Journal of Zhejiang University SCIENCE A
ISSN 1009-3095 (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Field investigation on effects of railway track geometric parameters on rail wear

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Received Oct. 20, 2005; revision accepted July 25, 2006

Abstract: Rail wear has dramatic impact on track performance, ride quality and maintenance costs. The amount of rail wear is influenced by various elements among which geometric parameters play an important role. The amount of wear in Iran's railway lines and its imposed maintenance costs oblige us to make modifications on the various geometrical parameters. In order to ensure the effectiveness of these changes, it is necessary to investigate these parameters and their effects on the wear. This research is aimed at studying the effects of different track geometrical parameters on the vertical and lateral wear by conducting a three phase field investigation. The first phase was carried out at the switches of a station, the second phase at a straight line, and the third at a curved line out of the station. The results obtained are analyzed and the role of each track geometrical parameter in the rail wear is discussed. Recommendations for prevention or reduction of rail wear are presented.

Key words: Rail wear, Vertical and lateral wear, Superelevation, Gauge, Longitudinal slope, Track geometry
doi:10.1631/jzus.2006.A1846 **Document code:** A **CLC number:** TU375

INTRODUCTION

Among the numerous components used in the railway industry for high axle load operations, wheels and rails comprise a major source of running expenditure. The wheel/rail interaction is the main technical factor determining design procedures and maintenance and replacement schedules for both vehicle and track. The rail wear is one of the most important factors causing reduction of the railway track life cycle. The re-profiling and replacement of worn wheels and rails is responsible for a significant part of railway systems operating costs (Sadeghi, 2002; Mutton and Marich, 1981).

Rail wear is one of the most crucial problems in Iran and every year a large amount of money is spent on rail/wheel maintenance and renewal due to this problem, whose resolution required looking into the factors influencing rail and wheel wear. The amount of the rail and wheel wear is influenced by various elements among which geometric parameters play an important role (Sadeghi, 2004). According to the literature, considerable potential exists for the reduction of wear rates by modifying the geometric parameters of the track (Mutton and Epp, 1983). The current study is aimed at determining the influences of the geometrical parameters on rail wear by a thorough field investigation of one of Iran's main railway lines in which a great degree of wear has been reported (Sadeghi, 2004). Using the results of the investigation, this paper discusses the influence of several geometric factors on the rail wear, leading to recommendations on methods of rail wear reduction.

RAIL WEAR AND INFLUENCING PARAMETERS

Where the wheel meets the rail, two types of movement occur: rolling and sliding. Due to the movement the rail/wheel contact area undergoes cyclic stresses causing various kinds of rail and wheel wear (Gahr, 1987). In general, rail wear is classified into vertical and lateral wear. Vertical wear occurs on the upper head of the rail. This type of wear is evident along the straight track or on the inner rail of the curves. Lateral wear is the wear of the railhead side. At curves, this type of wear is the most important parameter determining the operating life of wheel and rail. Local wear is not in this classification, because it occurs in the form of lateral or vertical wear (Spikes *et al*., 1986; Dearden, 1960; Allery, 1993). The shape of vertical and lateral wear and the related measurement point on the railhead are shown in Fig.1.

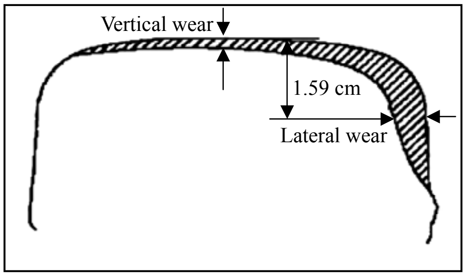


Fig.1 Vertical and lateral rail wear

The factors influencing the behavior of the wheel and rail wear can be divided into four main groups: operating condition, the geometric condition of track and vehicle, material properties, and rheological variables such as lubrication. The amount of wear and its imposed maintenance costs oblige us to make modifications in the various parameters related to the track system and vehicles to reduce wear. To ensure the effectiveness of these changes, it is necessary to investigate these parameters and their effects on the wear (Mutton and Epp, 1983). The parameters related to the track system, investigated here, include longitudinal slope, superelevation or cross-level, track gauge, and radius of the curves. These are discussed as follows.

Longitudinal slope influences the rail wear in two ways: (1) In steep slopes, locomotive wheels may spin causing severe local wear; (2) When the wagon passes a curve in a steep slope, the weight of the wagon is transferred to the inner rail and the railhead widens.

Superelevation or cant is one of the important factors affecting wear, especially lateral wear in the curves. Due to the centrifugal forces at the curves, the outer rail bears substantial amount of forces that wears it out. By applying a superelevation, wear can be decreased (Esveld, 2001). If the superelevation is less than the expected amount, lateral wear occurs on the outer rail. On the other hand, if the superelevation is more than the theoretical value, the inner rail of the curve goes under extensive stresses that result in wearing the inner rail. Since superelevation is not considered in junctions and switches, a great amount of force is applied to the switch rails. As a result, switches are subjected to a significant wear (Csontos, 1989).

