RA2023-1-I

RAILWAY ACCIDENT
INVESTIGATION REPORT

Railway accident with train derailment in the premises of Takamiya station, single track, Taga Line, Hikone City, Shiga Prefecture
OHMI Railway Co., Ltd.

January 19, 2023

Japan Transport Safety Board

The objective of the investigation conducted by the Japan Transport Safety Board in accordance with the Act for Establishment of the Japan Transport Safety Board is to determine the causes of an accident and damage incidental to such an accident, thereby preventing future accidents and reducing damage. It is not the purpose of the investigation to apportion blame or liability.

TAKEDA Nobuo
Chairperson
Japan Transport Safety Board

Note:

This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.

《Reference》

The terms used to describe the results of the analysis in "3. ANALYSIS" of this report are as follows.

i) In case of being able to determine, the term "certain" or "certainly" is used.
ii) In case of being unable to determine but being almost certain, the term "highly probable" or "most likely" is used.
iii) In case of higher possibility, the term "probable" or "more likely" is used.
iv) In a case that there is a possibility, the term "likely" or "possible" is used.

Railway Accident Investigation Report

Railway Operator	OHMI Railway Co., Ltd.
Accident Type	Train derailment
Date and Time	About 21:17, February 7, 2022
Location	In the premises of Takamiya station, single track, Taga Line, Hikone City, Shiga Prefecture

December 19, 2022

Adopted by the Japan Transport Safety Board

Chairperson TAKEDA Nobuo
Member OKUMURA Fuminao
Member ISHIDA Hiroaki
Member SODA Hisako
Member SUZUKI Mio
Member NIITSUMA Mihoko

SYNOPSIS

<SUMMARY>

At about 21:17 on February 7, 2022, the driver of inbound train #4110, a 2-vehicle train set (one-man operation) proceeding from Tagataisha-mae Station to Maibara Station on the OHMI Railway Co., Ltd. Taga Line, stopped the train due to feeling an impact while passing through a right-hand curve with a radius of 160 m at the premises of Takamiya Station.

When the driver checked the train after stopping, he discovered that the lead axle of the lead bogie of the lead vehicle, the lead axle of the rear bogie of the lead vehicle, and the lead axle of the lead bogie of the rear vehicle had been derailed.

About 100 passengers and one driver were onboard the train, and there were no injuries.

<PROBABLE CAUSES>

The Japan Transport Safety Board concludes that the probable cause of this accident is as follows: It is probable that the right wheels of the lead axle of the lead bogie of the lead vehicle, the rear bogie of the lead vehicle, and the lead bogie of the rear vehicle fell into the gauge due to the gauge widening significantly while the train was passing through a right-hand curve with a radius of 160 m.

It is more likely that the gauge widened significantly due to a large amount of static irregularity of gauge along this curve, and that a series of defective sleepers and poor rail fastening status resulted in lateral movement of the rails and rail tilt due to lateral force when the train was running, which caused the gauge to widen dynamically.

It is probable that the static irregularity of gauge was large due to the standard value for maintenance for irregularity of gauge being larger than the appropriate value.

The series of defective sleepers and poor rail fastening status is more likely because inspection methods and judgment criteria were not clarified, preventing proper maintenance from being performed.

It is possible that this accident occurred because the slack on this curve was relatively large, which resulted in a smaller margin against the derailment to inside gauge, and there were places where the guard rail was not fastened to the sleepers, causing rail tilt, etc. to occur from the lateral force acting on backside of wheel, etc., from right wheel, which dynamically increased the flangeway width, causing the derailment prevention function not to work sufficiently. Another probable factor to be involved was that the countermeasures implemented in response to the Japan Transport Safety Board UN-I-SAN No. 43, dated June 28, 2018, “On the opinion concerned with the prevention of the train derailment accident caused by the gauge widening,” were insufficient.

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1. PROCESS AND PROGRESS OF THE RAILWAY ACCIDENT INVESTIGATION

1.1. Summary of the Railway Accident

At about 21:17 on Monday, February 7, 2022, the driver of Train #4110, a 2-vehicle train set (one-man operation) proceeding from Tagataisha-mae Station to Maibara Station on the OHMI Railway Co., Ltd., Taga Line, stopped the train due to feeling an impact while passing through a right-hand curve with a radius of 160 m at the premises of Takamiya station. *Hereinafter the words the lead, rear, left, and right are based on the direction of the train travel.*

When the driver checked the train after stopping, he discovered that the front axle of the bogie in front of the lead vehicle, the front axle of the bogie behind the lead vehicle, and the front axle of the bogie in front of the rear vehicle had been derailed.

About 100 passengers and the one driver were onboard the train, and there were no injuries.

1.2. Summary of the Railway Accident Investigation

1.2.1 Organization of the Investigation

On February 7, 2022, the Japan Transport Safety Board designated a investigator-in-charge and an accident investigator to investigate this accident.

The Kinki District Transport Bureau dispatched its staff to the accident site etc., to support the investigation of the accident.

1.2.2. Implementation of the Investigation

February 8, 2022	Site investigation and hearing statements
February 9, 2022	Site investigation
March 11, 2022	Site investigation

1.2.3. Comments from Parties Relevant to the Causes

Comments were invited from the parties relevant to the cause of the accident.

2. FACTUAL INFORMATION

2.1. Process of the Train Operation

2.1.1. Statements of the Driver

The following is an outline of the events leading up to the accident, according to the statement from the driver, *hereinafter referred to as "the Driver"*, of Train inbound #4110, *hereinafter* *referred to as "the Train"*, proceeding from OHMI Railway Co., Ltd., *hereinafter referred to as "the Company"*, Tagataisha-mae Station to Maibara Station.

On the day of the accident, work roll call was taken at Yokaichi Station at around 06:52. The Driver left the parked vehicle at 07:12, and boarded Train #5100, which departed from Yokaichi Station at 07:21, bound for Maibara Station. After that, while taking breaks, the Driver worked aboard multiple trains, including a train that used the same vehicles as the Train, and worked aboard Train #2409, which departed Hikone Station at 20:32, bound for Tagataisha-mae Station. Also, on the day of the accident, the Driver did not notice anything abnormal about the site of the accident or the vehicles of the Train prior to the accident.

After working aboard Train #2409, the Driver worked aboard the Train. The train departed from the Screen station on time (21:15), After powering up until it reached 40 km/h, it coasted, and then decelerated to 20 km/h once the 20 km/h limit marker on the curve was visible. After that, while driving at 20 km/h around a right compound curve[*1] with radii of 160 m and 400 m (221 m–016 m from the Takamiya Station starting point; "Takamiya Station starting point" omitted hereinafter), *hereinafter referred to as, "the Curve"*, the Driver heard a sound like metal scraping coming from the vicinity of the bogie. After that, there was an audible impact that made a "thump" sound that they had not experienced up to that point, so the Driver applied the emergency brake to stop the Train.

After stopping, the Driver called the train dispatcher on his work mobile phone to notify the dispatcher about the high probability that the Train had been derailed. After that, the Driver disembarked from the train to check on the derailment status, He discovered that the right wheel of the front axle of the bogie in front of the lead vehicle of the Train had fallen between the rail and the guard rail[*2], so he notified the train dispatcher that the Train had been derailed. After some time had passed, the Drivers worked with staff from the train depot, maintenance of way office, and transportation office to help the passengers disembark. This started at around 22:10 and finished at around 10:30 PM, After that, they guided the passengers to Takamiya Station. Also, none of the passengers were injured.

[Refer to Attached Figures 1 to 3]

2.1.2. Records of Operating Status

The Train in was equipped with a device for recording the operation condition, hereinafter

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*1 "Compound curve" means a linear one with continuous curves in the same direction with different radii.

*2 "Guard rails" are rails installed on the insides of the gauges of the inner rails to prevent derailment.

referred to as "event recorder", and an outline of the operation status for the Train before and after the accident is shown in Table 1. Also, kilometerage indicates the front of the Train.

Table 1. Records from the Event Recorder

Time	Train speed [km/h]	kilometerage	Operation	Comments
21:15:47	0	779 m	Powering	Departure from Screen station
21:16:09	38	642 m	Notch off	
21:16:36	38	368 m	Brakes applied	Decelerated due to approaching a curve
21:16:49	19	262 m	Brakes off	
21:17:16	11	136 m	Emergency brake applied	
21:17:18	0	133 m		Stopped

*Time is corrected according to the GPS (Global Positioning System), but there may be some inherent errors in the train's speed and kilometerage owing to not being corrected through actual measurement tests, etc.

In addition, a drive recorder that records video and audio of the front of the train was installed in the driver's console in the lead vehicle of the Train, and records were made for the Train, but it was not possible to observe any obstacles, etc., within the structure gauge between the time the train departed from Screen station and when it stopped following derailment.

2.2. Death, Missing, and Injury of Persons

None.

2.3. Information on the Railway Facilities, etc.

2.3.1. Information on the Accident Site

The leading position of the Train stopped at around 133 m on the Curve, the position of the lead axle of the bogie of the lead vehicle that was derailed was around 135 m, the position of the lead axle of the rear bogie was around 149 m, and the position of the lead axle of the lead bogie of the rear vehicle was 155 m.

The derailment condition for the lead vehicle was that the right wheels of the lead axle of the lead bogie and the lead axle of the rear bogie were derailed between the right rail and the guard rail. Also, the left wheels of both axles of the lead bogie and the rear axle of the rear bogie had been in the status as floated several millimeters to several centimeters from the top surface of the left rail.

The derailment status for the rear vehicle was that the right wheel of the lead axle of the lead bogie was derailed between the right rail and the guard rail. *[Refer to Attached Figure 3]*

2.3.2. Information on the damaged Status, etc., of the Railway Facilities

(1) On the side of the head on the gauge corner[*3] side of the right rail (inner rail) around 162 m, the right wheel fell into the gauge and there were traces considered of rubbing on the front rim surface of the wheel in three spots, *hereinafter to as "Derailment traces"*. Also, no derailment traces were observed right in front of this or in the same spot on the left rail (outer rail).

(2) Between 162 m and 135 m, where the lead axle of the lead bogie of the Train stopped, there were traces where it appears that the right wheel was in continuous contact with the side of the head of the left rail (inner rail). Also, there were traces in the same section where it appears that a flange tip ran continuously on the base of the right rail side of the guard rail. *[Refer to Attached Figure 4]*

2.3.3. Information on the Railway Facilities

2.3.3.1. Outline of the route

The route between Takamiya Station and Tagataisha-mae Station on the Company's Taga Line is a 2.5-km-long single track electrified (DC 1,500 V) route with a gauge of 1,067 mm.

In addition to the Taga Line, the Company also has a 47.7-km-long main line that connects Maibara Station and Kibukawa Station, as well as the Yokaichi Line, which is 9.3-km-long and connects Yokaichi Station and Omi-hachiman Station (both of which are single-track electrified (DC 1,500 V) routes), and the total length of railways operated by the Company is 59.5 km.

Also, the number of trains running between Takamiya Station and Tagataisha-mae Station per day is 58 in total, with 29 inbound and 29 outbound trains in two-vehicle sets.

(See Attached Figure 1: Ohmi Railway Route Schematic Diagram)

2.3.3.2. Outline of the railway track

Information related to the railway track for the Curve that was the site of the accident is as follows.

(1) The Curve is a right compound curve with radius of 160 m and 400 m. 221 m–211 m is a transition curve, 211 m–123 m is a circular curve with a 160 m radius, 123 m–103 m

*3 "Gauge corner" means the part that touches the flange of the wheel on the inside of the gauge of the head of the laid rail.

is an intermediate transition curve, 103 m–053 m is a circular curve with a 400 m radius, 053 m–033 m is an intermediate transition curve, 033 m–028 m is a circular curve with a 160 m radius, and 028 m–016 m is a transition curve. The accident occurred at 211 m–123 m on a circular curve with a radius of 160 m. Also, the circular curve with a radius of 160 m has a cant[*4] of 30 mm and a slack[*5] of 25 mm.

(2) The gradient of the permanent way is a downward gradient of 10.0‰ up to 222 m, and a downward gradient of 1.9‰ from 222 m onward.

(3) The track structure is a ballasted track, and the sleepers are primarily wooden sleepers, but some of them are PC sleepers. Along the Curve, one of the three sleepers around the area up to 221 m–153 m is a PC sleeper, and all of them from 153 m onward are wooden sleepers. Also, the rail is a 40 kgN rail.

(4) There is a rail joint (155 m) on the right rail in the space from around the spot where derailment traces were observed (162 m) to the stop position of the head of the Train (133 m).

(5) The distance between sleepers on the Curve is about 640 mm.

(6) Rails are fastened with four dog spikes per sleeper at wooden sleeper points.

[Refer to Figure 1]

The method for driving dog spikes into the wooden sleepers is described as follows in the Company's memoranda for track maintenance.

(Dog Spikes)

Article 028: Four dog spikes for one wooden sleeper, except in special cases, must be driven in a V-shape into the sleepers in a fixed direction, and a distance of about 50 mm must be maintained from the edge of the wooden sleeper to the center of the dog spike.

(Further Driving of Dog Spikes)

Article 029: Dog spikes can be driven in further as needed when inserting shims, pads, etc., or based on the status of the track, etc.

*4 "cant" means the difference in height between the outside rail and the inside rail on the curve that is set so that centrifugal force when driving on the curve does not have a negative influence on running safety or riding comfort.

*5 "Slack" means the amount to widen the gauge beyond the predetermined size in order to drive smoothly along a curve.

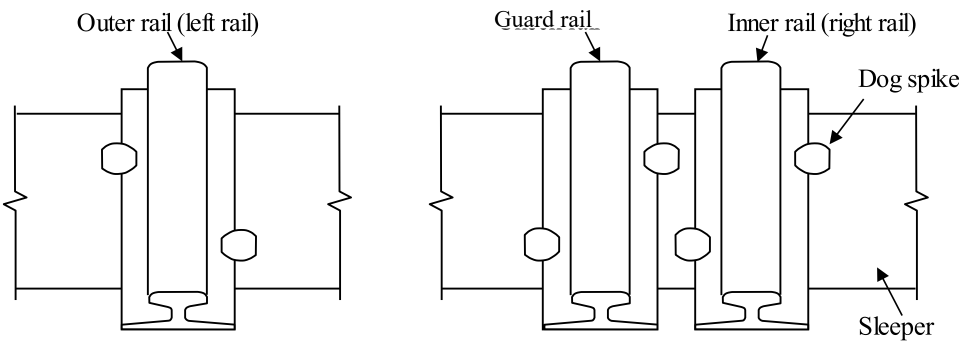


Figure 1. Main Rail Fastener at a Wooden Sleeper Spot on the Curve

(7) A plate spring-type double elastic fastening device is used for fastening PC sleepers to rails. *[Refer to Figure 2]*

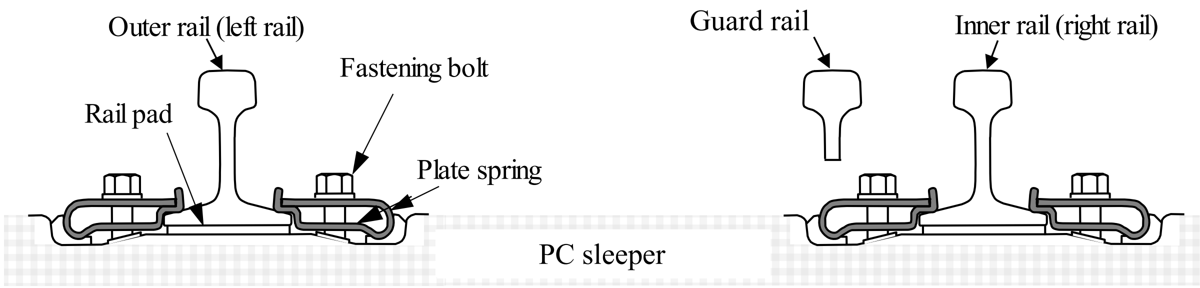


Figure 2. Rail Fastener at a PC Sleeper Spot on the Curve

(8) A 40 kgN guard rail is installed inside the gauge of the right rail along the entire length of the Curve. The guard rail is fastened to wooden sleepers by one dog spike each on the inside and outside. *[Refer to Figure 1]* However, as shown in Figure 3, there were spots where it was not fastened with dog spikes.

