Special edition paper

Introduction of New Methods for Train Operation Control in Strong Winds

Since the derailment accident between Kita-Amarume and Sagoshi stations on the Uetsu Line, JR East has worked jointly with the Railway Technology Research Institute (RTRI) to study creation of “a method to properly assess the effect of wind force on railcars for operational restrictions.”

As a result, we reviewed the wind observation method and the calculation method for overturn resistance of vehicles, taking into account investigation results of recent accidents due to strong wind and research results. In light of that review, we put into practical use a safer and more rational new operation control method use in strong winds based on technical evidence. This method has been introduced on some lines from the winter of 2011 after discussions at technical meetings and committees that also included external experts.

Keywords: Critical wind speed of overturning, RTRI Detailed Equation, Wind observation, Three anemometers, Operation control

1 Introduction

After the derailment and overturn accident of the “Inaho” limited express on December 25, 2005, several railway operators including JR East lowered the wind speed at which operation suspension commands are issued in train operation control according to wind speed from 30 m/s to 25 m/s as a provisional safety improvement measure. However, the report of a fact-finding investigation into the accident by the Aircraft and Railway Accidents Investigation Commission (Current Japan Transport Safety Board) of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) deduced that the cause was localized gusts. This means that it would have been difficult to prevent that accident through wind observation using anemometers along the lines. On the other hand, there has been little quantitative evaluation of lowering the wind speed at which operation control is issued or review of rationality and validity of the current operation control rules up to now.

We thus investigated and verified a method of assessing calculation of critical wind speed of overturning of rolling stock and a wind observation method more in line with actual conditions based on investigation results of recent accidents due to strong winds and related research results. This work was done with the cooperation of the Railway Technology Research Institute (RTRI). As a result, we created a safer and more appropriate new operation control method in strong winds that incorporated such investigation and verification results, and we put it into practical use.

This article will explain the RTRI Detailed Equation and the three-anemometer method that are the core of the new operation control method and report the specifics of that method.

2 Operation Control under Wind Based on the RTRI Detailed Equation

Our new operation control method in strong winds (hereinafter, the “New Method”) adopted the RTRI Detailed Equation as the method calculating critical wind speed of overturning of rolling stock and the three-anemometer method as the method for wind observation. Combination of the RTRI Detailed Equation and the three-anemometer method allows introduction of the New Method.

2.1 RTRI Detailed Equation

Past methods of operation control under wind used the Kunieda formula to calculate critical wind speed of overturning of rolling stock. In contrast, our New Method adopted the RTRI Detailed Equation proposed by RTRI.

The RTRI Detailed Equation is an equation that incorporates knowledge obtained from recent research on vehicle overturn accidents due to strong winds. It has an advantage of more detailed assessment of aerodynamic force that particularly affects overturning than the Kunieda formula does.

Major differences between the RTRI Detailed Equation and the Kunieda formula are listed in Table 1.

The major features of the RTRI Detailed Equation are as follows.

(1) Incorporates dependency of aerodynamic force on shape of car body and wayside structures and on difference between leading cars and intermediate cars.

(2) Takes into account lift and rolling moment as well as side force as the aerodynamic force of crosswinds.

Table 1 Differences between the RTRI Detailed Equation and the Kunieda Formula

<table>
<thead>
<tr>
<th>Items compared</th>
<th>RTRI Detailed Equation</th>
<th>Kunieda formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of the formula</td>
<td>Analytical equation using detailed dynamic models</td>
<td>Simple analytical formula that secures margin of safety by assuming larger height of center of gravity</td>
</tr>
<tr>
<td>Wind</td>
<td>Diagonal wind resultant of natural wind and wind acting on front of running train</td>
<td>Cross wind only</td>
</tr>
<tr>
<td>Aerodynamic force acting on car body</td>
<td>Takes into account lateral force, lift, and moment</td>
<td>Takes into account lateral force only, assuming lateral force coefficient is 1.0</td>
</tr>
<tr>
<td>Effect of wayside structures</td>
<td>Taken into account as the aerodynamic force coefficient</td>
<td>Not taken into account (assuming flat ground)</td>
</tr>
<tr>
<td>Effect of car body shape</td>
<td>Taken into account as the aerodynamic force coefficient</td>
<td>Taken into account as a cuboid</td>
</tr>
<tr>
<td>Car specifications</td>
<td>Takes into account displacement of air springs and axle springs</td>
<td>Spring system simplified with height of gravity center increased 1.25 times</td>
</tr>
</tbody>
</table>

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(3) While the Kunieda formula deals with winds to cars at a right angle only, the RTRI detailed equation evaluates aerodynamic force according to the relative wind angle to the vehicle, assuming that the resultant vector of the vector of the wind acting on the front of a running train and the wind speed vector of natural wind acts on the vehicle.

