

E P Kearsley, S C van As

Deterioration of rail track geometry

Synopsis

The condition of a railway track tends to deteriorate with time. The objective of this paper is to investigate this deterioration and to determine whether improvements in track geometry can retard the deterioration, and thus reduce maintenance requirements. A further objective of the paper is to investigate the effect of train lengths, axle loads and speed limits on deterioration. Maintenance problems are more acute on heavy haul lines and the coal line linking the Transvaal coal fields with Richards Bay was therefore selected for the study.

Samevatting

Die geometrie van 'n spoorbaan neig om met tyd agteruit te gaan. Die doel van die artikel is om hierdie agteruitgang te ondersoek en om te bepaal of verbeteringe aan spoorbaangeometrie die agteruitgang kan verminder en sodoende die behoefte aan instandhouding kan beperk. Aangesien instandhoudingsprobleme meer akueel is op lyne wat aan hoë belastings onderwerp word, is die ondersoek geloot op seksies van die koolllyn wat die Transvaalse steenkoolvelde met Richardsbaai verbind.



Mrs E P Kearsley is a senior lecturer in the Department of Civil Engineering at the University of Pretoria. She holds the degrees BEng (Civil) (Pretoria) and MEng (Civil) (Pretoria). The subject of her master's dissertation, on which this paper is based, was 'Deterioration of track geometry'.



Prof S C van As is a professor of the SARB Chair in Transportation Engineering at the University of Pretoria. He holds the degrees BSc (Eng) (Pretoria), MEng (Cum Laude) (Stellenbosch) and PhD (Southampton).

Introduction

There is an increasing demand upon railway operators to improve reliability, efficiency, transit times and costs. In order for rail to compete favourably against other modes of transport, it is imperative to provide cost-effective tracks that can handle increased operating speeds and train sizes. An important consideration in the provision of a track is the cost of maintenance.

The objective of this paper is to investigate track deterioration and to determine whether improvements in the geometry of a track can retard track deterioration and thus reduce maintenance requirements. Curve radius in particular could have a significant effect on track deterioration. A further objective is to assess the effect on track displacement of train lengths, axle loads and speed limits in combination with track geometry.

Observations of track displacement

Maintenance problems are more acute on heavy haul lines and the coal line linking the Transvaal coal fields with Richards Bay harbour was selected for the investigation of track geometry deterioration. Track displacements were monitored on 12 curves at regular time intervals over a period of three years. The selected curves are between 100 m and 850 m in length and have radii varying from 521 m to 2 000 m. Gradients on the curves vary between -1,5 per cent and :1 per cent. Trains operated at speeds of between 45 km/h and 80 km/h on the curves.

During the study, approximately 79 per cent of the total tonnage was moved on the 'down line' towards Richards Bay, while the other 21 per cent was moved on the 'up line' towards Ermelo. The curves monitored during this study are situated on the down line. The average daily tonnage moved on the down line per month remained fairly constant throughout the study period. An average of eight trains with an approximate length of 200 trucks transported an average of 172 176 t per day along the track. Because of the small variation in daily tonnage, track displacements are presented in this paper as a function of time rather than tonnage. This approach provides a clearer picture of the change in deterioration on a track.

Track displacement is not uniform, but tends to vary randomly along the length of a curve. Two parameters were therefore used to investigate track displacement, namely the 'average' and the 'standard deviation'. The average displacement is an indication of the systematic displacement of the curve. This is important with regard to the positioning of the rail in relation to other structures. The standard deviation is an indicator of the differential movement, which is a measure of riding smoothness.

During the construction or maintenance of a track, it is not possible to obtain a perfect geometric standard. Furthermore, the geometry of a track deteriorates with time, resulting in the track being displaced from the designed position. Spoornet (SATS, 1984) prescribes three standards of track tolerances. The highest standard, denoted as the A standard, is prescribed for the more important lines such as the coal line. This standard was used in the study to determine maintenance needs.

Vertical settlement

Vertical settlements were observed by means of accurate levelling. A typical example of the average vertical settlement as observed on a curve is given in Fig 1 as a function of time after maintenance. The first measurement shown in Fig 1 was taken on the day after maintenance action took place on the line. The specific curve shown in the figure was lifted approximately 20 mm during the tamping operation. The track settled back to its initial level shortly after maintenance, at a rate that is nearly constant.