Also, the base of the guard rail is cut at spots with PC sleepers so that it does not interfere with the rail fastening system. *[Refer to Figure 2]*

In addition, according to the "guide to controlling the track management shown in the photos[*6]," the method for laying guard rails and fastening them to sleepers is said to be "fastening the guard rail to each sleeper with dog spikes, etc."

*6 "Guide to controlling the track management shown in the photos" (Japan Railway Civil Engineering Association, 2016, p. 232)

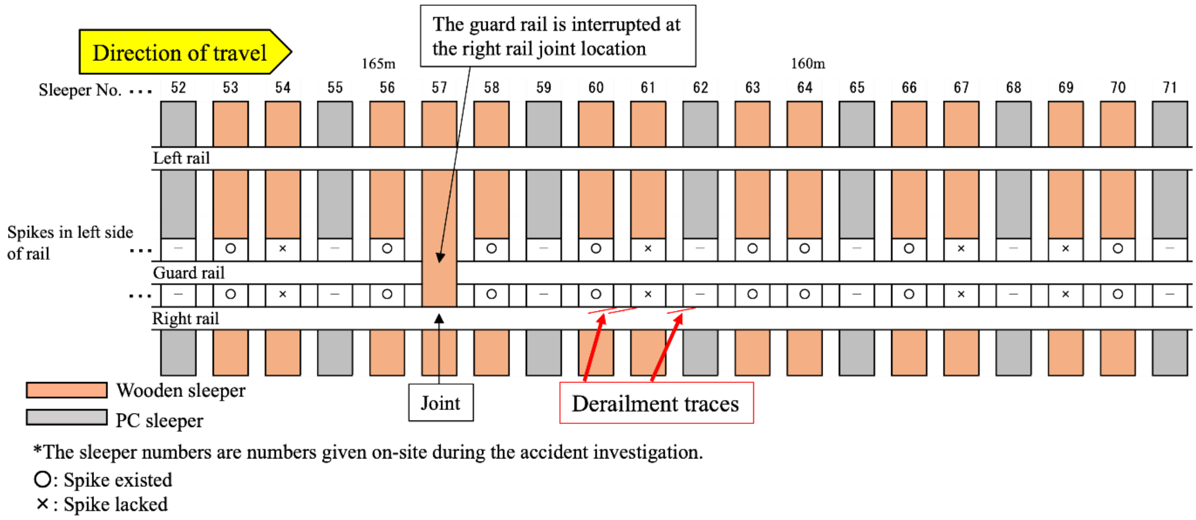


Figure 3: Fastening Guard Rails

2.3.3.3. Periodic Inspections of Tracks, etc.

(1) Periodic inspections of track irregularity

Based on the "Ministerial Ordinance to Provide Technical Regulatory Standards on Railways" (Ministry of Land, Infrastructure, Transport and Tourism Ordinance No. 151, 2001), the standard values related to the maintenance of irregularity of gauge, irregularity of cross level, irregularity of line alignment, irregularity of longitudinal level, and irregularity of twist of 5 m in the main line defined in the "Civil Engineering Facility Implementation Standards," which is part of the implementation standards reported to the Director-General of the Kinki District Transport Bureau, *hereinafter referred to as "reported implementation standards"* (track irregularity measured under unloaded condition*7), are shown in Table 2. In addition, maintenance deadlines when standard values are reached are not defined.

Track irregularity was measured using a portable track irregularity measuring device to calculate track irregularity using an 18-m primary moving average method*8, and irregularity of gauge was also compared with the design value. Also, the standard period for periodic inspection of track irregularity is 1 year.

Table 2: Standard Value for Maintenance for Track Irregularity

*7 "Track irregularity measured under unloaded condition" means track irregularity in a state where no train load (or a load equivalent to that) has been applied, measured through manual inspection (stringlining by manual force) or inspection using a track irregularity measuring device, etc. On the other hand, "track irregularity measured under loaded condition" means track irregularity in a state where an applied train load is measured through inspection using a track evaluation vehicle.

*8 "Track irregularity using a moving average method" means the value obtained by subtracting the mean value of a certain section length near the station from the measured value from track irregularity inspection. The Company has set the certain section length at 18 m.

(Track irregularity measured under unloaded condition)

(Units: mm)

Type of track irregularity	Standard value for maintenance
Irregularity of gauge	+18　-6
Irregularity of cross level	According to twist
Irregularity of line alignment	22
Irregularity of longitudinal level	22
Irregularity of twist of 5 m	18

The most recent periodic inspection of track irregularity prior to the accident that was performed near the site of the accident was conducted on June 30, 2021, and August 20, 2021, when track irregularity was measured under unloaded condition using a track irregularity measuring device. Measured values for every 5 m were compiled as a track irregularity inspection sheet based on the results of this *hereinafter referred to as "track irregularity measured values prior to the accident"*.

The measurement results for track irregularity near the site of the accident and evaluations are shown in (i) to (v) below. Also, size relationships for track irregularity aside from irregularity of gauge are evaluated with the absolute value. Also, the track irregularity value is the result of arithmetic processing of 0.25 m pitch measurement data measured by a track irregularity measuring device.

(i) Irregularity of gauge near 156 m calculated using the moving average method was -12 mm, which exceeded the standard value for maintenance (-6 mm). Also, the largest value for irregularity of gauge including slack was near 143 m (+39 mm), and irregularity of gauge calculated using the moving average method at the same spot was +5 mm, which was within the standard value for maintenance (+18 mm).

(ii) The largest value for irregularity of cross level was near 164 m (+7 mm).

(iii) The largest value for irregularity of line alignment was near 166 m (+22 mm) (the value before rounding up was +22.04 mm), which exceeded the standard value for maintenance (±22 mm).

(iv) The largest value for irregularity of longitudinal level was near 178 m (+12 mm), which was within the standard value for maintenance (±22 mm).

(v) The largest value for irregularity of twist of 5 m was near 134 m (-12 mm), which was within the standard value for maintenance (±18 mm).

[Refer to Attached Figure 5 and the Attached Material 1]

(2) Periodic inspections of track members

The “Civil Engineering Facility Implementation Standards” state that the standard period for performing periodic inspections of track members such as rails and sleepers shall be 1 year. The results of the periodic inspections of track members near the site of the accident right before the accident were as follows.

(i) Inspection of sleepers

A sleeper inspection was conducted on September 9, 2021. The status of sleepers and rail fasteners were checked and ranked, and the status of each sleeper was recorded in the inspection ledger.

The inspection results for near the site of the accident are shown in Figure 4. According to this same figure, there were 3 defective sleepers found near the site of the accident.

In addition, inspection items, inspection methods, and judgment criteria related to rail fasteners were not clearly specified in the “Periodic Inspection Manual (Track Version),” which serves as the Company’s internal regulations. Also, while there were descriptions of the inspection methods and judgment criteria used for sleepers, there were no manuals, etc. to supplement the rules, such as a defect judgment flow, judgment examples with photos, etc.

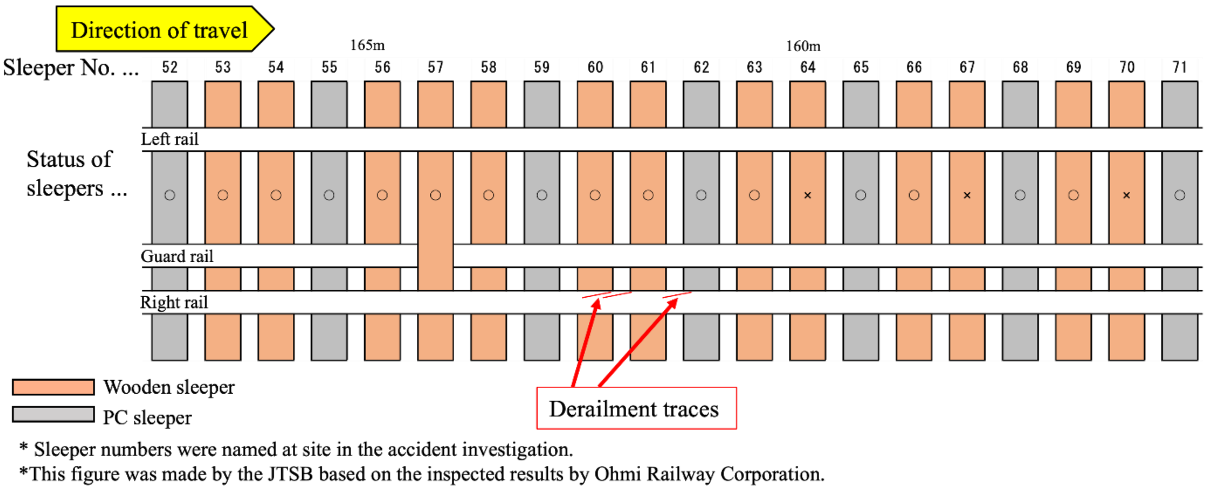


Figure 4. Sleeper Inspection Results

(ii) Inspection of rails

The rails were inspected on September 22, 2021, and September 29, 2021, and their status were checked for wear, damage, etc. For the rails at the 162 m spot, which is the station near the spot where derailment traces were observed, 1.0 mm of rail wear was recorded for the inner rail, and 10.2 mm for the outer rail (amount of wear on rail sides in both cases), which was less than the rail replacement target value (15 mm).

(iii) Inspection of guard rails

The guard rails were inspected on November 8, 2021. No particular issues were noted in the inspection records for the checks performed on the fastening status and flangeway width of the guard rails. According to the Company, the design value for the flangeway width on the Curve was 85 mm, and flangeway width values were measured using the measuring tool shown in Figure 5 and recorded on the inspection sheet only for spots that were too narrow and caused the tool to get caught on the guard rail and spots that were too wide and had gaps.

Figure 5. Measuring Tools for Flangeway Width

(3) Permanent way inspection tours

The "Civil Engineering Facility Implementation Standards" state that inspection tours of permanent ways must be completed at least once every 8 days.

An inspection tour for trains was conducted on February 7, 2022, near the site of the accident right before the accident occurred, and there were no records of anything abnormal in the train inspection tour record book.

Also, an inspection tour was conducted on foot on January 21, 2022, near the site of the accident right before the accident occurred, and there were no records of anything abnormal in the walking inspection tour record book.

2.3.3.4. Status of Tracks After the Accident

(1) Track irregularity status

Track irregularity measured under unloaded condition near the site of the accident was measured using a track irregularity measuring device right after the accident (February

9, 2022). The results from measuring the spots where derailment traces were observed, *hereinafter referred to as "measured value for track irregularity after the accident"*, were as follows. These track irregularities may have affected the accident.

(i) Irregularity of gauge including slack was +36 mm.

(ii) Irregularity of cross level including cant was +30 mm.

(iii) Irregularity of line alignment including versine amount from the curve radius (left, outer rail) was +65 mm.

(iv) Irregularity of longitudinal level (right, inner rail) was -3 mm.

(v) Irregularity of twist of 5 m was +4 mm.

(2) Track member status

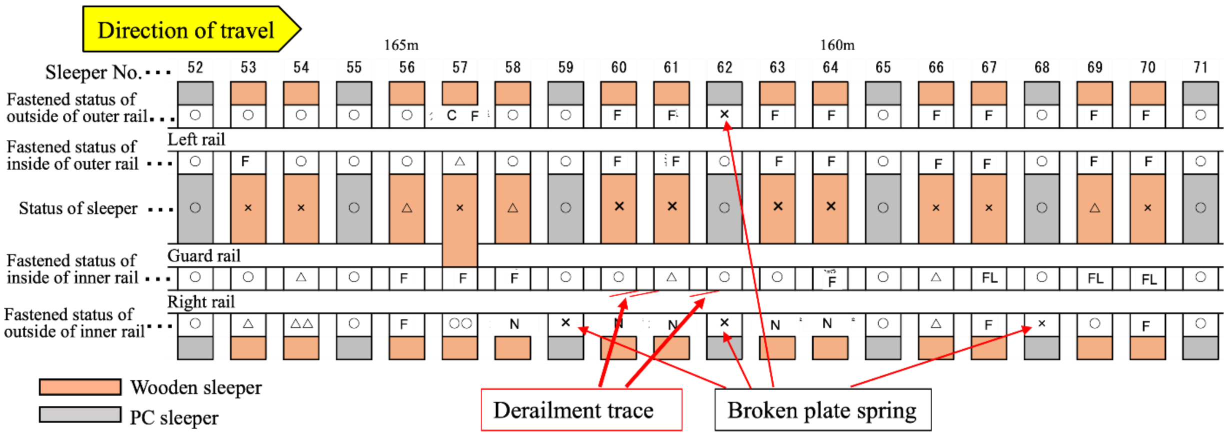
The results from investigating track members for rails, sleepers, etc. near the site of the accident right after the accident occurred were as follows.

(i) The amount of wear on the rails was 9 mm on the side of the left rail (outer rail) near 162 m. This is within 15 mm, which is the standard value for maintenance for rail wear specified in the Company's "Civil Engineering Facility Implementation Standards."

(ii) The results from the investigation of sleeper status and rail fastening status near the site of the accident are shown in Figure 6. The sleeper numbers in the same figure are ones that were given to on-site sleepers during the accident investigation. As shown in the same figure, the plate springs on the outside of the left rail and the outside of the right rail for No. 62 for the PC sleeper fastening device were broken, as were the plate springs on the outside of the right rails for No. 59 and No. 68.

Also, as shown in Figure 6, a large number of instances of defective sleepers and floating dog spikes were observed in the wooden sleepers, especially in the vicinities where derailment traces were observed, and the sleepers were in a continuously defective state along with the poor fastening of adjacent PC sleepers. Floating dog spikes, pushed-out dog spikes, and broken plate springs are shown in Figure 7. Also, the cut surface of a plate spring is shown in Figure 8. As shown in Figure 8, rust was observed in the cut surface of the plate spring for No. 59. On the other hand, a cut surface that was believed to have been recently cut was observed for No. 62.