The cross-level, not to be confused with the superelevation, is the amount of vertical deviation between the left and the right rail from their intended distance. The intended distance refers to the amount of allowable superelevation. In fact, the cross-level is superelevation deficiency (Kramp, 1998). In this paper, the vertical deviation between the rails in switches and straight rails is called cross-level and in the curve is considered as superelevation deficiency.

Track gauge is the distance between the inside of the railheads, measured 14 mm below the surface of the rail. The issue of gauge is more of concern at curves and switches (Esveld, 2001). The standard gauge in most countries including Iran is 1435 mm.

Another geometric parameter influencing rail wear is the radius of the curves. The radius of the curves is designed according to the speed of the vehicles and the design limitations. It is apparent that by reducing the radius of the curve the forces exerted from the wheel to the outer rail increase, resulting in the lateral wear of the outer rail.

FIELD INVESTIGATIONS ON TRACK GEOMETRIC PARAMETERS

The field investigations of the track geometric parameters influencing rail wear focus on railway lines in Isfahan (the central province of Iran), where a great deal of wear have been observed. The geometric parameters considered in this investigation are the track gauge, longitudinal slope, cross-level (superelevation deficiency), and radius of the curve. In this investigation, an attempt was made to directly measure the mentioned parameters to study their role in the rail wear. The field investigation was performed in three phases.

The first phase addresses the switches of a curved railway line at Hassanabad station. Along the switches, the measurements were made at: (1) the beginning of the switch blade, (2) three meters from the beginning of the switch blade, (3) the middle of the switch blade, (4) the end of the blade, (5) the beginning of the frog, and (6) the end of the frog. The curved line starts from the frog of switch No. 17 to the end of the frog of switch No. 25. A schematic view of the location of the switches at the station is presented in Fig.2.

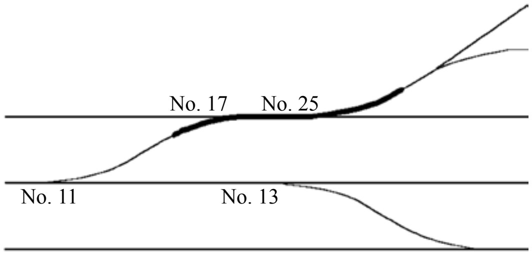


Fig.2 Schematic view of location of the station switches

In this phase, the gauge, cross-level, and longitudinal slope were measured at specific points of switches where the amount of wear was measured. To measure the wear along the switches, calipers and rulers were used and track templates were utilized to measure the geometric parameters of the track. Table 1 presents the results of the measurement for gauge, cross-level, and longitudinal slope.

In the second phase of the inspections, a straight railway line out of the station was studied. The length of this line is 180 m. Geometric parameters and the amount of rail wear were measured at specific points (every 10 m). These were measured by particular kinds of rail templates. The measurement results for the geometric parameters and the amount of vertical and lateral rail wear are presented in Table 2, where a positive cross-level means that the right rail is higher than the left rail and vice versa.

Finally, in the third phase, a 300 m long curved railway line out of the station was investigated. The geometric parameters and the amount of wear were measured every 10 m. The defect related to the superelevation is defined as the difference between the existing superelevation and the designed superelevation. The allowable (designed) superelevation at this curve, based on the radius of the curve (2000 m) and the allowable speed of 60 km/h, is 22 mm (Profillidis, 2000). The measurement results for the geometric parameters and the amount of vertical and lateral rail wear in the third phase of study are presented in Table 3.

The results obtained in this investigation indicated that there are severe lateral, normal and local wear in the railway line. Some views of the rail and switch wear are shown in Fig.3.

Table 1 Measurement results for gauge, cross-level and longitudinal slope, Phase 1

Place of measurement	Gauge (mm)	Longitudinal slope (‰)	Cross-level (mm)	Gauge deficiency (mm)	Vertical wear (mm)	Lateral wear (mm)
End of switch frog No. 17	1427	1.3	−5	−5	9	6
Beginning of frog No. 17	1439	1.3	1	4	15	5
End of switch blade No. 17	1442	1.3	0	7	14	4
Middle of switch blade No. 17	1428	1.3	−8	−2	11	13
Beginning of switch blade No. 17	1434	1.3	−12	−1	18	9
Beginning of switch No. 17	1437	1.3	−10	2	15	5
Between two switches	1435	1.3	−2	0	14	3
Between two switches+10 m	1433	1.3	2	−2	11	4
Beginning of switch No. 25	1435	1.3	0	0	14	8
Beginning of switch blade No. 25	1440	1.3	−1	5	20	6
3 m from beginning of blade	1431	1.3	−5	−4	15	16
Middle of switch blade No. 25	1425	1.3	−5	−8	16	18
End of switch blade No. 25	1437	1.3	−3	2	11	7
Beginning of frog	1437	1.3	−4	2	16	9
End of switch frog No. 25	1435	1.3	−2	0	9	4

