Interpretive Article

Research and Development for Eliminating Wheelclimb Derailment Accidents

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Almost 180 years have passed since the railway made its debut in 1825, and 130 years have elapsed since 1872 when a railway was first opened for services in Japan. Even now, derailment (wheelclimb derailment, assumed as being caused by multiple factors) occurs. Derailment is likely to have a direct connection with human life, and must be eliminated. A traveling safety evaluation method based mainly on derailment coefficient has already been established. This paper discusses part of the JR East research and development efforts to work out a more realistic evaluation methods and to clarify the mechanism of its occurrence.

1 Introduction

Prevention of derailment accidents raises a very crucial issue for a railway company since the resultant damage is very likely to be directly connected to human life.

Derailment is caused by many factors. One type of derailment is caused by a factor that can be specified as a particular cause, such as collision with an automobile at a crossing, collision with a falling rock, expansion of rail gauge by earthquake, axle breakdown and excessive train speed. In the other type of derailment, one particular factor cannot be specified as a cause for derailment, and multiple causes related to the car and track have combined to cause the derailment. This is exemplified by the accident that occurred in March 2000 close to Naka-meguro station on the Hibiya subway line.

For the former type of derailment, it is sufficient to work out measures that eliminate specific causes. For the latter type of derailment, some of the causes are not yet clarified and various types of research and development are required for their clarification.

2 Form of derailment

Derailment assumed to be caused by multiple factors can be divided into three types according to the form.

<1> Wheelclimb derailment accident

In this type of derailment, the attack angle (formed by the wheel and rail, see Fig. 1) is positive (the wheel flange climbs up the rail in the direction of motion), and transversal force is produced between the wheel and rail, with the result that wheel climbs up the rail.

<2> Slide-up derailment

In this type of derailment, the attack angle is negative, and the wheel is faced in the direction away from the rail, where force in the lateral direction is greater than that is applied, whereby the wheel slides up the rail.

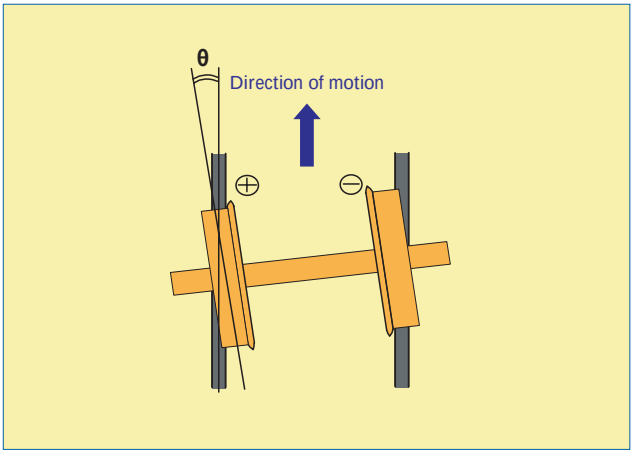

Fig. 1: Attack angle

<3> Jump-up derailment

In this type of derailment, abrupt force in the lateral direction is produced to cause the wheel to collide with the rail.

Of these three types of derailment, the wheelclimb derailment is most likely to occur. The aforementioned accident having occurred on the Hibiya line belongs to this type.

In the wheelclimb derailment, the flange of the wheel contacts the shoulder of the rail (gauge corner portion), as shown by a circle in Fig. 2 (①). Then the flange starts to climb up the rail (②). Then it climbs to reach the top position in the final step (③).

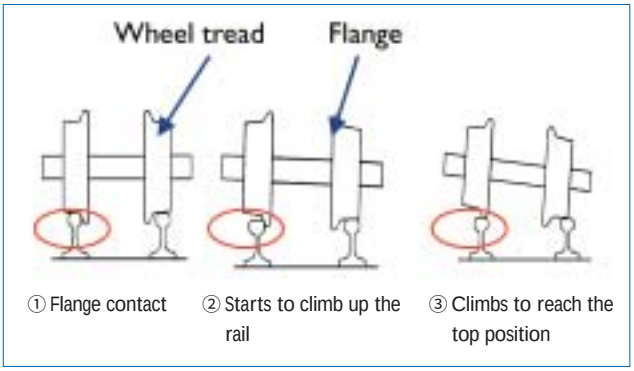

Fig. 2: Process of climbing

3 Wheelclimb derailment evaluation procedure (traveling safety evaluation procedure)

3.1 Force acting on contact point between the wheel and rail

In the railway car, the wheel travels along the rail. Fig. 3 shows the force acting on the contact point between the wheel and rail in this case.

Force *F* acting on the contact point between the wheel and rail is divided into perpendicular component *P* (wheel load) and horizontal component *Q* (transversal pressure). Further, the force "*fy*" of the contact point in the tangential direction is called lateral creep force. As will be discussed later, this is assumed to affect the wheelclimb derailment. It should be noted that Fig. 3 shows that the wheel flange is in contact with the rail. In this case, the contact angle forms flange angle α.

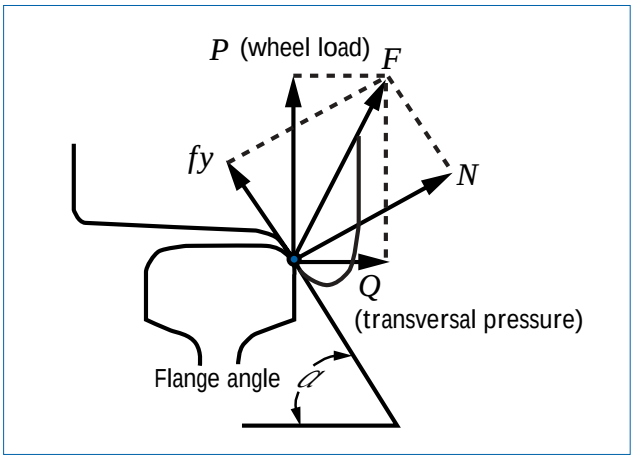

Fig. 3: Force acting on contact point between the wheel and rail

3.2 Current evaluation method

From Fig. 3, if force acting on the contact point between the wheel and rail is kept in balance, we get the following using *P* and *Q*:

$P\sin\alpha - Q\cos\alpha = fy$

$P\cos\alpha + Q\sin\alpha = N$ (where *N* denotes the force acting in the normal direction of contact point)

From this, we get:

$$\frac{Q}{P} = \frac{\tan\alpha - fy/N}{1+(fy/N)\tan\alpha}$$

This *Q/P* is called the "derailment coefficient." The greater the *Q/P*, the smaller the "*fy*". In other words, if one assumes that contact is made by the flange and balance is maintained, then the limit is approached at smaller *Q/P* as "*fy*" is greater. It is said that, if the attack angle is increased, the "*fy*" will also be increased, without exceeding the frictional force. Thus, the maximum value of "*fy*" is substituted into frictional force μN (where μ denotes the friction coefficient). The minimum value of *Q/P* is given by:

$$\frac{Q}{P} = \frac{\tan\alpha - \mu}{1+\mu\tan\alpha}$$

This is called Nadal's equation representing the limit value of derailment.

Since the wheel load (*P*) and transversal pressure (*Q*) can be measured with comparative ease, the derailment coefficient has been used as an index for evaluating the traveling safety.

Fig. 4 shows the limit value (critical derailment coefficient) of derailment coefficient according to Nadal's equation. The smaller the friction coefficient μ and the greater the flange angle α, the greater will be the limit value of the derailment coefficient. This means a higher safety level. At present, the friction coefficient is assumed as 0.3, with the allowance of 15% (0.85 times the critical derailment coefficient), we evaluate traveling safety, assuming a reference value of 0.8 for the basic wheel tread (flange angle:60 deg.) and a reference value of 0.95 for the corrected arc wheel tread (flange angle: 65 deg.) as shown in Table 1. It should be noted that, when this value remains unchanged for 15 msec. or more, it is subjected to evaluation.