Also, there were no clear differences between the inner and outer rails in terms of rail fastening status.



Sleeper No. were named at site in the accident investigation.
Meanings of the symbols of sleeper status are as follows.
○: No problem in sleeper status.
△: Not in the status of ○ but not in the status of ×.
×: There are erosion and crack, etc., which required exchange.

Spike had driven additionally in the place with two symbols.
Meanings of the symbols of fastened status are as follows.
○: No problem in the fastened status.
△: Not in the status of ○ but not in the status of the followings.
F (Float): Spike was floating, and head of spike apart from rail bottom in vertical direction. (L: Large)
N (Not sticking): Spike head apart from rail bottom in lateral direction.
C (Corner fold): A part of spike head was lacked.

Figure 6. Sleeper status and Rail Fastening status

Figure 7. Dog Spike and Spring Plate Status

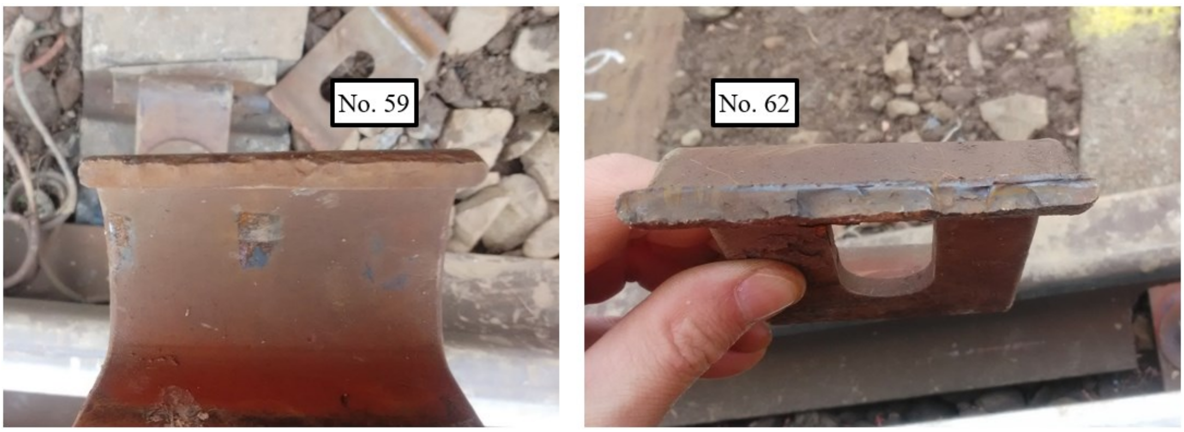


Figure 8. Spring Plate Cut Surface

2.3.3.5. Sleeper installation status

A total of 100,756 sleepers had been installed by the Company on all lines at the time of the accident, 48,122 of which were wooden sleepers, 51,404 PC sleepers, and 1,230 synthetic sleepers.

2.3.3.6 Track maintenance system

At the Company at the time of the accident, track maintenance was performed by a total of 9 people in charge headed by the chief of the maintenance of way office, which is the field organization in charge of track maintenance. The main regular work performed by the persons in charge is the inspection and repair of tracks, engineering structures, etc.

Also, for track inspection and repair work, relatively large-scale inspection and repair work like replacing the rails is performed through outsourcing, but simple inspection and repair work, including replacing sleepers, etc., is handled by the Company.

2.4 Information on Vehicles

2.4.1 Outline of Vehicles

The composition of the Train is shown in Figure 9. The specifications of the vehicles on the Train are shown in Table 3.

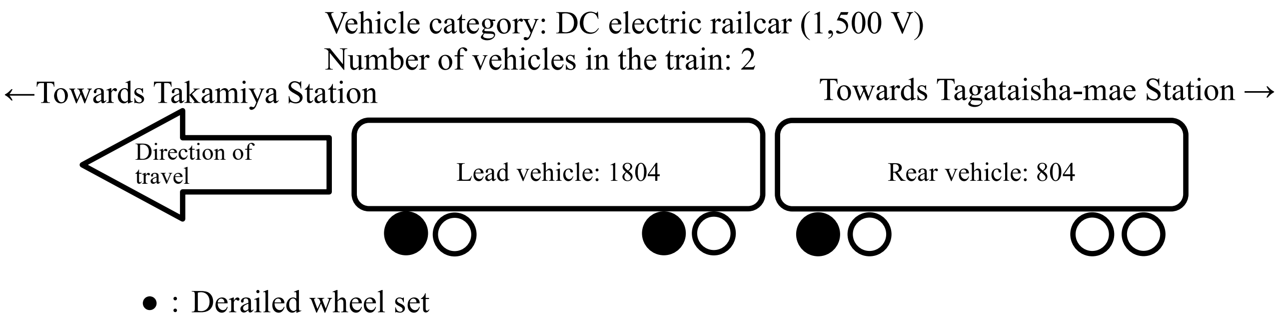


Figure 9. Composition of the Train

Table 3. Specifications of the Vehicles on the Train

Specifications	Vehicle	
	Lead vehicle: 1804	Rear vehicle: 804
Type of rolling stock	Moha 1800	Moha 800
Train set nominal passenger capacity	136 people (Seating capacity: 56 people)	
Tare	37.8 t*9	
Vehicle length	20.0 m	
Distance between two bogies	13.6 m	
Type of truck	FS-372 Axle box suspension: Pedestal type Carbody suspension system: Direct mount type	
Wheel base	2.2 m	
Wheel head profile	Conical profile	
Wheel flange angle	70°	
Wheel diameter	860 mm	
Width of rim	125 mm	
Year manufactured	1967	

2.4.2 Information on the Maintenance of Vehicles

The maintenance of vehicles is defined by the “Electric Railcar Maintenance Implementation Standards,” which are part of the reported implementation standards. There are three types of periodic inspections for vehicles: General inspection*10, critical parts inspection*11, and monthly inspection*12. These are conducted periodically according to the periods defined for each type of inspection or vehicle mileage. Also, depending on the usage status of the vehicles, train inspections are conducted for each period not exceeding six days for vehicle consumables and primary part functions.

General inspections, critical parts inspections, and monthly inspections are performed on wheelsets to inspect the back gauge, wheel thickness*13, wheel flange height, and half distance between the outside surfaces of wheel flanges*14.

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*9 ［Unit Conversion］ 1 t = 1,000 kg (weight), 1 kg (weight): 1 kgf, 1 kgf = 9.8N

*10 “General inspection” is one type of periodic inspection in the Company, and it means inspections conducted for each period not exceeding 8 years to check all aspects of the vehicle.

*11 “Critical parts inspection” is one type of periodic inspection in the Company, and it means inspections conducted every period not exceeding 4 years or 600,000 kilometers driven by that vehicle (whichever period is shorter) to check the vehicle’s power generator, running gear, brake equipment, and the primary parts of other critical devices.

*12 “Monthly inspection” is one type of periodic inspection in the Company, and it means inspections conducted for each period not exceeding 3 months to check the condition and functions of the vehicle.

*13 “Wheel thickness” mentioned here means the distance from the center of a wheel to a measurement point installed at a fixed location. The Company uses it to control wheel diameter.

*14 “Half distance between the outside surfaces of wheel flanges” means the distance from the center line of a pair of wheels to

The usage limiting value for each item is shown in Table 4.

Also, the static wheel load for vehicles is controlled by measuring it during general inspections and critical parts inspections, and the ratio of wheel load unbalance*15 is to be controlled within 10%, with a limit of 15%.

(See Attached Figure 6: Force Acting Between Rail Wheels)

Table 4. Usage Limiting Value for Wheel Set

Item	Usage limiting value
Back gauge	At least 989 mm and no more than 994 mm
Wheel thickness	At least 24 mm
Wheel flange height	At least 25 mm and no more than 33 mm
Half distance between the outside surfaces of wheel flanges	At least 519 mm and no more than 527 mm

2.4.3 Information on the Implementation Status of Vehicle Periodic Inspections, etc.

2.4.3.1 Implementation Status of Periodic Inspections, etc.

The implementation statuses for periodic inspections, etc. for the Train right before the accident were as follows. The assembly dimensions of the vehicles and bogie were within the standard values for maintenance, and nothing indicating abnormalities was found in the records for each inspection.

General inspection: From July 6, 2020, to August 11, 2020

Monthly inspection: December 15, 2021

Train inspection: February 7, 2022

2.4.3.2 Wheelset Status

The results from regular inspections conducted right before the accident and the results obtained from measurements taken after the accident are shown in Table 5. Back gauge, height of wheel flange, half distance between the outside surfaces of wheel flanges, and wheel thickness for the Train were all within the usage limiting values shown in Table 4, and no abnormalities were observed.

the outside surfaces of the wheel flanges.

*15 "Ratio of wheel load unbalance" means the value obtained by dividing the wheel load of a wheel on one side for a single-axle wheel set by the average wheel load on that axle. The control value is expressed in a percentage as the absolute value of the difference with respect to 100%.

Table 5. Results from Measuring the Dimensions of Each Part of the Wheel Set

Item	Inspection type	Lead vehicle (1804)							
		Front bogie				Rear bogie			
		Front axle		Rear axle		Front axle		Rear axle	
		Left	Right	Left	Right	Left	Right	Left	Right
Back gauge [mm]	Monthly inspection	990.0		990.0		990.0		990.0	
	Measurements taken after the accident	991.0		991.0		991.0		991.0	
Wheel thickness [mm]	Monthly inspection	54.5	54.5	54.0	54.0	54.0	54.0	54.5	54.5
	Measurements taken after the accident	54.0	54.0	53.5	53.5	54.0	53.5	54.0	54.0
Height of wheel flange A [mm]	Monthly inspection	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
	Measurements taken after the accident	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5
Half distance between the outside surfaces of wheel flanges [mm]	Monthly inspection	522.0	522.0	522.0	522.0	522.0	522.0	523.0	523.0
	Measurements taken after the accident	522.5	521.5	521.0	523.0	522.0	522.0	523.0	522.5

Item	Inspection type	Rear vehicle (804)							
		Front bogie				Rear bogie			
		Front axle		Rear axle		Front axle		Rear axle	
		Left	Right	Left	Right	Left	Right	Left	Right
Back gauge [mm]	Monthly inspection	990.0		990.0		990.0		990.0	
	Measurements taken after the accident	991.0		991.0		991.0		991.0	
Wheel thickness [mm]	Monthly inspection	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0
	Measurements taken after the accident	51.5	51.5	51.5	51.5	51.5	51.5	51.5	51.5
Height of wheel flange A [mm]	Monthly inspection	27.5	27.5	27.5	28.0	27.5	27.5	27.5	27.5
	Measurements taken after the accident	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Half distance between the outside surfaces of wheel flanges [mm]	Monthly inspection	522.0	522.5	522.5	522.5	521.5	522.5	522.5	522.5
	Measurements taken after the accident	522.5	523.5	523.0	522.0	523.0	523.5	522.5	523.5

"Left" is the left wheel in the running direction, "Right" is the right wheel in the running direction

Monthly inspection: December 15, 2021

Measurements taken after the accident: February 8, 2022

2.4.3.3. Status of Static Wheel Load and Ratio of Wheel Load Unbalance

The results obtained from measurement of static wheel load right before the accident and the results obtained from measurements taken after the accident are shown in Table 6. All the ratios of wheel load unbalance were within 10% of the control value, and no abnormalities were observed.

Table 6. Results from Measuring Static Wheel Load

Item	Inspection type	Lead vehicle (1804)							
		Front bogie				Rear bogie			
		Front axle		Rear axle		Front axle		Rear axle	
		Left	Right	Left	Right	Left	Right	Left	Right
Back gauge [kN]	General inspection	48.0	50.0	47.0	46.0	49.0	42.0	42.0	49.0
	Measurements taken after the accident	46.0	50.0	46.0	48.0	50.0	42.0	44.0	49.0
Ratio of wheel load unbalance [%]	General inspection	2.0		1.1		7.7		7.7	
	Measurements taken after the accident	4.2		2.1		8.7		5.4	

Item	Inspection type	Rear vehicle (804)							
		Front bogie				Rear bogie			
		Front axle		Rear axle		Front axle		Rear axle	
		Left	Right	Left	Right	Left	Right	Left	Right
Back gauge [kN]	General inspection	44.0	42.0	41.0	48.0	48.0	44.0	48.0	43.0
	Measurements taken after the accident	45.0	44.0	42.0	46.0	48.0	44.0	46.0	46.0
Ratio of wheel load unbalance [%]	General inspection	2.3		7.9		4.3		5.5	
	Measurements taken after the accident	1.1		4.5		4.3		0.0	

2.4.4. Information on the Damaged Status, etc., of the Vehicle

Scratch marks were observed on the front rim surfaces of the right wheels of the lead axle of the lead bogie and the lead axle of the rear bogie of the lead vehicle on the Train. Also, there were no similar scratch marks, etc. on the other wheels of the Train, and there was no damage to the vehicles either.

2.5. Information on the Train Crew

The Drive: 41 years old

Class A electric railcar driver’s license issued on December 24, 2008

2.6. Information on the Handling Operation, etc.

Handling operation is stipulated by the “Operation Handling Guide,” which is part of the reported implementation standards, and operating speed is stipulated as follows.

(i) Maximum train speed (between Maibara and Yokaichi (including the Taga Line)): 70 km/h

(ii) Speed restriction for a curve with a radius of 160 m: 30 km/h

Also, according to the Train performance diagram*16 that the Company uses for operating the Train, the passing speed near the site of the accident was 18 km/h.

2.7. Information on the Weather Condition

The weather was cloudy near the site of the accident at the time of the accident, and according to the recording chart of the Hikone Local Meteorological Office, which is the closest one to the site of accident, there was no precipitation or snowfall on the day of the accident between the hours of 9 PM and 10 PM. Also, as of 9 PM, the snow cover was 12 cm, the temperature was 1.0°C, the humidity was 91%, and the wind direction and speed were east-southeast at 1.7 m/s.

2.8. Information on the Action Taken for Similar Accidents in the Past

The Japan Transport Safety Board UN-I-SAN No. 43, dated June 28, 2018, "On the opinion concerned with the prevention of the train derailment accident caused by the gauge widening,", *hereinafter referred to as "Japan Transport Safety Board Opinion"*, to the Minister of Land, Infrastructure, Transport and Tourism for the prevention of train derailment accidents caused by gauge widening*17.

The Kinki District Transport Bureau informed the Company about the Japan Transport Safety Board opinion according to KIN-UN-TETSU-GI No. 116 and KIN-UN-TETSU-AN No. 105, "Response to the Opinions of the Japan Transport Safety Board," dated June 29, 2018. Furthermore, written guidance was provided on the necessary measures for sleepers, etc. through KIN-UN-TETSU-GI No. 117, "Promotion of Measures to Prevent Gauge Widening in Local Railways, etc.," dated July 2, 2018. These measures included conducting periodic inspections of materials and maintenance status, keeping records, and, depending on the status, implementing measures to prevent gauge widening, such as replacing or adding dog spikes, replacing sleepers, installing gauge ties (metal fittings for retaining the gauge) *[Refer to Figure 10]*, etc.

