Study on the Factors Which Cause the Wheel Skidding of JR Ltd. Express EMUs

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Authors made an experimental event recorder, which can record not only the behavior of a train, but also accurately identify the site of the track where wheel slip and spin occur. The recorder was installed on a JR Ltd Express electric motive unite operated on conventional lines. They analyzed the data piled up in the recorder, and found several wayside factors which cause the wheel skiddings. The wheel skid occurrence rate par 1 000 km train running distance was discussed under various weather conditions. Moreover, the results of the investigation were also discussed on the wheel skid occurrence rate in a snow bound area and the relationship between a snow weather condition and wheel skid occurrence rate.

Key Words: Railway, Rolling Stock, Wheel, Rail, Adhesion, Skidding

1. Introduction

Railway rolling stock wheel skidding ordinary occurs when the adhesion coefficient (hereafter, indicated by “µ”) has decreased on a rail, and in order to prevent wheel skidding of a running train, it is first necessary to study the factors that cause the decrease in µ. Related studies of µ behavior have been conducted using the slipping adhesion test truck, which can continuously measure µ on main lines such as JR Tohoku Main Line, Yamanote Line, Iida Line, Chikuhi Line, Houhi Main Line, and Nikko Line(1),(2). The studies have clarified that the tracks and structures on the way-side such as turnouts, grade crossings, and rail lubricators, as well as fallen leaves in thickly wooded areas and needles from coniferous trees can cause large, localized decreases in µ, and that rain, snow, etc., that wet the rails can cause decreases in µ over wide areas. This study, however, does not refer to the evaluation of the degree to which the various factors that cause a decrease in µ affect wheel skidding. Several studies of wheel skidding on main lines had been done for Ltd. express trains on the JNR Sanyo Main Line and commuter trains on the JR Chikuhi Line(3),(4). However, the studies did not specify the sites where wheel skidding occurred, nor did they specify factors contributing to the wheel skidding. This is because the sites of wheel skid occurrence were not accurately specified in the studies, so it was not possible to identify the ground-side factors related to wheel skidding.

In order to resolve these problems, the authors prepared an event recorder, which could accurately specify the sites where wheel skidding occurred, and which could automatically record detailed vehicle operation conditions at the time of wheel skid occurrence. The event recorder was installed over a long period of time on a JR Ltd. express electric motive unite (hereafter, “EMU”) operating on conventional lines. The results of the analysis of the data obtained with the event recorder made it possible to identify numerous ground-side factors contributing to wheel skidding and to quantitatively evaluate the degree to which these factors contribute to wheel skidding.

2. Methods Used to Collect Wheel Skid Data

2.1 Event recorder installed on the EMU and details of the recorded data

The device for recording wheel skid data was installed on the Ltd. express EMU “Hakutaka” operating on conventional lines connecting 261.5 km between Kana-
zawa on the JR Hokuriku Main Line and Echigo-Yuzawa on the JR Joetsu Line via the third sector Hokuetsu North Line. The EMU was a 485-Series standard model JR AC-DC dual-purpose train in the configuration shown in Fig. 1. The train set consists of eight cars — six cars consisting of power cars with pantographs (M′) and power cars with control units (M), one driving trailer Tc and one 1st class driving trailer Tsc. The maximum’s speed for this train is 120 km/h (130 km/h on the Hokuetsu North Line). The event recorder installed on the train automatically collected the data shown in Table 1 while the power source to the train was turned on. Information about speed was obtained through tacho-generator tachometers installed on the front axle (the Kanazawa side) of the first car (hereafter, “trailer”) and on the last axle (the Echigo-Yuzawa side) of the fourth car (hereafter, “power car”).

2.2 Standards for judging wheel skid occurrence

A commonly used method to detect the wheel skidding is a method based on fluctuations in deceleration speed. However, with the tachometer generator (JR standard model AG20) installed on the experimental train, it is difficult to ascertain deceleration speed with a high degree of precision, so it is, therefore, difficult to detect minute levels of wheel skidding. Therefore, for this study, if the difference in wheel speed between the trailer and the power car reached 1.0 km/h or higher, wheel skidding was considered to have occurred for the axle with the slower wheel speed.

