Study on under-floor flow to reduce ballast flying phenomena

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Abstract
Between under-floors of cars and tracks, there are complex flows caused by interaction between them. The flow is a main cause of ballast flying phenomena and snow-accretion on the under-floor of the cars. The accreted snow dropping from the running trains can cause flying of the ballast.

To study under-floor flow, we measured the under-floor flow in on-track tests and confirmed that smoothing the under-floor of the cars made the under-floor flow decrease. To investigate the possibility of reduction of the impact of the under-floor flow by modification of under-floor shape, we carried out wind tunnel tests. Comparing the under-floor flow in on-track tests and that in wind tunnel tests, we verified that the under-floor flow in the on-track tests was reproduced in the wind tunnel tests. We measured the velocity profiles of the under-floor flow. We understood that the more we smooth the under-floor shapes, the more the under-floor flow decreases. Furthermore, we developed a model running facility that enables us to estimate the velocity of the flow on the ground when the train passes by.

Next, we performed a study on a new measure (passive flow control by deflectors with which car bodies are equipped) to reduce the snow-accretion. By wind tunnel tests, we confirmed that by means of deflectors the velocity of the flow decrease and that the bigger the angle of the deflectors is, the larger the velocity reduction effect is. To verify the effect of the deflectors to decrease the snow-accretion we carried out the wind tunnel tests using artificial snow particles. We found out that the snow particle flux decreased near the bogies by means of the deflectors and the effect of the snow particle flux reduction extended over large area near the bogies.

1. Introduction
Between under-floors of cars and tracks, there are complex flows caused by interaction between them. The flow is a main cause of ballast flying phenomena and snow-accretion on the under-floor of the cars. It is considered that when the train passes by, relatively light ballasts rolled by the induced flow by the train, sometimes jump up when they hit other ballasts and sleepers, and the jumped up ballasts fly when the train hits them accidentally. The accreted snow dropping from the running trains can cause flying of the ballast(1). In Japan, measures against these ballast-flying phenomena(2) have been usually taken on the track. However the measures on the track cost a great deal compared with those on the cars because the measures on the track have to be large in scale. Therefore, we can reduce the total cost of the measures, if we can make use of the measures on the car body. We report a study on the under-floor flow which causes the ballast flying phenomena directly and the snow-accretion on the under-floor of the cars.

2. Under-floor flow
2.1 On-track tests
(1) Method
We measured a under-floor flow in on-track tests because the flow can cause the ballast flying phenomena directly. Figure 1 shows the arrangement of measuring instruments. We measured the vertical velocity profiles of flow above the ballast by using comb Pitot tubes, and the non-steady flow caused by a train-set by means of a hot wire anemometer that can measure high frequency data(3kHz). In measurement by the hot wire anemometer, we chose a film probe because there was some possibility that the probe was exposed to the wind and rain.
Figure 2 shows the under-floor shapes of the train-set of which we measured the flow in on-track tests. In the figure, two types of under-floor shapes are indicated:

Type1: Equipment covers
Type2: Body mount

The equipment covers are composed of flat plates to cover the under-floor equipment, and the body mount means the covers consisting of curved side surfaces and plane bottom surfaces to shroud the under-floor equipment.

Figure 1 Measurement of flow above the ballast

Type 1

Type 2

Figure 2 Under-floor shape of the car

(2) Results and discussion

Figure 3 shows the velocity of the flow measured by the hot wire anemometer. By dividing the measured velocity by the train speed, we obtain the nondimensional velocity. The flow was strongly turbulent above the ballasts; therefore in order to analyze the flow, we averaged these data in the following way.

- choose the data of the same series of the train-sets of nearly the same speed
- average these train speeds
- standardize the each train speed to the averaged speed
- add all time series data
- divide added time series data by the number of time series data

Owing to the above mentioned averaging method, it seems that we can reduce the signal noise and some components of the turbulent flow that was independent of the local under-floor shapes like differences between bogies and other parts. When the train passed above the ballast, the velocity of the flow above the ballast increased gradually, reached roughly the constant value after the 3rd car passed, and became larger temporarily at a tail part. We understood that in both the Type1 and the Type2, the local under-floor shapes like differences between bogies and other parts did not affect the velocity of the flow above the ballast directly.