(4) Uses values appropriate to the vehicle and track conditions for car body lateral acceleration.

In terms of the effect the shape of car body and wayside structures have on the overturn resistance of vehicles (aerodynamic characteristics) in (1) above, wind tunnel test results have been gained. Those tests were conducted with a combination of five typical car types (commuter, double decker, limited express, passenger car, freight wagon) and seven wayside (track) structures (single-track bridges of girder heights 1 m, 2 m, and 3.5 m, double-track viaducts of girder heights 1.5 m, 3.5 m, and 6 m, and single-track embankment of slope gradient 1.5 and height 8.72 m). (See Fig. 1)

With the New Method, the nearest cross-sectional shape is selected from the five typical shapes of cars shown in Fig. 1 for calculation of the overturn resistance of the vehicle. For shape of wayside structures, wayside structures are to be regarded as one of the seven typical shapes of wayside structures shown in Fig. 1 based on the wayside structure assessment in the section subject to operation control under wind. If it is difficult to select one from among the typical shapes in Fig. 1, assessment must be done on the safe side.

If the shape of the car to be calculated is unique and cannot be regarded as one of the typical shapes, or if the exact aerodynamic characteristics of the car shape are needed, calculation is done based on wind tunnel tests using a model of that car.

Fig. 2 shows the resultant wind from natural wind and wind acting on the front of a running train. The Kunieda formula deals with winds to cars at a right angle only, but we know that wind acting on the front of a running train increases as train running speed increases, affecting the critical wind speed of overturning. The RTRI Detailed Equation can appropriately incorporate the effects of wind direction and speed of the resultant wind.

- Critical wind speed of overturning usually means the wind speed at which the decrease ratio of wheel load on the windward side reaches 100%. With the New Method, however, the allowable decrease ratio of wheel load is set at less than 100%, giving some leeway, and wind speed and permissible running speed up to that allowable decrease ratio of wheel load is allowed. Hereafter, we express the wind speed calculated based on the allowable decrease ratio of wheel load as “critical wind speed of overturning” and the calculated wind speed and permissible running speed collectively as “overturn resistance.”

Using those parameters, we can calculate the following values of specific vehicles running on specific wayside structures.
- Critical wind speed of overturning in terms of running speed
- Permissible running speed in terms of wind speed
- Overturn resistance for inside and outside of a curve

2.2 Three-anemometer Method

In conventional wind observation, instantaneous wind speed of a single anemometer that represents the wind speed of a section subject to operation control under wind is used for operation control under wind. In contrast, the New Method employed a three-anemometer method as a rational method of assessing wind against the car body. This is a method where three anemometers are equally spaced in a distance equal to the total length of a car (20 m for cars of conventional lines) and the instantaneous wind speed values of individual anemometers are spatially averaged (RMS value) at the same moment to be used as the wind speed for operation control. Fig. 3 shows the conventional wind observation method and the new three-anemometer method.

By employing the three-anemometer method, wind that blows uniformly against the side surface of a car in a certain space can be more rationally observed than by using only one anemometer. In observation using only one anemometer, uneven wind in the space is detected too, but in the three-anemometer method...
method employed, such wind that does not affect the overturn resistance of a vehicle is no longer observed.

The Disaster Prevention Research Laboratory is preparing to introduce a newer wind observation method that uses time averaged observation values by one anemometer. This method can observe the wind situation at a level equal to that of using three anemometers by analyzing wind speed data gained by introduce by the three-anemometer method. The theme of time averaging is discussed in the article “Statistical Study on a Method of Assessing Wind Speed Used in Train Operation Control” in this issue of JR East Technical Review.

The New Method is a scheme where operation control rules in strong winds can be flexibly studied while making use of advantages of the RTRI Detailed Equation. However, advance studies and procedures will be more complex than in conventional operation control under wind.

In operation control based on the Kunieda formula, it is assumed that a car has a structure that can withstand a specified wind speed (30 m/s) regardless of wayside structure shape, train running speed and curve and cant conditions. It is also assumed that the car does not overturn at any place and while running at any speed, provided that the wind speed is less than 30 m/s. On the other hand, the RTRI Detailed Equation can take into account differences in wayside structure shapes, train running speeds, and curve specifications to calculate detailed overturn resistance.