Table 2 Measurement results for gauge, cross-level and longitudinal slope, Phase 2

Distance (m)	Longitudinal slope (‰)	Cross-level (mm)	Gauge deficiency (mm)	Lateral wear (mm)		Vertical wear (mm)	
				Right rail	Left rail	Right rail	Left rail
0	3.1	2	0	3	4	12	13
10	3.1	3	0	2	5	11	19
20	3.1	2	−4	12	13	13	14
30	3.1	13	−2	5	11	9	22
40	3.1	2	0	2	3	12	11
50	3.1	2	2	4	3	18	19
60	3.1	0	−5	19	15	16	14
70	3.1	9	−2	5	9	11	19
80	3.1	−8	2	5	3	20	10
90	3.1	3	0	6	5	11	15
100	3.1	2	1	1	2	13	14
110	3.1	6	1	3	5	9	17
120	3.1	2	0	2	3	16	16
130	3.1	3	3	2	7	17	19
140	3.1	2	0	1	2	15	17
150	3.1	−1	−1	4	3	18	14
160	3.1	0	−1	4	3	15	15
173	3.1	0	−1	1	2	14	14
180	3.1	−2	0	4	2	18	13


(a) (b) (c) (d)

Fig.3 (a) Local wear; (b) Vertical wear; (c) Lateral wear; (d) Lateral wear of switch blade

Table 4 presents the maximum values of vertical and lateral wears and the allowable values of rail wear and switches wear. The allowable values depend on the maximum train speed and type of rails (Iran Ministry of Roads and Transportation, 2004).

RESULTS AND DISCUSSION

The results obtained from the field, presented in the last section, indicated that the amount of wear is substantially high. In order to investigate the role of the track geometric parameters in the rail wear, the results obtained were analyzed and discussed by putting the results together in a comparative form and obtaining a series of meaningful diagrams. The authors tried to draw out recommendations for prevention or reduction of rail and wheel wear by providing some suggestions on the modification of track geometrical conditions.

Cross-level and gauge deficiency versus the amount of vertical and lateral wear, are presented in Figs.4 and 5 respectively. The amount of lateral and vertical wear at the station is more than that out of the station. This indicates that the switch rails are more prone to wear. Considering the gauge deficiency and

Table 3 Measurement results for gauge, cross-level and longitudinal slope, Phase 3

Distance (m)	Longitudinal slope (‰)	Gauge deficiency (mm)	Superelevation deficiency (mm)	Lateral wear (mm)		Vertical wear (mm)	
				Outer rail	Inner rail	Outer rail	Inner rail
0	6.5	−1	6	6	4	15	9
10	6.5	−1	2	6	3	8	7
20	6.5	−4	2	7	3	12	10
30	6.5	−1	5	4	4	7	11
40	6.5	−3	7	3	6	6	9
50	6.5	−3	6	5	2	11	12
60	6.5	−5	4	18	8	12	12
70	6.5	−1	6	4	2	10	10
80	6.5	−3	8	4	6	9	10
90	6.5	−4	9	10	7	11	13
100	6.5	−1	5	6	3	10	8
110	6.5	1	6	3	4	9	9
120	6.5	0	3	6	5	10	11
130	6.5	−1	2	5	4	10	11
140	6.5	−1	−1	6	3	8	7
150	6.5	5	−2	3	2	21	6
160	6.5	0	2	3	3	11	8
170	6.5	0	6	3	3	8	10
180	6.5	3	8	2	6	13	11
190	6.5	−1	10	2	8	11	14
200	6.5	−1	7	5	4	14	12
210	6.5	−3	6	13	9	17	12
220	6.5	0	8	4	6	16	14
230	6.5	1	8	2	5	7	9
240	6.5	−3	9	5	5	12	11
250	6.5	−3	8	6	6	12	12
260	6.5	−1	9	4	7	10	13
270	6.5	−2	7	8	4	10	12
280	6.5	−4	6	17	3	9	9
290	6.5	0	4	7	2	10	8
300	6.5	−1	5	7	3	11	10

Table 4 Maximum rail wear and maximum switches wear

Type of wear	Maximum speed (km/h)		Maximum wear (mm)		Allowable wear (mm)	
	Rail wear	Switches wear	Rail wear	Switches wear	Rail wear	Switches wear
Vertical	60	15	24	20	16	14
Lateral	60	15	19	18	16	14

the amount of lateral wear in switches Nos. 17 and 25, it can be concluded that where the gauge is narrow, lateral wear increases (especially in the middle of the switch blades). As an illustration, the gauge deficiency in the middle of the switch blade No. 25 is more than the gauge deficiency in the middle of the switch blade No. 17; consequently, lateral wear in switch No. 25 is greater. Fig.4 does not show a clear relationship between vertical wear and gauge deficiency; therefore, it can be deduced that gauge deficiency is not influential in vertical wear at switches.

