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Geometrical degradation of railway turnouts: A case study from a Swedish heavy haul railroad

Iman Arasteh khouy[1], Per-Olof Larsson-Kråik[1,2], Arne Nissen[2], Jan Lundberg[1] and Uday Kumar[1]

Abstract

Turnouts are critical components of track systems in terms of safety, operation and maintenance. Each year, a considerable part of the maintenance budget is spent on their inspection, maintenance and renewal. Applying a cost-effective maintenance strategy helps to achieve the best performance at the lowest possible cost. In Sweden, the geometry of turnouts is inspected at predefined time intervals using the STRIX / IMV 100 track measurement car. This study uses time series for the measured longitudinal level of turnouts on the Iron Ore Line (Malmbanan) in northern Sweden. Two different approaches are applied to analyse the geometrical degradation of turnouts due to dynamic forces generated by train traffic. In the first approach, the recorded measurements are adjusted at the crossing point and then the relative geometrical degradation of turnouts is evaluated by using two defined parameters, the absolute residual area and the maximum settlement, In the second approach, various geometry parameters are defined to estimate the degradation in each measurement separately. The growth rate of the longitudinal level degradation as a function of million gross tonnes / time is evaluated. The proposed methods are based on characterisation of the individual track measurements. The results facilitate correct decision-making in the maintenance process through understanding the degradation rate and defining the optimal maintenance thresholds for the planning process. In the long run, this can lead to a cost-effective maintenance strategy with optimised inspection and maintenance intervals.

Keywords

Turnouts, track geometry degradation, maintenance interval, maintenance thresholds

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Introduction

Today's railway industry handles an increasing number of trains that travel at higher speeds and have higher axle loads; this combination of circumstances results in faster degradation of railway assets and higher maintenance costs. Under this scenario, high-quality track standards can be maintained by shifting the focus of the maintenance strategy from meeting safety limits to obtaining cost-effective maintenance thresholds through reliability and life cycle cost (LCC) analyses.

Turnouts are one of the main subsystems of the railway superstructure in terms of safety, operation punctuality and maintenance cost. A study of train delay statistics for the period 2001–2003 in the Swedish railway system showed that the share of switch and crossing (S&C) failures in the total number of infrastructure-related delays was about 14%.[1] In 2009, the maintenance cost of turnouts in Sweden was around 8% of the total maintenance cost.[2]

Both static and dynamic loads cause the turnouts to deteriorate due to[3]:

- geometrical degradation;
- tear, wear and plastic deformation of components.

Several studies have modelled the track geometry degradation process.[4–6] Some researchers have also proposed models to optimise track geometry maintenance by increasing the track availability and reducing the maintenance cost.[7,8] However, most studies have been conducted on plain tracks, i.e. straight lines and curves. Particularly in the case of turnouts, only a few attempts have been made to model degradation in

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addition to optimising maintenance. An exception is Zwanenburg[3] who modelled the degradation process of turnouts for maintenance and renewal planning on the Swiss railway network. The European project, INNOTRACK, has specified the key parameters for monitoring turnouts by using the failure mode effects and criticality analysis method.[9] The INNOTRACK project has also studied the optimisation of turnouts by optimising the geometry and track stiffness.[10]

Some researchers have examined the dynamic interaction between the train and the turnout to simulate the wear, rolling contact fatigue (RCF) and plastic deformation in turnout components.[11,12] Others have evaluated the effects of the switch angle and frog angle on the wear rate. For instance, Elkins et al.[13] concluded that the wear at the switch can be reduced by decreasing the entry angle to the switch.

The present study uses time series for the measured longitudinal level of turnouts on the Iron Ore Line (Malmbanan) in northern Sweden to analyse the vertical geometry degradation rate due to dynamic loading forces generated by train traffic. It also evaluates the growth rate of the longitudinal level degradation as a function of million gross tonnes (MGT). Note that the deterioration of turnout components in terms of wear, RCF and plastic deformation has not been analysed.

Background to the studied line

The Iron Ore Line runs from Narvik to Riksgränsen (Ofotenban) in Norway and from Riksgränsen to Boden in Sweden (Malmbanan). The Swedish mining company LKAB transports iron ore pellets from its mine at Kiruna to Narvik and from its mine at Vitåfors, near Malmberget, to Luleå (see Figure 1).[14] In 2000, LKAB increased the axle load on the Iron Ore Line from 25 to 30 tonnes and the maximum speed of a loaded train from 50 to 60 km/h.