The Company received these instructions and installed gauge ties on curves that had not been changed to ones with PC sleepers. They also revised the periodic inspection manual (track version) by specifying sleeper inspection methods and judgment criteria, judgment categories, measures, etc. However, the content was insufficient, and it was not a manual that would enable appropriate

*16 A "train performance diagram" is for graphing train speed changes, travel time, etc. for planning efficient operation based on restricted speed and train performance. The vertical axis shows speed and time, and the horizontal axis shows distance.

*17 "Gauge widening" means a state where the gauge has widened due to damage to the rail fastening device from lateral force (force where the wheels press on the rail in the lateral direction) or due to increased rail wear. When the gauge spreads beyond a certain point, it creates a state where either the left or right wheel cannot be supported by the rail head, resulting in derailment. In this context, gauge widening due to lateral force in conjunction with the train running means "dynamic gauge widening."

judgment and measures to be taken for the status of sleepers and rail fasteners. Also, countermeasures such as revising the standard value for maintenance for irregularity of gauge have not been started yet.

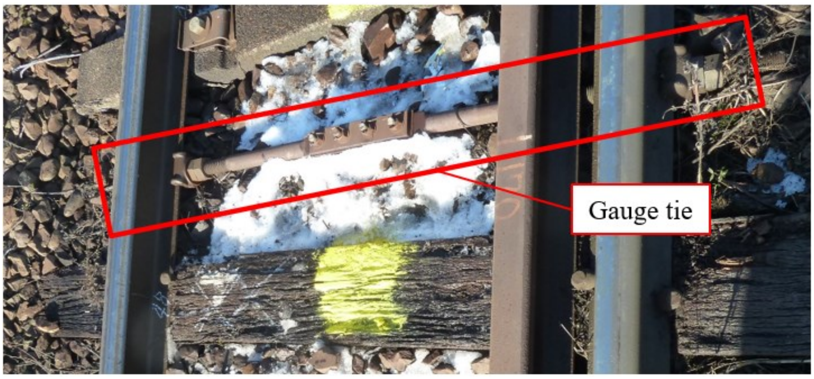


Figure 10. Example of Gauge Tie Installation

3. ANALYSIS

3.1. Analysis on the Status of the Derailment

The JTSB concludes the followings.

3.1.1. On the Derailment Starting Point

As mentioned in 2.3.2(1), the right wheels of the lead axle of the lead bogie of the lead vehicle, the lead axle of the rear bogie of the lead vehicle, and the lead axle of the lead bogie of the rear vehicle fell into the gauge at the side of the head on the gauge corner side of the right rail (inner rail) near 162 m, there were traces of rubbing on the front rim surfaces of the right wheels, and no traces of derailment were observed right in front of this or in the same spot on the left rail (outer rail). Based on this, it is more likely that the spot where derailment occurred initially was near 162 m, *hereinafter referred to as "derailment starting point,"* and that the right wheel became derailed in the gauge of the right rail.

3.1.2. On the Derailment of the Lead Bogie of the Lead Vehicle

The lead axle of the lead bogie of the lead vehicle on the Train:

(1) As mentioned in 2.3.1, the right wheel derailed between the right rail and the guard rail, and it stopped near 135 m.

(2) As mentioned in 2.4.4, scratch marks were observed on the front rim surface of the right wheel.

Therefore, it is probable that as the Train was passing through a right-hand curve with a 160 m radius, its right wheel fell between the right rail and the guard rail near 162 m, and after that, it traveled while pushing out the gauge and flangeway and stopped near 135 m.

3.1.3. On the Derailment of the Rear Bogie of the Lead Vehicle

The lead axle of the rear bogie of the lead vehicle on the Train:

(1) As mentioned in 2.3.1, the right wheel derailed between the right rail and the guard rail, and it stopped near 149 m.

(2) As mentioned in 2.4.4, scratch marks were observed on the front rim surface of the right wheel.

Therefore, it is probable that, as the Train was passing through a right-hand curve with a 160 m radius, its right wheel fell between the right rail and the guard rail near 162 m, and after that, it traveled while pushing out the gauge and flangeway and stopped near 149 m.

3.1.4. On the Derailment of the Lead Bogie of the Rear Vehicle

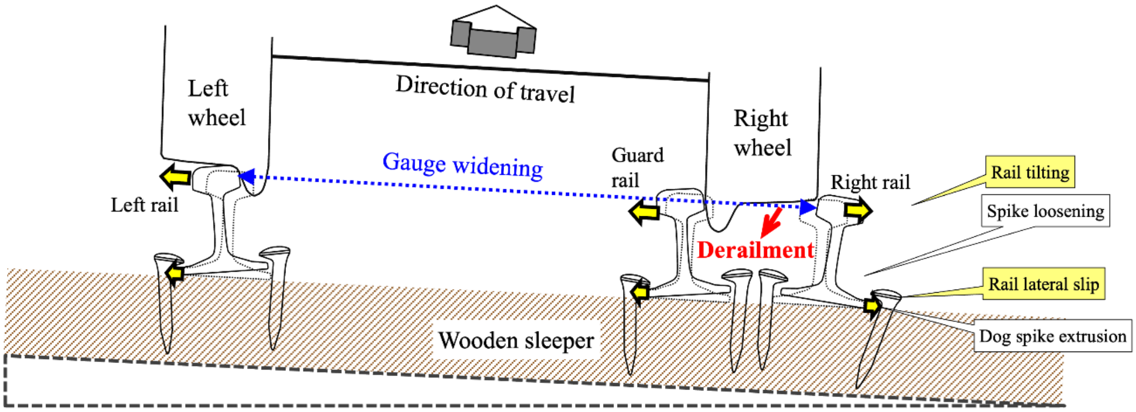
As mentioned in 2.3.1, the right wheel on the lead axle of the lead bogie of the rear vehicle on the Train derailed between the right rail and the guard rail, and it stopped near 155 m. Therefore, it is probable that what may have happened is that as the Train was passing through a right-hand curve with a 160 m radius, its right wheel fell between the right rail and the guard rail near 162 m, and after that, it traveled while pushing out the gauge and stopped near 155 m.

[Refer to Attached Figures 3, 4]

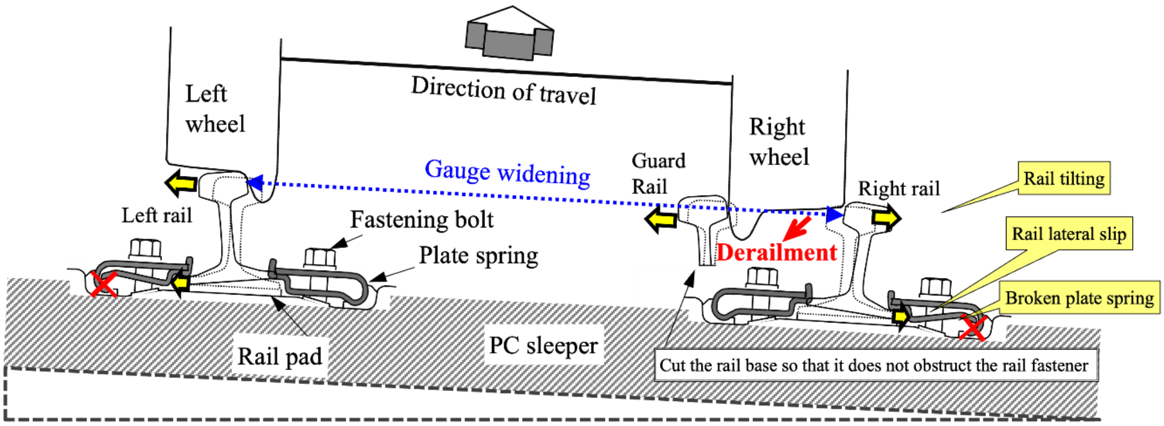
3.1.5. On the status of the Derailment at the Start Point of Derailment

The JTSB conclude that it is more likely that the phenomenon mentioned in 3.1.2–3.1.4 where the right wheel of the Train fell into the gauge of the right rail near 162 m, *hereinafter referred to as "derailment by gauge widening"*, had been caused by dynamic gauge widening from rail tilting[*18] from lateral force while the train is running and rail lateral movement, which will be cover later in 3.3.3(1), *hereinafter referred to as "rail tilting, etc."*, The image of derailment by gauge widening in the accident is illustrated in Figure 11. Also, more detailed information on gauge widening will be explained later in 3.3.4.

*18 "Rail tilting" refers to a phenomenon where a rail is tilted due to the load exerted on it by wheels.



(a) Wooden sleeper spot



(b) PC sleeper spot

Figure 11. Illustrated Image of Derailment by Gauge Widening in the Accident

3.2. Analyses on the Time of Occurrence of the Accident and the Speed of the Train

As shown in Table 1, based on the records from the event recorder, it is probable that the accident occurred at around 21:17.

Also, based on the same records, it is probable that the Train was traveling at a speed of 19km/h when it derailed, and, as mentioned in 2.6, it is more likely that this speed was not excessive, as the restricted speed for the Curve with a 160 m radius is 30 km/h.

3.3. Analysis on the Tracks

3.3.1. On Track Irregularity

(1) On the standard value for maintenance for track irregularity

As mentioned in 2.3.3.3 (1), the Company performs track maintenance based on the standard value for maintenance for track irregularity defined in the “Civil Engineering Facility Implementation Standards.”

The standard value for maintenance for irregularity of gauge (track irregularity measured under unloaded condition) is 18 mm. Based on the relationship between dynamic irregularity of gauge and static irregularity of gauge in Attached Materials 2, this corresponds to 24 mm for dynamic irregularity of gauge and becomes 49 mm when combined with the 25 mm of slack for the Curve.

On the other hand, as shown in Attached Materials 2, the limiting value for irregularity of gauge is 40 mm including the slack. Based on this, the Company's standard value for maintenance for irregularity of gauge is 9 mm larger, and it can be said that 9 mm is the appropriate standard value for maintenance for irregularity of gauge for the Curve *hereinafter referred to as "appropriate standard value for maintenance"*. Because it is more likely that the accident could have been prevented ahead of time if the appropriate standard value for maintenance had been applied before the accident, it would be preferable to revise the standard value for maintenance for irregularity of gauge to the appropriate standard value for maintenance.

Also, as mentioned in 2.3.3.3 (1), regarding what should be done when the track irregularity defined by the "Civil Engineering Facility Implementation Standards" reaches the standard value for maintenance, there was no clear deadline set for track maintenance. According to the Company, track maintenance was being performed as needed based on the standard value for maintenance, but for steady track maintenance, it would be preferable to have a clear deadline set for performing track maintenance once track irregularity reaches the standard value for maintenance. *[Refer to Attached Material 2]*

(2) On measured values for track irregularity

As mentioned in 2.3.3.3 (1), with the exceptions of irregularity of line alignment near 166 m and irregularity of gauge on the gauge reduction side near 156 m, all the measured values for track irregularity obtained before the accident on the Curve were within the standard value for maintenance.

However, regarding the irregularity of gauge on the gauge widening side, if the appropriate standard value for maintenance mentioned in 3.3.1 (1) had been applied, irregularity of gauge excluding the slack near 168 m would have been +9.3 mm, which would have reached the standard value for maintenance. *[Refer to Figure 12]*

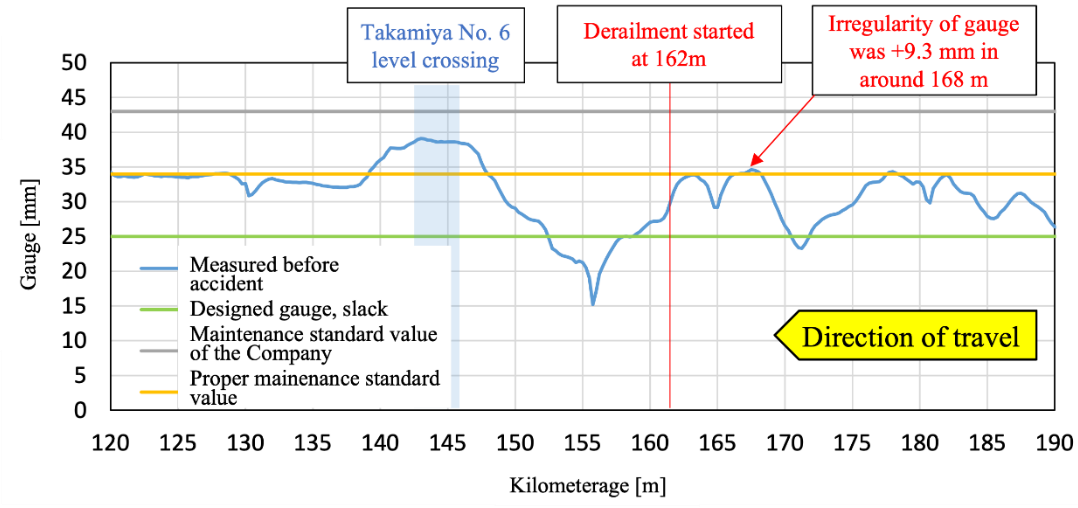


Figure 12. Irregularity of Gauge on the Curve

Also, with regard to the measured value for track irregularity after the accident mentioned in 2.3.3.4 (1), the wave shape of the irregularity of longitudinal level near 160 m–135 m was different compared to the one for the value obtained by measuring track irregularity before the accident. Along with this, the wave shapes for the cross level and twist in the same section were different before and after the accident. This is possible to be track irregularity caused by the accident.

Furthermore, the irregularity of gauge at 162 m–153 m widened based on the value obtained from measuring track irregularity before the accident mentioned in 2.3.3.3 (1). It is more likely due to the influence of the significant rail tilting, etc. that occurred during the accident remaining.

Other track irregularities were mostly equivalent to the values obtained from measuring track irregularities before the accident mentioned in 2.3.3.3 (1).

Therefore, it is more likely that it may have been likely for derailment by gauge widening to occur at the derailment starting point (near 162 m) at the time of the accident due to gauge widening along with dynamic displacement from rail tilting, etc. while the gauge was relatively large compared to the standard dimension (1,067 mm).

Also, with regard to track irregularity other than irregularity of gauge, as mentioned in 2.3.3.3 (1), irregularity of line alignment reached the standard value for maintenance at a location about 4 m behind the derailment starting point, or irregularity of gauge reached the standard value for maintenance at a location about 6 m ahead of the derailment starting point, but it is more likely that this was not directly related to the cause of derailment in the accident, rather than it being something that significantly affected gauge widening.

(3) On measuring methods for irregularity of gauge

As mentioned in 2.3.3.3 (1), track irregularity measured under unloaded condition is measured for the Company's periodic inspection of track irregularity.

With regard to the accident, as mentioned in 3.3.1 (2), it is more likely that it was possible to grasp abnormalities in the gauge since the static irregularity of gauge was large, but, as covered later in 3.3.4, as it is possible that the derailment was caused by dynamic gauge widening, it is more likely that it would have been possible to discover an abnormality beforehand and prevent the accident by measuring the dynamic irregularity of gauge.