As shown in Fig.5, where the cross-level is negative, the vertical wear increases. It is indicated at the beginning of switch blade No. 17 and at the middle

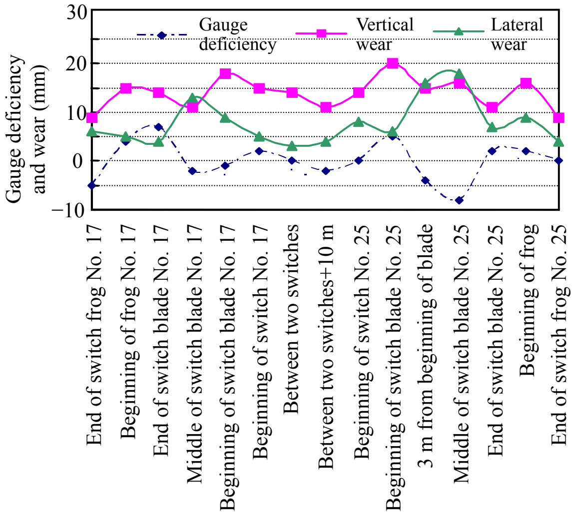


Fig.4 Amount of vertical and lateral wear and gauge deficiency, curved track at station

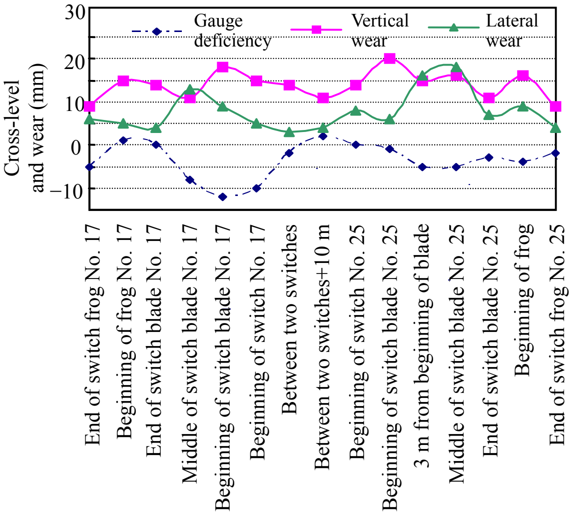


Fig.5 Amount of vertical and lateral wear and cross-level, curved track at station

of switch blade No. 25. On the other hand, in some sections such as the middle of switch blade No. 17, although the cross-level is negative, a reduction in the amount of vertical wear is observed. Therefore, it can be concluded that cross-level has moderate influence on vertical wear. As shown in Fig.5, cross-level has also an identical moderate effect on lateral wear. To draw a reasonable conclusion, the results should be considered and discussed in a holistic manner. For instance, in some points such as the middle of switch blade No. 17, in spite of the fact that the gauge deficiency is slight, because of a high cross-level, the amount of lateral wear is significant.

Fig.6 presents the amount of vertical and lateral wear in different parts of the switches Nos. 17 and 25. These parts are: the beginning of switch blade, the middle of switch blade, the end of blade, the beginning of frog, and the end of frog. Fig.6 indicates that the amount of wear measured at different points of the switches is not consistent. As it is evident in the figure, the end of the frog has the lowest vertical and lateral wear. It means that the end of the frog is the most resistant part of the switch to wear. As can be seen, vertical wear at the beginning of the frog is high, but the lateral wear is not significant. Therefore, the beginning of the frog that bears the wheel loads of both the main line and the branching line is a critical point for the case of vertical wear. The results of the measurement in the middle of the switch blade show that the lateral wear in this section is substantially high and is more than the amount of vertical wear. At the beginning of the switch blade, where the impact of wheels is severe, the amount of vertical wear is substantially high as indicated in Fig.6.