The turnouts selected for the study are on the main line at track section 111, between Kiruna and Riksgränsen (see Figure 1). In addition to the iron ore trains, the line is used by two passenger trains per day. The train speeds vary from 50–60 km/h for loaded iron ore trains, 60–70 km/h for unloaded ones and 80–135 km/h for passenger trains. The annual passing tonnage of the line is about 28 MGT. The track consists of UIC 60 rails and concrete sleepers. The ballast type is M1 (crushed granite) (SS-EN 13450) and the track gauge is 1435 mm. The region is subject to harsh climate conditions: large amounts of winter snowfall and extreme temperatures, ranging from -40 °C in the winter to +25 °C in the summer.[15] The specifications of the studied turnouts are listed in Table 1.

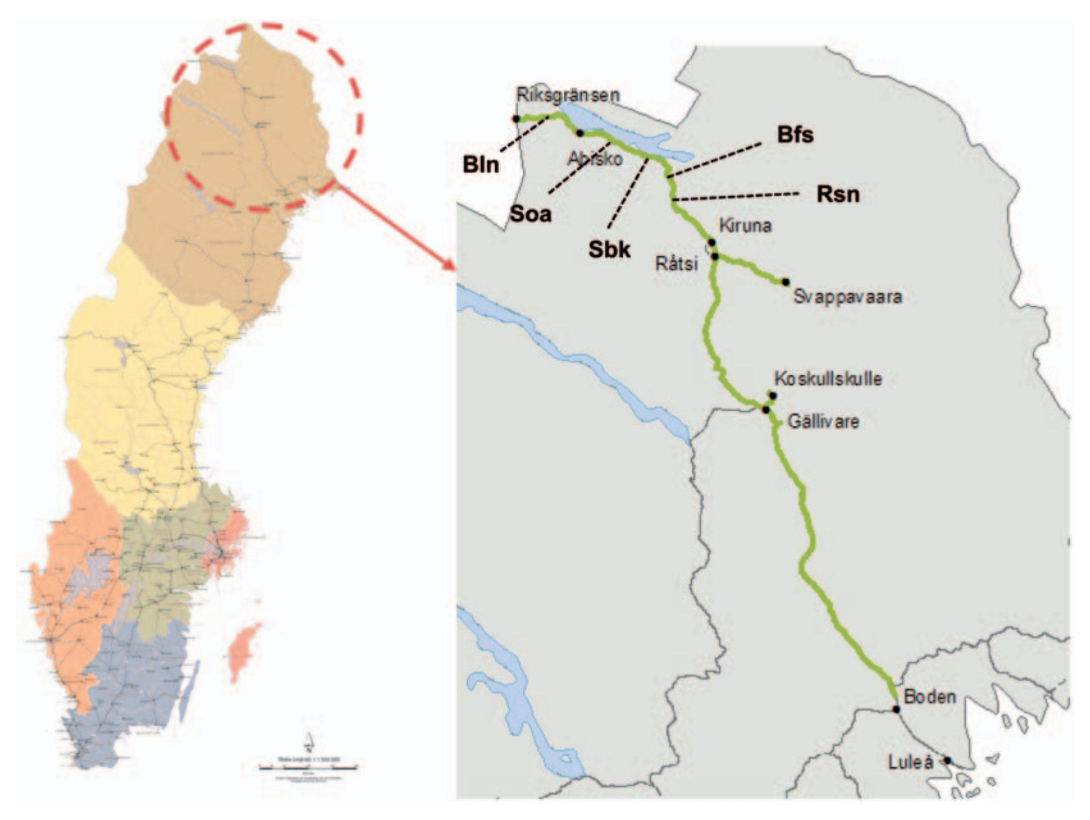

Figure 1. Iron Ore Line from Boden to Riksgränsen. Reproduced with permission from.

Table 1. The specifications of the studied turnouts.

Turnout	Turnout type	Turnout direction	Installation year	Sleeper type	Ballast type
Rsn 2	EV-UIC60-760-1:15	Left	2001	Concrete	M1
Rsn 1	EV-UIC60-760-1:15	Right	2003	Concrete	M1
Bfs 2	EV-UIC60-760-1:15	Right	1999	Concrete	M1
Sbk 1	EV-UIC60-760-1:15	Right	2000	Concrete	M1
Soa 2	EV-UIC60-760-1:15	Right	2000	Concrete	M1
Bln 2	EV-UIC60-760-1:15	Right	2003	Concrete	M1

Table 2. The frequency of available inspections for each year.

	2007	2008	2009	2010	2011
Measurement dates	28 April	18 April 13 June 27 September	13 June 08 August 02 October	16 May 29 June 03 September 16 October	01 April 11 June 16 August 23 September 06 October 04 November

Data collection and data treatment

Six turnouts in section 111 of the Iron Ore Line, located between Kiruna and Riksgränsen, were selected for the case study. To ensure comparable data, only turnouts of type EV-UIC60-760-1:15 were considered and the other types of turnout were excluded.

Two different approaches were applied in this study to analyse the geometrical deterioration of turnouts. The data collection and data treatment for each of these approaches are described in the following sections.

First approach

The design and inspection information for the selected turnouts was extracted from two databases at Trafikverket, BIS (track asset information system) and Optram. BIS contains information on Trafikverket's infrastructure and facilities, e.g. the turnout type, turnout position, sleeper and ballast type, etc. Optram is a maintenance decision support system implemented in 2009 that can be used to graphically show the results of track geometry measurements. Only measurement data after 2007 are available in this database.

The main track geometry parameter considered in this study is the longitudinal level. Hence, the longitudinal level values of turnouts from 2007 to 2011 were collected from Optram. For this time interval, the data of 17 measurements were available. Table 2 shows the frequency of the measurements for each year.

Information on the history of the performed maintenance was collected from two other databases, Bessy and Ofelia. Bessy (Trafikverket's inspection report system) contains information on inspections and the types of actions performed after inspection recomendations.[16] The data on corrective maintenance actions are held in Ofelia (Trafikverket's failure report system), which contains report information from the track maintenance contractors concerning fault symptoms, reasons for faults, the actions performed, the times of fault occurrence and repair, the time required for repair, etc.[16]

Considering that the STRIX / IMV 100 inspection car has an error tolerance of 10–15 m in specifying the longitudinal location of the track, the first step in data treatment was to adjust the sampled measurement data according to a well-defined reference point. This was accomplished by finding the crossing location for each measurement and adjusting all the measurements based on this reference point. Figure 2 illustrates an example of the specification of the crossing location for one measurement. In this example, the crossing reference point was located between kms 1453.17 and 1453.18.

Two parameters are considered in the geometrical degradation analysis, namely, the *absolute residual area* (AR_a) and the *maximum settlement* ($S_{\max.}$). The AR_a is defined as the absolute value of the area obtained from the differences in the longitudinal level values between two adjusted measurements at the crossing point. Figure 3 shows this parameter as the grey dashed area between two measurements performed on 28 April 2007 and 18 April 2008.

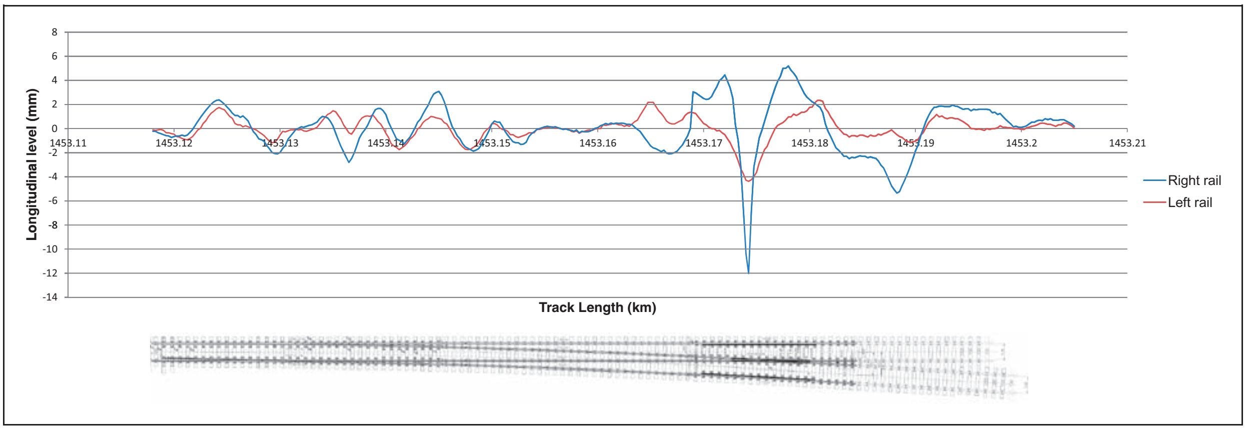

Figure 2. Specifying the crossing location for each measurement.