A track does not settle uniformly along its length, and irregularities are formed as a result of uneven settlement. The standard deviation of observed settlements was used to quantify the extent of these irregularities. A typical example of this standard deviation of settlements is also shown in Fig 1 as a function of time. The standard deviation of vertical settlement is at its worst immediately after maintenance and actually improves during the first month of operation. Thereafter the standard deviation remains fairly constant for some time before it starts to increase as deterioration of the track gradually starts to increase. The standard deviation, however, remained within prescribed tolerance limits during the period of

observation.

The observations of vertical settlement confirmed that, although the tamping process can rectify levels, it also has a loosening effect on the ballast, which is the main reason for the high rate of settlement immediately after maintenance (Selig, 1992). The relationship between the lift applied during maintenance and residual lift two months after the maintenance was obtained at a large number of sites and is indicated in Fig 2. The relationship is significant; 86 per cent of the variation in residual lift can be explained by the applied lift. This indicates that a track should be 'over-lifted' to correct for settlement.

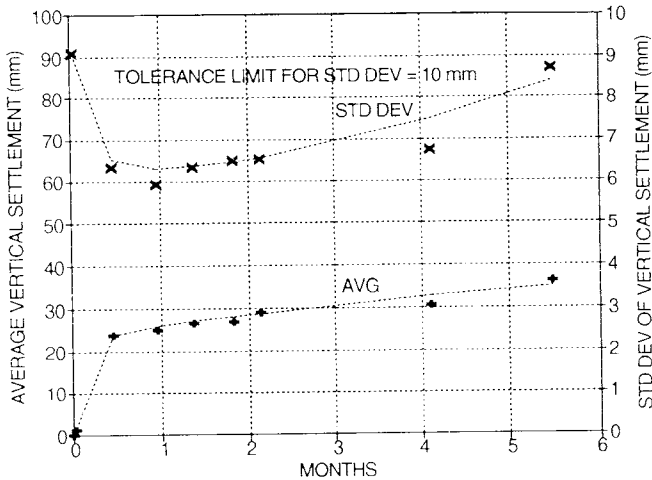


Fig 1: Vertical settlement

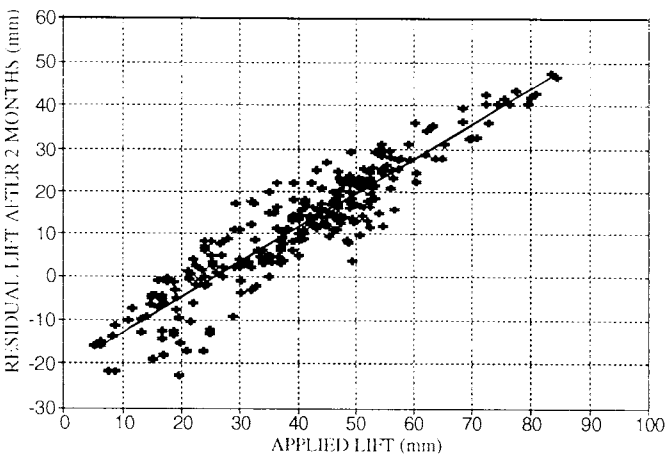


Fig 2: Residual lift as a function of lift

Cant

An example of the deterioration in average cant (or superelevation) along the circular section of a curve is shown in Fig 3. The cant applied to the curve in the example during maintenance was greater than the required or desired cant and the cant settled back to this desired value soon after maintenance. The greatest change in cant occurs immediately after the maintenance action and very little change is detected thereafter.

The standard deviation of cants measured along the example curve is also shown in Fig 3. On some of the curves a slight improvement was found immediately after maintenance, but thereafter standard deviation tended to show a slight but steady deterioration with time. However, it remained within prescribed tolerance limits for the duration of the study.