The RTRI Detailed Equation tends to calculate a lower overturn resistance than the Kunieda formula with wayside structures that are easily affected by wind (embankments, bridges, viaducts). Even with sharp curves, curves of high cant, or curves of low cant passed at relatively high speed, overturn resistance is often calculated to be lower. In the New Method, we consider how to apply operation control or countermeasures such as windbreak fences to specific locations where those conditions apply within the section subject to operation control based on calculation results with the RTRI Detailed Equation.

With the New Method, we have also developed and introduced a calculation system for critical wind speed of overturning of vehicles to minimize calculation work. The aim of this is to allowing easy application of the RTRI Detailed Equation, which requires a larger volume of calculations than with the Kunieda formula.

### 3.1 Introduction of Calculation System for Critical Wind Speed of Overturning

The calculation system for critical wind speed of overturning (hereinafter, the “System”) automatically performs a huge amount of RTRI Detailed Equation calculations and outputs the results. The required parameters include car specifications (major dimensions, weight, spring coefficients, type of car body cross-sectional shape, etc.), wayside structure shapes, curve specifications, and speed conditions, which are compiled in a database on the System. The curve specifications are data of the curve database JR East managed companywide (TRAMS data), and the speed conditions are data of the train operation speed list compiled in a database.

By the user simply designating the car type, line section and station or kilometrage, the System automatically searches necessary parameters on the database and calculates overturn resistance. The system also has the functions of partially changing car specifications and estimating overturn resistance with different wayside structures and curve specifications.

We simplified the system operation screen as much as possible. Using many pull-down menus and check boxes, the user interface could be made very user-friendly. Output of calculation results is shown on a carefully designed format and color-coded for visual ease of understanding. Fig. 4 is an example of output of calculation results.

The System is built as a server on the JR East intranet, so authorized users can use the System from PCs at their own desks.

### 3.2 Work Required before Introduction of New Method

Different types of trains enter and different wayside structures and curves exist in the sections where the New Method will be introduced. The System searches necessary data and performs calculations according to the calculation conditions the user designates, so all the required data must be registered to databases in advance. Users must therefore compile the databases for car specifications and wayside structures.

For the car specifications, the types of cars which entry to that section has been confirmed must be registered. Currently, most car types have already been registered, except for some new types of cars and freight cars.

Wayside structures have to be assessed by users. As in the example shown in Fig. 5, for the section between Stations A and B subject to operation control under wind, users check what types of wayside structures there are, divide the section into fixed

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**Fig. 4** Example of Output of the Calculation System for Critical Wind Speed of Overturning of Vehicles

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**Fig. 5** Image of Section Subject to Operation Control Under Wind and Wayside Structures
intervals, and select the wayside structure that is most affected by wind in that interval and register that to the database. As selections for wayside structure shape, the System has the seven typical wayside structure shapes illustrated in Fig. 1 as well as flat ground, each with and without windbreak fences, so users select the most appropriate one from those.

Should flat ground, embankments, and bridges be lined up in an interval, the wayside structure that is easily affected by winds is the embankment or bridge, so users have to perform calculations to select that which is more severely affected.

Some wayside structures are difficult to be regarded as any of the selections. In such a case, the rule is to select the wayside structure for which overturn resistance is more severely calculated so as to make a decision on the safe side.

Once wayside structures are registered in the database, overturn resistance in the section subject to operation control under wind can be easily figured out by the System thereafter, unless the wayside structures are changed.

3.3 Consideration of Operation Control Method and Wayside Measures

Once databases of car specifications and wayside structures are readied, overturn resistance can be calculated by the System.

Here, we will explain how the operation control method and wayside measures can be considered using a calculation example.

Fig. 6 shows overturn resistance calculation results of car types A and B on three types of wayside structures: flat ground + sharp curve, straight bridge, and high embankment + sharp curve. The speed limits in the figure are the curve speed limit on sharp curves or the maximum speed of the section or of a car on a straight bridge.

(1) Determination necessity of taking measures

As seen in Fig. 6, the RTRI Detailed Equation calculates overturn resistance on the high embankment as being lower than it should be. When there are wayside structures such as high embankments, bridges, or viaducts in the section for which lower overturn resistance is undercalculated, deciding what measures to be taken for that section becomes an issue.