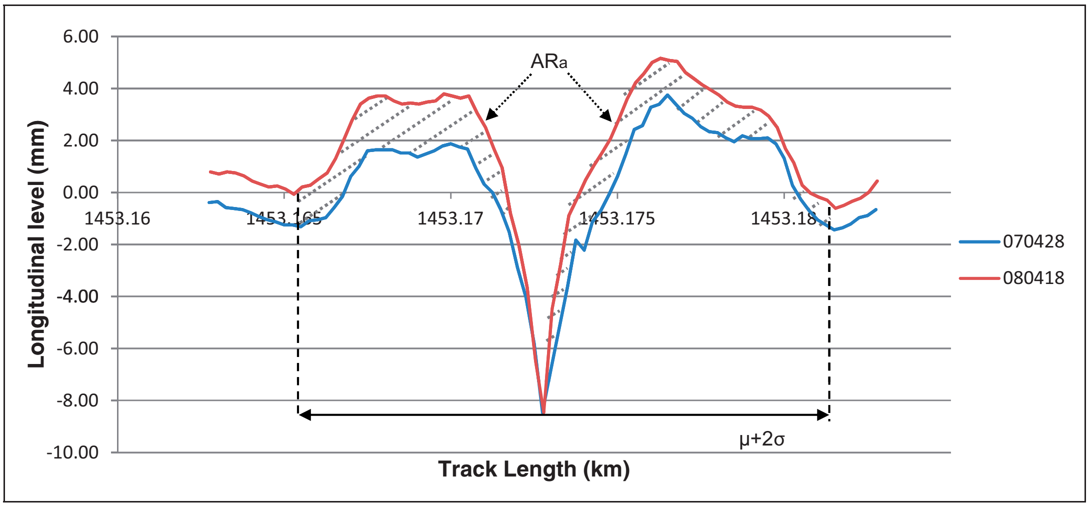

Figure 3. Illustration of the AR_a between two measurements.

The trend of the AR_a indicates how much the track has settled due to the accumulated loading from traffic over a certain period. This parameter is calculated between the lower peaks immediately before and immediately after the crossing point (Figure 3). To define this interval, the distance between the peaks for every inspection and turnout (in total six turnouts x 17 measurements, see Tables 1 and 2) is measured to obtain the mean (μ) and the standard deviation (σ). Then the distance of $\mu + 2\sigma$, which covers approximately 95% of the total measurement population, is used to calculate the AR_a. This means that the crossing point will be considered as the reference point and the AR_a is calculated at an interval of $[-(\mu + 2\sigma)/2, (\mu + 2\sigma)/2]$ for each individual S&C; see Figure 3.

The maximum settlement ($S_{\max}$) is defined as the difference between the value of the longitudinal level at the crossing point and the value obtained from the intersection of the vertical line passing through the crossing point with the straight line connecting the positive peaks before and after the crossing point. This parameter is shown in Figure 4 by the blue line.

In the trend analysis of both parameters, the first measurement (28 April 2007) is considered to be the starting and reference time point, and the rest of the consecutive measurements are compared to this reference point.

However, the shortcoming with this approach is that the longitudinal level of the reference point is considered constant, leading to results that estimate the relative geometrical degradation rate instead of the actual one.

Second approach

To overcome the shortcoming in the first approach, various geometry parameters were defined to estimate the degradation in each measurement separately. This approach was inspired by surface roughness

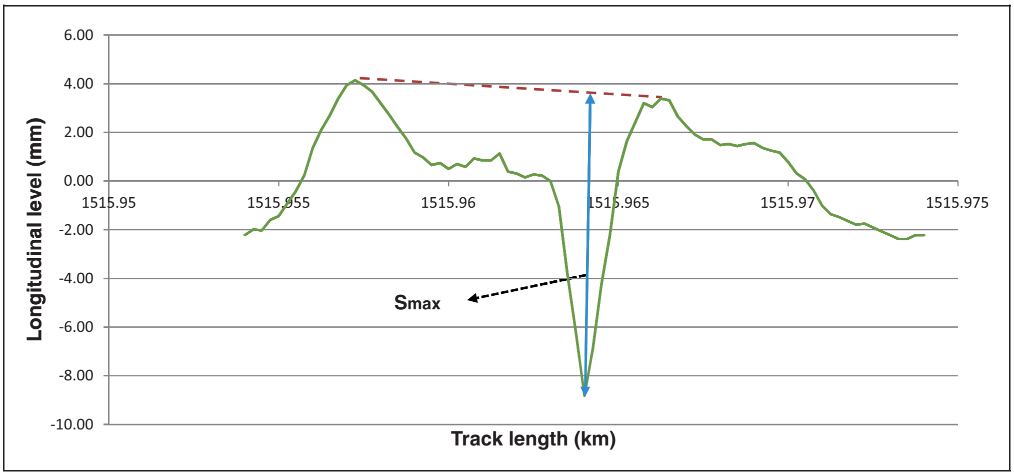

Figure 4. Illustration of the maximum settlement (S_{max}).