Versines

Stringlining was used as a simple, inexpensive method to measure the curvature of horizontal curves. The middle ordinate or versine is the horizontal distance between the edge of the railhead and the centre of a 10 m long chord. Different sets of versine measurements along a curve were compared to establish whether the shape of a horizontal curve changed with the tonnage moved across a curve. Fig 4 is an example of two sets of

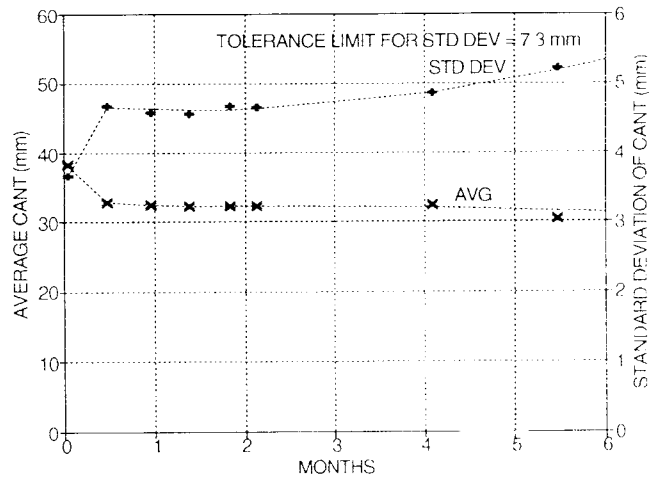


Fig 3: Cant in circular curve

versines measured nearly one year (322 days) apart on the same curve. Although approximately 52 million t was moved over this curve during the period, little change occurred in the shape of the curve.

Average versines for the circular section of a particular curve as a function of time are shown in Fig 5. This figure indicates that the radius of a curve is not affected by track deterioration. The standard deviation of versines measured along the circular section of a curve is at its poorest soon after a maintenance action, as indicated in Fig 5. The alignment of the curve actually improves with time, since there is a general tendency for the standard deviation to decrease with increased tonnage. This means that (shor-

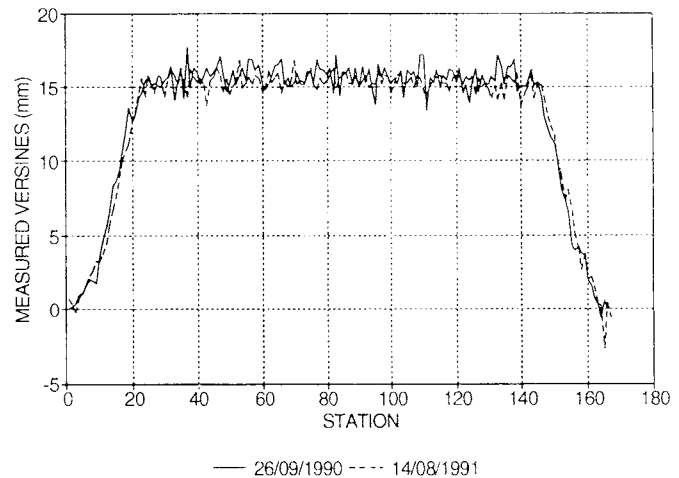


Fig 4: Measured versines

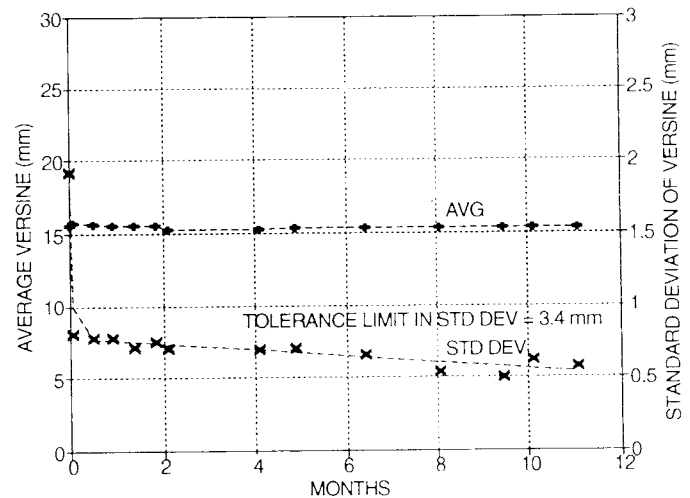


Fig 5: Versines in circular curve

ter) kinks on curves are generally reduced over time as trains move along the track.

Horizontal displacement

Versines only provide an indication of the radius of a curve and not horizontal displacement. Horizontal displacement of curves was therefore determined by measuring offsets at 10 m intervals between reference pegs and the track and comparing different sets of offsets. The average horizontal displacement observed on a particular curve as a function of time is shown in Fig 6. All observations during the study showed a significant rate of displacement outwards in the direction of the centrifugal force. This horizontal displacement appears to be the most important cause of track deterioration.