2.3 Methods of specifying the site of wheel skidding and the factors contributing to wheel skidding

When calculating the just running position from the number of wheel rotations, errors can occur due to slight shifts in the stopping target points at stations, which serve as the basis for the calculations. The errors can also occur due to slight wheel skidding, etc. Therefore, in this study, the authors focused their attention on the track circuit. By using the search coils for track electric current detection, which are installed at the center of the train set, to detect the sending end of the track circuit(35),(36), the authors were able to calibrate the running distance calculations. The average length of the track circuit is approximately 1 km, so site point calibrations could be made for each short section(37). In order to identify the groundside factors that contribute to wheel skidding, images recorded by a video camera installed on the head end cab were also used to investigate the conditions near the sites at which wheel skidding occurred.

2.4 Period of the study

This study was conducted for approximately one year, from March 12, 2001 to March 22, 2002. The study included all of the data obtained during train operation, including deadhead runs in and out of the depots, but not including days on which the event recorder was not available for the purpose of inspections, adjustment, etc. The total distance run during this duration was approximately 208 000 km.

2.5 Methods of studying the weather conditions that the train encountered

The weather the train encounters during operation is one factor that deeply affects wheel skidding. In order to study the effects of weather conditions, the area through which the train ran was divided into three areas based on prefectural boundaries, taking the stations nearest the prefectural borders, Kurikara and Ichiburi, as the dividing points for the Ishikawa Prefecture Area (track distance in area: 17.8 km), the Toyama Prefecture Area (100.1 km) and the Niigata Prefecture Area (143.5 km). Weather observations made at 3:00 PM by local meteorological stations near each respective area, in Kanazawa, Toyama and Takada, were taken as the weather conditions encountered by the train when in the corresponding area. Also, because the train is essentially unaffected by weather while in a tunnel, a separate “tunnel” weather classification was used for the weather encountered by the train while in any of the 77 km of tunnels in the train operation.
3. Wheel Skidding Due to Groundside Factors

3.1 Wheel skidding caused by a decrease in $\mu$

It is estimated that much wheel skidding occurs at sites with low $\mu$. In this section, the authors will examine some cases in which wheel skidding was judged to have occurred as a result of groundside factors that cause a decrease in $\mu$.

3.1.1 Track side Factors

In this section, the authors will look at cases in which wheel skidding was judged to be caused by groundside factors, or more specifically, by factors related to facilities and equipment specific to the wayside factors.

Figure 2 illustrates a case of wheel skidding that occurred when the brake was applied to stop the train at a station. From the figure, the authors can see that when the straight air pipe pressure (hereafter, “SAP pressure”), which indicates the service brake application, is pressurized to 290 kPa, applying the braking force, the trailer speed drops suddenly at around 70 km/h and wheel skidding occurs. The SAP pressure for maximum service braking force is normally 440 kPa, so the braking force in this case is not so strong, and the weather was clear and sunny, and under such conditions, commonsense would indicate as not being conducive to wheel skidding. Furthermore, although the SAP pressure was maintained at a constant level, re-adhesion took place approximately 70 m from the site where wheel skidding began. Plus, it could be surmised that the wheel skidding is occurring within a localized area where there is a decrease in $\mu$.

The results of the study have verified that there is a turnout near the site where wheel skidding occurred. According to the studies conducted using the slipping adhesion test truck, oil coated on the fish plate of a turnout oozes onto the running surface of the blade, resulting in a localized decrease in $\mu$. For this reason, the authors consider that the decrease in $\mu$ at the turnout was the cause of the wheel skidding in this case. From the author’s study using the same slipping adhesion test truck, it was also found that mud, etc., transferring to the running surface of the rail from the tires of automobiles at grade crossings traversed by a large number of automobiles results in a localized decrease in $\mu$ as well. This study also recognized numerous cases of wheel skid occurring at grade crossings in the same way as the wheel skid occurring at turnouts. Because the decrease in $\mu$ due to these factors is localized, in many cases of wheel skidding due to such factors, once the train passes the site of decreased $\mu$, re-adhesion will occur. As such, there is a direct connection between wheel skidding and track structures, so in this paper, the authors will refer to factors causing this type of localized decrease in $\mu$ as “trackside factors”.