Therefore, when there are concerns about dynamic gauge widening based on the maintenance status of sleepers and rail fasteners, etc., it would be preferable to investigate measuring the dynamic irregularity of gauge with a track evaluation vehicle, etc. Also, when it's difficult to measure track irregularity measured under loaded condition and track irregularity is controlled by measuring just track irregularity measured under unloaded condition, it's necessary to pay attention to the risk of dynamic gauge widening happening due to rail tilting, etc., and to control the sleepers and rail fasteners sufficiently.

In addition, development*19 is currently underway on a device to measure simple track irregularity under loaded condition (irregularity of gauge and irregularity of twist) for local railways.

(4) On track irregularity calculation methods and curve management

Although not directly involved in this accident, the following are notes on how to calculate track irregularity and curve management.

As mentioned in 2.3.3.3 (1), the Company performs management based on track irregularity through a moving average method. On the other hand, it's stated in the "Periodic Inspection Manual (Track Version)" that "The standard length for twist shall be 5 m, including decreases in cant." The Company said that it confirms the values obtained by measuring twist for sections with decreased cant. However, in other sections, it is not appropriate to manage irregularity of twist calculated by the moving average method that subtracts the current alignment component, and it needs to be managed based on the value obtained from measuring.

Also, Figure 13 shows irregularity of line alignment measured by a track irregularity measuring device, including the amount of versine from the curve radius. Both the 18 m moving average value of for irregularity of line alignment including the amount of versine (standard line from the moving average method) and the design value based on the curve profile are listed in this figure. Based on this figure, the current alignment differs from the design value. Specifically, based on the wave shape of the 18 m moving average value, the

*19 "Examining Deformation in Tracks During Vehicle Travel" (Yosuke Tsubokawa, Tomoyuki Ishikawa, Railway Technical Research Institute, RRR, Vol. 76, 2019, pp. 20–23) amount of curve versine near 120 m–140 m is about 105 mm, which is an alignment that's identical to a curve with a radius of about 120 m. Also, the amount of curve versine near 150 m–210 m is about 60 mm, which is an alignment that's identical to a curve with a radius of about 200 m. In this way, in order to perform appropriate curve management based on track irregularity from the moving average method, if there is a large difference between the design values and obtained values for curve radius and cant, it's preferable to modify the curve profile and manage it according to that curve profile.

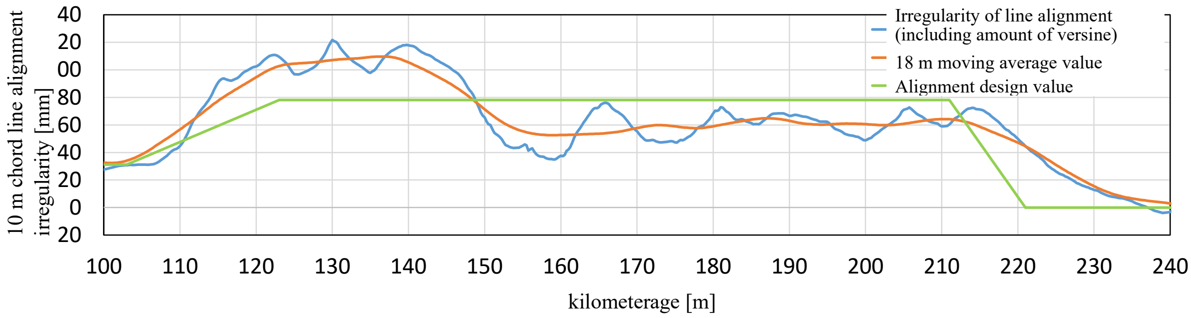


Figure 13. 18 m moving average value and design value for irregularity of line alignment

3.3.2. On Sleepers

With regard to sleepers near the derailment starting point, as mentioned in 2.3.3.3 (2) (i), a periodic inspection was conducted on September 9, 2021, and three defective sleepers were found near the site of the accident. However, as mentioned in 2.3.3.4 (2) (ii), in the investigation conducted on February 9, 2022, after the accident, a series of spots were found near the derailment starting point that were suspected to be defective sleepers.

As mentioned in 2.3.3.3 (2) (i), the Company stated that it was impossible to discover any defects through daily inspections because there was no manual, etc. to supplement the regulations through things such as a sleeper defect judgment flow or examples of judgment, etc. based on photos, etc.

The Company also stated that there was a sense that maintaining the sections where all the sleepers installed were wooden ones took precedence than sections like the Curve where about 1/3 sleepers installed were PC sleepers.

Based on the above, it is more likely that appropriate maintenance was not conducted: either the defective state of the sleepers was overlooked during periodic inspection, or maintenance of the Curve was postponed as a result of maintenance of sections where all of the sleepers installed were wooden ones taking precedence.

Accordingly, the Company needs to proceed with preparing a manual, etc. to make it possible to perform appropriate judgment and maintenance for the state of sleepers. They also need to perform maintenance in a planned manner for locations that require it, regardless of which type of sleepers are installed there.

3.3.3. On Rail Fastening

(1) On rail fastening condition

As mentioned in 2.3.3.3 (2) (i), the rail fasteners near the derailment starting point were checked during a sleeper inspection conducted on September 9, 2021, and no instances of poor rail fastening condition were noted in the inspection records. Also, as mentioned in 2.3.3.3 (3), no abnormalities were recorded during the permanent way inspection tour that was conducted on foot on January 21, 2022.

However, as mentioned in 2.3.3.4 (2) (ii), a large number of instances of poor rail fastening condition were discovered in a series of PC sleepers and wooden sleepers near the derailment starting point during the investigation after the accident. Also, based on rust observed in the cut surface of the plate spring, it is likely that the plate spring may have broken prior to the accident. The Company stated that, among the various inspection items checked during the walking inspection tour, it may not have been possible to check the status of individual fastening devices, and the broken plate spring may have been overlooked. Also, as mentioned in 2.3.3.3 (2) (i), they stated that no inspection methods or judgment criteria had been established for rail fasteners, so the condition of the rail fastener could not be judged correctly.

The series of instances of poor rail fastening condition were more likely to have affected the accident as well, but in general, spike loosening and extrusion and broken plate springs occur from rail tilting, etc. due to lateral force while the train was running, and because rail fastening status worsen as these thing happen repeatedly, it is possible that poor rail fastening status were present in a series to some degree near the derailment starting point when the accident happened. In addition, as mentioned in 3.3.2, it’s believed that the fact that there were a large number of defective sleepers was related to there being a large number of instances of poor fastening condition.

Based on the above, as mentioned in 3.1.2–3.1.4, it is more likely that the gauge widened dynamically due to rail tilting, etc. from lateral force while the Train was running at a place where poor rail fastening status were present in a series to some degree near the derailment starting point, which resulted in the right wheel falling into the gauge of the right rail (inner rail) near 162 m.

Therefore, when inspecting track members, such as during a sleeper inspection, and when conducting a permanent way inspection tour, etc., the Company needs to check for things like wooden sleeper corrosion, floating dog spikes, cracked PC sleepers, and broken fastening devices, establish judgment criteria, and replace or add dog spikes, adjust fastening torque, replace plate springs, replace sleepers, install gauge ties, etc. according to the situation. In particular, even in sections where 1 in 3 of the sleepers installed are PC sleepers, they need to reacknowledge that a train derailment due to gauge widening could happen if there are rail fastener defects such as broken plate springs, and they need to correctly understand the states of PC sleeper rail fasteners as well rather than just prioritizing wooden sleepers.

In addition, when it comes to managing sleepers, rail fasteners, etc. on curves, in general, more attention tends to be paid to the outer rail side where it's easy for large amounts of lateral force to occur, but because lateral force also occurs on the inner rail side in the direction in which the curve turning lateral force*20, etc. pushes the rails toward the outside, it needs to be managed with attention equal to that devoted to the outer rail side.

In addition, because the danger of derailment by gauge widening increases in particular when poor rail fastening condition occurs in a series or when it happens on a sharp curve with a large amount of slack, care must be taken to prioritize maintenance in these status.

(2) On rail fastening methods

As mentioned in 2.3.3.2 (6), the rails were fastened with 4 dog spikes at wooden sleeper locations on the Curve , and tie plates were not used. In addition, there were locations where dog spikes were added, but the Company stated that they were added based on the judgment of the on-site person in charge and that no clear standard had been established.

It is probable that increasing the number of dog spikes driven in or using tie plates would be effective at preventing rail tilting, etc., so it would be preferable for the Company to implement countermeasures such as double spikes while prioritizing locations where there are concerns about gauge widening on sharp curves, etc. to increase rail fastening force. Also, it would be preferable for them to establish the requirements for tie plate usage and the standard number of dog spikes to be driven in by curve radius.

(3) On guard rail fastening

As mentioned in 2.3.3.2 (8), it would be preferable for the guard rails near the derailment starting point to be fastened at each sleeper, but in addition to the PC sleeper locations not being fastened, there were also wooden sleeper locations that were not fastened. Therefore, it is probable that the resistance against guard rail tilting, etc. was relatively small in these areas.

Also, as mentioned in 2.4.1, the width of rim of the Train is 125 mm, and, as mentioned in 2.3.3.3 (2) (ii), the standard guard rail flangeway width on the Curve is 85 mm, which prevents

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*20 "Curve turning lateral force" means the lateral force generated on a bogie traveling on a curve when the wheels on the outer rail side of the front axle of the bogie are pushed against the inner rail side and the wheels on the inner rail side resist this due to friction.

derailment in terms of dimensions. Also, since there were no issues in particular in the inspection records, it is more likely that the flangeway width prior to the widening caused by the accident near the derailment starting point was roughly 85 mm, and it is probable that it widened as a result of the derailment caused by the accident.

Based on this, as mentioned in 3.1.2–3.1.4, it is more likely that the train running after its right wheel got into the space between the right rail and the guard rail and the guard rail being unable to prevent derailment happened because rail tilting, etc. from lateral force generated along with the train running on the right rail and guard rail and inward lateral force exerted from the backside of the wheel caused the flangeway width to expand dynamically.

Therefore, it would be preferable to install guard angles[*21] instead of guard rails, which are impossible to fasten at locations with PC sleepers, in order to be effective in the event of a derailment.

3.3.4 On Gauge Widening

Derailment by gauge widening may occur in the event that the sum of the wheel flange thickness of the wheelset of the opposite side that falls (in the case of this accident, the left wheel), the back gauge of the wheelset, and the width of rim of the falling side (in the case of this accident, the right wheel) (sum of these three dimensions: hereinafter, “wheelset dimension”) is less than the sum of the gauge basic dimension (1,067 mm on the main track), the irregularity of gauge, and slack (sum of these three dimensions: *hereinafter referred to as “gauge dimension”*), under conditions where the impact for rail wear and wheel end chamfering are not taken into account. *[Refer to Figure 14]*

The gauge dimension mentioned in 2.3.3.4 (1) (i) that was calculated from irregularity of gauge after the accident, including the slack measured statically, was +36 mm at the derailment starting point, near 162 m, resulting in 1,103 mm (= 1,067 + 36).

Also, it is more likely that the wheelset dimension at the time of the accident was 1,144.5 mm (= 28.5 + 991 + 125), based on the wheelset dimension of the front axle of the bogie in front of the lead vehicle mentioned in 2.4.3.2 that was measured after the accident.

Based on this, the estimated value of the amount of wheel engagement on the rail near the derailment starting point at the time of the accident is 41.5 mm, the value obtained from

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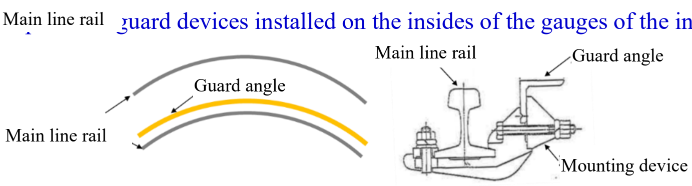
*21 “Guard angles” are L guard devices installed on the insides of the gauges of the inner rails to prevent derailment.



measuring immediately before the accident, a dimension that would not have resulted in derailment by gauge widening. However, as derailment did occur, it is probable that the total value for dynamic gauge widening on the inner and outer rails from rail tilting, etc. near the derailment starting point at the time of the accident was a value that exceeded about 41.5mm.

In addition, while the amount of widening for each of the inner and outer rails is unknown, as mentioned in 2.3.3.4 (2) (ii), there were no clear differences between the inner and outer rails in their fastening status near the derailment starting point immediately after the accident, etc., so assuming that the amount of widening was roughly the same for each, it is more likely that this amount may have been about 20.75 mm (= 41.5/2) apiece for the inner and outer rails.

Based on this, it is possible that the amount of flangeway width widening from right side (inner rail side) guard rail tilting, etc. may have been 19.25 mm. *[Refer to Attached Material 2]*

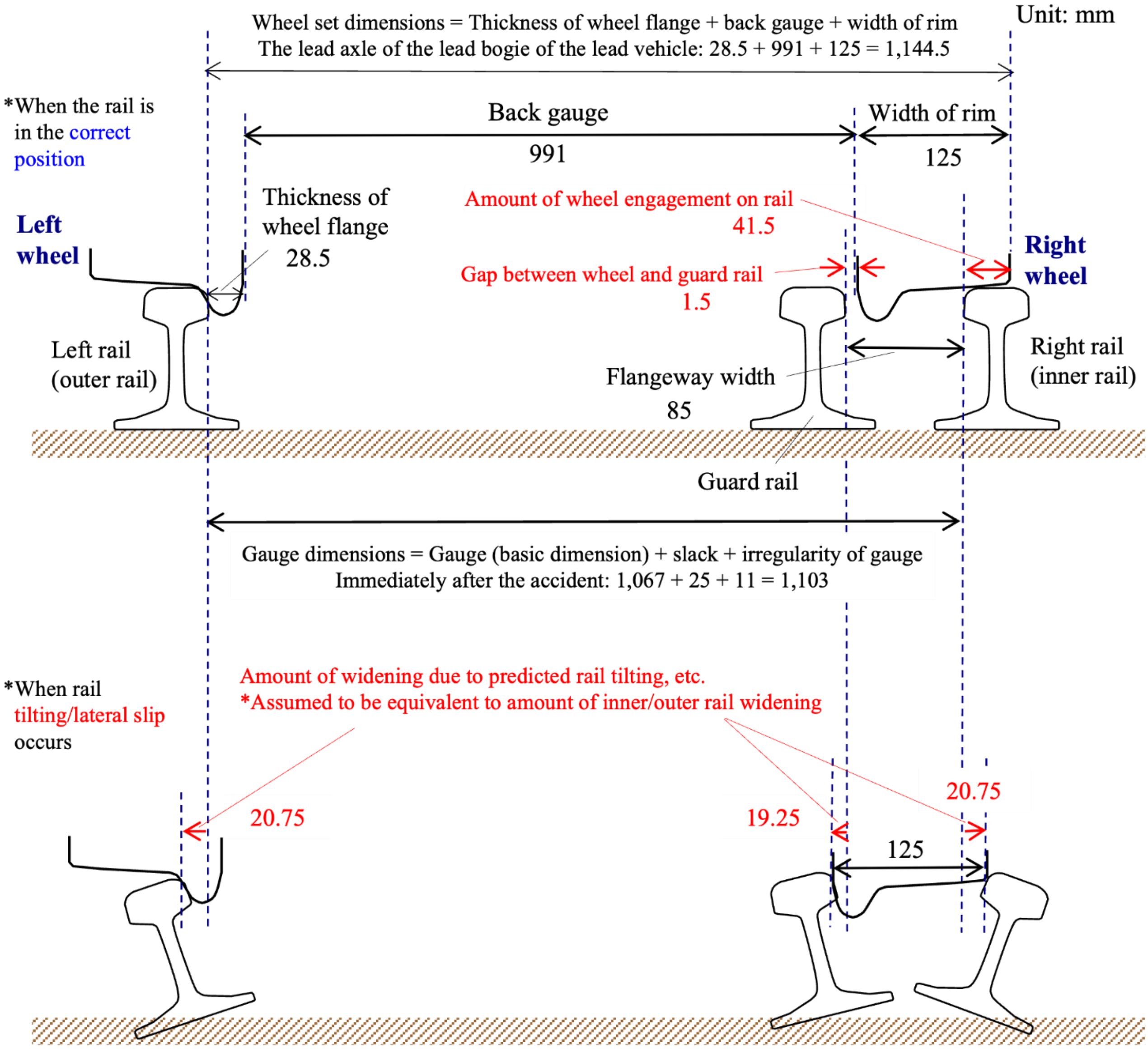


Figure 14. Estimated Gauge Widening Status

3.3.5. On Slack

As mentioned in 2.3.3.2 (1), the slack set on the Curve was 25 mm.