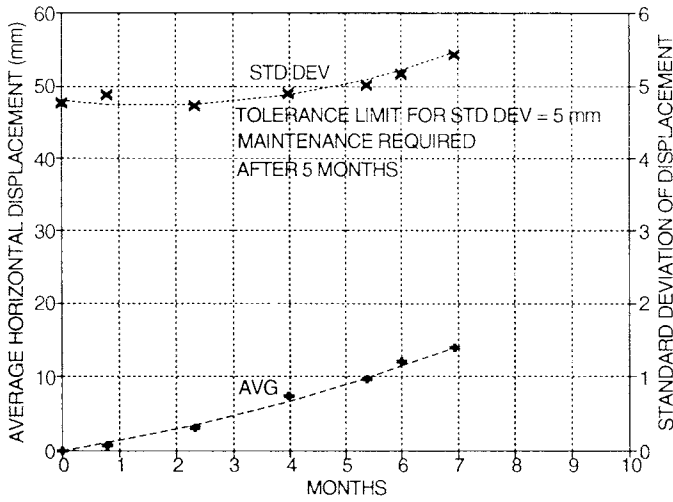


Fig 6: Horizontal displacement

The standard deviation of horizontal displacements along the example curve is shown in Fig 6. All observations have also shown a slight but steady increase in standard deviation of horizontal displacement with time. The standard deviation is also significantly greater than the standard deviation of versines. The explanation for this difference is that 'short' kinks on curves tend to straighten while 'long' kinks worsen with time. These long kinks are not measured by versines, while offset measurements include the effect they have.

The monthly rate of horizontal displacement is shown as a function of the centrifugal rate of acceleration in Fig 7. The centrifugal rate of acceleration was determined using the average speed of trains on curves. The rate of horizontal displacement was obtained by fitting straight lines through the older portions of the displacement-time graphs. A correlation coefficient of 77 per cent was calculated, indicating a significant correlation between horizontal displacement and the centrifugal rate of acceleration. This provided an indication that a simulation program could be developed to predict average horizontal displacement.

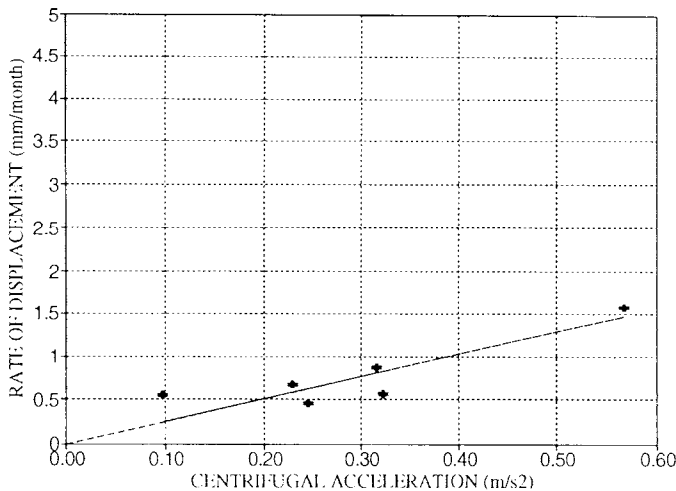


Fig 7: Horizontal displacement and acceleration

Computer simulation of track movement

Track maintenance is required to remedy vertical, rotational and horizontal displacements caused by the forces exerted by trains moving along a track. No empirical evidence was found to link either vertical or rotational track displacement to the geometry of a railway line. Horizontal displacement, however, clearly depends on the horizontal alignment of the track. Moreover, with trains of two kilometres and longer, this displacement could also be affected by the geometry of the line over a relatively long distance.

Horizontal movement is caused by horizontal forces exerted by trains on the track. A simulation model was developed to model such horizontal forces and displacements. This model is a simplification in that it is not possible to take into account all possible static and dynamic forces acting on the railway line. The simulation program, called RAILSIM, was written in FORTRAN 77 for use on personal computers. The program uses the train composition, speed profile (as indicated in Fig 8), horizontal alignment and vertical alignment to calculate predicted annual horizontal displacements. An example of the output of the program is shown in Fig 8. The program was calibrated using observed track displacements on the coal line.