3.1.2 Surrounding area factors along the wayside

In this section, the authors will look at cases of wheel skid occurrence due to factors, other than trackside factors, that cause a decrease in $\mu$ on the groundside. From Fig. 3, the authors find that when the train was near mileage point 179 km 820 m, wheel skidding occurred at the trailer followed by re-adhesion. After progressing approximately 80 additional meters, the power car also underwent the same type of wheel skidding followed by re-adhesion. Because the distance between the axle of the trailer and the axle of the power car is approximately 80 m, the authors can consider that the wheel skidding occurred at the same ground site. Furthermore, because the SAP pressure at this time was low, 150 kPa, the authors know that the wheel skidding was caused by a localized decrease in $\mu$. However, there were none of the $\mu$-decreasing track side factors described earlier, such as turnouts or grade crossings,
at the site of this wheel skidding. Using video recordings to check the conditions at the site, they found that there were large Japanese cedar trees in the vicinity of the track. According to the study conducted with the slipping adhesion test truck, fallen leaves and needles that contain a large amount of oil, such as those from the Japanese cedar, cause a notable decrease in $\mu$. Accordingly, it was understood that this wheel skidding was caused by a localized decrease in $\mu$ due to the fallen needles from the Japanese cedar trees by the way side. There are, in fact, many clumps of Japanese cedar trees in the corresponding area, and the fallen needles from these trees are thought to cause numerous cases of wheel skidding in late autumn and early winter.

Figure 4 shows a case of minor trailer wheel skid occurring approximately 80 m from the entrance on the terminal point side of a long bridge (near mileage point 321 km 600 m), after which re-adhesion occurred at the center of the bridge, near mileage point 321 km 760 m. However, none of the previously described trackside factors were found on the bridge. Furthermore, the SAP pressure at the time of the wheel skidding was approximately 250 kPa, and strangely enough, although this pressure was, then, increased to a stronger braking force of approximately 330 kPa, re-adhesion took place. In other words, the wheel skidding is thought to have been caused by a localized decrease in $\mu$. From the results of the study, the authors understand that although there is a riverbed running under most of this long bridge, there is a strong stream in the portion directly under the site of the wheel skidding. From this, the authors could surmise that water vaporized from the river surface near the wheel skid site moistened the running surface of the rail, causing a decrease in $\mu$. Similar cases of wheel skidding have also been observed at this type of site on other long bridges.

These factors are groundside factors causing a localized decrease in $\mu$, but are not factors that are directly related to the railway tracks and structures. In this study, they refer to these factors as “surrounding area factors along the wayside”, and treat these as a new concept in
wheel skid factors. According to the results obtained with the slipping adhesion test truck, thick clumps of trees along railway tracks, coniferous trees in late autumn, etc., can cause a large decrease in $\mu$\(^{(1)}\). In this study, they have observed wheel skidding caused by these types of factors, and can also consider these to be classified as surrounding area factors along the wayside.

Thus, several factors clarified by previous studies as causing a decrease in $\mu$ have, naturally, been verified by this study as well to be factors causing wheel skidding.

### 3.2 Wheel skidding caused by the geographic factors

The cases of wheel skidding the authors have looked at thus far have been caused due to factors that cause a decrease in $\mu$. However, wheel skidding can also occur if a strong braking force is applied, even at sites where the $\mu$ is not low. The result of this study has shown that wheel skidding can occur frequently when strong braking force is applied at the entrance to a curve or on a downgrade. A common reason for wheel skid occurrence at the entrance to a curve is thought to be the application of strong braking force in order to decelerate to the speed limit for the curve. On downgrades, much of the wheel skidding is thought to be caused by the driver attempting to achieve the same level of deceleration on the downgrade as on a level section of track and, therefore, applying additional braking force. On a 10\(^{\circ}\) downgrade, for example, the braking force must be increased by roughly 15\% in order to achieve the same level of deceleration as on a level section. The application of this additional braking force may be directly related to the wheel skid occurrence.

Therefore, in this study, the authors have considered curves and downgrades themselves as functioning as factors that contribute to wheel skidding in the case of wheel skid occurrence during deceleration at the entrance to a curve and in the case of wheel skid occurrence during deceleration on downgrades of approximately 5\% to 10\%. Accordingly, for this study they refer to curves and downgrades that can trigger wheel skidding as "geographic factors".

### 3.3 Degree to which each groundside factor contributes to wheel skid occurrence

In this study, in addition to verifying cases in which trackside factors, surrounding area factors along the way-side and geographic factors contribute independently to wheel skidding, they also verified numerous cases in which multiple factors contributed simultaneously to wheel skidding. When the wheel skidding was found to occur as a result of geographical factors acting together with either trackside factors or surrounding area factors along the wayside, they considered these cases to be caused independently by simply either the trackside factors or surrounding area factors along the wayside. The authors then, attempted to study the degree to which the various groundside factors contributed to wheel skidding, as a ratio of the total number of wheel skid cases. In this study, they found no cases of wheel skidding thought to be caused by a combination of both trackside factors and surrounding area factors along the wayside.