Therefore, based on the conditions under which derailment by gauge widening occurred that were mentioned in 3.3.4, the smaller the total value of gauge (basic dimension), slack, and irregularity of gauge, the safer it is from derailment by gauge widening happening. Therefore, it would be preferable to consider reducing the slack as much as possible in order to increase the range for permissible irregularity of gauge to avoid derailment by gauge widening and to increase the clearance for derailment by gauge widening.

Slack on the curves used by former Japanese National Railways shown in "Commentary: Technical Standards for Railways (Civil Engineering Edition), 3rd Edition"*22 was gradually reduced in order to increase clearance for vehicle structure transitions and wide gauge derailment, and was set to 20 mm (other than in sections where only 2-axle trains run) in 1987 for curves with radius less than 170 m. The slack for the Curve was 5 mm larger than this value, and it is more likely that the clearance for derailment by gauge widening decreased.

In addition, as covered later in 5.2.2, for track maintenance after the accident, the Company is changing the slack for this curve to 20 mm.

3.3.6. On the Track Maintenance System

As mentioned in 2.3.3.6, track maintenance in the Company was being performed by a team of 9 people at the time of the accident. Constant track maintenance was being done successfully based on rules, such as performing track-related inspections within a standard period and performing simple repair work, including replacing sleepers, etc., under direct supervision, and thus it was more likely that there were no significant issues with the work performance abilities of any of the personnel in charge of track maintenance.

However, there was also a lack of technical capabilities as an organization, as evidenced from the standard value for maintenance for irregularity of gauge being larger than the appropriate standard value for maintenance as mentioned in 3.3.1 (1), irregularity of twist calculated by the moving average method being controlled as mentioned in 3.3.1 (4), the inspection methods and judgment criteria manual used in sleeper inspection being insufficient, preventing sleeper defects from being discovered as mentioned in 3.3.2, broken plate springs on PC sleepers being overlooked/being unable to judge rail fastener status correctly as mentioned in 3.3.3 (1), and locations on the guard rail with PC sleepers not being fastened/locations where wooden sleepers were not fastened also existing, etc., as mentioned in 3.3.3 (3).

In order to make up for the lack of technical capabilities for this type of organization, it would be preferable to enhance education on track maintenance and management by actively utilizing technical support and training sessions provided by various corporations, and by exchanging information with other companies. Also, considering immediacy and certainty, it would be preferable to proceed with hard countermeasures, such as changing to PC sleepers and introducing track evaluation cars.

*22 "Commentary: Technical Standards for Railways (Civil Engineering Edition), 3rd Edition" (supervised by the Railway Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, issued by the Japan Railway Civil Engineering Association, 2014, p. 119)

3.4. Analysis on the Vehicles

It is more likely that there were no abnormalities in the vehicles on the Train related to the derailment occurring, based on nothing abnormal being found in the results of the periodic inspection of the Train as mentioned in 2.4.3, and based on the Driver stating that they did not notice anything abnormal prior to the accident happening on the day that it happened as mentioned in 2.1.1. In addition, the damage and marks on the vehicles mentioned in 2.4.4 are believed to have happened due to the Train running after being derailed, based on the damage and marks on the tracks.

3.5. Analysis on the Weather Condition

As mentioned in 2.7, the weather near the site of the accident at the time of the accident was cloudy, there was no precipitation or snowfall, the temperature was 1.0°C, and the wind direction and speed was east-southeast at 1.7 m/s. There was 12 cm of snowfall, but none was observed on the rails or flangeway. Based on this, it is probable that there were no weather conditions directly related to the derailment.

3.6. Analysis on the Action Taken for Similar Accidents in the Past

As mentioned in 2.8, the Company was informed by the Kinki District Transport Bureau about the Japan Transport Safety Board's opinion on the prevention of train derailment accidents due to gauge widening similar to this accident, and as a countermeasure, the Company installed gauge ties on curves which had not been changed to ones with PC sleepers. They also revised the periodic inspection manual (track version) by specifying sleeper inspection methods and judgment criteria, judgment categories, measures, etc. However, the content was insufficient, and it was not a manual that would enable appropriate judgment and measures to be taken for the condition of sleepers and rail fasteners. Also, countermeasures such as revising the standard value for maintenance for irregularity of gauge have not been started yet.

It is more likely that the preventive measures for train derailment accidents due to gauge widening described in the Japan Transport Safety Board's opinion would have been effective in preventing this accident from happening. Therefore, it is probable that the Company needed to do what they could to implement measures at an early stage, such as revising the standard value for maintenance for irregularity of gauge mentioned in 3.3.1 (1), and enhancing the sleeper inspection methods and judgment criteria manual mentioned in 3.3.2.

3.7. Analysis on the Causes of the Derailment

(1) As mentioned in 3.1.2–3.1.4, it is more likely that this accident was one where the right

wheels of the lead axles of the lead bogie of the lead vehicle, the read bogie of the lead vehicle, and the lead bogie of the rear vehicle of the Train each fell into the gauge of the right rail (inner rail) near 162 m while the train was passing through a right-hand curve with a radius of 160 m, and then the train continued to travel while pushing out the gauge until it stopped with its tip near 133 m.

(2) As mentioned in 3.3.1 (2), it is more likely that the gauge widened significantly due to a large amount of static irregularity of gauge along this curve, and that, as mentioned in 3.3.2 and 3.3.3, due to a series of defective sleepers and poor rail fastening status near the derailment starting point, as mentioned in 3.1.5, the gauge widened dramatically from rail tilling, etc. due to lateral force when the Train was running.

(3) It is more likely that the static irregularity of gauge being large was related to insufficient track maintenance because of the standard value for maintenance for irregularity of gauge being larger than the appropriate value due to the amount of slack not being taken into account, as mentioned in 3.3.1 (1).

(4) The series of defective sleepers and poor rail fastening status is probable to be related to inspection methods and judgment criteria not having been clarified, preventing proper maintenance from being performed, as mentioned in 3.3.2 and 3.3.3 (1), or else to tie plates not being used for fastening wooden sleepers, as mentioned in 3.3.3 (2).

(5) It is more likely that this accident may have occurred because, as mentioned in 3.3.5, the slack on the curve was relatively large, which resulted in a smaller margin for derailment by gauge widening, and, as mentioned in 3.3.3 (3), there were places where the guard rail was not fastened to the sleepers, causing rail tilting, etc. to occur from inward lateral force from the right wheel, etc., which dynamically increased the flangeway width, causing the derailment prevention function not to work sufficiently.

Also, as mentioned in 3.6, it is more likely that the countermeasures implemented in response to the opinion of the Japan Transport Safety Board being insufficient and appropriate judgment, preparation of a manual that allows measures to be taken, revising the standard value for maintenance for irregularity of gauge, etc. for sleeper and rail fastener condition not being implemented successfully were related to the accident occurring as well.

[Refer to Attached Figure 7]

4. PROBABLE CAUSES

The JTSB concludes that the probable causes of this accident are as follows :

This accident is more likely to have occurred due to the lead axle right wheels on the lead bogie and the rear bogie of the lead vehicle and the lead bogie of the rear vehicle each falling into the gauge due to the gauge widening significantly while the train was passing through a right-hand curve with a radius of 160 m.

It is probable that the gauge widened significantly due to a large amount of static irregularity of gauge along this curve, and that a series of defective sleepers and poor rail fastening status resulted in lateral movement of the rails and rail tilt due to lateral force when the train was running, which caused the gauge to widen dynamically.

It is more likely that the static irregularity of gauge was large due to the standard value for maintenance for irregularity of gauge being larger than the appropriate value.

The series of defective sleepers and poor rail fastening status is probable to be due to the fact that inspection methods and judgment criteria were not clarified, preventing proper maintenance from being performed.

It is more likely that this accident may have occurred because the slack on this curve was relatively large, which resulted in a smaller margin for derailment by gauge widening, and there were places where the guard rail was not fastened to the sleepers, causing rail tilt, etc. to occur from inward lateral force from the right wheel, etc., which dynamically increased the flangeway width, causing the derailment prevention function not to work sufficiently. Another factor probable to be involved was that the countermeasures implemented in response to the Japan Transport Safety Board UN-I-SAN No. 43, dated June 28, 2018, “Opinions Related to the Prevention of Train Derailment Accidents Caused by Gauge Widening,” were insufficient.

5. SAFETY ACTION

5.1. Measures to Prevent Recurrence Considered as Necessary

(1) Steady implementation of track maintenance

(i) About the standard value for maintenance for track irregularity

It would be preferable to revise the standard value for maintenance for irregularity of gauge to make it the appropriate value and to have a clear deadline set for performing track maintenance as action to be taken when track irregularity reaches the standard value for maintenance.

(ii) About sleeper inspection

The inspection methods and judgment criteria manual for sleeper inspection need to be enhanced, and track maintenance needs to be performed along with this. It’s also necessary to perform maintenance in a planned manner for locations that require it, regardless of which type of sleepers are installed there.

(iii) About rail fastening status inspection and maintenance

When inspecting track members, such as during a sleeper inspection, and when conducting a permanent way inspection tour, etc., it's necessary to check for things like wooden sleeper corrosion, floating dog spikes, cracked PC sleepers, and broken fastening devices, and replace or add dog spikes, adjust fastening torque, replace plate springs, replace sleepers, install gauge ties, etc. according to the status.

In addition, because the danger of derailment by gauge widening increases in particular when these issues occur in a series or when it happens on a sharp curve with a large amount of slack, care must be taken to prioritize maintenance in these status.

In addition, when it comes to managing sleepers, rail fasteners, etc., on curves, in general, more attention tends to be paid to the outer rail side where it's easy for large amounts of lateral force to occur, but because lateral force also occurs on the inner rail side in the direction in which the curve turning lateral force, etc., pushes the rails toward the outside, it needs to be managed with attention equal to that devoted to the outer rail side.

(iv) About rail fastening methods

It would be preferable to implement countermeasures such as double spikes while prioritizing locations where there are concerns about gauge widening on sharp curves, etc., to increase rail fastening force. Also, it would be preferable for them to establish the standard number of dog spikes to be driven in by curve radius, as well as the method for doing this.

(2) Consideration of slack reduction

It would be preferable to reduce slack as much as possible in conjunction with improving the track in order to increase the clearance for derailment by gauge widening.

(3) Guard angle installation

It would be preferable to install guard angles instead of guard rails, which are impossible to fasten at locations with PC sleepers, so that the derailment prevention function is fully utilized.

5.2. Measures Taken by the Company After the Accident

The main measures taken by the Company after the accident are as follows.

5.2.1. Emergency Countermeasures

(1) Track maintenance near the site of the accident

Replaced the defective sleepers, adjusted the gauge, and performed maintenance on the track. Also, performed hammering sound tests on fastening devices, replaced fastening springs, and replaced and added dog spikes.

(2) Sleeper inspection on all lines

(i) All 17 curves with derailment prevention devices installed

(ii) All 9 curves with radii of 400 m or less

(iii) Other sections

Prioritized the above, and conducted hammering sound tests and sleeper inspections to check the fastening status of the fastening devices.

(3) Measuring wheel loads on all 19 train sets

Measured the wheel loads on all 19 train sets.

5.2.2. Permanent Countermeasures

(1) Re-education related to inspection methods

Decided to conduct educational training in an effort to increase knowledge and skills for general track maintenance techniques. Decided to take action aimed at increasing knowledge and skills similarly for other operation, electrical, and electric railcar departments.

(2) Changing to PC sleepers on all lines

A construction plan was developed in September 2022 to proceed with changing to PC sleepers on all lines. Along with changing to PC sleepers, the Company is also planning to replace the guard rails with guard angles.

(3) Improving slack

The slack for the Curve was improved by changing it to 20 mm through track maintenance performed after the accident. The Company is also planning to investigate improving the slack on other curves during track improvement work in the future.

Also, in response to Kinki District Transport Bureau Railway #8 “Safety Audit Results” dated April 22, 2022, and covered later in Section 5.3, the Company submitted an improvement report in which the following accident prevention countermeasures are described on September 7, 2022.

(1) Sleeper inspection manual maintenance

The Company created a sleeper inspection judgment flow and judgment examples, and specified them in the “Periodic Inspection Manual (Track Version).”

(2) Rail fastener inspection manual maintenance

The Company clearly specified inspection items (where to look), inspection methods, and judgment methods in the “Periodic Inspection Manual (Track Version).”

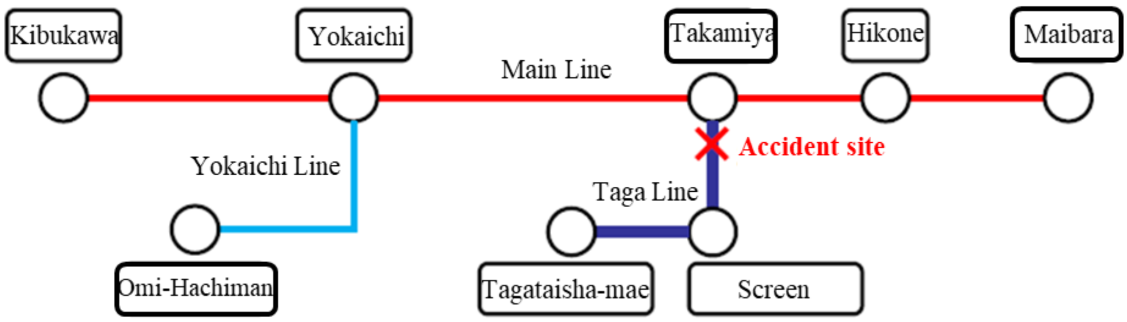
(3) Education system strengthening

The Company will incorporate education into their annual education plan for understanding the “Civil Engineering Facility Implementation Standards,” Periodic Inspection Manual, etc. correctly and being able to perform inspections appropriately, and will implement it systematically.