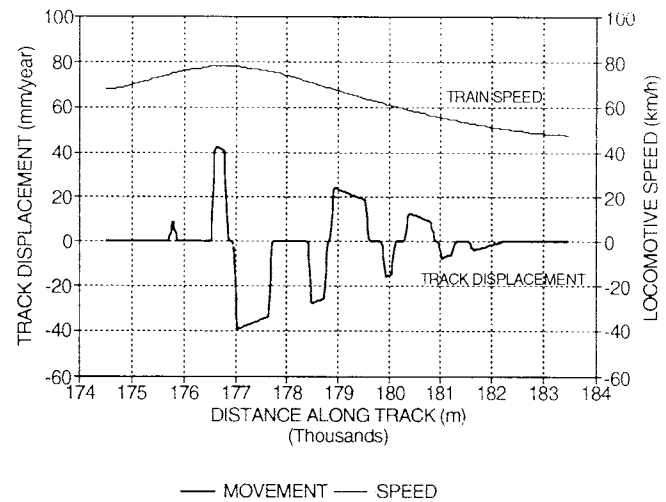


Fig 8: Speed profile and annual track displacement

The effect of track geometry on horizontal displacement

The simulation model was used to predict the effect of changes in the geometry of a track on the horizontal displacement of curves and thus the effort required to maintain a track in its required position. The simulation model was also used to investigate the effect of a number of factors on horizontal displacements, which included:

- Curve radius and train speed and length of transition curve
- Gradient
- Train composition

The investigation assumed a daily load of eight trains of 200 trucks with 26 t axle loads. A standard 800 m radius curve with 80 m transition curves on a zero gradient was used in all simulations, unless otherwise indicated. The movement was calculated for train speeds of 40 km/h, 60 km/h and 80 km/h. The substructure was assumed to be of a poor quality, which allows for a safety factor in the results. The average horizontal displacement along the circular portion of the curve was used to determine the effects of the various factors. A maximum allowable limit of 10 mm on the horizontal displacement was assumed and a required maintenance cycle was determined accordingly.

Curve radius and train speed

The effect of curve radius on horizontal movement is shown in Fig 9 for different train speeds and track gradients. This figure shows that excessive horizontal movement occurs for radii below 600 m at lower speeds and below 1 000 m at higher speeds. The radii of some of the curves on the coal line are in this range, which accounts for the high maintenance requirements on the line.

Speed also has a significant effect on horizontal movement, as shown in the figure. Increasing the speed from 40 km/h to 60 km/h (ie by only 50 per cent) results in an approximate doubling in horizontal movement. Main-

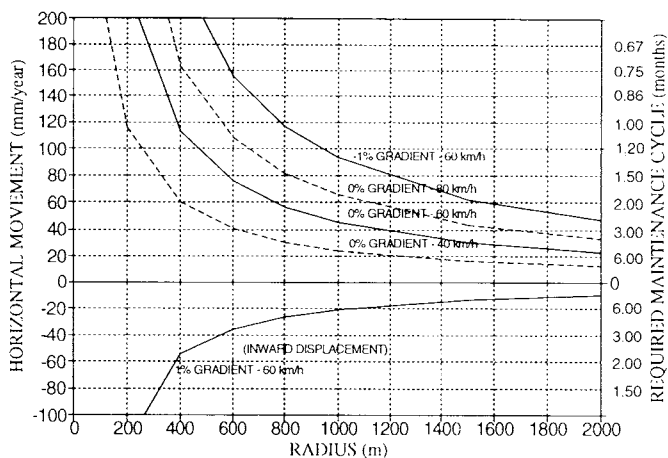


Fig 9: Movement as a function of radius

tenance requirements should therefore also be taken into account when speed limits are set for railway lines.

Gradient

The effect of gradient on horizontal movement is shown in Fig 10. Trains on downslopes tend to displace curves further outwards, but on the upgrades the inward component of the longitudinal force becomes greater than the centrifugal force and the curve may even be displaced inwards on steep downgrades.