In the high embankment section in Fig. 6, the critical wind speed of overturning is 18.5 m/s for car A and 21.7 m/s for car B. Operation control under wind involves early restrictions (slow-down control commands issued at 20 m/s, operation suspension commands issued at 25 m/s) and general restrictions (slow-down control commands issued at 25 m/s, suspension commands issued 30 at m/s), and early restrictions are applied for sections without windbreak fences. In early restrictions, there is possibility of overturn of a vehicle before a slow-down control command is issued because such a command is first issued when the wind speed reaches 20 m/s, which may be greater than the critical wind speed of overturning. In this case, the wind speed for car A is less than the wind speed for early restrictions, so some limitation for the high embankment part is necessary. The possible measures include…

- Operation control measures
  - Lowering the speed limit for car A to a running speed at which critical wind speed of overturning is 20 m/s or greater
  - Changing wind speed for slow-down control commands from the current 20 m/s to 18 m/s
- Wayside structure measures
  - Installing windbreak fences on high embankment sections
  - Improving linearity of sharp curves (decrease of cant, etc.)
- Vehicle measures
  - Modifying the vehicle to improve overturn resistance
  - Cancelling confirmation of entry for car A (do not allow entry to the section)

Furthermore, if general restrictions are applied to the embankment section, a 25 m/s or greater critical wind speed of overturning is required, so cars A and B both cannot meet conditions for general restrictions as they are. Further limitation is thus required.

(2) Flexible setting of operation control

If windbreak fences are installed to a high embankment section, the detailed critical wind speed of overturning is as shown in Fig. 7. Only two sections need to be taken into account: flat ground + sharp curve and straight bridge. The minimum critical wind speed of overturning in this case is 24.6 m/s for car A, so control applied can be changed to general restrictions by improving the critical wind speed of overturning by 0.4 m/s. One of the methods to ease operation control is setting the wind speed for issuing slow-down control commands for that section at 24.0 m/s, which is less than the 24.6 m/s minimum critical wind speed of overturning (see the arrow in Fig. 7). Currently, the wind speed for issuing slow-down control commands is fixed at 20 m/s in early restrictions and to 25 m/s in general restrictions. If more flexible change of that wind speed is allowed, such a control method can be an effective option.

(3) Revision of normal speed limit and slow operation speed

Fig. 8 shows the permissible running speeds at wind speeds of 20 m/s, 25 m/s, and 30 m/s on three types of wayside structures.

If early restrictions are applied for the section, trains can run at the maximum speed for that section at a wind speed of 20 m/s,
while they must be able to run at the slow operation speed of 25 km/h at a wind speed of 25 m/s. If general restrictions applied, trains can run at the maximum speed for that section at a wind speed 25 m/s, while they must be able to run at the slow operation speed of 25 km/h at a wind speed of 30 m/s. As seen in Fig. 8, car A can only run at up to 88 km/h at a wind speed 20 m/s, less than the 95 km/h speed limit for high embankments, and it can only run at up to 21 km/h at a wind speed of 25 m/s, less than the 25 km/h slow operation speed. Accordingly, car A cannot meet the conditions for early restrictions. So, some of the aforementioned limitation measures need to be implemented.

If trains cannot run at up to the speed limit of the section at wind speed where operation control commands are issued, there is a method of normal speed limitation or a method of setting a new slow operation speed for the car types regardless of whether or not there are strong winds. Looking at the case in Fig. 8 for car A in early restrictions, a normal speed limit of 85 km/h can be set; at the same time, the slow operation speed can be lowered from the current 25 km/h to 20 km/h. In that case, car A can run in that section even under early restrictions.

In contrast, Fig. 9 shows a case where slow operation speed can be increased. For example, we assume windbreak fences are installed in the high embankment section and appropriate operation control methods and the like can be set both for cars A and B at the wind speed where slow-down control commands are issued. Fig. 9 shows the minimum allowable running speed is 49 km/h at the 30 m/s wind speed where operation suspension commands are issued under general restrictions. We can also see that the current slow operation speed for that section can be increased from 25 km/h to 49 km/h, provided the slow operation speed can be changed.

When considering change to general restrictions, a serious problem is that the permissible running speed of car A is 0 km/h in the high embankment section at a wind speed 30 m/s (the decrease ratio of wheel load can exceed the permissible value even when standing) and that the permissible running speed of car B is 11 km/h, greatly less than the slow operation speed of 25 km/h. This can be seen in Fig. 8. In order to change from early restrictions to general restrictions even in such a case, the most practical solution would be installing windbreak fences.

As explained above, a variety of flexible operation control methods and wayside measures can be considered with the RTRI Detailed Equation as that equation can calculate overturn resistance according to individual combinations of car type and wayside structure shape.

We traditionally stipulated and adhered to fixed wind speed values for operation control commands and slow operation speed. With the New Method, however, we can set more effective operation control methods by more flexibly setting those values.