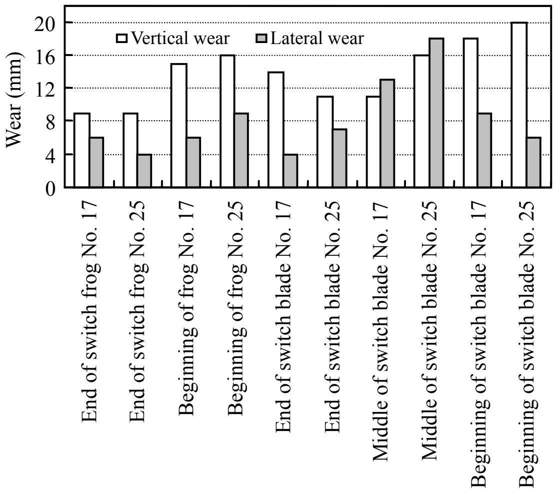


Fig.6 Different points along the switch and related wear

Figs.7 to 10 present the amount of gauge deficiency, cross-level, and rail wear of the straight railway line out of the station. The cross-level is calculated based on the difference between the elevations of the right and the left rails. Where the cross-level is negative, it means that the right rail is lower than the left rail. As shown in Fig.7, at most of the points, the lateral wear is less than 5 mm, except points 20 and 60 which have high negative gauge deficiencies. Based on this fact, it can be concluded that where the gauge

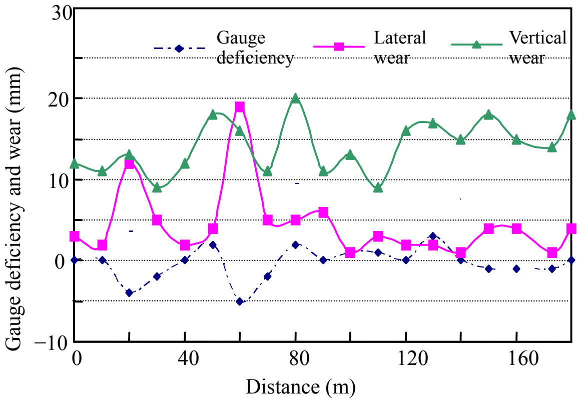


Fig.7 Amount of vertical and lateral wear of right rail and gauge deficiency, straight line out of station

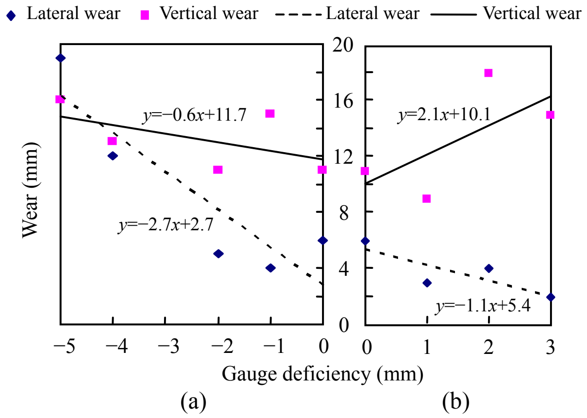


Fig.8 Amount of negative (a) and positive (b) gauge deficiencies vs the amount of wear

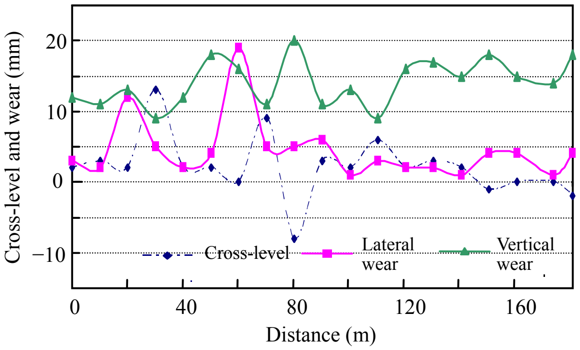


Fig.9 Amount of vertical and lateral wear of right rail and cross-level, straight line out of station

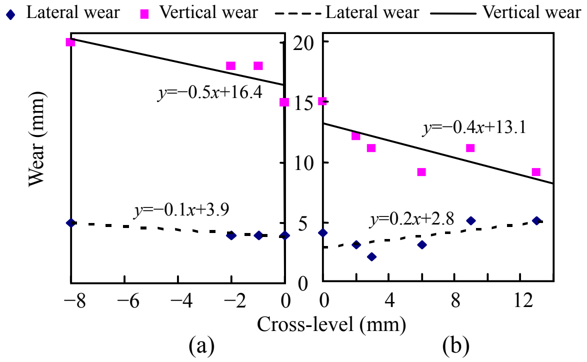


Fig.10 Amount of vertical and lateral wear vs the negative (a) and positive (b) cross-levels