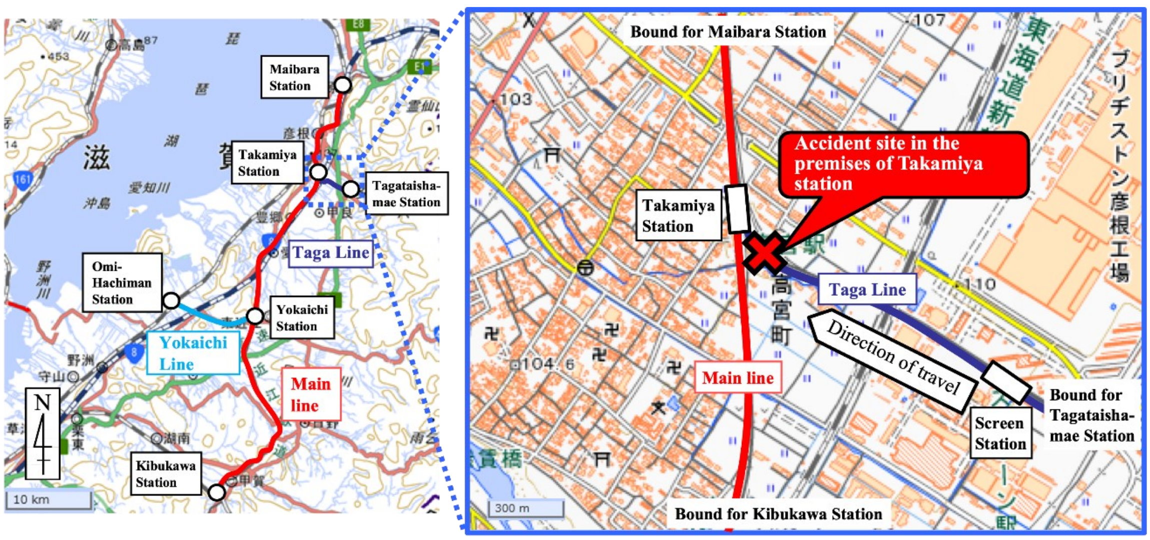
5.3. Measures Taken by the Ministry of Land, Infrastructure, Transport and Tourism After the Accident

The Kinki District Transport Bureau conducted a security audit of the Company from February 21, 2022, to February 22, 2022. Based on their recognition of items discovered during the audit that require improvement, the bureau issued KIN-UN-TETSU-TETSU No. 8 “Safety Audit Results” dated April 22, 2022, and gave the Company instructions on making improvements.

Attached Figure 1. Route Map of the OHMI Railway

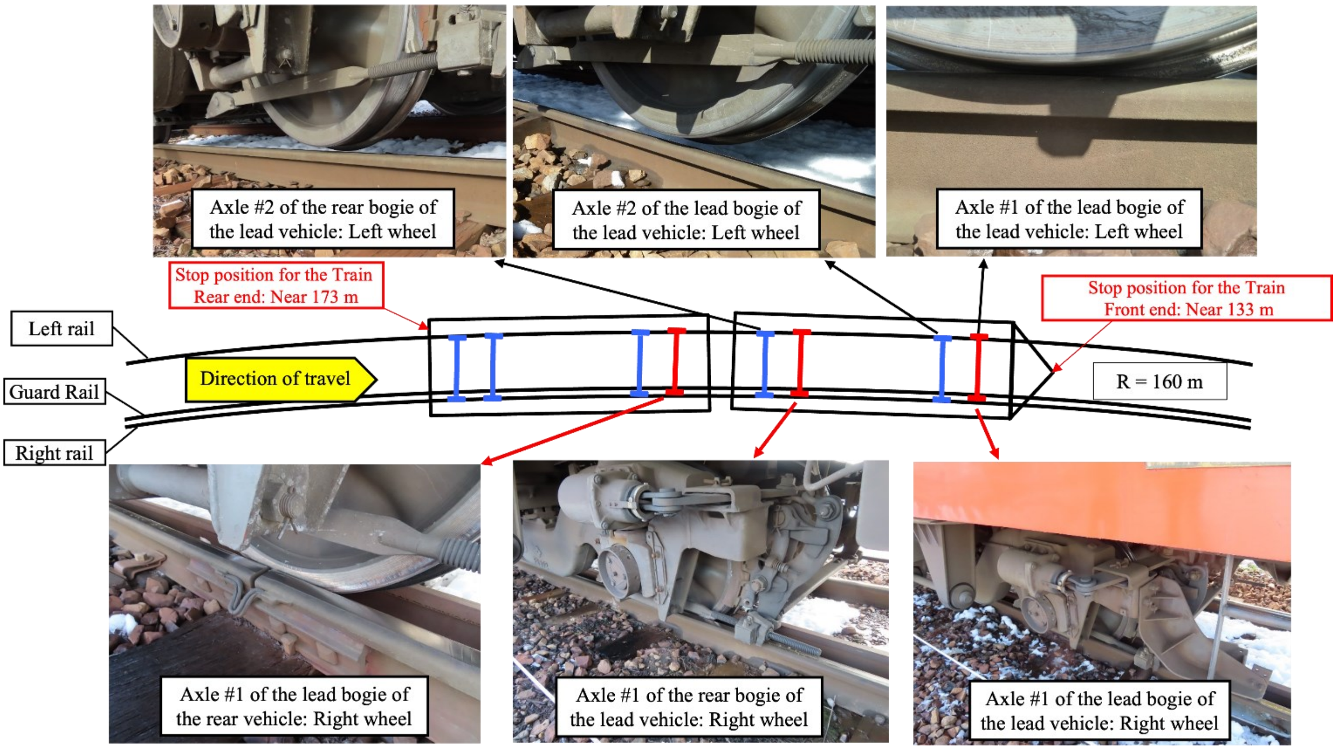


Attached Figure 2. Topographical Map of the Accident Site and Surrounding

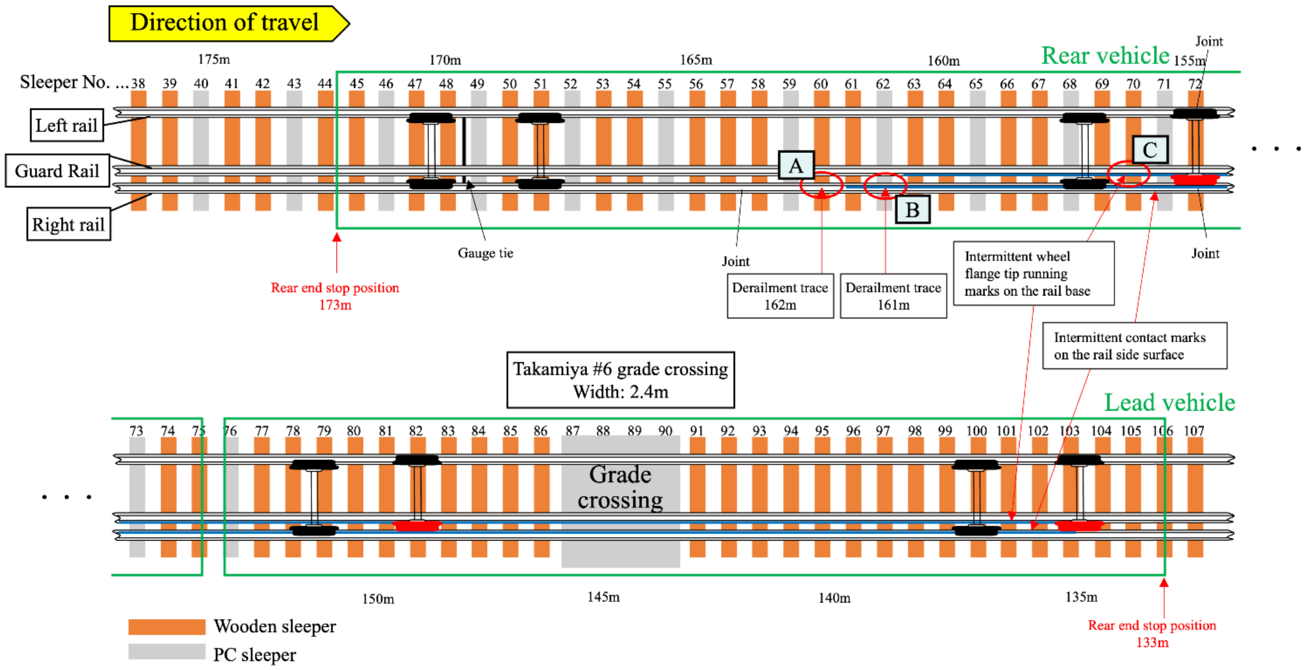


This figure was created using a map from the Geospatial Information Authority of Japan (the Denshikokudo Web System).

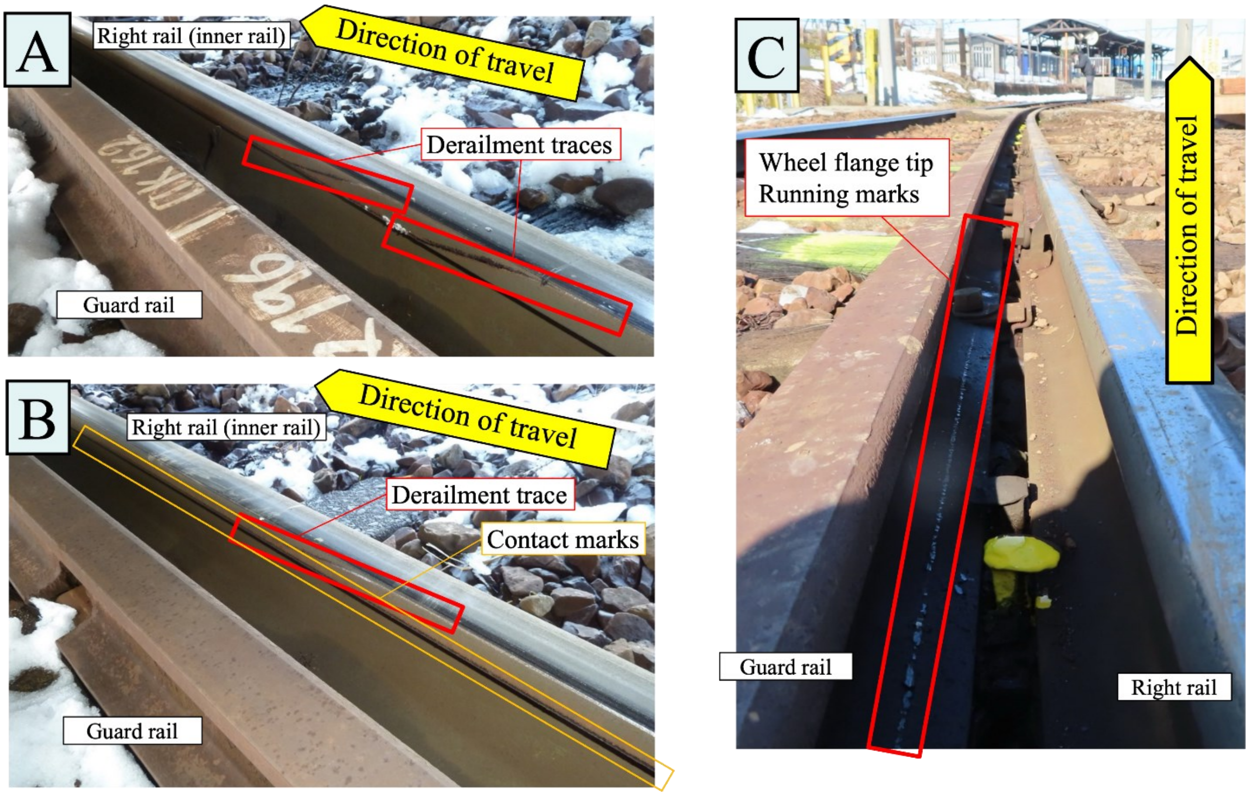
Attached Figure 3. Rough Map of the Accident Site and the Status of the Derailment



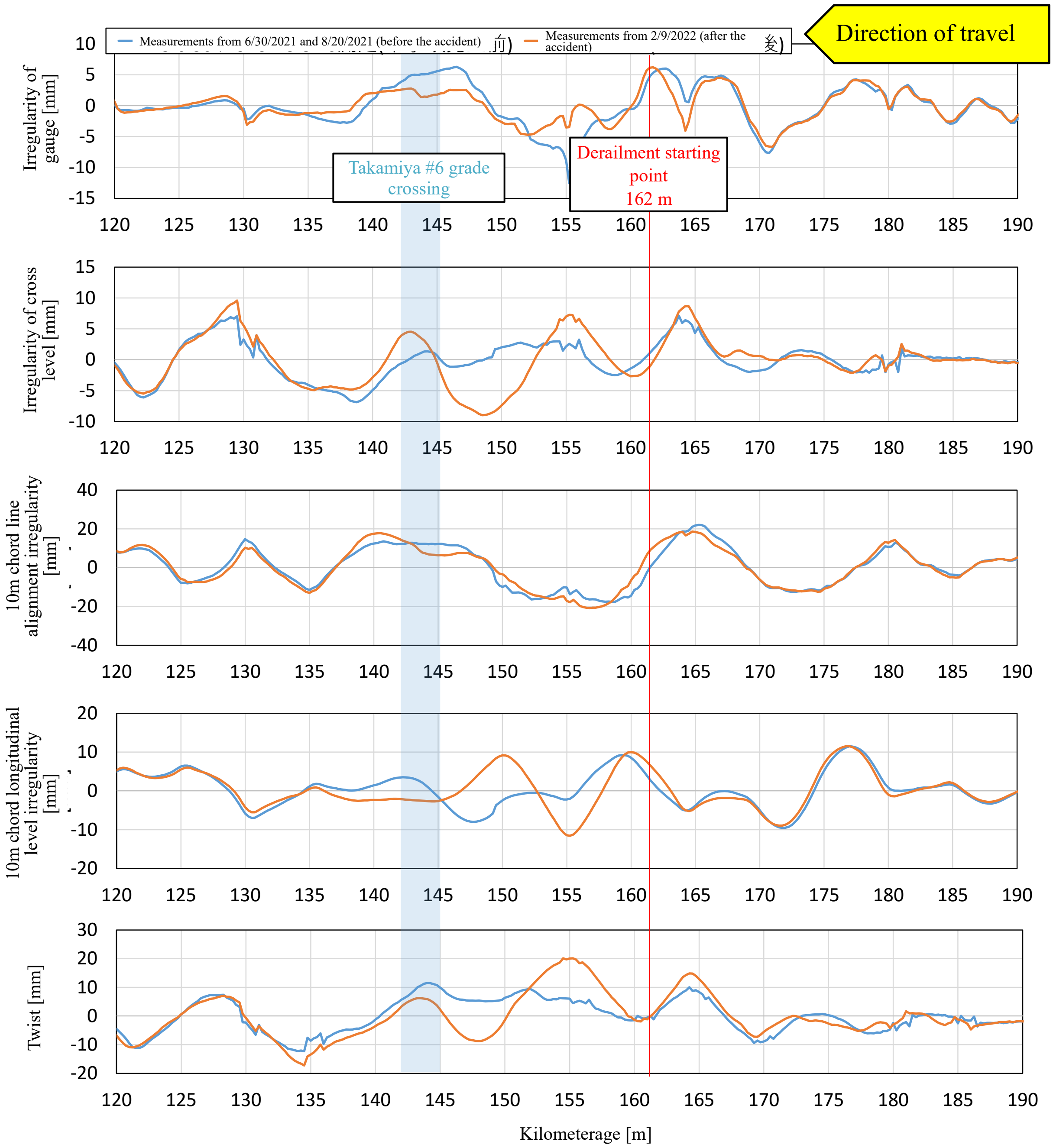
Attached Figure 4. Rough Map of the Accident site and the Traces of the Derailment



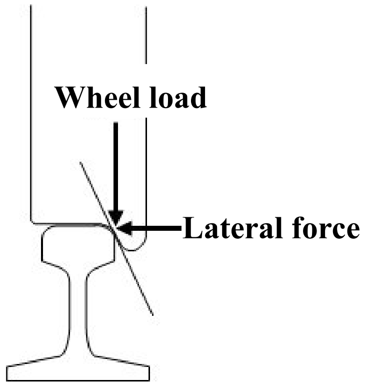
*The sleeper numbers are numbers given on-site during the accident investigation.