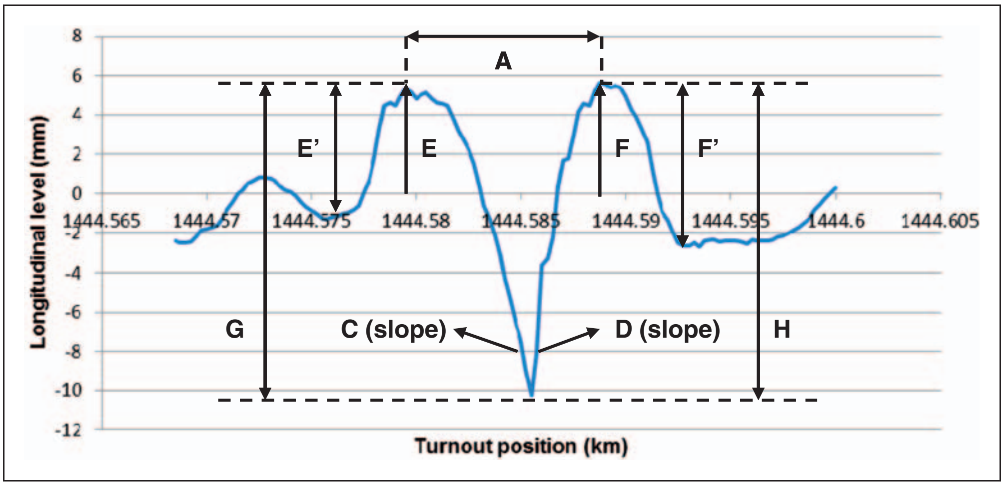

Figure 5. Defined geometry parameters in the second approach.

measurements, which have been a useful and reliable method for at least 60 years. The defined parameters in this approach are as follows (Figure 5):

- A: the distance between the peaks after and before crossing valley;
- C: the slope of the measurement line 1 m before the crossing point;
- D: the slope of the measurement line 1 m after the crossing point;
- E: the longitudinal level value at the first peak (before the crossing point);
- E': The difference in longitudinal level values between the first peak (before the crossing) and the valley before it;
- F: the longitudinal level value at the second peak (after the crossing point);
- F': the difference in longitudinal level values between the second peak (after the crossing) and the valley after it;
- G: the difference in longitudinal level values between the first peak (before the crossing) and the crossing valley;
- H: the difference in longitudinal level values between the second peak (after the crossing) and the crossing valley.

The trends of these parameters as a function of time for the turnouts Rsn 1 and Soa 2 were estimated for the time interval from 2004 to 2013. The measurement data for the period between 2004 and 2007 was collected from the track recording database.

Results and discussion

The normal distribution analysis of the distance between the negative peaks before and after the crossing point indicates that the values of the mean (μ) and the standard deviation (σ) are 24.16 and

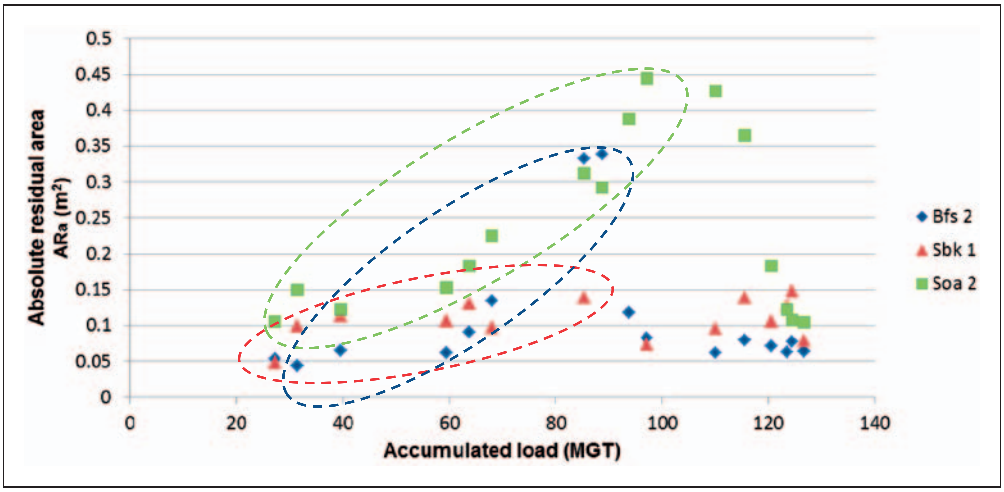

Figure 6. Trend of AR_a over time for the turnouts Bfs 2, Sbk 1 and Soa 2.

