.



For the last word on curves, I quote from the *Adelaide Times*, Monday, 31 January 1853, which provided a summary of a much more extensive treatise on railways that was taken from a ten-part series in the *Empire* (Sydney) that appeared in December 1852. It is a very comprehensive treatment of the subject based on the English experience. It was not attributed to any particular author but whoever wrote it had a remarkably clear understanding of both railways and the problems they would encounter in Australia.

Henry Parkes was the founder and editor of *Empire*. Had he taken copious notes regarding interviews of those who had arrived in Sydney regarding their railway experience in England?

It was obviously not read nor heeded by those who subsequently built the early Australian railways. I have said above that it was the last word. Or was it the first word? It seems that what was best in 1852 is much the same in 2023.

On the subject of curves on a railway to be worked by locomotive engine power, there can be no question that to have a sharp curve on such a railway is, at best, an evil, and ought not to be adopted unless to avoid some greater evil. Admitting the curve to be a true circular arc, and correctly set out (which it seldom is), each carriage in a train will have a continual tendency to fly off, that tendency will be increased in proportion to the smallest of the diameter of the circle of which the curve is a segment. The distance between the wheels on each side of the railway carriage is necessarily a straight line and the wheels and carriages are forced to move in a curvilinear direction; the friction therefore between the wheels and the rails, especially in an arc of a small circle, must retard the progress of the train, wear the materials, strain the carriages, and greatly increase the chance of accidents from the train being thrown off the rails, and even with the usual expedient of raising the outer rail. In order to counteract this tendency, the injury done to the engines and carriages on sharp curves is incalculable. ....There certainly can be no objection to curves of a mile or more in radius, but curves of a quarter of a mile radius, when passed at a speed of 30 miles an hour, are not only inconvenient, but have been proved in many instances to be dangerous.

#### DES SMITH'S DEN.

Des is looking at the survey map of the Alice Springs line. August 2023 JLW.



#### DES SMITH

Des is from Kelly country in Victoria. He studied Engineering in Melbourne, then got married, and scored a job with the Commonwealth Department of Works in Darwin. There was nothing flash about Darwin in 1954. Des and Betty lived in a shed with no fly screens. Meat was procurable in Darwin but was best avoided. Those in the know were able to get a better quality cut from the butcher in Katherine. Once a week, Des would go to the railway station at Darwin to pick up his parcel that came wrapped in brown paper and had come up from Katherine on the floor of the brakevan.

That was his introduction to Commonwealth Railways. There was an occasion in 1955 when Des had an encounter with Commonwealth Railways Commissioner, Pat Hannaberry. The Commissioner asked Des if he could use a theodolite. Des said 'yes', and Hannaberry said 'then you'll do', and gave him a job. Des commented to me that in his time with the Commonwealth Railways he had only met Hannaberry twice. The other occasion was at the opening of the railway to Marree. Pat Hannaberry continued as Commonwealth Railways Commissioner to 1960.

Des is now retired and living at Fitzroy in suburban Adelaide. Ironically that suburb takes its name from the man who was responsible for the break-of-gauge in Australia. Des is in his early 90s and remains physically and mentally agile. So too Betty, and the couple have a busy social agenda shared between family and fishing.

In his retirement Des has written his story. *TRACKS ACROSS AUSTRALIA - 44 Years in Railway Engineering on the East-West and North-South Transcontinental Railways*. It is a spiral bound volume, the first chapter of which seems to have been written about 2013. In its present form there are 122 pages but I suspect it is not finished. It has been produced in a very limited print run. The book tells of his job on the construction of the standard-gauge railway to Marree, and then his involvement with the upgrading of the Trans-Australian Railway, his involvement in the construction of the Whyalla line, his elevation to Chief Civil Engineer with Australian National Railways and building the new line to Alice Springs. He then undertook the early surveys of the Darwin line. I believe that this book is particularly valuable as an historical resource on the matter of transition from timber to concrete sleepers into standard practice on Australian railways. He has lodged one copy each with the State Library of South Australia and the National Library of Australia.

It has been a joy to have been welcomed by Des and Betty in their home. Of particular note is Betty's apricot slice, which is as much a part of the occasions as Des' pearls of wisdom.

John (and Patricia) Wilson