The results of this study are shown in Fig. 5. This figure shows the ratios of the total number of wheel skid cases at which trackside factors, surrounding area factors and geographic factors, contributed to wheel skid occurrence. As shown in the figure, groundside factors, including surrounding area factors and geographic factors with turnouts, fallen leaves, and steep curves contribute to a large ratio of the total number of wheel skid cases. In regard to geographic factors, a large ratio of steep curve and downgrade contribution is seen despite the fact that when these factors contribute to wheel skidding together with other factors, the wheel skidding was considered to have occurred as a result of the other factors. The ratio of contribution by the groundside factors to wheel skidding is much changed according to the section of the line, which the train is running.

### 4. Degree to Which Various Weather-Related Factors Contribute to Wheel Skidding

Weather conditions, snow and rain in particular, cause a decrease in $\mu$, and, therefore, act as a factor causing wheel skidding. Rain and snow are undoubtedly groundside factors that contribute to wheel skid occurrence in the same way as turnouts and clusters of trees along the tracks. However, because rain and snow cause a large decrease in $\mu$, this precipitation can at times completely cancel out the several effects of other $\mu$-decreasing factors, such as moisture from river streams. Accordingly, there are problems with studies to consider weather factors at the same level as other groundside factors when discussing the ratio of contributions each factor makes to wheel skid occurrence. Therefore, in this section, the authors will discuss...
the effects of weather conditions on the ratio of wheel skid occurrence, looking only at weather factors and giving no consideration at all to the relationship of weather factors to other factors.

4.1 Weather conditions encountered by the train

First, the authors investigated the number of kilometers run in each area for each weather classification, for the total of 208,000 km the train ran during this study (including the deadhead runs between the depots and the terminal stations of the train). Figure 6 shows the number of kilometers run classified by the types of weather that the train encountered, as determined by this method, as well as the ratio (as a percentage) of each classification to the total distance run. This information indicates that comparatively few kilometers were run on snow days, even in “snow bound areas”, and this was due to the fact that works such as recorder adjustments, which took considerable time, were being made during periods of snowfall. As shown in Fig. 7, there are many long tunnels along the lines, so the ratio of the “tunnel” weather classification is somewhat high.

4.2 Ratio of wheel skid occurrence for each weather classification

Figure 8 shows the results of the investigation of the number of wheel skid cases for each weather classification (hereafter, “wheel skid occurrence ratio”) for each 1,000 km of operation, investigated from the distance run under each weather classification and the number of wheel skid cases for each weather classification, as determined in the preceding section. From this figure, the authors see that weather greatly affects the occurrence of wheel skidding. During rainfall, the wheel skid occurrence ratio is extremely high, at 2.95, approximately four times greater than the ratio during fair weather. The ratio during days of snowfall is even higher than the ratio during days of rainfall, actually reaching 10.35. It is surmised that the wheel skid occurrence ratio is low in tunnel areas because there is no rainfall inside a tunnel.

It is also surmised that the wheel skid occurrence ratio is greatly affected by the number of brake applications per unit running distance. The “Hakutaka 3” used as the train for this study travels 26.1 kilometers between station stops, a much greater distance than, for example, the 1.2 km run between stations on the JR Yamanote Line in the Tokyo metropolitan area, and the authors can surmise that the number of brake applications per unit running distance is also much lower compared with the Yamanote Line. Accordingly, the wheel skid occurrence ratio shown here may itself fluctuate depending on the distance be-
tween station stops. However, there should not be major differences in the ratio of wheel skid occurrence in rainy weather compared with clear and sunny weather, and a indicating facts such as a much higher wheel skid occurrence ratio on days of rain or snow compared with days of clear and sunny weather should also be extensively applicable to other lines as well.

4.3 Effects of accumulated snow along the wayside on wheel skidding

As shown in the track cross-section in Fig. 7, the portion of the Niigata Prefecture Area located north of Naoetsu is a mountainous region with many tunnels and is at a comparatively high elevation. This area is subjected to some of Japan’s heaviest snowfalls. Figure 9 shows the conditions of snow piled up along the way side near Echigo-Yuzawa Station, the station at the highest elevation on the line, on February 12, 2002 — a day of sunny weather following a day of heavy snow that hit the Niigata Prefecture Area. As can be seen in this photograph, although the weather is sunny, there is a large amount of snow on the rail surface, a condition which, as far as the track is concerned, should be considered as snow for the weather classification. As such, such conditions contain problems when discussing the effects of weather on wheel skidding if the weather classification for the time at which a large amount of snow is accumulated on the tracks is recorded as “sunny” and treated in the same way as a true sunny weather condition in which the rails are dry.