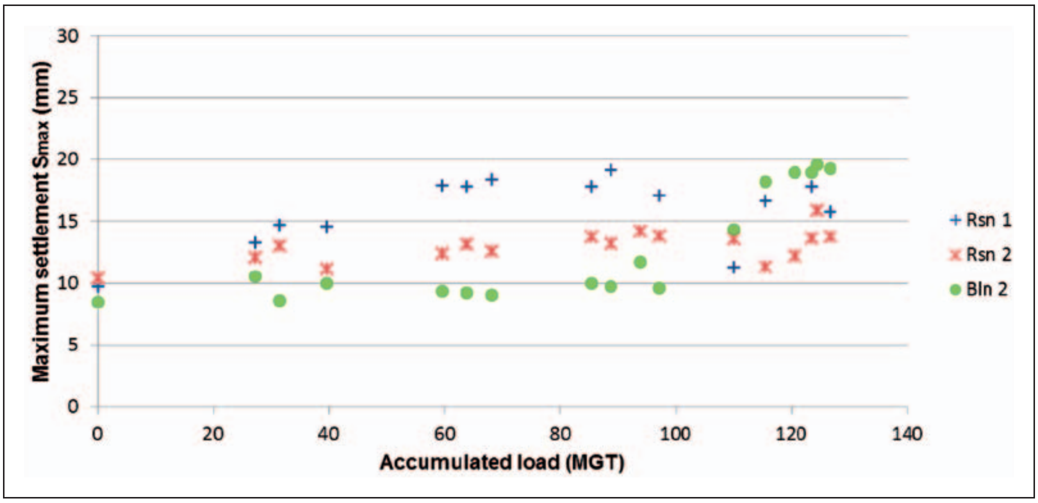

Figure 7. Trend of $S_{\max}$ for turnouts Rsn 1, Rsn 2 and Bln 2.

4.74 m, respectively. By considering these values, the AR_a was calculated on the basis of a distance of 33.64 m ($\mu + 2\sigma$) with reference to the centre of the crossing point. Figure 6 shows the variation of the calculated AR_a over time for the turnouts Bfs 2, Sbk 1 and Soa 2. The trend of this parameter before performing maintenance is illustrated by the dashed circles.

Assuming the longitudinal level of the reference points between the measurement events is constant, a number of results can be obtained from the first approach. As can be seen in Figure 6, the AR_a values for the turnouts Bfs 2 and Soa 2 increase with an increasing accumulated load to 0.35 and 0.45 m^2, respectively. Failure reports found in the corrective maintenance report system (Ofelia) gave information on the need to perform corrective maintenance on both turnouts around these points in time (corresponding to 90 and 110 MGT). After performing maintenance, the rate of geometry degradation stays low and constant for the remaining period of this study. At the same time, the degradation rate for the S&C Sbk 1 is lower than that for Bfs 2 and Soa 2. Nevertheless, corrective maintenance was carried out on Sbk 1 during the same period as the maintenance on Bfs2, lowering the value from 0.14 to 0.07 m^2.

The same pattern was observed for the AR_a values for the turnouts Rsn 1, Rsn2 and Bln 2. The AR_a values were lowered by maintenance performed after 90 MGT.

The trends of the $S_{\max}$ with an increasing accumulated load for the turnouts Rsn 1, Rsn 2 and Bln 2 are depicted in Figure 7. The $S_{\max}$ at the crossing position indicates when maintenance is needed. The AR_a seems to be more sensitive to changes than the $S_{\max}$.