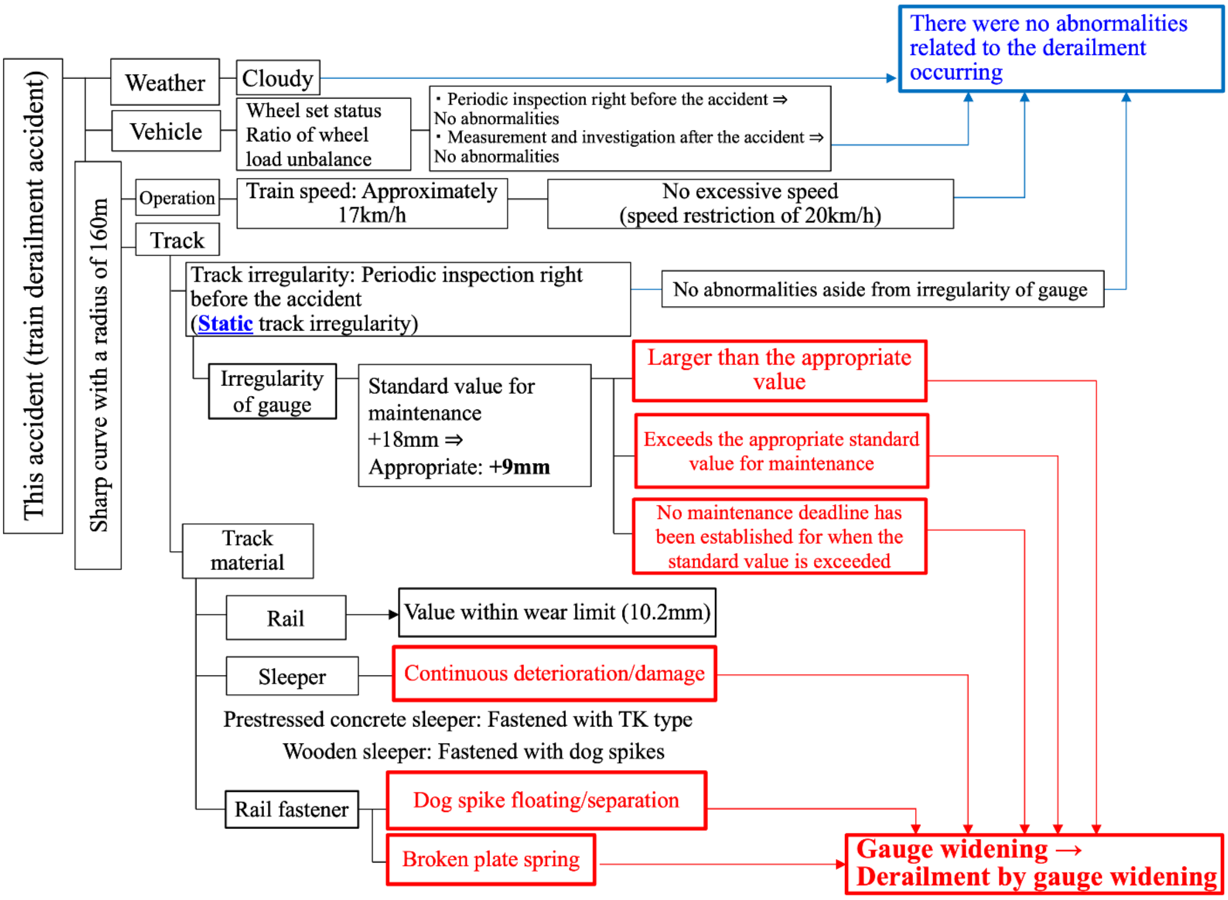
Attached Figure 5. Status of the Track Irregularity, etc., Around the Accident site



Attached Figure 6. Force Acting Between Rail Wheels

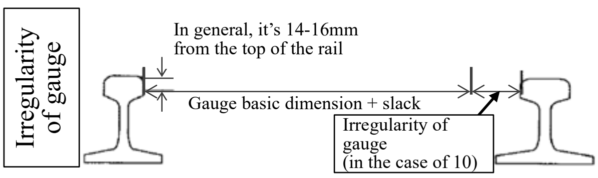


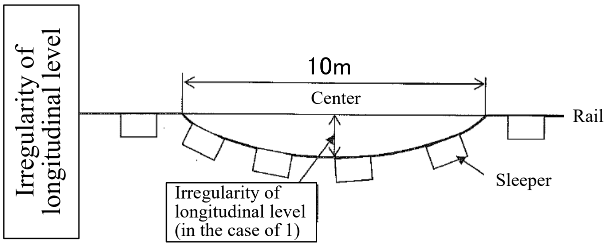
Attached Figure 7. Factors Involved in the Train Derailment Accident

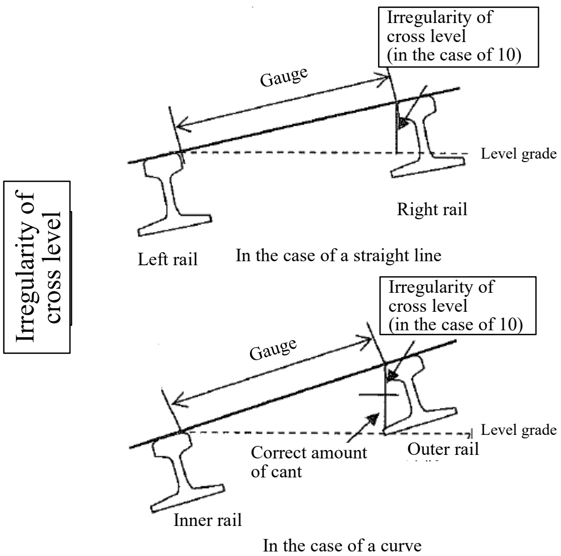


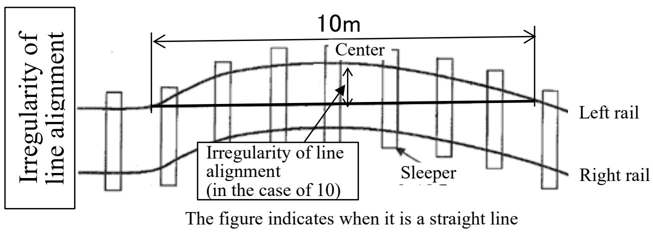
Attached Materials 1. Types of Track Irregularity and Definitions

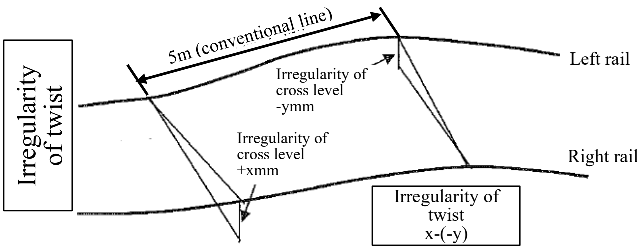
Track irregularity		Refers to deviation or deformation that occurs in each part of the track due to the train repeatedly passing over it and natural phenomena. In general, there are five types of track irregularity: Irregularity of gauge, irregularity of cross level, irregularity of longitudinal level, irregularity of line alignment, and irregularity of twist.
	Irregularity of gauge	The basic dimension (1,067 mm) and slack of the left and right rails are excluded from the distance between the inner surfaces of the gauge. See “Attached Materials 2: Concept of Limiting Value for Irregularity of Gauge” for the concept of the irregularity of gauge limiting value.
	Irregularity of cross level	Refers to the difference in the heights of the left and right rails. Also refers to the value obtained by subtracting cant when cant is set at the curve.
	Irregularity of longitudinal level	Refers to unevenness in the length direction of the top of the rail. In general, it is expressed by the distance between the rail and the thread at the center when a thread with a length of 10 m is stretched along the top of the rail.
	Irregularity of line alignment	Refers to unevenness in the length direction of the sides of the rail. In general, it is expressed by the distance (alignment versine) between the rail and the thread at the center when a thread with a length of 10 m is stretched along the inner sides of the rail gauge. Also, for curves, it is expressed by the value obtained by subtracting the versine amount of the curve radius from the alignment versine.
	Irregularity of twist	Refers to the difference in cross level between two points along the length of the rail, and represents the twisted state of the track with respect to the plane. If the distance between the two points is 5 m, then there’s said to be irregularity of twist of 5 m.











Attached Materials 2. Concept of Limiting Value for Irregularity of Gauge

As one of the judgment targets in terms of rolling stock running safety, the irregularity of gauge limiting value for preventing wheel derailment in the space between the rails is generally considered as follows, based on the relationship between the rail and the wheel set.

Clearance

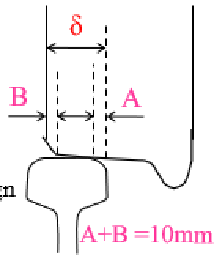
Irregularity of gauge limiting value[1)] = δ − (10) − (10) (mm)

Consider rail wear (A) + wheel tread end chamfering (B)

δ = Amount of wheel engagement on rail

= (width of rim + back gauge + thickness of wheel flange) - gauge (design value)

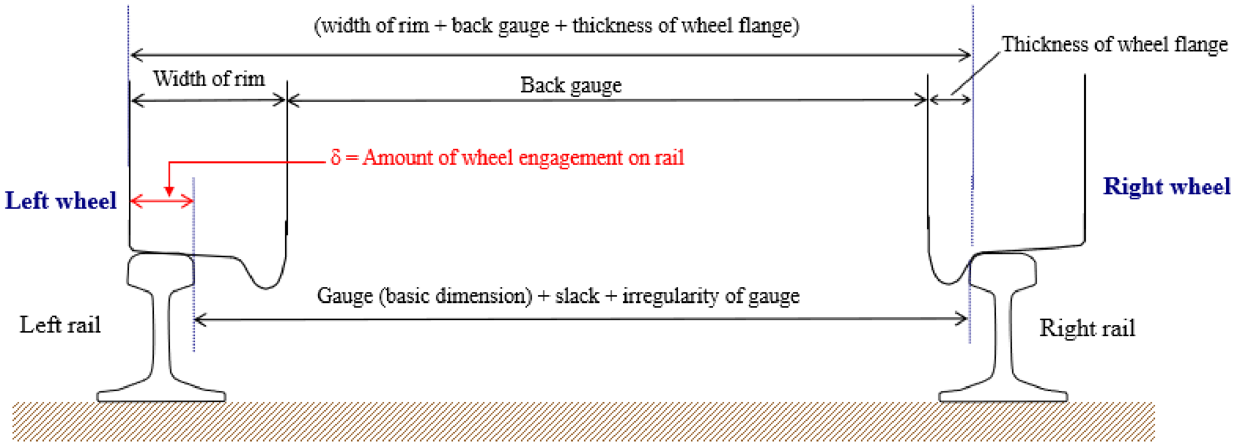
Gauge (design value) = Gauge (basic dimension) + slack



Since the smaller the wheel set dimension, the smaller the clearance for derailment by gauge widening, calculating the irregularity of gauge limiting value using the minimum value for the general wheel set dimension results in 40mm as shown below, which is the value generally used. In addition, gauge is 1,067mm, and slack is 0mm.

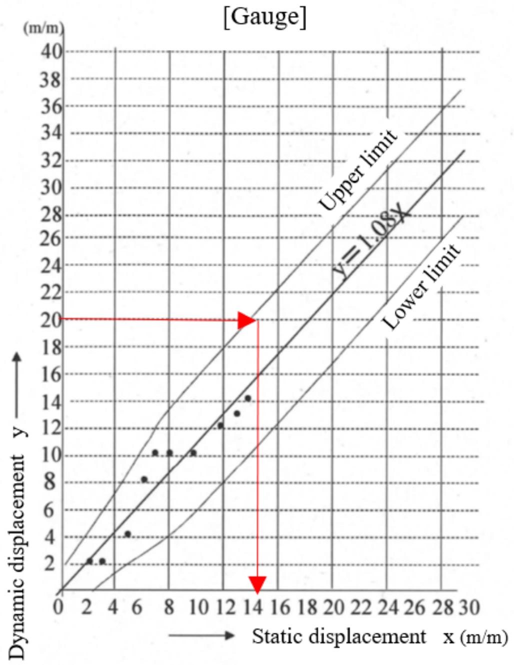
Irregularity of gauge limiting value = (width of rim + back gauge + thickness of wheel flange) − gauge (design value) − 10 − 10

= (120+988+22) − 1,067 − 10 − 10 = 43 ≒ 40 (mm)



For the standard value for track maintenance (with a conventional JR line as an example) 2), based on a limiting value of 40mm for the gauge widening amount, the upper limit for the standard value for maintenance shall be: Upper limit for the standard value for maintenance = Limiting value for the gauge widening amount - slack. For example, the standard maintenance value for dynamic irregularity of gauge for a curve with slack of 20mm would be 40 - 20 = 20mm.

Also, the standard value for maintenance for static irregularity of gauge is calculated from the relationship between dynamic irregularity of gauge and static irregularity of gauge 3), and the static irregularity of gauge would be 14mm when the standard value for maintenance for dynamic irregularity of gauge is 20mm.



Relationship between dynamic irregularity of gauge and static irregularity of gauge

References

1) Commentary: Technical Standards for Railways (Civil Engineering Edition), 3rd Edition, December 2014, p. 118, supervised by the Railway Bureau of the Ministry of Land, Infrastructure, Transport and Tourism

2) Commentary: Technical Standards for Railways (Civil Engineering Edition), 3rd Edition, December 2014, p. 661, supervised by the Railway Bureau of the Ministry of Land, Infrastructure

3) Guidance for Maintenance Management Standards for Railway Structures, etc. (Track Version), March 2007, Railway Technical Research Institute