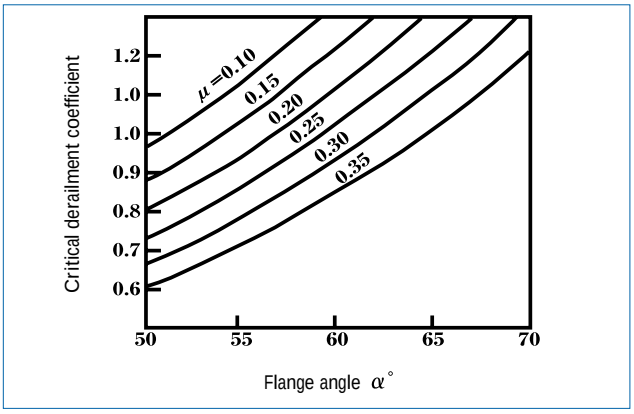

Fig. 4 Limit value of derailment coefficient according to Nadal's equation

Table 1: Reference value for flange angle and derailment coefficient

	Flange angle	Critical derailment coefficient (friction coefficient is assumed as 0.3)	Reference value for derailment coefficient (0.85 x critical derailment coefficient)
Basic wheel tread	60 °	0.94	0.8
Corrected arc wheel tread	65 °	1.12	0.95

According to the traveling safety evaluation method currently adopted, "PQ axle" - a wheel set intended exclusively for measurement - that allows the wheel load and transversal pressure to be measured is mounted on the car, and the derailment coefficient (*Q/P*) is found. The result is compared with the aforementioned reference value for evaluation. The derailment coefficient represents the ratio of wheel load to transversal pressure. Thus, the greater the wheel load and the smaller the transversal pressure, the smaller will be derailment coefficient, as shown in Fig. 5. This means a higher safety level.

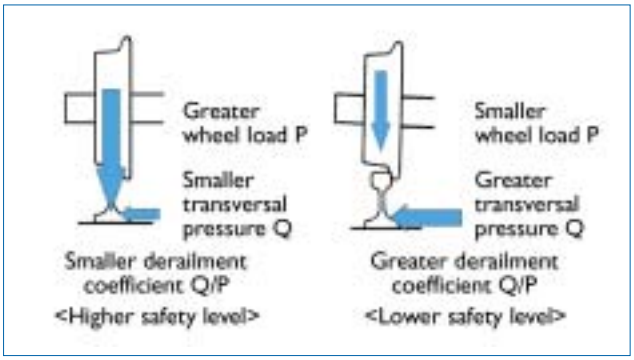

Fig.5: Derailment coefficient and traveling safety

In the evaluation of the traveling safety carried out in the speed improvement test, a marked wheel lead and remarkable transversal pressure leading to track breakdown, as well as the percentage of removed wheel load with respect to stationary wheel load are taken into account, in addition to the derailment coefficient.

3.3 Study of new evaluation method

As described above, at present we evaluate the traveling safety according to the derailment coefficient. Evaluation of derailment, especially the evaluation of wheelclimb derailment, cannot completely be explained by the derailment coefficient.

Fig. 6 shows the derailment coefficient and the amount of wheel rise (indicates the perpendicular distance from the reference position of the wheel tread as shown in Fig. 7), as well as an example of waveform representing the lateral creep force (theoretical value) in the case of flange contact, when climbing has occurred in the car traveling test at the eighth point and crossing side track conducted by JR East. This shows that climbing starts if the derailment coefficient is large. When climbing has started to occur (circled portion in Fig. 6), no correlation can be observed between the amount of wheel rise and derailment coefficient. A high level of correlation can be observed between the amount of wheel rise and lateral creep force.