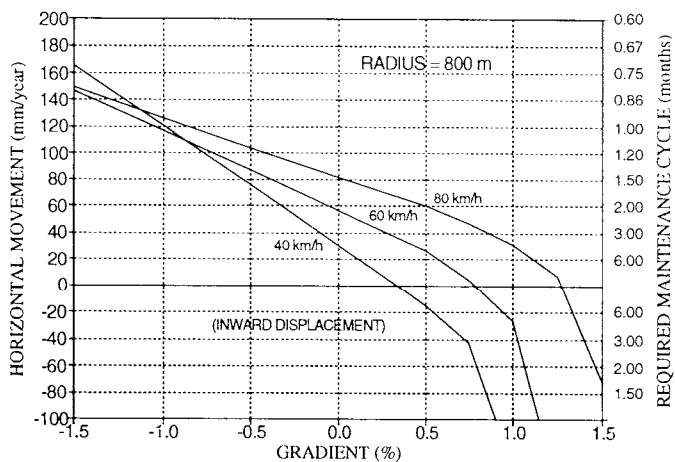


Fig 10: Movement as a function of gradient

Train composition

The effect of train length was investigated by varying the number of trucks but increasing or decreasing the number of trains to maintain the same total tonnage. The horizontal displacement is shown in Fig 11 as a function of number of trucks for different train speeds. Train length at higher speeds has little effect on horizontal displacement, but at lower speeds longer trains have a beneficial effect. The inward component of longitudinal force on longer trains is greater than on shorter trains, and therefore the centrifugal forces, which cause the outward movement of a track on a zero gradient, are smaller. Longer trains on upgrades could, however, result in a greater inward displacement of the track.

Conclusions and recommendations

Observations of track movement have shown that a track is displaced both vertically and horizontally when trains move along it. Track displacement is not uniform along the length of a curve, but tends to fluctuate. Displacement was therefore investigated by using two parameters, namely 'average' and 'standard deviation'. Both parameters generally showed a tendency to deteriorate with time, but in a few cases were found to improve immediately after maintenance. In these instances the track actually corrected its geometry, eliminating the irregularities caused by the maintenance action.

No evidence was found to link vertical settlement to vertical and

horizontal alignment and only the horizontal displacement was found to be significantly influenced by geometric factors. A simulation program was therefore developed that can be used to predict the effect of various factors on the horizontal displacement of a track.

An analysis of the various factors that might influence horizontal displacement showed that the radius of a curve and the speed of the train can significantly influence the amount of horizontal displacement that takes place along a track. The gradient of the track can either reduce or increase this displacement. Other factors, such as train length, train composition and axle loads, were found to have little effect on the horizontal displacement of a track. Longer trains tend to increase the longitudinal force in the train, which in turn tends to cancel the centrifugal force that is acting outward on a curve.

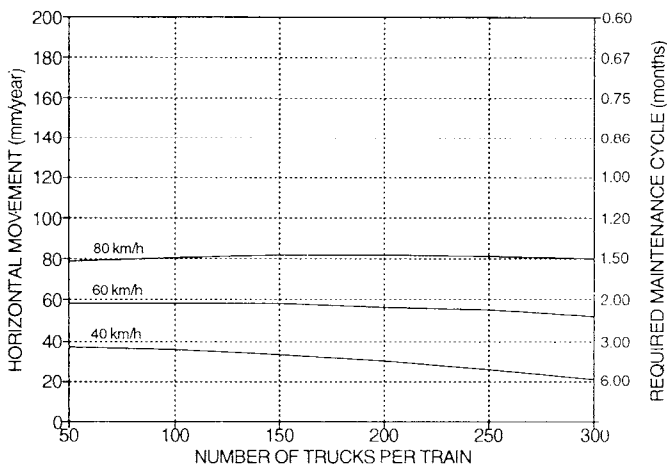


Fig 11: Train length

The results of this study have shown that the horizontal displacement of a track, and thus the effort required to maintain the track, can be significantly improved by improving the horizontal alignment of the track. The speed of the train was also found to have a significant effect.

The results of the study can be used in setting standards for new tracks or when setting target speeds on existing tracks. The simulation program itself can be applied to winding portions of track where different geometric elements may interact to exacerbate the problem of horizontal movement.

The results of the study are especially important at critical sections of the track, such as those adjacent to tunnels, bridges and loading platforms. Cognisance should be taken of the effect of track geometry on maintenance requirements during the design of such sections.

