Train operation control such as suspending operation or controlling (restricting) speed is performed on railways when rain gauges detect heavy rainfall in order to secure safety of train operation under rainfall. For many railways, rain gauges used for train operation control are set up in 10 km intervals for the qualitative reason of horizontal spread of cumulonimbus clouds being about 10 km.\(^1\)\(^,\)\(^2\) Train derailment accidents have been greatly reduced by combining such train operation control under rainfall (non-structural measures) and improvement of resistance to rainfall (structural measures).\(^3\)

Rain gauges set up in such a manner are able for the most part to detect heavy rain occurring at arbitrary locations along the track, but they are sometimes not able to detect highly localized heavy rainfall.\(^4\) In this study, we developed a method of train operation control that utilizes radar-observed rainfall information (area-wide rainfall) to detect localized rainfall that may not be detectable by railway rain gauges in order to improve safety of train operation under rainfall.

**Method of Train Operation Control**

East Japan Railway Company (JR East) implements train operation control in sections where rainfall observed by rain gauges set up in approx. 10 km intervals exceeds prescribed standard values for train operation control. When rainfall observed by rain gauges in ordinary sections becomes larger, train operation control is implemented in stages transitioning from ordinary operation to warning, speed control, and operation suspension. For rainfall indexes, effective rainfall in half lives of 1.5, 6, and 24 hours is used.\(^5\)

**Introduction**

Train operation control based on rainfall observed by rain gauges to ensure the safety of train operation during heavy rain. At JR East, the rain gauges are installed in approximately 10 km intervals. These rain gauges can detect the majority of occurrences of heavy rainfall in any area along the railways. However, there are a few cases when these rain gauges cannot detect localized heavy rainfall. Therefore, we developed a train operation control method that uses radar-observed rainfall. This method can detect localized rainfall that cannot be detected by rain gauges.

**Keywords:** Train operation control, Heavy rainfall, Rain gauge, Radar-observed rainfall

**Materials**

3.1 Rainfall Data

Analyzed rainfall of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and rainfall data observed by JR East rain gauges are used as rainfall data. Analyzed one-hour rainfall can be obtained in approx. 1 km meshes across Japan from 2006, and hourly values on CD-ROM/DVD are used. JR East rain gauges are tipping bucket type rain gauges that tip once for every 0.5 mm, and hourly rainfall is used as is done with analyzed rainfall. The term of analysis in this study was from 2006 to 2013 where rainfall data of both methods was available.

3.2 Rain Disaster Data

For rain disaster data, we used the 289 incidents where train operation was affected on JR East conventional lines from 2006 to 2013. Those can be broken down into 87 incidents of embankment collapse, 149 incidents of excavation/natural slope collapse, 2 incidents of mudslide, and 51 incidents of ballast washout/track flooding. Here, rain disasters are cases where there was 1 mm or more of rainfall measured by the rain gauge in the location where the disaster occurred. This definition was adopted because, while incidents are included where cause and effect relation of rain is not clear where rainfall was small, there is a possibility that rainfall is large in the location where the disaster occurred even though it was small in the location of the rain gauge.

For the 289 incidents of rain disaster, we compared rainfall when the disaster occurred and train operation control standard values for the section where the disaster occurred and separated the disasters into those that occurred when commands to suspend operation were issued (operation suspension), when commands to restrict speed were issued (speed control), when warnings were issued (warning), and in ordinary operation. Of the 289 incidents, 230 occurred at operation suspension, 25 at speed control, 20 at warnings, and 14 at ordinary operation.
control that can identify localized heavy rain that cannot be detected by rain gauges is an issue that needs to be addressed.

Suzuki and Oshima investigated the difference in effective rainfall between the location where disaster occurred and location where rainfall was measured for the aforementioned 289 rain disasters. Fig. 1 shows, using analyzed rainfall, effective rainfall with half lives of 1.5, 6, and 24 hours in the meshes that include the location of the rain gauge and location where the disaster occurred. According to that figure, points showing the relation between the two effective rainfall values at time of rain disaster are often have almost the same value on X and Y axis, forming straight line, and large differences between the two effective rainfall values are not seen in many disaster cases. From this, we believe that railway rain gauges will be able to detect for the most part heavy rain that causes disasters at arbitrary locations along lines. On the other hand, while the number of incidents is small, effective rainfall is sometimes many times greater at the location where the disaster occurred than at the location of the rain gauge. Fig. 2 shows that in such incidents, an area of heavy rain may extend in a line or that a localized area of heavy rain may be stationary between the rain gauge in question and the adjacent rain gauge. In other words, while the number of incidents is small, depending on the positional relationship between the rain gauge and area of heavy rain, rain gauges may not be able to detect heavy rain that causes a disaster.

For that reason, in order to improve safety of train operation in times of rainfall, development of a method of train operation control that can identify localized heavy rain that cannot be detected by rain gauges is an issue that needs to be addressed.

**5 Train Operation Control Utilizing Radar-observed Rainfall**

**5.1 Proposal of a Train Operation Control Method**

Rain gauges are, as previously mentioned, able for the most part to detect heavy rain that could cause a disaster occurring at arbitrary locations along the track. Therefore, we continue using train operation control by rain gauges. Along with that, we propose a method that supplements that using analyzed one-hour rainfall as a method of train operation control that can detect localized heavy rain in cases where railway rain gauges cannot detect the rain.