is considerably narrower than the standard gauge, lateral wear increases. The nature of vertical wear variations due to the changes in the track gauge deficiency is more sophisticated, that is, at the points having gauges more than the standard gauge (points 50, 80, and 130), the vertical wear is increased but, if the gauge is less than the standard gauge, the vertical wear is not affected noticeably. It reveals that the vertical wear is more influenced by broad gauges. To analyze the effect of gauge deficiency more precisely, the amount of negative and positive gauge deficiencies versus the amount of wear are presented in Figs.8a and 8b respectively. Fig.8a indicates that the negative gauge deficiency has significant effect on the lateral wear. As the gauge narrows, the amount of lateral wear increases with a high rate of 2.7 wear/gauge deficiency. Figs.8a and 8b show that the influence of broader gauge on the lateral wear is less than the effect of narrow gauge (at rate of 1.1 wear/gauge deficiency). As indicated in Fig.8b where the vertical wear is maximum, the lateral wear is minimum, and vice versa. The influence of narrow gauge on vertical wear is less than that on lateral wear as the gradient of vertical wear trend line is one fifth. Comparison of Figs.8a with 8b indicates that the vertical wear shows identical rising behavior with both narrowing and widening of the gauge. On the other hand, the results for lateral wear shows that widening of the gauge decreases the lateral wear.

Fig.9 shows the amount of vertical and lateral wear versus the cross-level in the straight line out of the station. Fig.9 indicates that where the cross-level is high (at points 30, 70, and 110), the vertical wear is decreased, and where the cross-level is low (point 80), the vertical wear is increased, from which we can conclude that there is a reverse relationship between the cross-level and the vertical wear. Fig.9 does not show any major effect of the cross-level variations on the amount of lateral wear. To draw clearer conclusion, the best fit linear line for the amount of vertical and lateral wear versus the negative and positive cross-levels is made in Fig.10. Unlike Figs.8a and 8b, the lateral wear shows identical ascending behavior with both rise and fall of the cross-level, but the change rate in the lateral wear is so insignificant, indicating that the cross-level is not influential in lateral wear. Fig.10 shows that higher amounts of cross-level decrease the vertical wear. According to the results presented in Figs.8 and 10, it can be deduced that in straight railway lines, gauge deficiency is more influential than cross-level in both vertical and lateral wear.

Figs.11 and 12 present the amount of superelevation deficiency, gauge deficiency, and wear of the inner rail in a curved line between the stations. Superelevation deficiency is the difference between the design superelevation and the existing superelevation. According to the theoretical postulates, where the superelevation is more than the allowable value, the inner rail is exposed to heavier loads and in turn, vertical wear on the inner rail increases (Csontos, 1989). Fig.11 indicates that, where the superelevation is more than the design value (e.g. points 90, 190, and 260), the amount of vertical wear of the inner rail is increased and where the superelevation is low (points 10, 150, and 290), this amount is decreased, proving the theoretical postulates. There is a direct relationship between the superelevation and the amount of lateral wear of the inner rail.

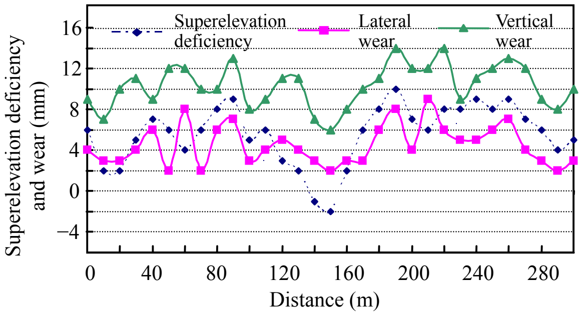


Fig.11 Amount of vertical and lateral wear of inner rail and superelevation deficiency

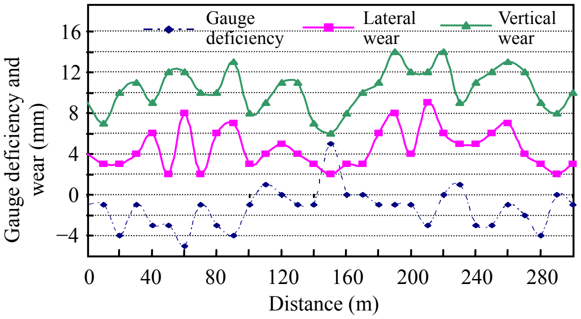


Fig.12 Amount of vertical and lateral wear of inner rail and gauge deficiency

The effect of gauge deficiency on lateral wear of inner rails is evident in Fig.12 indicating that where the gauge deficiency is negative (points 60, 90, and 210), the lateral wear of the inner rail becomes more severe which can be extended to the vertical wear. In order to explain the exceptional cases, it is necessary to consider all parameters. At point 60 in Fig.11, the superelevation is decreased, but the lateral wear is increased contradicting the mentioned theoretical postulate; although, as indicated in Fig.12, at point 60 the gauge is much narrower than standard gauge. Therefore, the increase in lateral wear is reasonable.