The Figure 4 shows the vertical velocity profiles of the flow above the ballast. In the Figure 4, the distance from the ballast surface to each measurement points is plotted on the vertical axis. The velocity is the value averaged over the section between the 3rd car and the 15th car where the flow velocity is almost constant. The flow velocity of the Type2 is smaller than that of the...
Type 1. We understood that smoothing the under-floor of the cars decreased the velocity of the flow above the ballast.

Figure 3 Time series data measured by hot wire anemometer

Figure 4 Velocity profiles of the flow above the ballast
2.2 Wind tunnel tests
In the on-track tests, we confirmed that the under-floor shapes of the cars influenced the flow above the ballast. Then, we investigated the possibility of reduction of the flow by modification of under-floor shape in the wind tunnel tests.

(1) Method
The wind tunnel tests were carried out by using a closed type test section of the Large-scale wind tunnel of Railway Technical Research Institute. The size of the test section is 5m wide, 3m high and 20m long. The wind velocity was 50m/s in the tests. In the research of the under-floor flow of the cars by using the wind tunnel, it is very important to simulate the ground effect. So, we used the moving-belt and the boundary layer suction device to simulate the flow between the car models and the ground. The size of the moving-belt is 2.7m wide and 6m long. The speed of the moving belt is the same as the wind velocity.

Figure 5 shows the arrangement of the models in the test section and measurement points of the under-floor flow. We used 1/7-scale car models consisting of three cars (representing head, intermediate and tail cars). The under-floor shapes are the same as those of the Type 2 (on-track tests). When we adopt the car width as the representative length and the maximum train speed or the maximum velocity of wind tunnel tests as the representative velocity, the Reynolds number of the wind tunnel tests (Re=2×10^6) is smaller than that of the on-track tests (Re=2×10^7) by a factor of 10. The blockage ratio is 1.5%. Since we cannot set the three cars on the moving-belt at the same time, we set the intermediate car on the center of the moving belt. We measured the velocity profiles of the under-floor flow of the intermediate car by using hot wire anemometers that was installed in a traverser mounted in the car model.

(2) Results and discussion
Figure 6 shows the velocity profiles of the under-floor flow of the wind tunnel tests. In the wind tunnel tests fast flow means slow flow on the ground because we measured the velocity of the flow relative to the car in the wind tunnel tests. The flow velocity means nondimensional velocity divided by the wind tunnel velocity. In the Figure 6, the distance from the car bottom to the measurement points is plotted on the vertical axis and the bottom of the axis indicates the
ground. We subtracted the result of the Type2 (on-track tests) from 1.0 and also illustrated it in Figure 6, where the measurement height of the on-track tests was scaled down to the model scale to compare the results of the wind tunnel tests with those of the on-track tests. Since Figure 6 shows that the velocity profiles in the on-track tests are similar to those in the wind tunnel tests near the bottom range, though the velocity profiles have some variations according to the measurement points. We consider that the under-floor flow in the on-track tests was reproduced in the wind tunnel tests.

To estimate the influence of smoothing the under-floor shapes on the under-floor flow, we changed the under-floor shapes and performed the wind tunnel tests. Figure 7 shows three types of the under-floor shapes of the car models.

Type A: body mount
Type B: body mount with fairings around bogies
Type C: without bogies, with bogie skirts, and under-bogie flat covers

Figure 8 shows that the flow velocity became faster in ascending order of the type A, type B, and type C. So, we understand that the smoothing the under-floor shapes decreased the under-floor flow which included the flow above the ballast.

![Figure 6 Velocity profile of the under-floor flow](image)
2.3 Development of model running facility

We understood that smoothing the under-floor shapes decreased the under-floor flow in the wind tunnel tests. However, in the wind tunnel tests, it is difficult to estimate the averaged velocity of the flow above the ballast when the train-set passes by, because in the wind tunnel tests the measurement points of the under-floor flow are fixed to the train and the velocity of the under-floor flow depends on the location of the measurement point. So we developed a model running facility that enables us to estimate the velocity of the flow on the ground when the train-set passes by.