The trends of the defined geometry parameters (in the second approach) are shown in Figure 8. As can be seen in Figure 8(a) the parameter A in both turnouts has an increasing trend until 29 June 2011. Since maintenance was carried out on Rsn 1 after 29 June 2010, the value of A for Rsn1 drops. However, after

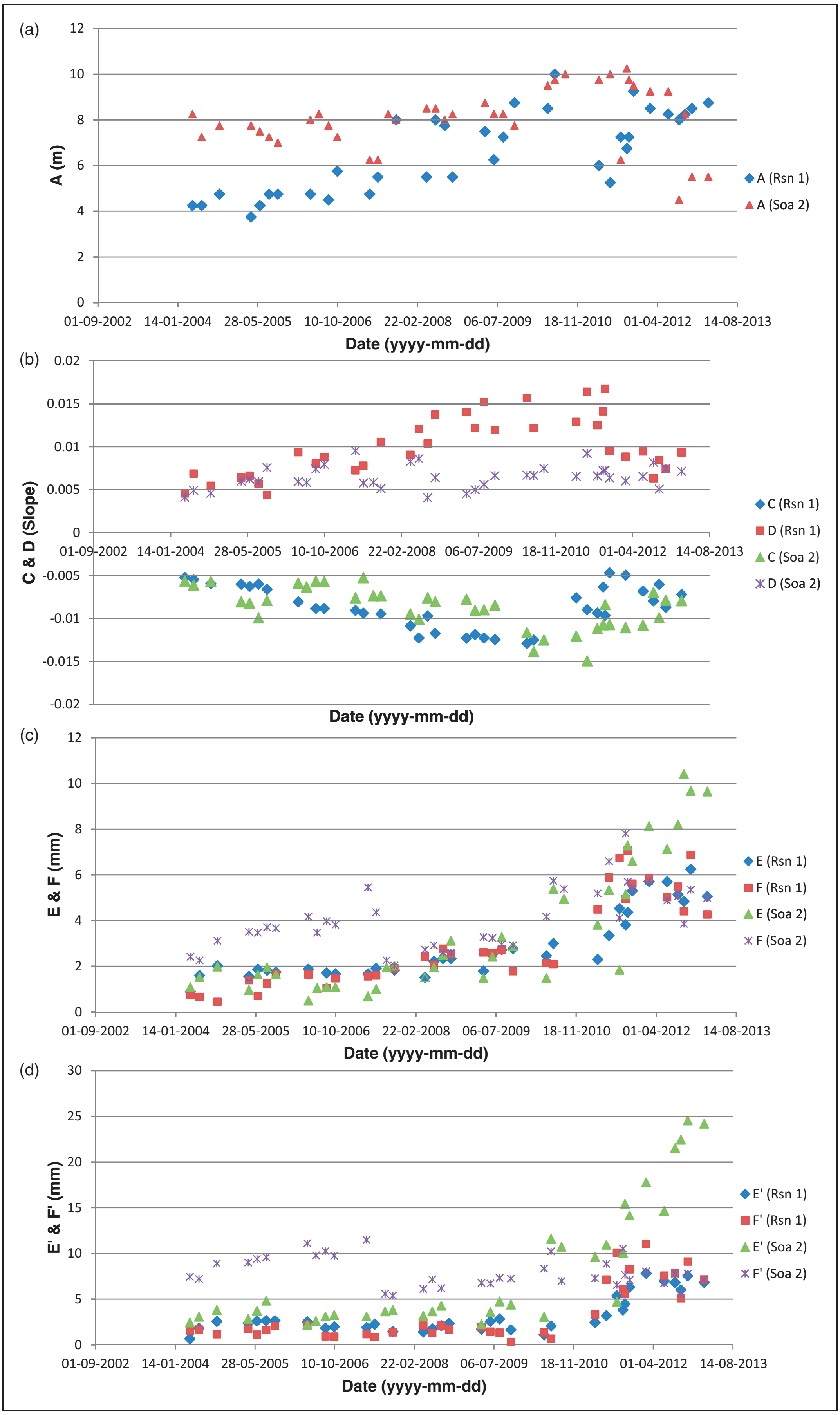

Figure 8. Trends of the defined geometry parameters in selected turnouts: (a) parameter *A*; (b) parameters *C* and *D*; (c) parameters *E* and *F*; (d) parameters E' and F'; and (e) parameters *G* & *H*.