As shown in Fig.13, increase of superelevation increases the lateral and vertical wear of the inner rail. The increase in the vertical wear (0.6) is more than the increase in the lateral wear (0.4), from which we can conclude that the influence of the superelevation on the vertical wear of the inner rail is more effective.

Fig.14 indicates the effect of gauge deficiency on the wear of the inner rail. It can be concluded that the vertical wear uniformly decreases at rate of 0.5 wear/gauge deficiency when gauge deficiency increases. Based on the results presented in Figs.13 and 14, it can be deduced that the factors influencing lateral wear are: gauge narrowing, rise of superelevation, and the gauge widening at rates of 1.3, 0.4, and −0.1 wear/parameter deficiency, respectively. In addition, vertical wear of the inner rail is influenced by rise of superelevation, and gauge narrowing at the rates of 0.6 and 0.5 wear/parameter deficiency, respectively.

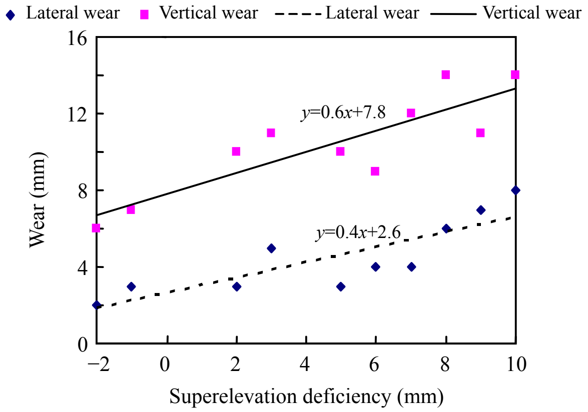
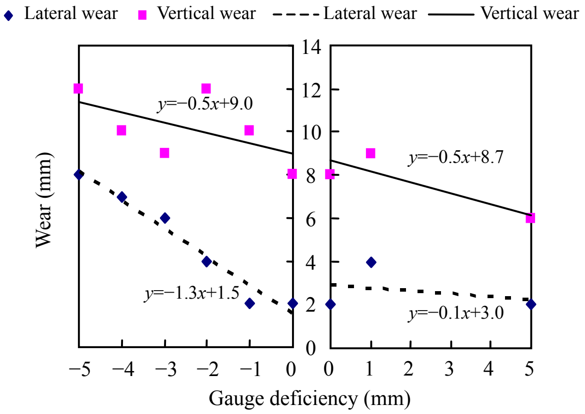


Fig.13 Superelevation deficiency vs wear, inner rail



(a) (b)

Fig.14 Amount of negative (a) and positive (b) gauge deficiencies vs the amount of wear, inner rail

The effect of superelevation deficiency on the wear of the outer rail in the curve can be observed in Fig.15. From the results presented in this figure, it can be concluded that the superelevation deficiency has a reverse relationship with the lateral wear of the outer rail, that is, in points with excessive superelevation (e.g. points 40, 110, and 190), lateral wear is low and vice versa. Where the superelevation is high, vertical wear of the outer rail is decreased too. Comparing the superelevation deficiency with the amount of wear at point 150 indicates that, where the superelevation is less than the amount required, the amount of vertical wear is too high. Fig.16 shows the significant influence of gauge deficiency on lateral wear of the outer rails. In all points with negative gauge deficiency (e.g. 60, 90, 210 and 280), the amount of lateral wear is increased. At point 90 (Fig.15), due to having narrow gauge, contrary to expectations, both superelevation deficiency and the lateral wear are increased. There are also some exceptions inexplicable by the above factors.

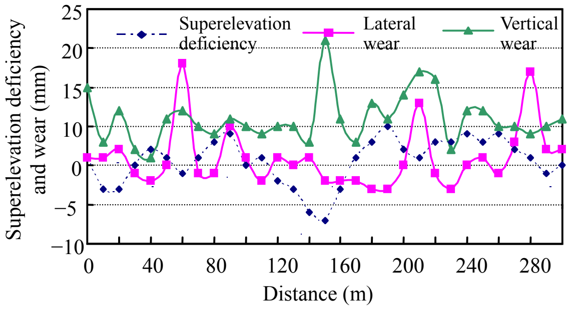


Fig.15 Amount of vertical and lateral wear of outer rail and superelevation deficiency