(1) Method

We have to remove disturbance like a natural wind to estimate the velocity of the flow near the ground by means of the model running facility set outdoors, therefore it is desirable that it should be installed indoors. Meanwhile we need a space large enough in length and in cross section for models running. To meet these requirements, we installed the facility in the Towing...
Wind Tunnel Facility\(^{(3)}\) owned by Tohoku University. It has a large closed test section, 3.5m in width, 3.3m in height, and 500m long. Figure 9 shows the arrangement of the model running facility. The model scale is 1/8.4. The blockage ratio of sectional area of model against that of test section is 1%. We used three car models (representing head, intermediate and tail cars). In the Towing Wind Tunnel Facility, we laid the tracks consisting of rails and sleepers for 200m, placed the three cars on it, and pulled them by an automobile. To avoid the influence of wake flow of the automobile, it ran outside the Towing Wind Tunnel Facility. We measured the velocity of the flow near the ground by means of a hotwire anemometer installed on the ground. The car models speed was 11m/s.

![Figure 9 Arrangement of model running facility](image)

(2) Results and discussion
Figure 10 shows the results of the velocity of the flow near the ground. We obtained the time-series data which indicated that the velocity increases at the head part, keeps constant value at the intermediate part, and temporarily is more increased at the tail part, similarly to those obtained in the on-track tests. Hereafter, by using the developed model running facility, we are planning to study the under-floor flow more in detail.
3. Snow-accretion

Under the car body there are under-floor equipment boxes and bogies. Covering between under-floor equipment boxes can reduce the snow-accretion to these boxes. However, it is difficult to attach covers to the bogies because of maintenance and displacement by running. Therefore, there is no effective countermeasure to reduce snow-accretion to bogies at present. So, we performed a study on a new measure (passive flow control by deflectors with which car bodies are equipped) because it can be an effective way to decrease the inflow of the snow to the bogies for reduction of the snow-accretion to the bogies.

(1) Method

We performed wind tunnel tests by using the open type test section of small-scale wind tunnel of Railway Technical Research Institute. Figure 11 shows the arrangement of a test section and measurement points. The size of a nozzle section is 0.72m wide and 0.6m high. We used the boundary layer scoop, the boundary layer suction device and the moving-belt, to simulate the flow between car models and the ground. The size of the moving-belt is 0.35m wide and 1.075m long. The wind velocity was 10m/s in the tests. The speed of the moving belt was the same as the wind velocity. We used two conventional cars, one is an intermediate car with a dummy head part, and the other is a tail car. We measured the velocity profiles around bogies by using hot wire anemometers. As, it considered that it will be effective for reduction of snow-accretion to change the direction of flow along the car side to the outside direction, the shape of the deflector should be triangular prisms basically. We designed the two deflectors (Figure 11) that protruded from the car side. The length protruding from the under-floor equipment side was set at the maximum value within the rolling stock gauge. We measured the velocity of the flow around bogies equipped with the deflectors. The measurement sections were at the front axle and the center of the bogie, and the measurement height was at the center of the deflector.
(2) Results and discussion