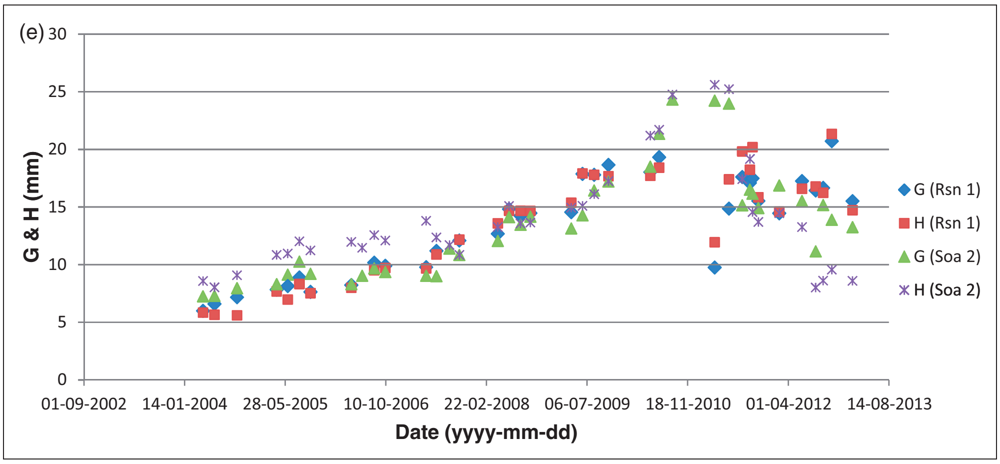

Figure 8. Continued.

the maintenance execution, the magnitude of A again increases, reaching 9.5 m by 29 June 2011. At this point, the growth trend ends and thus the magnitude of A remains constant. Similarly, C and D show an increasing trend in both turnouts until 11 June 2011; after this, they demonstrate a reducing trend until they ultimately become stable. This pattern shows that the crossing has continuously settled down until it reaches a limit. After reaching this limit, the crossing cannot settle anymore, and the geometry fault widens. As expected, the trend for E and F is similar to that for E' and F'; the degradation grows slightly until 11 June 2011, and after this time a sharp increase can be seen. To interpret these trends, it is necessary to consider the trends of G and H at the same time. The G and H grow exponentially until 11 June 2011; afterwards, they become constant. This indicates that the geometry fault wave at the crossing has reached its limit (about 25 mm) and the fault has transferred to the next wave in the crossing neighbourhood. This transfer can be perceived by the sharp increase in E/ F and E'/ F' trends.

Not surprisingly, the results show that the studied turnouts exhibit different geometrical degradation rates. Different factors such as the traffic, the subgrade quality, the age of the asset and the maintenance strategy selected can have an effect on the rate of degradation. Another important factor is the location and environment in which the turnout has been placed. The qualities of the subgrade and the weather affect the track stiffness; different track stiffness values result in dissimilar stress distribution behaviour and, consequently, different degradation rates. The geometry degradation analysis indicates that turnouts should be treated individually with different degradation rates and different maintenance frequencies.

The results also indicate that the maintenance was carried out at different geometry levels for different turnouts. Due to the limited maintenance resources available, it is important to analyse the degradation rate of the asset and to utilise maintenance decision support tools such as reliability, availability, maintainability and safety (RAMS) and also LCC to define a cost-effective maintenance threshold. This, in turn, will indicate the optimal time for performing maintenance to reduce the cost and increase the availability.

The analysis of the $S_{\max}$ and AR_a can be used to estimate the critical residual area in which the maintenance should be performed. On the other hand, the analysis of geometry parameters provides more accurate and reliable information on the deepening and widening growth rate due to the accumulated loads along the life cycle course of turnouts. It also indicates the limits for maximum track settlement in the crossing section. Trend analysis of the G and H parameters indicates that the maximum settlement limit for the studied turnouts (Rsn 1 and Soa 2) is about 25 mm (see Figure 8(e)). Although, the age and the location of the turnouts are different, similar trends can be seen in both of them. After reaching this limit the values of G and H become scattered. This shows that the geometry fault wave at the crossing has reached its limit and the fault has transferred to the next wave in the crossing neighbourhood. This transfer can be observed by the sharp increase in E/F and E'/ F' trends. Applying this knowledge within a LCC model facilitates the maintenance decision-making process to specify cost-effective alert / intervention limits.

Conclusions

The study proposes two different approaches to analyse the geometrical degradation of turnouts at crossing sections. The following conclusions are drawn.

1. The defined parameters in both approaches indicate that turnouts should be treated individually using different degradation rates and different maintenance frequencies.
2. The results of the second approach (i.e. the analysis of geometry parameters) indicate that a limit for crossing position settlement can be defined.

3. Before reaching this limit, the vertical degradation rate at the crossing point (deepening) is higher than the degradation rate in the vicinity of the crossing (widening). However, after reaching the settlement limit, the crossing can no longer settle and the geometry faults transfer to the next waves in the crossing neighbourhood.

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