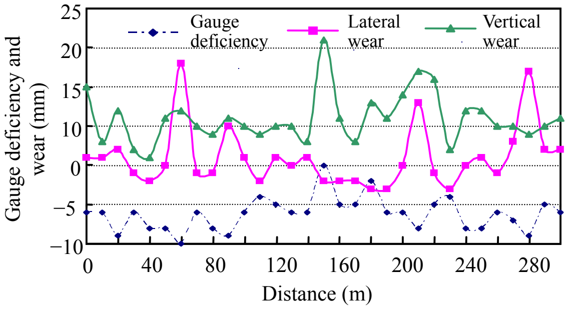
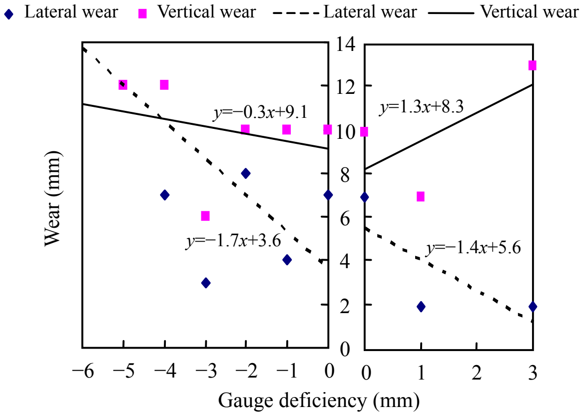


Fig.16 Amount of vertical and lateral wear of outer rail and gauge deficiency

Based on the results presented in Figs.17 and 18, it can be deduced that the influential factors related to the vertical wear of the outer rail are: the gauge widening, the gauge narrowing, and increase in superelevation, with the rates of 1.3, −0.3, and −0.2 wear/parameter deficiency, respectively. Moreover, it can be concluded from these figures that the lateral wear of the outer rail is mostly affected by the narrowing gauge, widening gauge, and superelevation deficiency with the rates of −1.7, −1.4, and −0.4 wear/gauge deficiency, respectively. By comparing the figures, it can be obtained that the amount of wear is more affected by the gauge deficiency than the superelevation deficiency.



(a) (b)

Fig.17 Amount of negative (a) and positive (b) gauge deficiencies vs wear, outer rail

Comparison of the results obtained from the lines with the slopes of 1.3‰, 3.1‰, and 6.5‰ indicates that slopes of up to 3‰, have less influence on the amount of rail wear while the higher slopes (such as 6.5‰) have considerable impact on the amount of rail wear.

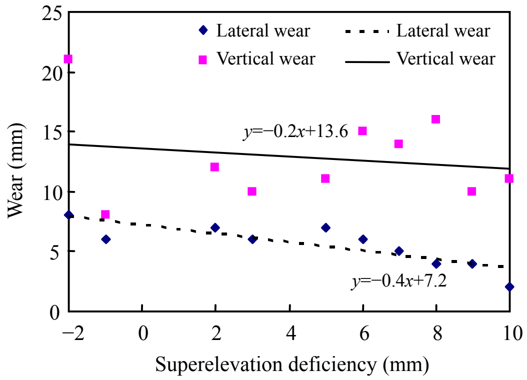


Fig.18 Superelevation deficiency vs wear, outer rail

CONCLUSION

In this study through a field investigation, the effects of track geometric parameters on rail wear were investigated and the following conclusions were drawn:

(1) In switches, the amount of wear differs from point to point. The end of the frog is the most resistant point to wear. However, the beginning of the frog and the beginning of the switch blade are most prone to vertical wear while the middle of the switch blade is more prone to lateral wear. The most influential geometric parameter in the switches wear is gauge deficiency (particularly for the case of lateral wear). Cross-level is not a significant factor in switches wear. The results of this investigation indicate that in order to decrease wear at the switches, rails with higher hardness should be used. Moreover, regular inspections should be implemented to control the geometrical parameters. Lubrication and rail grinding can also be helpful in reducing the amount of wear in switches.

(2) In straight railway lines, the gauge deficiency is the most significant geometric factor influencing the rail wear. Narrow gauge increases the lateral wear, while vertical wear is increased by widened gauge. In straight railway lines, cross-level influences only the vertical wear. As the cross-level increases, vertical wear decreases. Longitudinal slope is only responsible for local wear. In straight railway lines, regular inspections are highly recommended for controlling and decreasing track geometrical parameters deficiencies. Rail grinding and lubrication (lubricators with high viscosity to reduce the vertical wear) are also vital for reducing the wear.

(3) In the inner rail of the curves, the following geometric factors are influential in the lateral wear, in their order of importance: narrow gauge, high superelevation, and widened gauge. Additionally, vertical wear is influenced considerably by high superelevation and narrow gauge. In the outer rail of the curves, narrow gauge, broad gauge and high superelevation are more influential in the case of lateral wear and broad gauge, narrow gauge, and high superelevation are important factors in the case of vertical wear. As the lateral wear is critical in the curves, the causative factors should be removed. Therefore, regular inspections should be implemented to control the track gauge precisely. Additionally, during the construction of the track, more attention should be paid to the amount of the superelevation. Rail grinding and reprofiling of the rail to make an asymmetric rail are also recommended for reducing the lateral wear at the curves.

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