Acknowledgement

We would like to express our appreciation to the following organizations and persons who made this paper possible:

- Plasserail South Africa, on whose research project this paper is based
- Spoornet, for allowing access to the coal line and for the provision of information
- Mr B Bragge and Mr H Hone for their assistance

References

1. Esveld, C. 1989. *Modern railway track*. West Germany.
2. Kearsley, E.P. 1993. *Deterioration of track geometry*. MEng thesis. Pretoria: University of Pretoria.
3. Kearsley, E.P. and van As, S.C. 1993. The effect of heavy haul traffic on track geometry deterioration. *Proc: Fifth International Heavy Haul Conference*, Beijing.
4. Kuys, W.C. 1989. Track structure failure under 26 tonne axle loads on SA Transport Service's coal line. *Proc: Fourth International Heavy Haul Conference*, Brisbane.
5. Klintworth, P.J.W. *Speed limitations and geometric track standards for safety, comfort and economy*. Source unknown.

(Continued overleaf)

6. Malan, C E. 1990. *Maintenance planning for heavy haul railways*. Pretoria: Postgraduate course in railway maintenance, University of Pretoria.
7. Maree, J.S. 1989. Evaluation of track structure problems on the coal line. *Proc: Fourth International Heavy Haul Conference, Brisbane.*
8. Riessberger, K. 1989. Track alignment – New developments: Practices and methods. *Proc: Fourth International Heavy Haul Conference, Brisbane.*
9. Selig, E T. 1992. *Ballast maintenance cycle characteristics*. Special post-graduate course on fundamentals of track structure design and maintenance, University of Pretoria.
10. South African Transport Services (SATS). 1984. *Permanent way instructions*. Pretoria: SATS

Guidelines for submissions on disk

In response to the increasing use of computers for text origination, the Institution of Civil Engineers is encouraging submission to the *Journal* on disk. The successful utilization of your disk will retain the integrity of the text, minimize the incidence of literal errors being introduced during typesetting and thus reduce the time needed to proofread the material. The following guidelines should be used in conjunction with the standard 'Notes on the preparation of papers and technical notes'.

What to supply

- Supply the original manuscript for refereeing as usual.
- When you send in the final revised hard copy version of your manuscript (three copies), you should also send your wordprocessed disk. *The hard copy and disk must match exactly.*
- Either 3¼ inch or 5½ inch disks will be accepted.
- Text should be saved as a wordprocessor file in IBM-compatible MS-DOS format. We recommend Word Perfect or Microsoft Word as the wordprocessing software, but you may also provide the file in ASCII format.

Organization of disk content

- Present your manuscript as simply as possible. *Do not do any designing or formatting.* Regardless of how smart a manuscript looks, any complex formatting will have to be stripped out. Complex formatting will take up more of your time and will also complicate and delay the production process.
- We will copy-edit the manuscript and insert all required coding onto the disk. All design considerations for typefaces, page layout and artwork positioning will be handled by the editorial team.
- THE MOST IMPORTANT CONSIDERATION WHEN PREPARING YOUR DOCUMENT IS TO BE CONSISTENT.

- All copy must be double spaced.
- Tables may need to be rekeyed by the typesetter.
- All text should be ranged left, unjustified and without hyphenation.
- Be careful not to key in unnecessary spaces; only one space is necessary at the end of a sentence after a full stop. Space must be keyed after a comma or other punctuation, after an initial (Mr R F Jones) and before an opening parenthesis.
- Be careful not to confuse lower case ellis (l) with the number one (1), or the capital letter O with zero (0).
- Scientific material can present problems. Please note that displayed equations may need to be rekeyed by the typesetter from hard copy. Journal style should be followed for letter symbols: variable in italic, constants and Greek characters in roman type. If you import equations/scientific symbols from another program, please give exact details of the program used and what you have done.

Labelling

- Your disk should be labelled with the author's name, short title, file names and the date the files were created.

Packing your disk

- When sending your disk by post, ensure that it is properly protected from damage.
- It is advisable to write-protect your disk before submission.
- *It is important that you keep an identical copy of your disk in case it is damaged in transit.*

If you have any queries, please contact the editor on (011) 803-2681 (tel/fax during office hours).