Figure 12 shows the velocity profiles near the bogies. The cases regarding the deflectors were those equipped with nothing, V10, and V50. In the Figure 12, the distance from the car side surface to the measurement points is plotted on the horizontal axis and “0mm” means at the car side surface. We focused on the area near the bogies (in the Figure 12 minus area on the horizontal axis) because our aim is reduction of snow-accretion to the bogies. We understood that by means of deflectors the velocity of the flow decreased. Comparing the V10 and V50 deflectors, we understood that the V10 deflector decreased the velocity of the flow larger than V50 deflector.
3.2 Wind tunnel tests using snow
(1) Method
We understood that the deflectors decrease the velocity of the flow near the bogies. However, we could not make sufficiently clear the relationship between the velocity of the flow and the snow particles. In short, it is not always evident that the reduction of velocity reduces the snow-accretion to the bogies. So to verify the effect of the deflectors to decrease the snow-accretion, we carried out the wind tunnel tests using artificial snow particles. We used the wind tunnel in a cold room in the Shinjo branch of Snow and Ice Research Center in National Research Institute for Earth Science and Disaster Prevention. In the room there is a snowfall machine. We performed the wind tunnel tests using artificial snow made in the cold room and estimated the reduction effect of the spatial density of the snow particles. Figure 13 shows arrangement of the wind tunnel tests. The car models consisted of the head car and the tail part and their scale was 1/7. The temperature of the cold room was -10°C. The wind speed in the wind tunnel tests was set at 10m/s. We used two SPC (Snow Particle Counter). The SPC is a measurement device that can count the number of the snow particles by each size. In the wind tunnel tests, we set these SPC at the upstream and downstream of the deflector. We measured supplied snow particle flux by the upstream SPC and snow particle flux flowed in the bogies by the downstream SPC (Figure 13). Here, “the snow particle flux” means volume of snow particles passing per unit time and unit area. In the wind tunnel tests, we used the following three deflectors (Figure 14).
Sd1: above-mentioned shape (V10)
Sd2: big equilateral triangular prisms
Sd3: small equilateral triangular prisms
Here, the maximum length from the under-floor equipment side of Sd2 is the same as that of Sd1, and double of that of Sd3.

(2) Results and discussion
In the wind tunnel tests the supplied snow particle flux is not always uniform. So we estimated the reduction effect of the snow-accretion of the deflector by means of the ratio of the downstream flux to the upstream flux. Figure 14 shows the results of the wind tunnel tests. As the base for comparison, we have chosen the result of the case of no deflector. We found out that the snow particle flux decreased near the bogies by means of the deflectors. Comparing the result of Sd2 and that of Sd3, it was evident that when the length from the under-floor equipment side is larger, the effect of the snow-accretion reduction becomes larger.
We thought that in the downstream end the effect of the snow-accretion reduction was the smallest and in the area of the upper stream and center of the bogies the effect is larger. Therefore we made clear that the effect of the snow particle flux reduction extended over large area near the bogies.

![Figure 13 Arrangement of wind tunnel tests](image)

**Figure 13 Arrangement of wind tunnel tests**

![Figure 14 Snow-accretion reduction](image)

**Figure 14 Snow-accretion reduction**

### 4. Conclusion

We studied the under-floor flow of the car that can cause the ballast flying phenomena. Firstly, to estimate the under-floor flow under actual conditions, we measured the under-floor flow in on-track tests. To measure the flow, we used comb Pitot tubes and a hot wire anemometer. The test result showed that smoothing the under-floor of the cars reduced the under-floor flow. Secondly, to investigate the possibility of reduction of the under-floor flow by modification of under-floor shape, we carried out wind tunnel tests by using a closed type test section of the Large-scale wind tunnel that has the moving-belt and the boundary layer suction device to simulate the flow between car models and the ground. Comparing the under-floor flow in the on-track tests and that in wind tunnel tests, we verified that the under-floor flow in the on-track tests was reproduced in the wind tunnel tests. We measured the velocity profiles of the under-floor flow of the intermediate car by using hot wire anemometers. We understood that the more we smooth the under-floor shapes, the more the under-floor flow decreases. Furthermore, we developed a model running facility that enables us to estimate the velocity of the flow on the ground when the train passes by.
Next, we performed a study on a new measure (passive flow control by deflectors with which car bodies are equipped) to reduce the snow-accretion. It is an effective way to decrease the inflow of the snow to the bogies for reduction of the snow-accretion to the bogies. We performed wind tunnel tests by using the open type test section of small-scale wind tunnel equipped with boundary layer scoop, boundary layer suction device, and moving-belt to simulate the under-floor flow. We confirmed that by means of deflectors the velocity of the flow decreased and that the bigger the angle of the deflectors is, the larger the velocity reduction effect is. Next, to verify the effect of the deflectors to decrease the snow-accretion we carried out the wind tunnel tests using artificial snow particles. We found out that the snow particle flux decreased near the bogies by means of the deflectors and that the effect of the snow particle flux reduction extended over large area near the bogies.

References