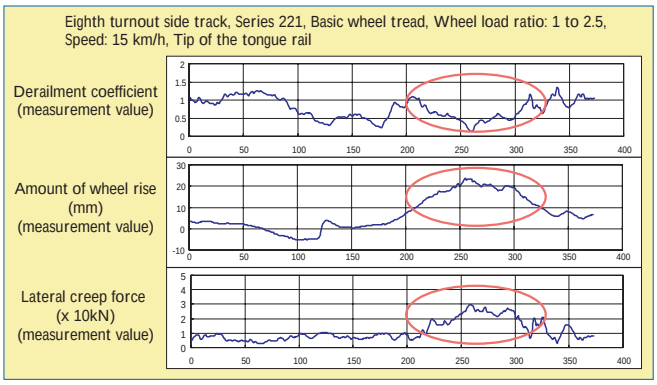

Fig. 6: Example of waveform in derailment reproduction test

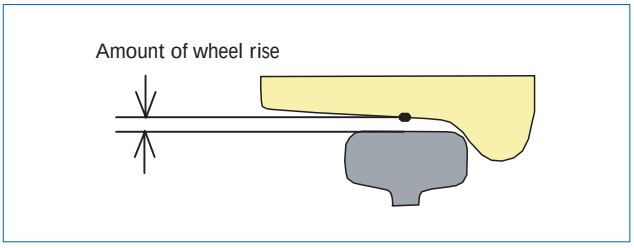

Fig. 7: Amount of wheel rise

Fig. 8 shows the relationship between the lateral creep force and amount of wheel rise when traveling several times at different speeds using the same point and crossing as that in Fig. 6. A very high level of correlation can be observed between the two. So we consider that lateral creep force must be taken into account in order to work out a more practical evaluation method and to clarify the mechanism of causing derailment, and we are proceeding with this study.

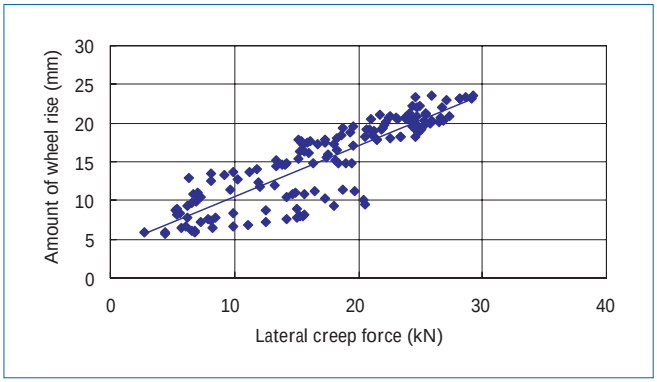

Fig. 8: Lateral creep force and amount of wheel rise

For this purpose, it is necessary to have accurate information on the lateral creep force. So far we have not been able to measure it

directly. JR East has developed a method of calculating the lateral creep force by measuring the contact position between wheel and rail. Details are described in the "Development of a device for continuous measurement of indirect contact position between axle and rail toward clarification of the derailment mechanism" on pages 29 and later in this journal.

We are currently studying a new method for evaluating wheelclimb derailment by grasping the lateral creep force using this device.

4 Study for prevention of wheelclimb derailment

To have accurate information on the derailment coefficient and lateral creep force discussed in 3.2 and 3.3, it is necessary to provide a PQ measuring axle and creep force measuring device. So this is not possible in normal traveling mode. This makes it necessary to make sure in the daily management and in determining specifications in the designing phase that the possibility of wheelclimb derailment can be eliminated.

4.1 Factors for wheelclimb derailment

According to the report [1] by a committee for the survey and study of the derailment accident on the Hibiya subway line, when the car with unbalanced wheel load (assumed as being unbalanced by 20% or more) was traveling along a sharp curve at a low speed of about 15 km per hour, the wheel on the outer track was lifted to climb up the rail surface, with the result that the derailment accident occurred. To prevent this, the following five items are mentioned in this report:

① Management of the stationary wheel load ratio of the car (where the target control value is 10%)

② Management of track distortion

③ Optimization of rail grinding profile
(For the sharp curve, the upper side of the gauge corner must not be ground at an oblique angle).

④ Change of wheel flange angle (65 to 70 deg. to be studied)

⑤ For the curve where the estimated derailment coefficient ratio is less than 1.2, a derailment guard should be provided.

In this case, the stationary wheel load ratio refers to the ratio of the larger wheel load with respect to the average wheel loads on the right and left of one and the same axle when the car stands still on a level line (horizontal line). It is represented as shown in Table 2. Further, the stationary wheel load ratio is also called the wheel load unbalance. It refers to the rate of the difference between each of the right and left wheel loads and average wheel load, with respect to the average wheel load.

Table 2: Example of wheel load ratio

Stationary wheel load (right)	Stationary wheel load (left)	Stationary wheel load ratio (stationary wheel load unbalance)
50 kN	50 kN	1.0 (0%)
45 kN	55 kN	1.1 (10%)
40 kN	60 kN	1.2 (20%)

The estimated derailment coefficient ratio refers to the ratio of the "critical derailment coefficient" discussed in 3.2 to "estimated derailment coefficient" calculated from the car and track conditions. It represents the margin with respect to derailment. If the value is "1" or more, derailment does not occur. The standard value is assume as 1.2 with a safety factor of 20% taken into account.

Based on the field running test and simulation, JR East has been studying the relationship among the car stationary wheel load ratio, the mutual conditions of the track alignment distortion and track distortion, and derailment.

As a result, as found in the measures against the aforementioned accident on the Hibiya line, items assumed to have caused wheelclimb derailment and its influence can be enumerated as follows:

○Car

・Wheel load ratio (wheel load unbalance)
Smaller wheel load on the outer track side on a curve → greater derailment coefficient

・Wheel flange angle
Greater flange angle → greater critical derailment coefficient

・Roughness on wheel surface
Greater friction coefficient → increased transversal pressure (greater derailment coefficient), reduced critical derailment coefficient

○Track

・Alignment distortion (including the joint breakdown (breakdown of rail corner))
Collision of wheel with rail → increased transversal pressure (greater derailment coefficient)

∗Alignment distortion refers to the "distortion" of the track in the horizontal direction (in the curved section, it refers to the distortion with respect to the preset linear form).

・Track distortion

In the three-point support system, wheel load removal is likely to occur. → Greater derailment coefficient

∗Track distortion refers to the "twist" on the track surface, namely, the difference in level distortion between two points on the track a certain distance away from each other (difference in the height of the right and left rails). On the transition curve, there is a change in cant, so a structural track distortion occurs.

Based on this understanding, we are currently conducting experiments and simulations to identify how the derailment coefficient and lateral creep forces are changed by a combination of the statuses of various items, and are studying the way of reflecting these results in adequate management value and design specifications.

4.2 Identifying the situation by traveling simulation

Computer-based car traveling simulation is used to ensure effective clarification of the mechanism of derailment and evaluation of traveling safety. A high-precision model is configured through comparison with the data of the field test. An example is given in Fig. 9.

In the future, this model will be modified into one more suited to the practical requirements and efforts will be made to create a simulation that permits the status to be grasped with higher precision without depending on the field test.

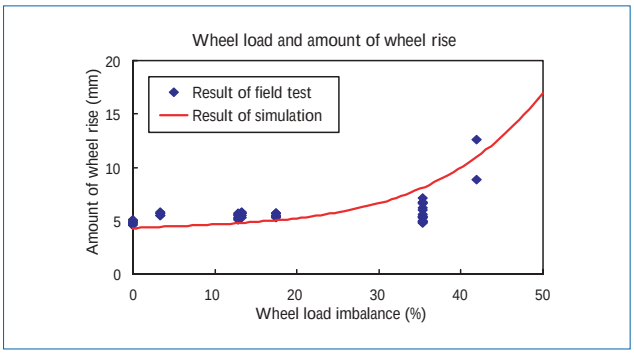

Fig. 9: An example of comparison between field test result and simulation result

5 Conclusion

Some of the causes for wheelclimb derailment have not yet been made clear. We will make continued efforts to find ways to prevent wheelclimb derailment through further research mainly based on simulation, using the findings and experience gained so far.

References:

1) Home page of the Ministry of Land, Infrastructure and Transport. http://www.mlit.go.jp/kisha/oldmot/kisha00/koho00/tetujiko22-6_html.