However, the aforementioned operation control methods and wayside measures have advantages and disadvantages, and none of them can be adopted easily. We should carefully think out which is most adoptable and effective based on consideration of the objectives, necessity, and risk of introducing the New Method in the section subject to operation control under wind. Still, one of the major features of the New Method is the ability to examine different means.

### 4 Introduction Results

The New Method was first introduced to the Uetsu Line in December 2011, after discussions at technical meetings and committees that also included external experts, and then to the lines and sections shown in Table 2. In those lines and sections, new operation control methods and measures have been set based on the calculated overturn resistance for all types of cars that would enter those lines and sections. As the wind observation method, the above-mentioned three-anemometer method has been adopted.

Early restrictions have been applied to the sections shaded in Table 2 (Uzen-Mizusawa to Uzen-Oyama on the Uetsu Line, Echigo-Akatsuka to Uchino and Aoyama to Sekiya on the Echigo Line) since the derailment and overturn accident on the Uetsu Line, but that was changed to general restrictions with the introduction of the New Method. This was done because

<table>
<thead>
<tr>
<th>Line</th>
<th>Section</th>
<th>Date introduced</th>
<th>Before introduction</th>
<th>After introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uetsu Line</td>
<td>Uzen-Mizusawa - Uzen-Oyama</td>
<td>December 9, 2011</td>
<td>Speed limit 25 m/s or greater</td>
<td>Speed limit 25 m/s or greater</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Operation suspension</td>
<td>Operation suspension</td>
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<tr>
<td></td>
<td>Kobashi - Uzen-Mizusawa</td>
<td></td>
<td>at wind speed 25 m/s or greater</td>
<td>at wind speed 25 m/s or greater</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td>at wind speed 25 m/s or greater</td>
</tr>
<tr>
<td></td>
<td>Shin-Narashino - Kamehamachi</td>
<td>March 22, 2012</td>
<td>at wind speed 25 m/s or greater</td>
<td>at wind speed 25 m/s or greater</td>
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<td></td>
<td></td>
<td></td>
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<td>at wind speed 25 m/s or greater</td>
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<tr>
<td></td>
<td>Ichibanshirai - Shinga</td>
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<td>Echigo-Akatsuka - Uchino</td>
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<tr>
<td></td>
<td>Aoyama - Sekiya</td>
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<tr>
<td></td>
<td>Hokusai - Nigata</td>
<td>December 20, 2012</td>
<td>at wind speed 25 m/s or greater</td>
<td>at wind speed 25 m/s or greater</td>
</tr>
</tbody>
</table>

Sections where wind speed at which operation control commands are issued was increased by 5 m/s
the overturn resistance of the aforementioned car types was calculated as values at which control could be changed to general restrictions.

New operation control methods and measures for those sections include setting speed limit by car type (normal speed limitation) for the Uetsu Line, modification of lightweight limited express cars for the Echigo Line (increasing car weight) to increase overturn resistance, and installation of windbreak fences for the Keiyo Line.

Fig. 10 shows the total time of operation control in strong winds in three sections on the Echigo Line above after introduction of the New Method. The graph of “after introduction” in the figure is the total time of actual operation control, and the graph of “before introduction” is the estimated time of operation control based on data of anemometers in that period if the New Method were not introduced (if operation control in wind based on the Kunieda formula).

Fig. 10 indicates the effect of increasing wind speed at which operation control commands are issued by 5 m/s for two sections where operation control was changed from early restrictions to general restrictions, resulting in considerable reduction in time of operation control in strong winds. Even in the section where operation control remains as the early restrictions, we can see the effect introducing the three-anemometer wind observation method, reducing the time of operation control over that of the estimation.

For two sections on the Keiyo Line in Table 2, we introduced the three-anemometer method while keeping the early restrictions, and data estimation for a year suggests reduction of the time of operation control by 10% to 20%.

![Fig. 10 Total Time of Operation Control in Strong Winds](image)

**6 Conclusion**

For operation control in strong winds, we put into practical use more rational and scientifically based methods of assessing overturn resistance of a vehicle and observing wind than before. Those are done using the RTRI Detailed Equation and the three-anemometer method.

Based on appropriate and precise calculation, we created operation control required for operation control under wind and a method of operation control under wind whereby a variety of rolling stock and wayside measures can be considered in a flexible manner.

In sections already where the New Method is already applied, we were able to achieve reductions in the total time of operation control in strong winds. There still are, however, many sections where excessive allowance for safety is made due to conditions of cars and wayside structures. We will therefore plan to proceed with further R&D to make the New Method more reasonable and practical.

**Reference:**

1) JR East, CSR Report 2013: 58