Therefore, in order to study the effects of snow accumulation, the authors defined the mountainous area from Echigo-Yuzawa to the entrance of the Nakajima Tunnel on the Hokuetsu North Line shown in Fig. 7 (52.8 km from Muikamachi) as a “heavy snow area”, and also defined the period from January to February, during which there is a large amount of snow accumulation in the area, as the “snow bound season” and the period from May to November, during which there is no snow accumulation at all, as the “non-snow bound season”. The authors, then, examined whether or not there were differences in the wheel skid occurrence ratio on days of similar weather conditions during the snow bound season and non-snow bound season. For this study, in order to eliminate the effects of fluctuations in $\mu$ due to rail wetting from rainfall, snowfall, etc., focusing this study only on the effects of snow accumulation in the vicinity of the rails on $\mu$ and wheel skidding, the weather categories covered by this study were limited to “sunny” and “cloudy”.

The results of this study are shown in Fig. 10. From these results, the authors can see that under cloudy weather condition, the wheel skid occurrence ratio during the snow bound season is far higher than the ratio during the non-snow bound season. In sunny weather, the wheel skid occurrence ratio during the snow bound season is considerably higher than the ratio during the non-snow bound season. This is thought to be due to the heat of the sunlight on sunny days melting the accumulated snow in the vicinity of the rails, wetting the rails and decreasing the $\mu$.

From these results, they can understand that accumulated snow in the areas around the railway tracks is a factor that greatly affects wheel skid occurrence. Accumulated snow in the vicinity of the tracks cannot be included in the weather classifications, and also cannot be classified as a trackside factor. As such, because accumulated snow is a factor that exists along the wayside and make to decrease the $\mu$ and increase wheel skidding in the same way as rivers and fallen leaves from tree clusters along the tracks, accumulated snow should be considered as a surrounding area factor along the wayside.

5. Conclusion

To investigated the behavior of wheel skid occurrence which was frequently observed on the JR Ltd. express train set on the conventional lines, the event recorder capable of specifying the sites where wheel skidding occurred, and which could automatically record detailed vehicle operation conditions at the time of wheel skid occurrence, was installed over a long period of time on the Ltd. Express EMU operating between Kanazawa and Echigo-Yuzawa. The piled up date in the recorder were analyzed.
and following results were obtained.

1) In the course of the analyzing the data, the authors identified several groundside factors, contributing to wheel skid occurrences, which existed in the wayside where wheel skidding were observed.

2) Several factors, which have been identified and classified as the ones causing decreases in $\mu$ in the several previously published papers, are verified as well to be factors directly causing wheel skiddings.

3) It has been clarified that the followings are contained within groundside factors which involve wheel skid occurrence: “track side factors” causing a localized decrease in $\mu$; newly defined “surrounding areas factors”, causing also a localized decrease in $\mu$, which related to the geography and surroundings on the way-side; weather factors causing decrease in $\mu$ for large area.

4) Grade crossings and turnouts are contained within the track side factors, and the stream under the bridge, Japanese cedar trees and accumulated snow in the vicinity of the rails are contained with in the surrounding area factors along the wayside. Both of these factors greatly affects wheel skid occurrence.

5) The above mentioned track side factors, and such surrounding area factors as the stream under the bridge and Japanese cedar trees cause decrease in $\mu$ in a so short section that re-adhesion is usually followed on the wheel skiddings caused by these factors.

6) The wheel skid occurrence ratio during rainfall is approximately four times greater than the ratio during fair weather, and snowfall is far higher than the ratio during days of rainfall.

7) To study the effects of snow accumulation by the wayside, differences in the wheel skid occurrence ratio on days of similar weather conditions during the snow bound season and non-snow bound season were investigated in the snow bound area. From these investigations, the authors found that under cloudy weather condition, the wheel skid occurrence ratio during the snow bound season is far higher than the ratio during the non-snow bound season. In sunny weather, the wheel skid occurrence ratio during the snow bound season is considerably higher than the ratio during the non-snow bound season.

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