Suzuki investigated derailment accidents caused by rain disaster and train speed when the driver discovered a disaster and stopped the train before derailment. The results showed that derailment accidents seldom occurred when the train was traveling at reduced speed limit or slower and that there were cases where the driver discovered a disaster and stopped the train when traveling at reduced speed. From this, we believe that the effect implementing speed control has on preventing derailment accidents is large. Therefore, we intend in train speed control by analyzed rainfall to implement speed control when rainfall exceeds prescribed standard values.
5.2 Assessment of Train Operation Control Methods

The basis of conducting train operation control for natural disasters is to sufficiently avoid hazards that incur due to natural external forces (secure safety) and then secure normal operation of trains as much as possible (secure stability). We thus assessed methods of train operation control utilizing analyzed rainfall from perspectives of both safety and stability of train operation. In analysis, we used observed values from rain gauges set up discretely for train operation control by rain gauges and rainfall values of meshes that include the rail line for train operation control utilizing analyzed rainfall, as shown in Fig. 3.

Safety is assessed by number of rainfall disasters where rainfall when the disaster occurs is greater than the standard value for speed control in cases where train operation control method and standard values for operation control are prescribed. This is the number of rainfall disasters captured. Stability is assessed by number of hours where rainfall is greater than the standard value for speed control in cases where train operation control method and standard values for operation control are prescribed. This is the speed control time.

In analysis, we used observed values from rain gauges set up discretely for train operation control by rain gauges and analyzed rainfall in a supplementary manner while continuing train operation control by rain gauges. Assessment of stability was performed for the 82 JR East lines where speed control in rain is implemented. Observed values from rain gauges and analyzed rainfall from 2006 to 2013 were used in analysis. For train operation control by rain gauges, speed control time was time when observed values by rain gauges at one or more location on the line were in excess of the prescribed standard value for speed control, and this is shown on the far left column of Table 1. With train operation control by analyzed rainfall, we set standard values for one-hour rainfall by analyzed rainfall when finding speed control time in 10 mm increments from 30 mm to 100 mm. In this case, we sought the number for hours where analyzed one-hour rainfall was in excess of the individual standard values in one or more meshes on the line when speed control is not issued in train operation control by rain gauges. This is the speed control time added to train operation control by rain gauges when implementing train operation control using analyzed rainfall while maintaining train operation control by rain gauges. Speed control time in Table 1 indicates the average of the individual numbers of hours added to speed control time of train operation control by rain gauges. The average of speed control time of train operation control by rain gauges added to this number of hours is the average speed control time when using train operation control by analyzed rainfall in a supplementary manner while maintaining train operation control by rain gauges.

The aforementioned 289 incidents of rain disasters where used for assessment of safety. As shown in section 3.2, in train operation control by rain gauges, 230 incidents occurred at operation suspension, 25 at speed control, 20 at warnings, and 14 in ordinary operation. From this, we see that a total of 255 incidents of rain disaster captured in train operation control by rain gauges occurred at speed control and operation suspension as shown in the far left column of Table 1. In train operation control by analyzed rainfall, we set standard values for one-hour rainfall in 10 mm increments from 30 mm to 100 mm when finding number of rain disasters captured. In train operation control by rain gauges, of rain, we investigated the number of rain disasters that occurred before speed was restricted when the maximum value of one-hour rainfall at the time of the disaster exceeded the aforementioned standard values in sections between stations that include the location of rain disaster when using analyzed rainfall of meshes that include the line. When using analyzed one-hour rainfall for train operation control, this is the number of rain disasters that can be captured added to those in train operation control by rain gauges. Fig. 4 shows the relationship between one-hour rainfall measured by rainfall gauge at the location of a rain gauge and maximum value of one-hour rainfall measured by analyzed rainfall at the mesh between stations that includes the location of rain disaster. In this case, the number of rain disasters that can be added to those in train operation control by rain gauges is shown in the number of rain disasters captured in Table 1. The number of rain disasters that occurred after speed control in train operation control by rain gauges added to this figure is the number of rain disasters captured when using train operation control by analyzed rainfall in a supplementary manner while continuing train operation control by rain gauges.

Table 1 shows number of disasters captured and average speed control time in train operation control by rain gauges and the ratio of those. It also shows additional number of rain disasters that can be captured and added average speed control time when
In this study, we proposed a method of train operation control that can capture localized heavy rain that cannot be detected by railway rain gauges in order to improve safety of train operation in rain. This method uses analyzed one-hour rainfall in a supplementary manner while maintaining train operation control by rain gauges.

The following issues in terms of practical use remain in introduction of this method. MLIT analyzed rainfall is updated in 30-minute intervals and time is required for its delivery, so it cannot be called real-time data. For that reason, it is difficult at present to utilize MLIT analyzed rainfall for train operation control, so we will have to use our own analyzed rainfall with shorter update interval and delivery time. The MLIT’s XRAIN system can be used for radar-observed rainfall on the Kanto plain, so we are considering utilizing XRAIN as well as analyzed rainfall in sections there. Moreover, standard values for analyzed rainfall need to be decided based on practical judgment. We are aiming to improve the disaster prevention system and put this method into practical use at an early stage upon overcoming these issues.

### Reference: