RA2007-8-I

Railway Accident Investigation Report

Train Derailment Accident between Urasa station and Nagaoka station
of the Joetsu Shinkansen of the East Japan Railway Company

November 30, 2007

Aircraft and Railway Accidents Investigation Commission

The objective of the investigation conducted by the Japan Transport Safety Board in accordance with the Act for Establishment of the Aircraft and Railway Accidents Investigation Commission 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.

Norihiro Goto
Chairman
Aircraft and Railway Accidents Investigation Commission

Note:

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

Railway Accident Investigation Report

Railway operator :	East Japan Railway Company
Accident type :	Train derailment
Date and time :	About 17:56, October 23, 2004
Location :	Around 206,207 m from the origin in Omiya Station, between Urasa station and Nagaoka station, Joetsu Shinkansen, Nagaoka City, Niigata Prefecture

November 1, 2007

Adopted by the Aircraft and Railway Accidents Investigation Commission

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1. PROCESS AND PROGRESS OF THE RAILWAY ACCIDENT INVESTIGATION

1.1. Summary of the Railway Accident

On Saturday, October 23, 2004, the outbound 325C train named as "Toki 325" composed of 10 vehicles, started from Tokyo station bound for Niigata Station of East Japan Railway Company, passed through Urasa station on schedule, 17:49. When the train was running at about 200 km/h in the straight track, after the head of the train got out of exit of Takiya tunnel, 205,701 m from the origin in Omiya station, the emergency brake had automatically acted with large jolts, and the train stopped at around 207,828 m from the origin in Omiya station.

When the train had stopped, 8 vehicles in the 10 vehicles train set, *i.e.*, 12 bogies in total 20 bogies, or 22 axles in total 40 axles, had been derailed. However, the 1st axle in the front bogie of the 1st vehicle did not largely deviate from the track, as the left rail had been sandwiched by the left wheel and the gear case, and the right rail had been sandwiched by the right wheel and the life guard. In addition, all the vehicles had been coupled with each other. Here, the expressions "front", "rear", "left" and "right" were based on the direction of the train destination and the vehicle number was counted from the front.

There were total 154 persons, *i.e.*, 151 passengers, 2 train crews and a cabin attendant, onboard the train, but there was no casualty.

There were damages in all the vehicles of the train, but there was no damage in the passenger rooms.

Here, the 2004 Niigata Prefecture Chuetsu Earthquake, of which the maximum seismic intensity was 7, and the epicenter was about 11 km south from the place where the train had stopped, occurred at about 17:56 on the same day.

1.2. Outline of the Railway Accident Investigation

1.2.1. Organization of the Investigation

On October 23, 2004, the Aircraft and Railway Accident Investigation Commission, ARAIC, designated the chief investigator and 4 railway accident investigators to engage investigation of the accident.

In addition, the ARAIC designated another railway accident investigator on January 20, 2006.

The ARAIC appointed 5 professional members to investigate professional subjects. In addition, the "Meeting to investigate derailed mechanism of the Joetsu Shinkansen train" was established on November 1, 2004, to investigate process before and after the derailment, and held the meetings 10 times. The meeting was composed of 5 professional members and 2 experts listed in the following table, in addition to the Board members of the ARAIC.

Organization	Title	Name	Fields
Research Institute of earthquake, The University of Tokyo.	Professor	K. Abe	Earthquake
Technology Center, Kokusai Kogyo Co. Ltd.	Senior Fellow General Manager	H. Oshima	Geology
Faculty of Engineering, Kokushikan University.	Professor	K. Okada	Disaster prevention of the ground
International and Cooperate Industry and University Research Center, the University of Tokyo	Professor	Y. Suda	Vehicles
Faculty of Engineering, Shibaura Institute of Technology.	Professor	A. Matsuura	Structures
Track Technology Division, Railway Technology Research Institute.	General Manager	H. Takai	Expert of railway track technology
Railway Dynamics Division, Railway Technology Research Institute.	General Manager	Y. Suzuki	Expert of vehicular technology

** Organizations and Titles are as of November 2004.*

The ARAIC also dispatched the Chairman, the Board members, professional members and railway accident investigators to the accident site etc., for the investigation.

The Hokuriku Shin-etsu District Transport Bureau dispatched its staffs to the accident site, to support investigation of the accident.

The ARAIC entrusted the analysis on the train running simulation during earthquake and analysis on the traces in wheels and tracks, to the Railway Technology Research Institute, RTRI, and obtained cooperation from the Institute.

1.2.2. Implementation of the Investigation

- Oct. 24 to 25, Nov. 2 to 3, 8, 10 to 13, 2004 — Investigation at the accident site
- Oct. 29, Nov. 13, 2004 and Jan. 26, 2005 — Interviews
- Nov. 17 to 19, 24 to 26, Nov. 29 to Dec. 1, Dec.7, 16 to 17, 2004, and Mar. 18, 2005 — Investigation of the vehicles
- Oct. 27, 2004 to Mar. 22, 2005 — Analysis on vehicle running simulation during earthquake
- Jan. 17 to Mar. 22, 2005 — Analysis on traces in wheels and tracks

1.2.3. Interim Report

On January 24, 2005, the interim report on process and progress of the investigation was presented to the Minister of Land, Infrastructure, Transport and Tourism and made public, based on the investigated results about the facts up to that moment.

1.2.4. Comments from Parties Relevant to the Cause

Comments from parties relevant to the cause were invited.

2. FACTUAL INFORMATION

2.1. Process of the Train Operation *[Refer to Figures 1, 2-I, 2-II, 3 to 5]*

2.1.1. Process of the Train Operation

According to the statements of the driver and the conductor of the outbound 325C train, *hereinafter referred to as "the accident train"*, of East Japan Railway Company, *hereinafter referred to as "the Company"*, the outline of the process to the derailment were as follows.

(1) The driver

I handed over operation of the accident train at Tokyo station with the comment that there was no problem in the accident train, and I drove the accident train from Tokyo station to Echigo-Yuzawa station on schedule. The accident train had departed from Echigo-Yuzawa station on schedule at 17:38 and passed Urasa station on schedule at 17:49. While the accident train was in cruising operation at about 200 km/h after it went out from Takiya tunnel, there was a violent vertical shake as if vehicles were heaving upward, and afterward it changed to lateral shakes. As the emergency brake had acted due to power failure, I was not sure which had triggered the emergency brake at first, my operation or the ATC[*1] system. Shakes and scraping sound were continued for a while.

I felt the spreading blurred light rather than the spark as crackle by the contact break of pantograph, as it was dark outside of the train. I was watching in front of the train praying to stop promptly and confirmed existence of rails. I was seated and bracing his legs firmly against the floor. When the train had stopped, the driver's cab was almost parallel to the track, not so leaned.

After the train had stopped, I communicated with the conductor using the on-train telephone to notify that the radio in the driver's cabin did not work, and asked to bring the JR cellular phone, which can be used in the section where LCX[*2] circuits are installed. Then I communicated the first report about the occurrence of the accident to the train dispatcher in the headquarter of Shinkansen train operation.

Here, I had found no abnormal status in the vehicles of the accident train, from the start of train operation to the occurrence of the accident.

*1 *"ATC" is the abbreviation of Automatic Train Control device.*

*2 *"LCX" is the abbreviation of Leaky Coaxial Cable that is the cable having functions to transmit radio information.*

(2) The conductor

There was no abnormal situation in the train operation from the departure from Tokyo station to Echigo-Yuzawa station. According to the Company's rule, I patrolled the passenger rooms and counted the number of passengers after the departure from Echigo-Yuzawa station, and found that 151 passengers were onboard. Here there was only one passenger in the 10th vehicle. As the remaining time to Nagaoka station was less than 5 minutes, I was preparing for arrival at Nagaoka station in the staff room in left side of the 2nd vehicle, where is the appointed position of watching arrival and door operation.

Just after the vehicle went out of tunnel, the vehicle once swayed to left as if trains passed each other. After that, vertical shakes had been continued until to stop. The vertical shakes were almost regularly and violent as my body seemed to be raised into the air unless holding armrests of both sides of the seats.

I heard the sound as if chains were snapped, from underfloor, and it faded away as the vehicle velocity became slower. The shakes became gently just before the train had stopped, and I felt as if I had pitched forward when the train had stopped. When I looked outside of windows, the pale sparks were falling from upward, and felt as hazy by stirred up clouds of dust.

After the train had stopped, I communicated with the driver by the on-train telephone. The driver said that the train seemed to hit something, as he seemed not to understand what had happened, at first. As the driver asked me to bring the JR cellular phone because the radio in the driver's cab did not work, I walked to the driver's cab in the 1st vehicle bringing it with him. While the driver was talking with the train dispatcher, a violent shake occurred, the viaducts waved and the overhead trolley swayed laterally, then we understood that earthquake had occurred.

2.1.2. Status of the Passenger Room etc.

According to the statements of a passenger A boarded on the 9th vehicle of the accident train, the process to the accident and the status of inside passenger room were as follows.

Passenger A was seated and sleeping in right window side seat of the third or fourth row in the 9th vehicle. Suddenly, there was the violent shock with the rattling sound, and I was thrown out forward from the seat, and supported my body by hands against the floor. After I felt the shock, the vehicle leaned to right soon, in 2 to 3 seconds or shorter.

When I felt that the brake had acted, I heard the scraping sound as if something was scraping, without shakes and the rattling sound. The train had stopped without large jolts and halted being leaned to right. My baggage fell from overhead rack to the seat. After the train had stopped, I noticed that earthquake had occurred as the aftershock had occurred. The room lights went out by the first shock, but the emergency lights had turned on immediately. I could hear the in-train announcement by the conductor.

2.1.3. Statements of Witness of the Accident

According to the statements of the witness who saw the accident at around Tokamachi viaduct, the outline of the status of the accident was as follows.

When the earthquake happened, I was walking with a dog as the railroad on my back, and I heard sound of the accident train went out of tunnel. I was sure that the accident train went out of tunnel because the sound was the same as usual.

Just after the accident train had gone out of the tunnel, the ground shook by the earthquake. I did not hear an abnormal sound before all the vehicles of the accident train had gone out of the tunnel. I heard sounds of usual train running. When I looked at the direction of the railroad, the sparks had initiated at about the time when the whole train went out of the tunnel, and gradually expanded. He remembered that the sparks seemed to initiate at around the derailed position and became small gradually. The train looked as running smoothly as if it was sliding, I did not feel that the train was jolting. At that time, I could not recognize whether the train was derailed or not.

Here, the accident had occurred at about 17:56.

2.2. Injuries to Persons

None

2.3. Information on the Damages in the Railway Facilities and the Vehicles

2.3.1. Status of the Major Damages in the Railway Facilities *[Refer to Figure 2]*

(1) Track

(a) The down track

It was found that there was the gauge widening beyond about 205,960 m from the origin in Omiya station. *Hereinafter "from the origin in Omiya station" is omitted*.

A lot of anchor bolts, fastening bolts, spring clips, etc. of the directly connected 8 type rail fastening device, were damaged and scattered from around 206,207 m of the right rail and around 206,227 m of the left rail, to around the position where the 1st vehicle had halted.

The rails were partly displaced to right or left or turned over. A part of the left rail fell into the channel for the evacuation of melting snow[*3] in the left side of the track in around 206,500 m to 206,600 m and around 206,700 m to 206,810 m, and a part of the right rail fell into the channel for the evacuation of melting snow between up and down tracks in around 206,700 m to 206,750 m and around 206,850 m to 207,550 m.

In the insulated joint at around 206,696 m, the glued joint bars of the right and left glued insulated rails[*4] were removed, and front and rear rails at the joint were separated and broken, furthermore, there were lacks and cracks in a part of right edge of the slab track. Here, there was the hit trace considered as caused by the wheel on the removed glued joint bar. The right rail was broken at around 206,717 m and around 206,741 m. Here, there was the hit trace considered as caused by wheels in the side surface of the bottom of the broken rail.

*3 *"Channel for the evacuation of melting snow" is the watercourse on the viaduct to collect water etc., from the sprinkler for melting snow.*

*4 *"Glued insulated rail" is the unified rail by the strong glue, that the insulators were inserted between rail edges and between rail and glued joint bars to reinforce the insulated joint.*

(b) The up track

There were damages considered as hit by the broken rail of the down track, on the left rail at around 206,735 m. In addition, a part of the upper left edge of slab track was lacked in around 206,720 m to 206,750 m. However, there was no damage as to cause the derailment.

(2) Bridges

The rail levels of left rail in the down track had relatively sank about 7 cm in maximum in around Jodogawa bridge, located at 206,014 m to 206,057 m, and about 3 cm in maximum in around Tokamachi viaduct T3, respectively. Here, in the name of track structures, "T" expresses the girder type, "R" expresses the rigid frame type, and number is added in order in each bridge. Refer to 2.5.1(3) about positions of the structures. The track of the up track had relatively displaced to left about 4 cm in maximum, in around the edge in the direction to Omiya station of Jodogawa bridge. However, there was no remarkable damage in these bridges such as falling girder.

There were damages by removal of concrete at 28 points in the piers around 206,900 m to 207,370 m on Muramatsu viaduct, and the pier at around 207,658 m on Higashi Ooshin-e bridge.

There were sank grounds and gaps around the roots of many piers, and mud pumping and sand pumping were found in around the ground surface and the side surfaces of the lower part of piers, respectively. The maximum depth of the sunk ground in around the root of piers were about 65 cm in Tokamachi viaduct R6 and Nakajima viaduct R6, and the maximum gap was about 15 cm at Muramatsu viaduct T14.

(3) Overhead contact line

The many poles had leaned and many hangers were damaged in around the accident site. The both two stem insulators of the hinged cantilever in up track at around 206,900 m, were damaged and being hung from the contact wire. Here, tip of the horizontal pipe of the hinged cantilever was deformed.

2.3.2. Status of the Major Damages of the Vehicles

Major damages in each vehicle are as follows.

As the window glasses in the passenger rooms of all the vehicles are the insulated glass[*5], the damages described in the followings are for the outer laminated glasses[*6], inner toughened glasses were not damaged at all. Here the window glass of the doors for getting on and off for passengers were composed of only laminated glass.

(1) The 1st vehicle, 222-1505 *[Refer to Figure 4-I and Figure 6]*

(a) A part of flange of left wheel in the 1st axle of the front bogie was worn away, and there were the hit traces on its outer tread.

(b) The main life guard and the auxiliary life guard were damaged and there were traces considered as caused by coming into contact with rail, etc., in the brushing rubber of the auxiliary life guard.

(c) There were damages considered as worn away in the portion, close to right shoulder of right rail, of the fitting arm of the right side main life guard, and in the portion, close to the right shoulder, of left rail of the gear case of the 1st axle in the front bogie, respectively.

(d) A laminated glass of left side window in the passenger room was damaged.

(e) The pantograph cover was damaged.

(f) The coupling rod of the anti-rolling damper device, between the 1st and the 2nd vehicles, was damaged.

(g) The shank guide of the rear coupler was bent.

(2) The 2nd vehicle, 215-31 *[Refer to Figure 4-II]*

(a) There were damages considered as caused by the coupler, in the front end of the vehicle body.

(b) The pantograph cover was damaged.

(c) Two laminated glasses of the left side windows in the passenger room were damaged.

(3) The 3rd vehicle, 226-1033 *[Refer to Figure 4-III]*

(a) There were damages as worn away in the portion close to left shoulder of right rail of the gear case of the 2nd axle in the rear bogie.

(b) A laminated glass of left side window in the passenger room was damaged.

(c) The horn and the auxiliary horn in the left side of the pantograph in operation, were bent.

(4) The 4th vehicle, 225-482 *[Refer to Figure 4-IV]*

Each one of the laminated glasses of right and left side windows in the passenger room were damaged.

(5) The 5th vehicle, 226-1009 *[Refer to Figure 4-V]*

(a) A laminated glass of the window in right side of the passenger room was damaged.

(b) The jumper bar of the ultra high voltage jumper coupler in the rear end of the roof-top was damaged.

(6) The 6th vehicle, 225-1004 *[Refer to Figure 4-VI]*

(a) A part of wheel flanges of left and right wheels of the 2nd axle in the rear bogie were worn away in the same phase in the circumferences of the both left and right wheels.

(b) The porcelain tube of the ultra high voltage jumper coupler in the rear end of the roof-top was damaged.

(7) The 7th vehicle, 226-1032 *[Refer to Figure 4-VII]*

(a) The porcelain tube of the ultra high voltage jumper coupler in the front end of the roof-top was damaged.

(b) A part of the flange of right wheel of the 1st axle in the front bogie were worn away, and there were worn hollows in the tread in outside of the worn flange.

(c) There were linear damages considered as caused by rail on the bottom surface of the vehicle body.

(d) The Pantograph cover was damaged.

(e) The auxiliary horn in right side of the pantograph in operation, was bent.

(8) The 8th vehicle, 225-1013 *[Refer to Figure 4-VIII]*

(a) There were linear damages considered as caused by rail, in the bottom surface of the vehicle body.

(b) Two laminated glasses of the left side window in the passenger room were damaged.

(c) The coupling rod of the anti-rolling damper between the 8th and the 9th vehicles were damaged.

(9) The 9th vehicle, 226-1043 *[Refer to Figure 4-IX]*

(a) A laminated glass of the front left door for getting on and off for passengers was damaged.

(b) Five laminated glasses of the left side windows in the passenger room were damaged.

(c) There were the linear damages considered as caused by rail, at the bottom surface of the vehicle body.

(d) A part of the flange of the left wheel of the 2nd axle in the rear bogie was worn away.

(e) The coupling rod of the anti-rolling damper between the 9th and the 10th vehicles was damaged.

(10) The 10th vehicle, 221-1505 *[Refer to Figure 4-X]*

(a) There were relatively large hit traces in a part of right wheel flange of the 2nd axle in the front bogie and in a part of right wheel flange of the 1st axle in the rear bogie, respectively.

(b) The pantograph cover was damaged.

(c) There was the damage as being worn away in almost right triangular cross section orthogonal to direction of train running, in the bottom of the main electric motor of the 1st axle in the front bogie.

(d) A laminated glass of the window in each right and left side of the passenger room were damaged.

(e) A laminated glass of the rear left door for getting on and off for passengers was damaged. The damage was reached to inside of the door.

(f) There were damages considered as caused by the slab track of the up track in the lower part of right side surface of rear part of the vehicle body, and damages considered as caused by the channel for the evacuation of melting snow between up and down tracks in bottom edge in the right side surface of rear part of the vehicle body, respectively.

(g) There were linear damages considered as caused by rails in the bottom surface of the vehicle body.

(h) Ten cover boards for the bottom of the vehicle body were fallen away, and almost all cover boards including fallen boards were damaged.

(i) A part of the front cover of right side axle box of the 1st axle in the rear bogie was broken.

(j) The main life guard and the auxiliary life guard were damaged.

*5 *Insulated glass is the glass that the dry air was sealed in the intermediate layer between the outer laminated glass and the inner polished toughened glass.*

*6 *Laminated glass is the glass that the transparent film is sandwiched and adhered by the polished sheet glass and the toughened polished sheet glass.*

2.4. Information on the Train Crews

The driver was 41 years old male. He had driver's license for Shinkansen electric motor car issued on November 28, 1995.

The conductor was 36 years old male.

2.5. Information on the Railway Facilities, etc.

2.5.1. Outline of the Railway Facilities *[Refer to Figures 1 and 2-I]*

The track of the Joetsu Shinkansen line was the double track and its gauge was 1,435 mm.

The track in around the accident site was laid almost north and south direction and composed of continuous bridges. The outline of the railway facilities in around the accident site were as follows.

(1) Track layout

The track from 202,159 m to 207,135 m was the straight section, and from 207,135 m to 207,700 m was the transition curve of the 10,000 m radius left curve.

(2) Gradient

The track from 204,461 m to 206,211m was the 3 ‰ downgrade, from 206,211 m to 206,911 m was the 6 ‰ downgrade and from 206,911 m to 208,163 m was the 1 ‰ downgrade.

(3) The railway structures

Takiya tunnel	203,028 m to 205,701 m
Watarisawa Minami viaduct	205,701 m to 205,821 m
Watarisawa Kita viaduct	205,871 m to 206,014 m
Jodogawa bridge	206,014 m to 206,057 m
Tokamachi viaduct	206,057 m to 206,625 m
Sawaguchi bridge	206,625 m to 206,648 m
Muramatsu viaduct	206,648 m to 207,432 m
Muramatsu bridge	207,432 m to 207,520 m
Katada viaduct	207,520 m to 207,658 m
Higashi Ooshin-e bridge	207,658 m to 207,696 m
Nakajima viaduct	207,696 m to 208,183 m

(4) Rail

The 60 kg rail.

(5) Rail fastening device

Directly connected 8 type.

(6) Ballast

Slab track.

2.5.2. Inspection of the Railway Facilities

The latest inspections obeying the Company's rule at that time, such as "Implementing Standards of Shinkansen Track Facilities", "Implementing Standards of Shinkansen Railroad Structure", etc., were implemented as shown in Table 1. There was no abnormal result in the records of these inspections.

Table 1. Dates of Implementation of the Latest Inspections for the Railway Facilities

Category of inspections	Period of inspections*	Date of implementation.
Inspection of railway structures	Two years	April 28, 2003, May 29, 2003
Inspection of ballast and roadbed	One year	May 31, 2004
Inspection of rail etc.	One year	December 24, 2003 : Glued insulation June 4, 2004 : Damages June 22, 2004 : Abrasion
Inspection of slab	One year	July 30, 2004
Inspection of track irregularity etc., in the main line	One month	October 19, 2004. Implemented by the Shinkansen electric and track inspection car.
General patrol of the track	Two weeks	October 20, 2004

**Implement every term, not exceed the listed terms.*

2.5.3. Status of Topography, Geology, etc.

The geographical features in around the accident site were, in turn, the river terrace, alluvial flat face, alluvial fan and alluvial flat face, continued to the broad Niigata plain. As for the geological features, the gravel and sand layer of the alluvial fan had existed broad and thick under the alluvium, based on the investigation[*7] implemented prior to the construction of the Joetsu Shinkansen. The alluvium layer was around 5 m thick and composed of sand layer with particles of relatively same diameters with the N value[*8] of 10 to 30, and the soft clay layer with the N value of 2 to 5. Most of the gravel and sand layer of the alluvial fan was the support bedrock stable as the N value of above 50, and the sand layer supposed as partly composed of the diluvium had existed below the support bedrock.

Here, the support bedrock described in above paragraph was to support vertical load of the structures, and was not the bedrock in the response analysis on the structures described in 2.13.3(2).

*7 *"Geographic chart of Joetsu Shinkansen, between Minakami and Niigata", Niigata Shinkansen Construction Agency, Japan Railway Construction Public Corporation, March 1980, in Japanese.*

*8 *"N value" is the number of beating sampler for the standard penetration test by free falling hammer of the predetermined weight, required to penetrate the sampler into the ground at the predetermined depth. "N value" indicates the relative values for hardness or softness and firmness of the ground.*

2.6. Information on the Vehicles

2.6.1. Outline of the Vehicles

Vehicle classification	AC electric railcar, 25,000 V, 50 Hz
Number of vehicles in the train set	10 vehicles
Symbol, number and specifications	Indicated in Table 2

Table 2. Symbol, Number and Specifications of the Vehicles

Vehicle position	1st vehicle	2nd vehicle	3rd vehicle	4th vehicle	5th vehicle
Symbol & number	222-1505	215-31	226-1033	225-482	226-1009
Date of production	July 27, 1984	May 14, 1982	July 13, 1984	Jan. 29, 1982	Dec. 24, 1983
Tare [t]	61.6	57.3	57.8	56.5	57.8
Passenger capacity [person]	60	52	95	70	95
Vehicle length [m]	25.150	25.000			
Vehicle height [m]	4.490	4.110	4.490	4.110	4.490
Pantograph	Equipped.	Not equipped.	Equipped in use	Not equipped.	Not equipped.
Vehicle width [m]	3.385				
Wheelbase [m]	2.500				
Wheel diameter [mm]	910, when newly produced.				

Vehicle position	6th vehicle	7th vehicle	8th vehicle	9th vehicle	10th vehicle
Symbol & number	225-1004	226-1032	225-1013	226-1043	221-1505
Date of production	Dec. 24, 1983	July 13, 1984	July 13, 1984	Aug. 9, 1984	July 27, 1984
Tare [t]	57.3	57.8	57.3	57.8	61.5
Passenger capacity [person]	80	95	80	95	50
Vehicle length [m]	25.000				25.150
Vehicle height [m]	4.110	4.490	4.110	4.490	4.360
Pantograph	Not equipped.	Equipped in use	Not equipped.	Equipped.	Not equipped.
Vehicle width [m]	3.385				
Wheelbase [m]	2.500				
Wheel diameter [mm]	910, when newly produced.				

Here, the vehicles had adopted the body mount structure*9.

In addition, the life guards were equipped in the 1st and the 10th vehicles. There were the main life guard and the auxiliary life guard in the life guard. The main life guard in the 1st vehicle was attached to the lower part of the axle box of the 1st axle in the front bogie by the fitting arm of the life guard, and the brushing rubber was attached to its bottom edge. On the other hand, the auxiliary life guard was attached to the skirt of the vehicle body, and the brushing rubber was attached to its bottom edge. Distance in the front to rear direction between the brushing rubber of the auxiliary life guard and the 1st axle in the front bogie of the 1st vehicle was about 2 m. *[Refer to Figure 6]*

*9 *"Body mount structure" is one of the measures against snow fall for the vehicle. In this structure, the cover boards cover the underfloor space of the vehicle body and the underfloor equipments are mounted inside the covered space.*

2.6.2. Inspection of the Vehicles

The latest inspections obeying the Company's rule "Implementing Standards for Maintenance of Shinkansen Electric Railcar" at the time of the accident, were implemented as shown in Table 3. There was no abnormal record in these inspections.

Table 3. Dates of Implementation of the latest Inspections for the Accident Train

Category of inspections	Period of inspections*	Implemented date
General inspection	36 months or running distance 900,000 km	Oct. 16, 2003
Regular inspection	30 days or running distance 30,000 km	Oct. 21, 2004
Performance inspection of ATC device	90 days	Oct. 16, 2004
Inspection of train radio device	6 months	Sept. 21, 2004

** Implement in every term not exceed the designated terms, or every running distance not exceed the designated distance.*

2.6.3. Recorded data in the ATC onboard device

The inspection and record device in the ATC onboard device, *hereinafter referred to as "the ATC recording device"*, recorded the operating status of the receiver control device and ATC related apparatus, etc. The error of the velocity check in the ATC recording device was ±1 km/h, and the data were recorded every 0.3 second. Information obtained from the ATC recording device of the accident train was shown in Table 4.

Table 4. Information Obtained from the ATC Recording Device

Time	Position	Recorded data
17:56:03.2	206,067 m	Power failed, when running in powering operation at 204 km/h
17:56:04.7	206,151 m	Output ATC brake signal, when running at 204 km/h

2.7. Information on the System to Stop Trains Urgently when Earthquake had Occurred

The Shinkansen of the Company adopted the Urgent Earthquake Detection System for Shinkansen, named as "Compact UrEDAS", as the system to stop trains urgently when earthquake had occurred.

The wayside seismographs of the Joetsu Shinkansen were located about every 20 km, including 13 wayside substations. The system issues the P-wave[*10] alarm when the main shock was estimated over 120 gal, when the early stage tremor had been detected, and issues the S-wave[*11] alarm, when the earthquake of over 40 gal had been detected. The system stops power feeding at 0.1 second after the alarms, in the peripheral feeding sections within about 40 km. Then, the power of overhead contact line was turned off, and the ATC system in the related trains operated emergency brake automatically to stop the trains, without operations by the drivers. In addition, the train dispatcher can notice the information on earthquake instantaneously, such as the maximum acceleration of the earthquake and the section where the power feeding had stopped through the displays using the private communication circuit.

When the Niigata Prefecture Chuetsu Earthquake had occurred, all the Joetsu Shinkansen trains had stopped according to the operation of the Compact UrEDAS system. The status of trains in around the accident site at that time, except for the accident train, were shown in Table 5.

*10 *"P-wave" is the vertical wave observed at first when earthquake occurred.*

*11 *"S-wave" is the horizontal wave reached following P-wave.*

Table 5 The Status of Trains Except for the Accident Train

Train number	Track Section	Estimated velocity when earthquake had occurred	Stopped position[3)]
327C	Between Jomo-Kogen station and Echigo-Yuzawa station, outbound train.	About 200 km/h[1)]	Around 145,900 m
332C	Between Urasa station and Echigo-Yuzawa station, inbound train.	About 203 km/h[2)]	Around 177,700 m
406C	In the premises of Nagaoka station, inbound train.	About 25 km/h[1)]	Around 213,800 m
8361C	Between Nagaoka station and Tsubamesanjo station, outbound train.	About 220 km/h[1)]	Around 225,800 m

1) The velocity when the ATC recording device detected the power failure.

2) The velocity reported from the train crew. There was no record in the ATC recording device due to its trouble.

3) The kilometerage reported from the train crew.

Here, the 8361C train, Toki 361, ran in the down track in around the accident site about 10 minutes before the accident, and the 332C train, Toki 332, ran in the up track in around the accident site about 9 minutes before the accident, respectively, without any abnormal situation.

2.8. Information on the Weather Condition

Weather in around the accident site at the time of the accident was fine.

2.9. Information on the Earthquake

2.9.1. Outline of the Earthquake

According to the Japan Meteorological Agency, JMA, the "Heisei 16th Year, 2004, Niigata Prefecture Chuetsu Earthquake", *hereinafter referred to as "Niigata Prefecture Chuetsu Earthquake"*, had occurred at 17:56:00.30, October 23, 2004. The hypocenter was in 37°17' 37" N, 138°53' 23" E, 13 km in depth, and the magnitude[*12] was 6.8. The maximum seismic intensity 7 was observed. The error in estimation of the time of the occurrence of the earthquake was ±00.11 sec.

The estimated arrival times of P-wave and S-wave at the representing point selected in around the accident site, 206,000m, *i.e.*, 37°22' 25.55" N, 138°50' 49.31" E, were 17:56:02.87 ±0.20 second, and 17:56:05.03 ±0.28 second, respectively. Here, distance from the epicenter to the above representing point was about 9.6 km, and about 11 km to the position where the train had halted. *[Refer to Figure 5]*

*12 *"Magnitude" expresses the scale of earthquake, corresponds to the energy emitted by the earthquake.*

2.9.2. Recorded Data in the Seismographs Located in around the Accident Site

The maximum acceleration etc., by the Niigata Prefecture Chuetsu Earthquake observed in the seismographs located around the accident site were shown in Figure 5.

The maximum displacement of the ground surface calculated from the recorded data in the Shin-Nagaoka auxiliary sectioning post, the nearest post to the accident site, was about 152 mm in north and south direction, about 144 mm in east and west direction and about 51 mm in vertical direction.

2.9.3. Issued Time of the Alarm from the Wayside Seismographs Located in Substations, etc., of the Joetsu Shinkansen

Among the wayside seismographs described in 2.7, the times when the alarms had issued based on the detection of the Niigata Prefecture Chuetsu Earthquake by the seismographs located in around the accident site, were listed in Table 6.

Here, there was no abnormal situation in these seismographs in the latest inspection implemented before the accident.

Table 6. Issued times of alarms.

	Shin-Kawaguchi substation	Shin-Nagaoka auxiliary sectioning post
P-wave alarm	17:56:03.1	17:56:04.2
S-wave alarm	17:56:03.3	17:56:05.9

2.10. Information on the Accident Site

2.10.1. Status of the Derailment *[Refer to Figure 2, 3]*

(1) The 1st vehicle

The all two axles in the front bogie had derailed to left by about 20 cm, respectively. The 1st axle had stopped as the left wheel and the gear case sandwiched the left rail, and the right wheel and the fitting arm of the main life guard sandwiched the right rail, and these wheels halted being stepped on the rail fastening devices.

(2) The 2nd vehicle

The all two axles in the front bogie had derailed to right by about 50 cm, respectively, and the right wheels had come into contact with the right edge of the slab track in the down track.

(3) The 3rd vehicle

The 2nd axle in the rear bogie had derailed to right by about 10 cm, and stopped as the right wheel and the gear case sandwiched the right rail, and the wheels of the 2nd axle halted being stepped on the rail fastening devices.

(4) The 4th vehicle

No axle was derailed.

(5) The 5th vehicle

No axle was derailed.

(6) The 6th vehicle

The 2nd axle in the rear bogie had derailed to left by about 5 cm.

(7) The 7th vehicle

The right wheels of three axles, *i.e.*, all two axles in the front bogie and the 1st axle in the rear bogie, had derailed to inside of gauge, and the 2nd axle in the rear bogie had derailed to left by about 5 cm, respectively.

(8) The 8th vehicle

All two axles in the front bogie and all two axles in the rear bogie had derailed to left by about 10 cm, respectively. Here, the right rail had been overturned to right to around the center of the 8th vehicle.

(9) The 9th vehicle

All two axles in the front bogie had derailed to left by about 5 cm, the 1st and the 2nd axles in the rear bogie had derailed to right by about 80 cm, and about 90 cm, respectively.

(10) The 10th vehicle

The 1st and the 2nd axles in the front bogie had derailed to right by about 100 cm and about 140 cm, respectively. All two axles in the rear bogie had derailed to right by about 140 cm. The right wheels of all two axles in the front bogie and all two axles in the rear bogie had fallen into the channel for the evacuation of melting snow between up and down tracks, so that the vehicle body had leant to right about 30 degrees, and the lower part in the right side surface in the rear part of the vehicle body had come into contact with slab track in the up track, and the bottom edge of the right side surface in the rear part of the vehicle body had come into contact with the channel for the evacuation of melting snow between up and down tracks. Here, the vehicle body was in the position where the train collision accident might occur if the opposite train was operated.

2.10.2. Traces by the Derailment *[Refer to Figure 2]*

(1) Traces on the rail in the down track

(a) There was linear trace considered as caused by the right wheels on rail surface of the right rail in around 206,191 m to 206,207 m.

(b) There was linear trace considered as caused by the right wheels in the right bottom of the right rail in around 206,207 m.

(c) There was linear trace considered as caused by the left wheels on rail surface of the left rail in around 206,217 m to 206,227 m. There were seven discrete linear traces of about 1 to 5 m long, on rail surface of the left rail in around 206,264 m to 206,303 m.

(d) The black residual substance was adhered to rail surface of the left rail in around 206,232 m to 206,238 m.

(2) Traces on the slab track in the down track

There were many traces considered as caused by the wheels and the vehicle body on the upper surface and the right edge of the slab track beyond about 206,300 m. The traces on the upper surface meandered in around 206,400 m to 206,500 m, and in around 206,600 m to 206,900 m, respectively.

(3) Traces in the channel for the evacuation of melting snow between up and down tracks.

(a) There were the linear traces towards the vehicle body and the right wheel of the 10th vehicle, in around 206,820 m to 206,870 m and in around 206,920 m to 207,580 m, where the 10th vehicle had been halted.

(b) There were linear traces considered as caused by the right wheels in around 206,905 m to 207,600 m, where the 1st axle in the front bogie of the 10th vehicle had been halted.

(4) Traces on the slab track in the up track

There were discrete traces continuing to the vehicle body of the10th vehicle on the left edge of the upper surface of the slab track in around 206,828 m to 207,580 m, where the 10th vehicle had been halted.

2.11. Information on the Actions of the Company after the Accident

The Company established the "Headquarters for Measures against Earthquake in Niigata District" in the Head Office, Niigata Branch Office and Headquarter for Shinkansen Operation of the Company, at about 18:00, just after the Niigata Prefecture Chuetsu Earthquake had happened. Among these organizations, the Headquarter for Measures against Earthquake in Niigata District in the Head Office was consisted of the general manager of the Railway Business Division as the chairperson, and the senior managers of the related section as the members, to tackle decision of the rescue plan for passengers, comprehension of the status of the derailment and the railway facilities' damages, decision of plan for substitute transportation and the recovery plan, etc.

In addition, the Company established the "Onsite Headquarter for Measures" in Nagaoka station. After that, the Company dispatched 10 station staffs from Nagaoka station to the accident site and implemented investigation of the status of the derailment, etc.

2.12. Information on the Guidance for Evacuation, etc.

According to the statements of the driver, the conductor and the plural passengers, the status of the guidance for evacuation, etc., in the accident were summarized as follows.

When the driver communicated with the train dispatcher as the first report of the occurrence of the accident, he was instructed from the train dispatcher, to confirm whether the passengers had injured or not at first, then to report the status of the train. The conductor announced, using the in-train announcing device in the first vehicle, not to get off the train as the aftershock had occurred.

Although only the emergency lights were lighting in the passenger room, passengers were calm. As the conductor was notified from the passenger that the 10th vehicle was tilting, the driver, the conductor and the Company staff boarded on the 9th vehicle went to the 10th vehicle to rescue a passenger in the 10th vehicle. The gangway door could not be opened as the gangway between the 9th and the 10th vehicles was transformed significantly, then the driver and the Company staff got off the train once and went into the 10th vehicle, while the conductor was waiting in the 9th vehicle.

It was difficult to walk aisle unless the driver and the Company staff held something in the 10th vehicle as it had leant to right and the emergency lights were turned off. They rescued the passenger staying in the 10th vehicle and guided to the forward vehicle which was not leaned and asked to wait.

After that, the driver and the conductor returned to the driver's cab in the 1st vehicle, then reported the status until then to the train dispatcher and asked the instruction about the procedures to rescue passengers.

The instruction from the train dispatcher was to rescue passengers to walk on the viaduct to Nagaoka station considering the status of road traffic, and to let the passengers move to the safe vehicles and wait for the arrival of the track maintenance staffs who had already dispatched from Nagaoka station and the staffs of the Onsite Headquarter for Measures who would be dispatched soon. While waiting for the arrival of the Company staffs, the passengers were well informed of these situations by train crews using the in-train announcement. In addition, train crews turned off the batteries of the unused units to save battery lives, and prepared the ladders, etc., to get off the train.

After a while, the track maintenance staffs arrived, and the staffs of the Onsite Headquarter for Measures also arrived. It was about 21:50 when the passengers started to get off the train.

The passengers walked in a line along the passage in the right edge of the viaduct, for about 2 hours to Nagaoka station, guided by the staff of the Onsite Headquarter for Measures. The last passenger got off the train at about 22:30 and arrived at Nagaoka station at about 0:20 in the next day. According to the JMA, the aftershock of 5 weak and above class seismic intensity was not observed in these time span. After that, the driver and the conductor were waiting in the driver's cabin in the 1st vehicle to take over the train operation to the staffs from the Vehicle Center.

2.13. Tests and Studies to Determine the Facts

2.13.1. Material Analyses

The material analysis was implemented to identify the residual substance adhered to the rail. The results of the analysis were as follows.

(1) Investigated object

The black residual substance adhered to the top surface of the left rail in around 206,232 m, described in 2.10.2 (1), was picked up.

(2) Result of the analysis

According to the result of the material analysis, it is supposed that the residual substance was the brushing rubber of the life guard.

2.13.2. Analyses on the Traces in the Wheels and the Track

(1) Investigated object

Rail etc.

- Right rail in around 206,720 m
- Left rail in around 206,696 m
- Glued joint bar of left rail in around 206,696 m
- Glued joint bar of right rail in around 206,696 m

Wheels, 13 samples

- Left wheels of the 1st axle in the front bogie of the 1st vehicle.
- Right wheel of the 1st axle in the front bogie of the 2nd vehicle.
- Right wheel of the 2nd axle in the rear bogie of the 6th vehicle.
- Right wheel of the 1st axle in the front bogie of the 7th vehicle.
- Right wheel of the 1st axle in the front bogie of the 8th vehicle.
- Left wheel of the 1st axle and right wheel of the 2nd axle in the front bogie of the 9th vehicle.
- Right wheel of the 1st axle and left wheel of the 2nd axle in the rear bogie of the 9th vehicle.
- Right wheel of the 1st axle and right wheel of the 2nd axle in the front bogie of the 10th vehicle.
- Right wheel of the 1st axle and left wheel of the 2nd axle in the rear bogie of the 10th vehicle.

(2) Items of the investigation

The investigated objects were measured their three dimensional shapes, then recorded as the numerical data and analyzed the collided object, the angle of collision, the collided speed, etc., by the image processing.

(3) Result of the analyses

It could not be determined what made the hit trace or abrasion by the results of the analysis. Also, the collision angle, the collided speed, etc. could not be estimated.

2.13.3. Analyses on the Vehicle Running Simulation during Earthquake *[Refer to Figure 7]*

(1) Observation of the aftershocks

The observation of the the aftershocks was implemented from October 31 to December 14, 2004, to install four seismographs on the viaduct and the ground near the pier in the two points designated as the observing point, *i.e.*, one was in the down track side of Tokamachi viaduct at around 206,203 m, 37°37'56" N and 138°84'77" E, in near the accident site, and another one was in the down track side of No.1 Nagasou viaduct at around 212,228 m, 37°42'95" N and 138°85'32" E, where the train was not derailed.

Among the recorded data obtained by the observation of aftershocks, two aftershocks of which the magnitude announced by the JMA was over 5 and all seismographs in the two designated observing points had recorded data normally, were selected to evaluate the waveforms of the acceleration, velocity and displacement, etc. As the result, no peculiar seismic ground motion was observed in the designated observing points to observe aftershocks, and it was confirmed that there was no problem to study seismic ground motion, as the vicinity of the accident site was not a peculiar point.

(2) Vehicle running simulation

(a) Estimation of waveforms of seismic ground motion

At first, the waveforms of acceleration at the bedrock just below the observing point was estimated based on the waveforms of acceleration of seismic ground motion observed on the ground surface. Then the waveforms of the seismic ground motion on the ground surface at around the accident site was estimated by assuming that the same seismic ground motion had propagated to the bedrock right under the accident site, and propagated to the ground surface around the accident site.

The reference seismic ground motion[*13] was selected by using the recorded data in the Shin-Nagaoka auxiliary sectioning post of the Company, nearest to the accident site where the existing seismograph had been installed, and the soil investigation to the depth of about 70 m had been implemented. The reference seismic ground motion was shown in Figure 5. Here, the component in east and west direction, *i.e.*, the lateral direction for the running train, and the vertical components of the seismic ground motion were studied, because the track at around the accident site was nearly in north and south direction, and the component of the seismic ground motion in the direction of the running train was considered as affect little to the derailment.

The seismic ground motion in the surface layer of the ground was estimated by assuming the layer, where the velocity of the shearing elastic wave was about 700 m/s, as the bedrock, to remove effects of the non-uniform propagation pattern of the seismic ground motion caused by the complex geology in around the surface layer of the ground, in general. The estimated waveforms of acceleration in the bedrock were shown in Figure 7-II (b). Here, the waveform of acceleration at the bedrock at around just below the accident site was estimated considering damping and variation due to the different distances from the hypocenter to the accident site and the designated observing points.

There is the sandstone layer considered as the bedrock in the depth of about 70 m from the ground surface, and the relatively hard layer composed of the mudstone etc., existed in the shallower layer, and the gravel and sand diluvium had existed in its upper layer in around the accident site. Above this gravel and sand layer, there exist the alluvium in which clay, sand, gravel and sand layers are alternately piled in complex, but the gravel and sand layer was dominant in the direction of the start point of the train, and the clay layer was dominant in the direction of the terminal of the train.

The analytical model of the surface ground was modeled by the two dimensional finite element method, FEM, for about 800 m long section from Takiya tunnel to Tokamachi viaduct around the accident site. The ground structure and the nonlinear characteristics in the modeled section were surveyed, by the soil investigation implemented in 8 points after the earthquake.

The ground structure around the accident site was modeled as shown in Figure 7-III, based on the results of the soil investigations implemented after the earthquake and prior to the construction. The model was basically composed of square mesh elements of 2 m side length, and the number of the total elements was about 9000.

The measured values were used for the density of the soil and the velocity of shearing elastic wave. Here, the average velocity of shearing elastic wave was used for a continuous stratum.

As for the relationships between stress and distortion of soil, the accurate analysis could be performed because the used model completely satisfied the dynamic distortion characteristics obtained from the element test of the soil in the range from small to large distortion.

The waveform of the seismic ground motion on the ground surface in the section described in the above paragraph, was estimated by the calculation using the seismic ground motion of the bedrock as the input waveform to the analytical model. The maximum acceleration of the ground surface was shown in Figure 7-III. The maximum acceleration observed in the ground surface in around Tokamahi viaduct R3 was about 390 gal. In the result of the simulation, the local amplification of the seismic ground motion on the ground where the bedrock is leaned, was not identified. The estimated waveform of acceleration on the ground surface in Tokamachi viaduct R3 was shown in Figure 7-II (b), as an example.

Here, the calculated results for the aftershocks using the analytical model well agreed with the observed results of the aftershocks described in (1).

*13 *"Reference seismic ground motion" in this context is the seismic ground motion recorded in the practical observation on the ground surface, and used as the reference in the following simulation.*

(b) Response analysis of the structures

The response analysis of the structures was implemented for the structure from Watarisawa Kita viaduct to Tokamachi viaduct, where considered as necessary to analyze the mechanism of the derailment. The foundations of Watarisawa Kita viaduct and Tokamachi viaduct were consisted of the RC[*14] pile foundations, and length of the piles varied from 7 to 14 m according to the geological condition, and the support layer was the gravel and sand layer, etc., of alluvium and diluvium. The foundations of Jodogawa bridge and a part of Tokamachi viaduct were the spread foundation.

The track structures in the analyzing section were all viaducts structures. Tokamachi viaduct was composed of rigid frame bridges and girder bridges partly supported by the wall type piers. Takizawa-Kita viaduct and Jodogawa bridge were composed of girder bridges supported by the wall type piers, and their upper structures were composed of the simple T-shaped girders of around 10 m span and the trough PC[*15] girder types of 30 m span, etc. The maximum heights of piers were less than 15 m.

The load vs. displacement characteristics of the structure was estimated by the nonlinear static analysis of the structures in the orthogonal direction to the track, *i.e.*, lateral direction. The analysis was implemented in accordance with the Design Standards and Comments of Railway Structures etc., Seismic Design[*16].

In the dynamic analysis, the structures were replaced to one degree of freedom, DoF, system composed of the equivalent spring and mass, and the response waveforms of seismic ground motion on the top of the structure, *i.e.*, the track surface, when the structures were acted by the seismic ground motion waveforms at the ground surface estimated in the previous paragraph (a), was calculated. Here, the characteristics of the equivalent spring was determined based on the load vs. displacement curve estimated by the nonlinear static analysis.

The supposed waveform of the acceleration at the top of the structures, *i.e.*, the track surface, estimated by input the supposed waveforms of the acceleration on the ground surface to Tokamachi viaduct R3, was shown in Figure 7-II (b).

According to the relationships between history of responses and results of nonlinear static analysis, the responses in all the structures were in the elasticity area containing a little plasticity, which had accorded with the visual inspection in around the accident site that there was no remarkable damage in the structures.

As there were plural different type structures in around the accident site, the behaviors of the whole structures should be estimated to proper evaluation of the behaviors of the vehicles running on the structures. Then the effects of the dynamic angular rotation in horizontal direction was considered by assuming the buffer section considering the rigidity of rails and the elasticity of the rail fasteners were properly in the boundary portions as the response characteristics against seismic ground motion were different in individual structures.

*14 *"RC" is the abbreviation of "Reinforced Concrete".*

*15 *"PC" is the abbreviation of "Prestressed Concrete".*

*16 *RTRI, "Design Standards and Comments of Railway Structures etc., Seismic Design", Maruzen, 1999, in Japanese.*

(c) Behavior analysis of the vehicle

The vehicle dynamics simulation program[*17] can be used for large displacement of the individual components of the vehicle, then the phenomena such as the wheels leaving from the rail could also be simulated. The dependence on the vehicle velocity of the simulated results was shown as small in the analysis. In addition, the program had been verified its accuracy of the simulated results by the vibrating tests using the commercial bogie[*18].

A Shinkansen electric vehicle equipped with the direct mounted[*19] bogies with bolster used in the accident train was modeled with the 70 DoFs, *i.e.*, 6 DoFs each for a vehicle body, two bolsters, two bogie frames and four wheelsets, and 2 DoFs each for the eight rails just under the wheels, total 70 DoFs for 17 objects. Here, connecting elements between objects were laid out consistent with the bogie bolsters, the side bearings, the various stoppers, etc., as same as in the practical vehicle in the modelling. The modelled vehicle was the front vehicle and the intermediate vehicle of the 200 series Shinkansen electric vehicles in empty condition, and the simulation was implemented for one vehicle train set, considering that the effects from the neighboring vehicles in the trainset would be small in the simulation until to the derailment.

The input waveforms of the displacement to the vehicle model were calculated by integrating the acceleration waveforms on the track surface of the structure due to the seismic wave of the Niigata Prefecture Chuetsu Earthquake estimated in the previous paragraph (b). Here, the seismic ground motion acting on the wheels were input for the two directions, *i.e.*, lateral and vertical directions, and for the four axles in the same phase and independently. The same phase vibrations were input to the four axles to implement simulation for the single structure, and the vibrations different for each axle were input independently to implement simulation considering dynamic angular rotation while vehicle were passing though the continuing different structures.

As an example, the waveforms of the estimated absolute displacement in the lateral direction used in the simulation for Tokamachi viaduct R3, were shown in Figure 7-II (c). The behavior of axles passing through the top of the structures were estimated to change the deformation of the structure and the position of the axle every moment.

The front vehicle and the immediate vehicle showed the same behaviors in the simulation for the single structure in case of the seismic ground motion had occurred when the vehicle was running at 204 km/h in the straight track section without track irregularity. The raised height of wheels and the relative lateral displacements between wheel and rail of all the wheels in the intermediate vehicle estimated by the simulation considering the dynamic angular rotation when the vehicle passed though the track composed of the continuing structures, are shown in Figure 7-V and 7-VI. The status of the derailment was determined when the relative displacement in lateral direction between wheel and rail had exceeded 70 mm, according to the derailed status defined in "Design Standards and Comments of Railway Structures etc., Seismic Design". Here, simulation was stopped when one of the wheels became to the derailed status.

The simulation showed that all the wheels were raised up and the maximum raised height of wheel was about 34 mm, exceeded height of tire flange, *i.e.*, 30 mm. The simulation also showed that the wheel became to the derailed status, *i.e.*, the relative lateral displacement of wheel against rail exceeded 70 mm, because the axle moved to lateral direction by the changed direction of the track vibration while the one side wheel had been raised up over the height of tire flange.

*17 *T. Miyamoto, et al., "Behavior analyses of railway vehicles during earthquake", Transactions of the Japan Society of Mechanical Engineers, Ser.C, Vol.64, No.626, pp.236-243, Oct. 1998, in Japanese.*

*18 *T. Miyamoto, et al., "Vibrating test of the commercial scale railway vehicles by large displacement track vibration", Transactions of the Japan Society of Mechanical Engineers, Ser.C, Vol.71, No.706, pp.1849-1855, June 2005, in Japanese.*

*19 *"Direct mounted type" indicates the type of damper spring between vehicle body and bogie frame which the secondary suspension was equipped just under the vehicle body and laid out bolster beams, center pivots, side bearings, etc., beneath the secondary suspension.*

2.14. Information on the Status of Passengers, etc., in the Accident

The status of passengers etc., in the accident were shown in Table 7.

Table 7. Status of Passengers etc., in the Accident

Boarded vehicle		Status when the accident occurred	Status just after the accident
5th vehicle	Passenger B	I felt impact to heave upward and knocked forward and violent swaying.	I held chair back and armrest of the front seat and endured until the train stopped in the posture to twist my body.
6th vehicle	Cabin attendant	I was knocked and fell. The sales wagon turned over.	I stood up and rearranged goods in the sales wagon but fell again by the aftershock.
8th vehicle	Passenger C	While writing manuscripts, I felt rattling and immediately understood earthquake had occurred. But I did not feel shock such as heaving upward.	I put my bag on the overhead rack, put back table, and held chair back of the front seat. But I did not feel my body heaved or knocked while shaking by earthquake and rattling by the derailment.
	Passenger D	When the train approached to Nagaoka station, I felt sudden jolts, swayed violently as if I was caught and shook violently in the crowd.	I endured until the train stopped, keeping posture to hold chair back of the front seat with both hands and lowered my head.
9th vehicle	Passenger A	While seated and sleeping, I felt violent impact from downward.	I was thrown out of my seat and supported my body with hands against floor.
	Passenger E	Vehicle was running being make noise and swaying, but I could not understand what happened.	I held chair back of the front seat tightly.
	Passenger F	When the train went out of tunnel and outside of windows were lightened, I felt impact heaving from bottom of seat once and as if my body was levitated.	I felt that the vehicle was running straight for a few seconds, afterwards shaking in vertically and laterally, and felt as if my body was jumping.
	Staff of the Company	I felt that I was raised up by vertical impact with sound as banged, to the height that my hip was higher than armrest and hit lower back against something.	I thought that the train had derailed as I heard abnormal sound while running, and I laid down on the seat.

3. ANALYSIS

3.1. Analysis on the Vehicles

It is highly probable that there was no abnormal situation in the vehicles before the occurrence of the accident, according to the statements of the driver and the conductor described in 2.1.1, and the records of inspections described in 2.6.2.

3.2. Analysis on Damages in the Railway Facilities by the Niigata Prefecture Chuetsu Earthquake

It is highly probable that there was no damage in the railway facilities before the occurrence of the Niigata Prefecture Chuetsu Earthquake because there was no abnormal situation in the records of the latest inspection as described in 2.5.2, and the foregoing train ran in the down track about 10 minutes before the accident, and the opposite train ran in the up track in around the accident site about 9 minutes before the accident, respectively, without any abnormal situation as described in 2.7.

In addition, it is probable that there was no damage as caused the derailment in the down track in around the accident site before the accident train had running in around the accident site even after the occurrence of the Niigata Prefecture Chuetsu Earthquake, because there was no damage to cause the derailment in the track of the neighboring up track, and there was no remarkable damage in the bridges in around the accident site, as described in 2.3.1 (1) to (3).

Here, it is probable that the lean of poles etc., were caused by the seismic ground motion.

3.3. Analysis on the Process from the Occurrence of the Niigata Prefecture Chuetsu Earthquake to the Derailment

3.3.1. Analysis on the Position of the Accident Train when Power Feeding had Stopped

According to the data recorded in the ATC recording device, the electricity had stopped at 17:56:03.2 and the brake command was issued at 17:56:04.7, respectively, as described in 2.6.3.

It is probable that the position of the front head of the accident train was at around 206,050 m to 206,067 m when the power feeding had stopped, and at around 206,134 m to 206,151 m when the brake command was issued, respectively, by the rough calculation considering that the running velocity was 204 km/h and the data were recorded every 0.3 second.

3.3.2. Analysis on the Position of the Accident Train at the Estimated Arrival Time of the Seismic Ground Motion in around the Accident Site

The estimated arrival times of the seismic ground motion at around 206,000 m in the accident site, were 17:56:02.87 ±0.20 sec for the P-wave and 17:56:05.03 ±0.28 sec for the S-wave, as described in 2.9.1.

Then the positions of the front head of the accident train at these times were estimated as at around 206,037 to 206,059 m and at around 206,154 m to 206,186 m, when the P-wave and S-wave were supposed to arrive at around 206,000 m, respectively, by the calculation based on the information about position and velocity obtained from the data recorded just before these supposed arrival times in the ATC recording device.

3.3.3 Analysis on the Gauge Widening

It is probable that the gauge widening beyond about 205,960 m, described in 2.3.1(1), was caused by the train running as its wheels had been pushing rails due to the laterally swaying motion of the track, as the accident train had received the seismic ground motion by the Niigata Prefecture Chuetsu Earthquake, in the down track beyond around 205,960 m, based on the analysis on the estimated arrival times of the seismic waves described in 3.3.2, and there was no gauge widening in the up track and in the origin side track of the down track.

3.3.4. Analysis on the Process of the Derailment

As the plural axles were derailed in the accident as described in 2.10.1, it is highly probable that the 1st axle in the front bogie of the 1st vehicle had derailed to left at first at around 206,227 m, considering the following analysis.

(1) It is highly probable that the linear traces on the rail surface of the left rail in around 206,217 m to 206,227 m described in 2.10.2(1), was caused by the wheel flange considering their shapes.

(2) The broken rail fastening devices of left rail described in 2.3.1(1), following the traces described in (1), had been continued to around the position where the 1st axle in the front bogie of the 1st vehicle had stopped.

(3) There were traces in the brushing rubber of the auxiliary life guard considered as caused by rail as described in 2.3.2(1), 2.6.1, 2.10.2(1) and 2.13.1, and the distance from the end point of the trace on the rail surface of the left rail in around 206,227 m, to the start point of the residual substances in around 206,232 m, was consistent with the distance from the left wheel of the 1st axle in the front bogie to the brushing rubber of the auxiliary life guard in the 1rst vehicle, and the residual substances were estimated as the brushing rubber of the life guard.

(4) It is probable that the residual substances were adhered because the brushing rubber of the auxiliary life guard came into contact with the rail surface of the left rail when the front bogie of the 1st vehicle derailed to left, based on the description in (3).

(5) When the 1st axle in the front bogie of the 1st vehicle was in around 206,227 m, the 2nd axle in the rear bogie of the 3rd vehicle should be in about 70 m behind it, *i.e.*, in around 206,157 m. However, it is probable that the 2nd axle in the rear bogie of the 3rd vehicle ran to around 206,207 m and derailed to right, as described in the following paragraph.

On the other hand, it is probable that the 2nd axle in the rear bogie of the 3rd vehicle derailed to right at around 206,207 m, because the traces on the rail surface of the right rail continued to right bottom of the right rail in around 206,207 m, and the broken rail fastening devices for right rail had existed continuously from that point to the position where the 2nd axle in the rear bogie of the 3rd vehicle had stopped.

However, it is probable that the damages were not enlarged as the derailed accident train did not deviate largely from rails, because it is probable that these axles ran being in contact with rail after derailed as described in the following paragraph 3.4, and considering the status of the stopped train described in 2.10.1(1), (3). It is somewhat likely that the fact that all the vehicles kept being coupled each other was also related to prevent enlargement of the damages.

Therefore, the measures from the view points of the railway facilities and the vehicles are effective to prevent enlargement of damages by the large deviation of the vehicles from rail, even when the train derails.

It was shown that the vehicle became to the derailed status, *i.e.*, the wheel flange raised up over the flange height 30 mm, and the relative lateral displacement of wheel against rail became to over the standard value, 70 mm, due to the seismic ground motion, in the vehicle running analysis descried in 2.13.3(2).

When the north bound train, just as the accident train, received huge seismic ground motion as in the Niigata Prefecture Chuetsu Earthquake having large shaking component in east and west direction, it is somewhat likely that a vehicle derailed by the rocking derailment, *i.e.*, axles jolted violently in vertical and lateral direction, then the wheels in one side were raised up from rail surface while the other side wheels had been in contact with rail, and the wheels being in contact with rail slipped on the rail surface and the axle moved to lateral direction keeping its posture, then the falling wheel flange of the other side of the axle fell on the rail surface and went out of rail.

It is highly probable that the accident train derailed due to receiving the large seismic ground motion, because the position of the running train when the seismic ground motion had arrived at around the accident site described in 3.3.2, and the position of the traces in around 206,227 m, was close with each other.

Here, it is probable that the discrete traces in seven points on rail surface of left rail described in 2.10.2(1), were caused by the derailment due to the seismic ground motion.

It is probable that the 10th vehicle derailed before around 206,828 m and leaned towards right because the right wheels dropped from the slab track of the down track, then the vehicle body came to contact with the slab track in the up track, based on the damages in the vehicle body and the traces on the slab track in the up track described in 2.3.2(10) and 2.10.2(4).

3.4. Analysis on Damages of the Tracks

It is probable that the 1st axle in the front bogie of the 1st vehicle and the 2nd axle in the rear bogie of the 3rd vehicle ran being in contact with rails as destructing rail fastening devices of mainly left rail and right rail, respectively, after derailed, then broke the glued insulated joint bars, fish bolts and nuts, etc., of the glued insulated joint rail in the insulated joint in around 206,696 m, based on the damages of the track and the position of wheels of the stopped accident train described in 2.3.1(1), 2.10.1(1) and (3). In addition, it is probable that the wheels derailed afterwards, ran as destructing rail fastening devices, etc., and scattering fragments around them, according to their positions.

Furthermore, it is probable that the rails were moved by the weights of the following vehicles after the fastening forces of the rails were reduced by the destruction of rail fastening devices. In addition, it is probable that the rails were displaced largely as dropped into the channel for the evacuation of melting snow between up and down tracks, because the glued insulated rails were separated with each other as the glued joint bars were removed and came off from the slab track in around the rail joint.

Therefore, it is expected to research on the measures to prevent break or overturn of rails, to study about measures against destructions of rail fastening devices and rail joints by the derailed wheels.

Here, it is somewhat likely that the right glued insulated rails were separated and broken at least after the 1st axle in the rear bogie of the 6th vehicle had passed, and the left glued insulated rails were separated and broken at least after the 1st axle in the rear bogie of the 7th vehicle had passed, because the right wheel of the 1st axle in the rear bogie of the 6th vehicle and the left wheel of the 1st axle in the rear bogie of the 7th vehicle had not derailed when the accident train had stopped as described in 2.10.1(6) and (7).

3.5. Analysis on the Damages of the Vehicles

3.5.1. Analysis on the Damages of the Wheels

It is probable that the wear of the wheel flange described in 2.3.2(1), (6) and (9), was caused by the wheels running in the locked status by the emergency brake as being in contact with the surface of the slab track, because there were many traces considered as caused by the wheels on the surface of slab track in the down track, these wheels were derailed on the surface of the slab track when the train had stopped as described in 2.10.2(2), and it is highly probable that the emergency brake had acted based on the statements of the driver, etc., and the descriptions in 2.6.3.

It is probable that the hit traces on the wheel treads described in 2.3.2(1), were caused by hitting the glued joint bars, because there were hit traces considered as caused by wheels in the broken glued joint bars, and the wheels were in the position to hit glued joint bars when the derailed wheels ran being in contact with rail, as described in 2.3.1(1) and 3.4.

On the other hands, it is somewhat likely that the hit traces in the wheel tread described in 2.3.2(10), were caused by trampling the displaced rail due to the broken rail fastening devices, because there were hit traces in the side surface of rail bottom as described in 2.3.1(1) and 3.4.

3.5.2. Analysis on the Damages of Bottom of the Vehicles

It is probable that the linear damages in the bottom of the 7th and the rear vehicles described in 2.3.2 (7) to (10), were caused as the derailed vehicles ran in the status that the bottom of them had been running being in contact with rail, considering their shapes and that these derailed vehicles had not deviated from the track when the train had stopped as described in 3.3.4. In addition, it is somewhat likely that the cover boards of the 10th vehicle fell away because the broken fastening bolts, etc. had hit them.

3.5.3. Analysis on the Damages of the Life Guard

It is probable that the main life guard in the 1st vehicle wore down and damaged because it is probable that the 1st vehicle ran in the status that the main life guard and right wheel had sandwiched the rail, as described in 2.10.1 (1) and 3.4. It is probable that the auxiliary life guard was damaged by coming into contact with the rail surface, the fastening bolts, etc., because the front bogie of the 1st vehicle had derailed to left as described in 3.3.4. On the other hand, it is probable that the life guard in the 10th vehicle was damaged because the bottom of the vehicle had come into contact with the rail, as same as the damages of bottom of the vehicle body described in 3.5.2.

3.5.4. Analysis on the Damages of the Window Glasses

It is probable that the damages of the many window glasses described in 2.3.2, were caused as being hit by the broken fastening bolts, etc., because there were many fastening bolts etc., of the down track being broken and scattered, after the accident as described in 2.3.1(1).

3.5.5. Analysis on the Damages of the Roof-Top Equipments

It is probable that the damages of the roof-top equipments such as pantograph covers, etc., described in 2.3.2, were caused by hitting the hinged cantilevers, etc., because the poles were leaned due to the seismic ground motion as described in 2.3.1 (1) and 3.2.

3.6. Analysis on the Reasons why Damages were not Expanded Worse

It is probable that the accident train did not overturn nor deviate largely although eight vehicles in the ten vehicles train set were derailed as described in 2.10, because of the following situations.

(a) There was no remarkable damage in the railway structures.

(b) It is probable that the 1st axle in the front bogie ran as the left wheel and the gear case had sandwiched the left rail, and the right wheel and the fitting arm of the main life guard had sandwiched the right rail, in the 1st vehicle.

(c) It is probable that the 2nd axle in the rear bogie of the 3rd vehicle ran as the right wheel and the gear case had sandwiched the right rail.

(d) All the 10 vehicles kept being coupled.

(e) The 10th vehicle was derailed relatively largely but the vehicle body fell into the channel for the evacuation of melting snow between up and down tracks.

On the other hand, the vehicle body of the 10th vehicle leaned to right by about 30 degrees, and right side surface was in contact with slab track in the up track, then the vehicle body was in the position where the train collision might occur against the opposite train. However, there was no inbound train running in around the accident site at that moment, in addition, power feeding to the overhead contact line in the up track had stopped by the operation of the urgent earthquake detection system for Shinkansen.

It is probable that these situations prevented the enlargement of the damages.

3.7. Analysis on the Fears of Human Damages in the Passenger Rooms

The accident was the first accident never happened before in Japan that the Shinkansen train, running at about 200 km/h and boarded with total 154 persons consist of passengers and the train crews, derailed when the earthquake occurred. As there was no casualty in the accident, the fears of the human damages in the passengers were investigated in the followings.

It is probable that the behaviors of the vehicles were complex due to the large seismic ground motion in addition to the rapid deceleration of the accident train, based on the statements of the passengers, etc., the data recorded in the seismographs described in 2.9.2, the status of passengers, etc., at the time of the accident described in 2.14 and the traces due to the derailment, etc., described in 2.10.2.

The human damages by the secondary impact[*20] in the seated postures affect by the preparatory postures against impact, direction and magnitude of the acceleration or the deceleration, and the position and the shape of the impacted objects, etc. As there are many passengers seated facing the direction of train running in the Shinkansen train, it is anticipated that many injuries are caused by the collisions with the front seats, etc., when the seated passengers received the large impacts, etc.

Therefore, the relaxation, etc. of the impact forces should be considered for various facilities in the passenger room, as it is considered that there are the fears of the human damages by the secondary impacts, in the derailment accident such as the accident in question.

*20 *The impact directly acted to vehicle is called as the primary impact. The impact acted for passengers etc., being collided with the vehicle facilities caused by the primary impact is called as the secondary impact.*

4. PROBABLE CAUSES

It is highly probable that the train derailed in the accident because the wheel was raised up over the wheel flange height, and the relative lateral displacement of the wheels with respect to rail exceeded the limits value due to the large seismic ground motion, while the accident train was running in the track where there had been damage considered as to cause the derailment, before the accident train was running.

5. REMARKS

When the train encounters the huge earthquake in around its epicenter as in this accident, it is considered that the train derailment accident may occur, but it is difficult to prevent train derailment completely, in the present railway system.

To prevent the train derailment such as this accident, it should be considered to install the equipments or facilities in the vehicles or the railway facilities to prevent train derailment against large seismic ground motion as far as possible, comprehending as the problems for the whole railway system.

In addition, the measures form the view point of both the railway facilities and the vehicles should be promoted to prevent enlargement of damages by the large deviation of vehicles from the track, even if the train derailment could not be prevented.

Here, it is necessary to promote continuously the measures such as the earthquake resistant reinforcement, to prevent enlargement of damages for the train running in bridges, etc. when these structures are remarkably damaged by the earthquake.

6. REFERENTIAL MATTERS

6.1. Measures taken by the Company after the Accident

The Company implemented the various investigation of the railway structures, the decision of the earthquake resistant reinforcement programs and the acceleration of their implementation, studied the methods to stop trains earlier when an earthquake occurred, analyzed of the derailment phenomena and studied counter measures, etc., for the further reduction of the damages by the earthquake.

The Company has been implementing the following measures according to the results of discussions in the "Meeting for Measures against Derailment of Shinkansen", *hereinafter refferred to as "the Meeting"*, established by the Railway Bureau, the Ministry of Land, Infrastructure, Transport and Tourism, MLIT.

(1) Installation of the vehicle guide mechanism to prevent large deviation from rail for the vehicle after derailed.

(2) Improvement of rail fastening devices to prevent turn over and large lateral displacement of rails, so that rails can guide wheels even if the wheels are derailed and rail fastening devices are damaged.

(3) Improvement of the glued insulated joints to prevent destruction by the derailed wheels.

(4) Newly installation of the power failure detection devices in vehicles to shorten the time required to operate emergency brake.

6.2. Measures taken by the Ministry of Land, Infrastructure, Transport and Tourism, after the Accident

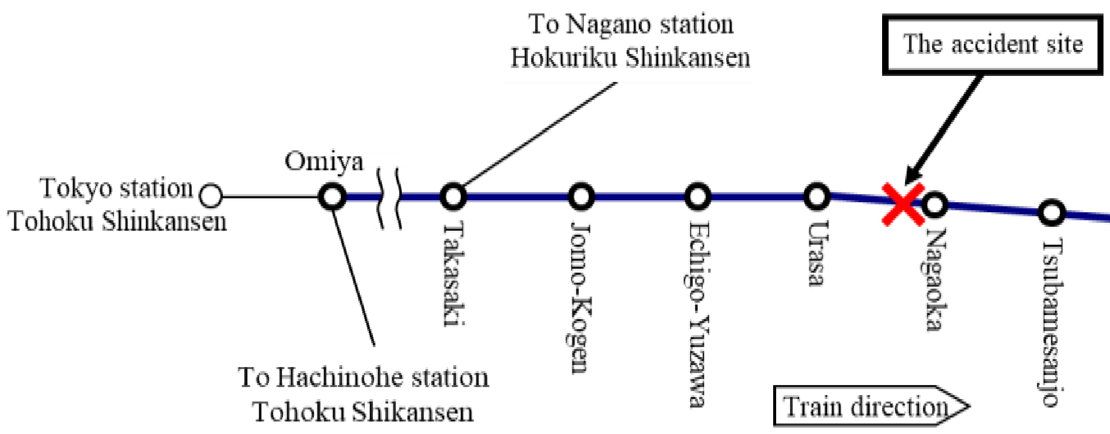
On October 25, 2004, the Railway Bureau of the MLIT established the Meeting, exchanged information on the accident and examined possibilities of the measures against derailment that could be implemented urgently in the railway facilities and in the vehicles.

On October 29, 2004, the Bureau directed the related railway operators to accelerate implementation of the earthquake resistant reinforcement program for the piers of viaducts in the Shinkansen, and to implement earthquake resistant reinforcement of the tunnels crossing the active faults, based on the status of the damages by the Niigata Prefecture Chuetsu Earthquake.

On March 30, 2005, the Meeting released the interim report on the measures against derailment in railway facilities and vehicles that could be urgently implemented, proposing the following measures, *i.e.*, (1) the earthquake resistant measures in railway facilities, (2) measures to prevent derailment, (3) measures to prevent deviation, etc.

Figure 1. Route Map of the Joetsu Shinkansen and Schematic Diagram around the Accident Site

Joetsu Shinkansen : From Omiya station to Niigata station, double track,
kilometer of construction was 269.5 km, railway business mile was 303.6 km.



Schematic Diagram around the Accident Site

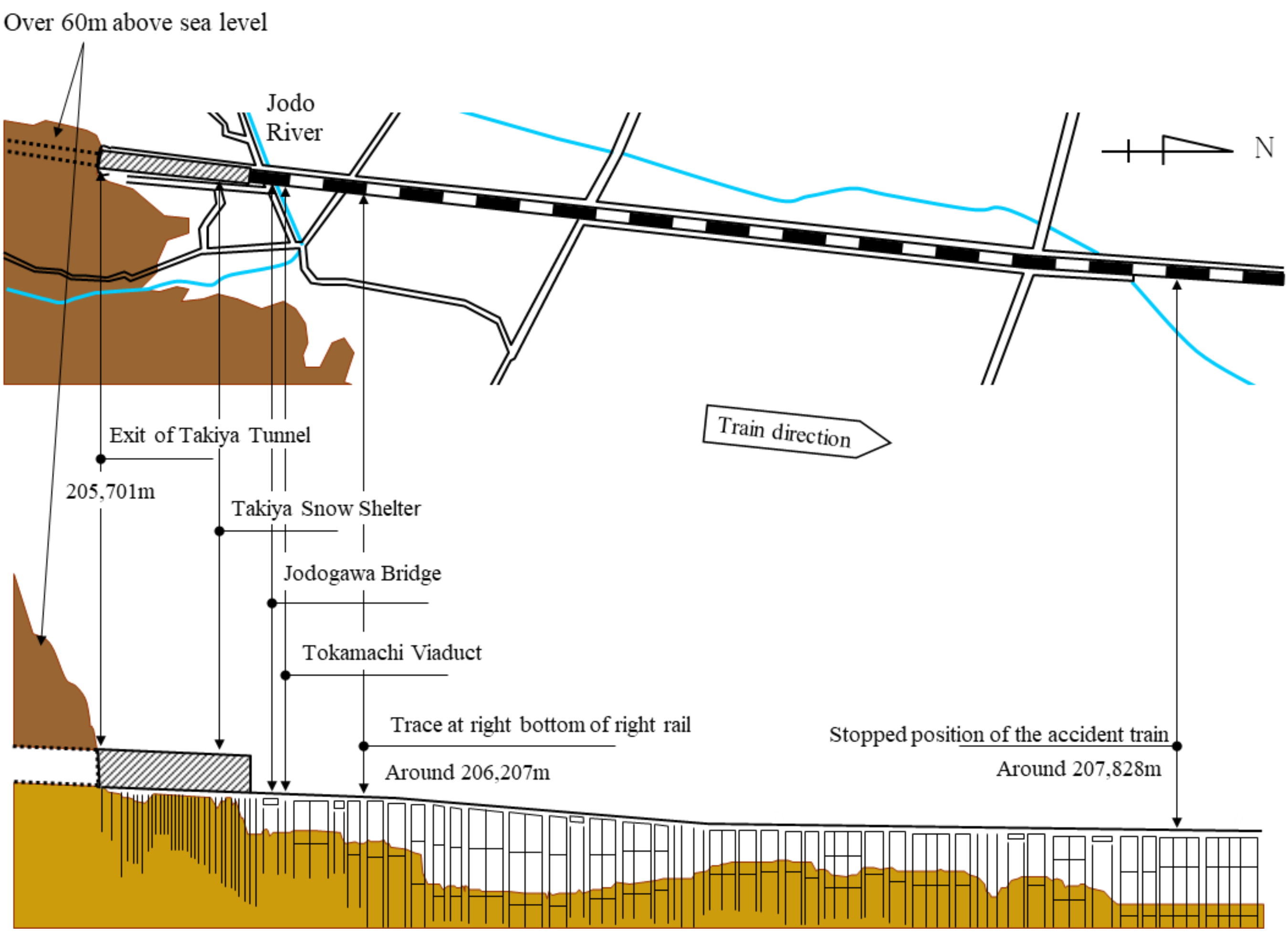


Figure 2. Status of Damages of the Tracks I (1/7)

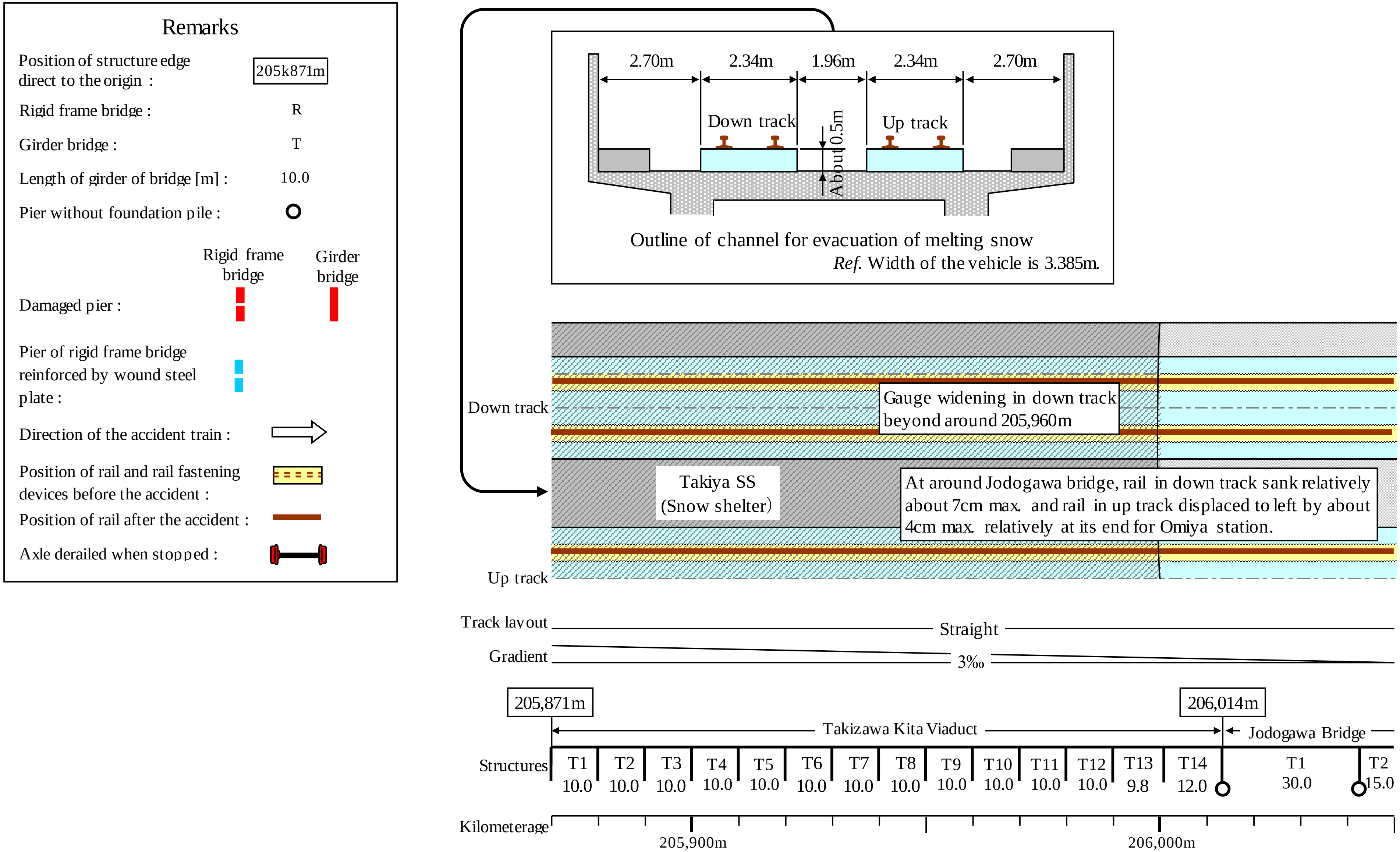


Figure 2. Status of Damages of the Tracks I (2/7)

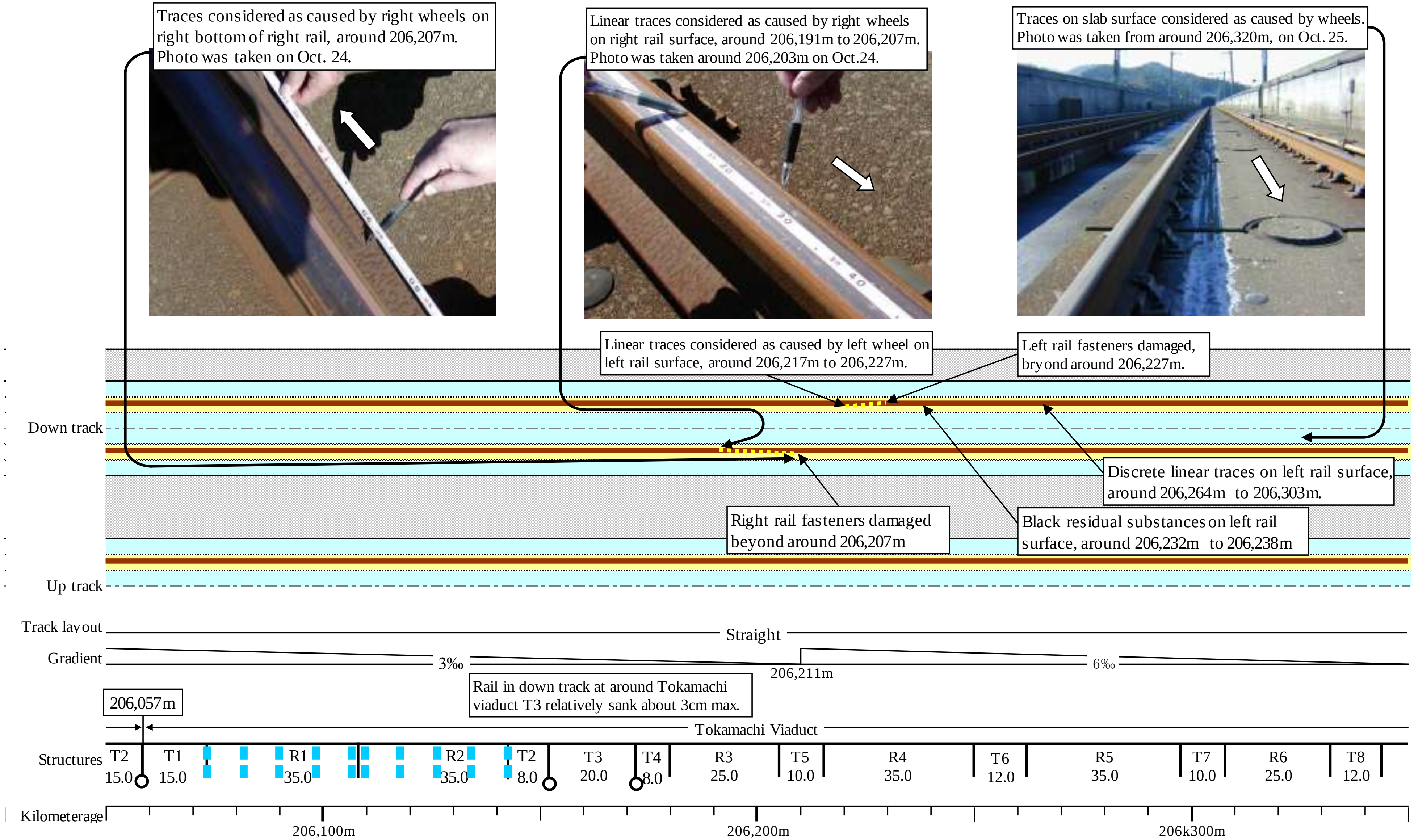


Figure 2. Status of Damages of the Tracks I (3/7)

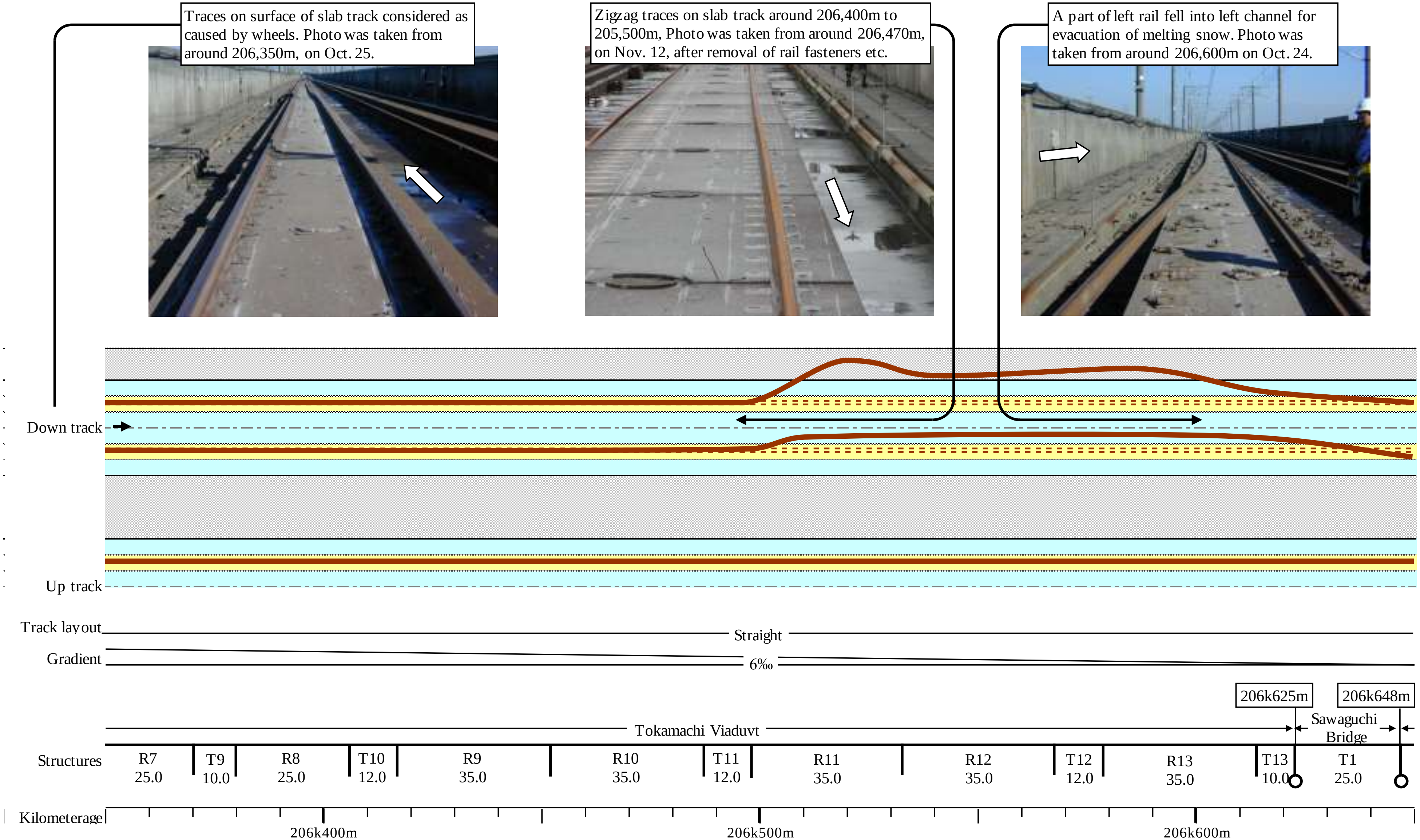


Figure 2. Status of Damages of the Tracks I (4/7)

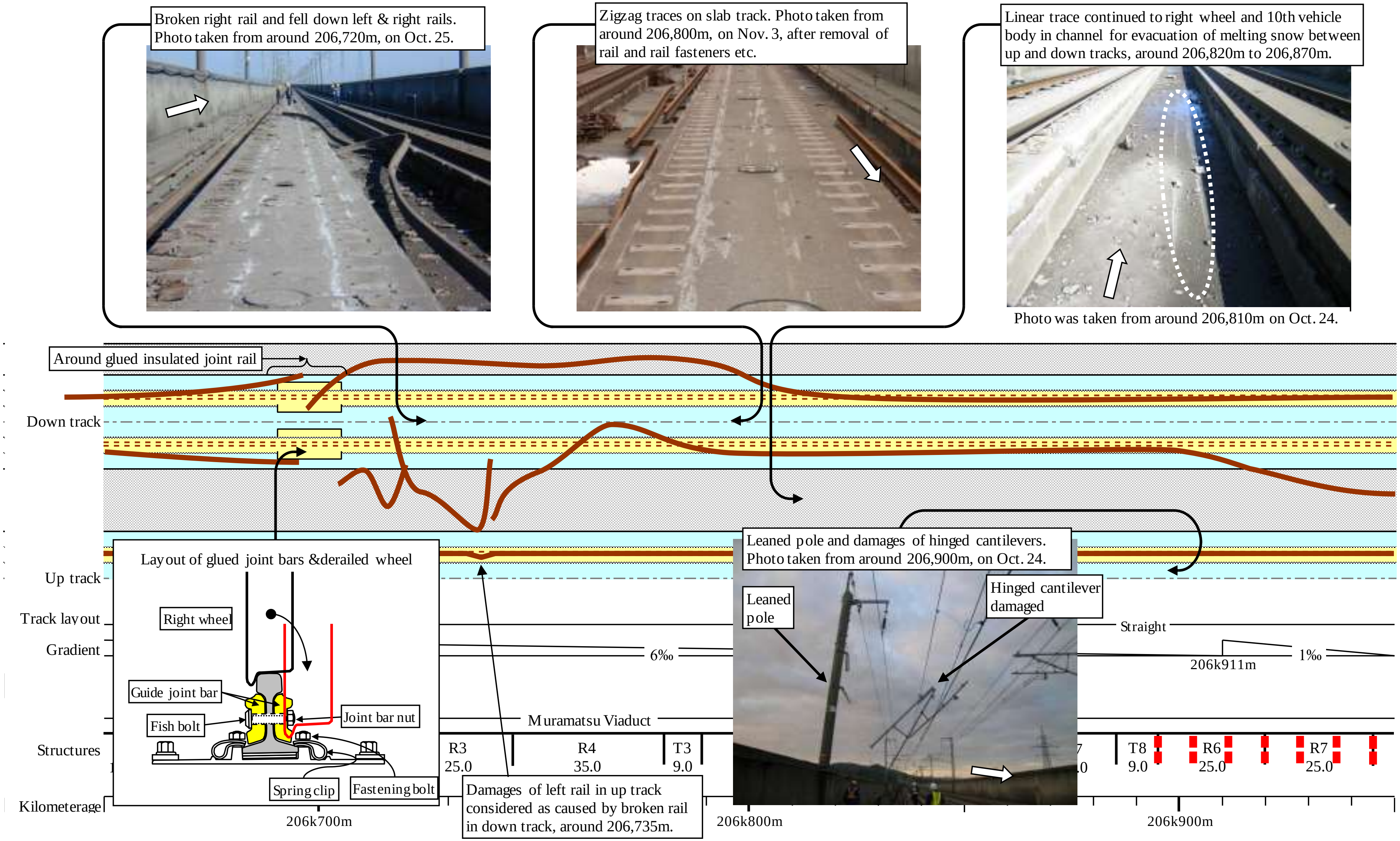


Figure 2.　Status of Damages of the Tracks I (5/7)

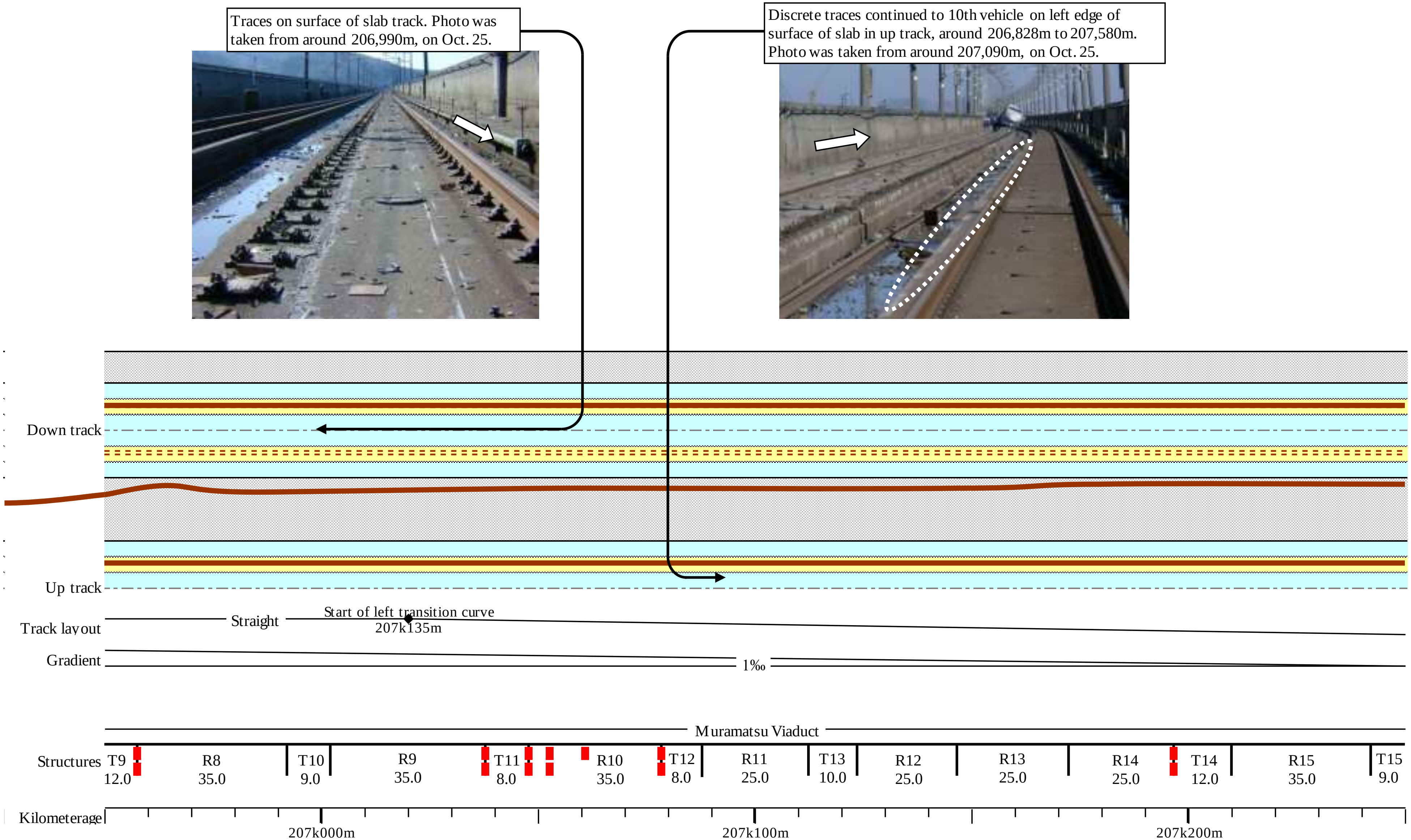


Figure 2. Status of Damages of the Tracks I (6/7)

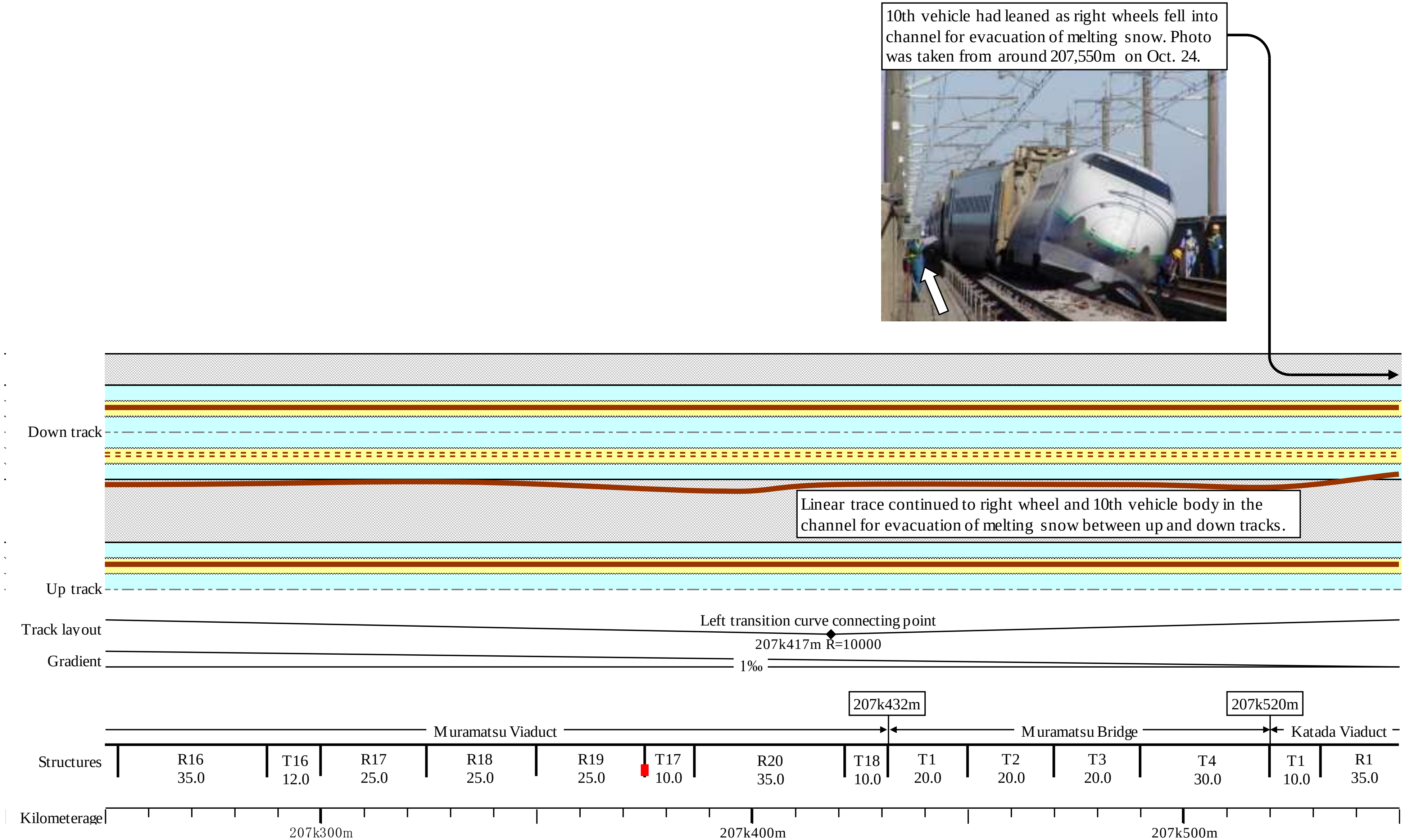


Figure 2. Status of Damages of the Tracks I (7/7)

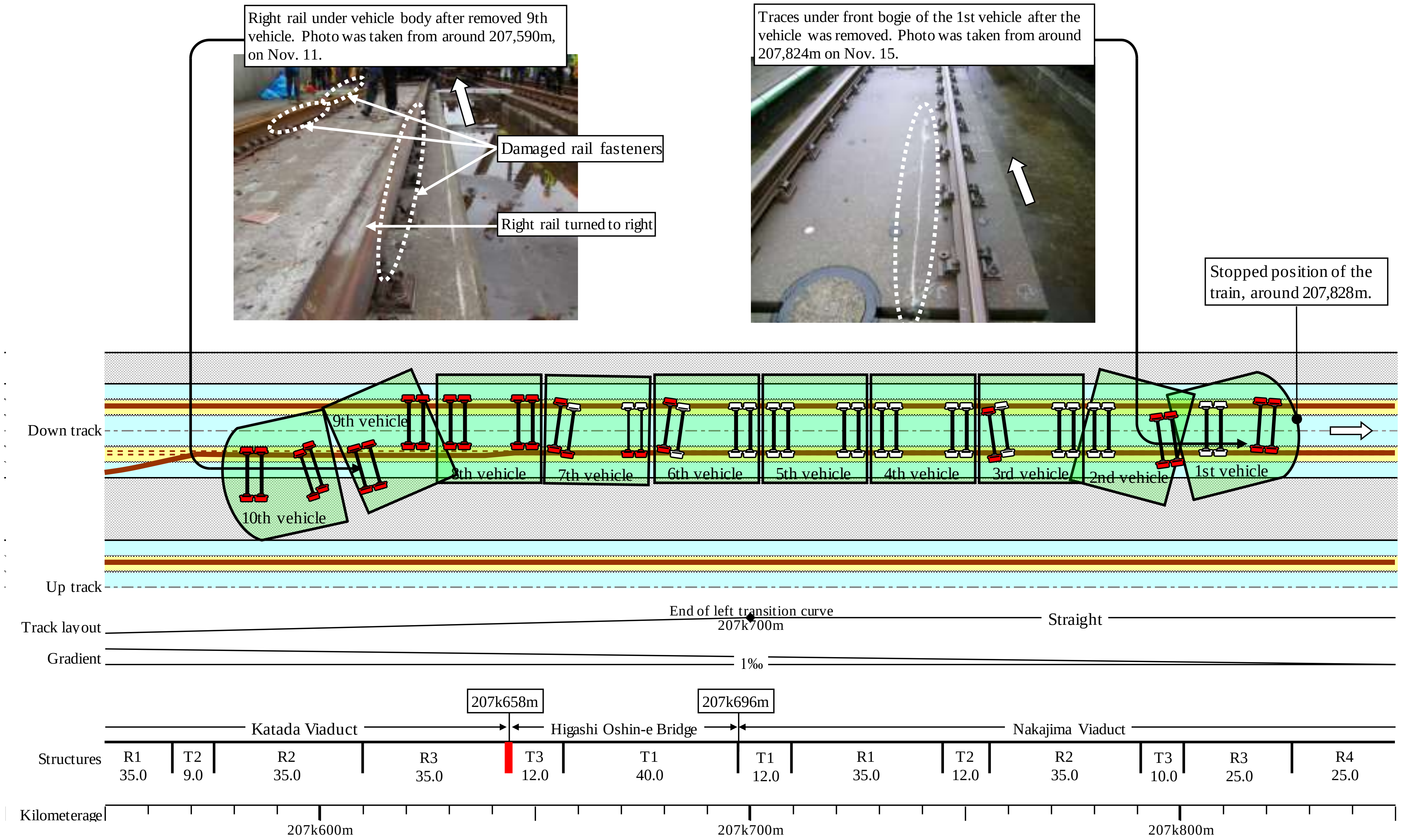
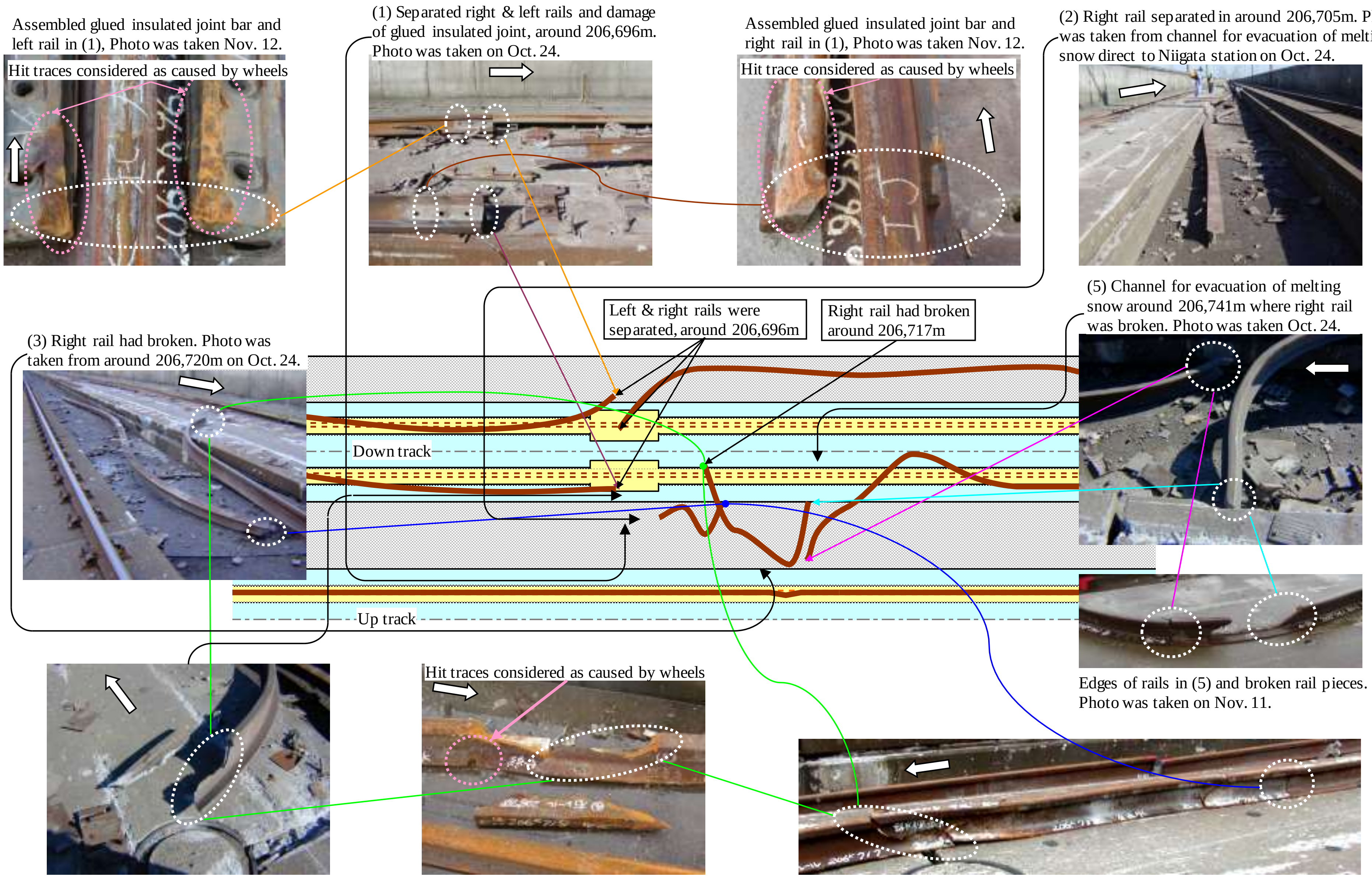


Figure 2. Status of Damages of the Tracks II (Around Glued-Insulated Joint Rail)



* Kilometerage of rail edge indicate position after separated and broken.

Figure 2. Status of Damages of the Tracks III (Status of the Track Irregularities)
Down track, measured on October 30, 2004.

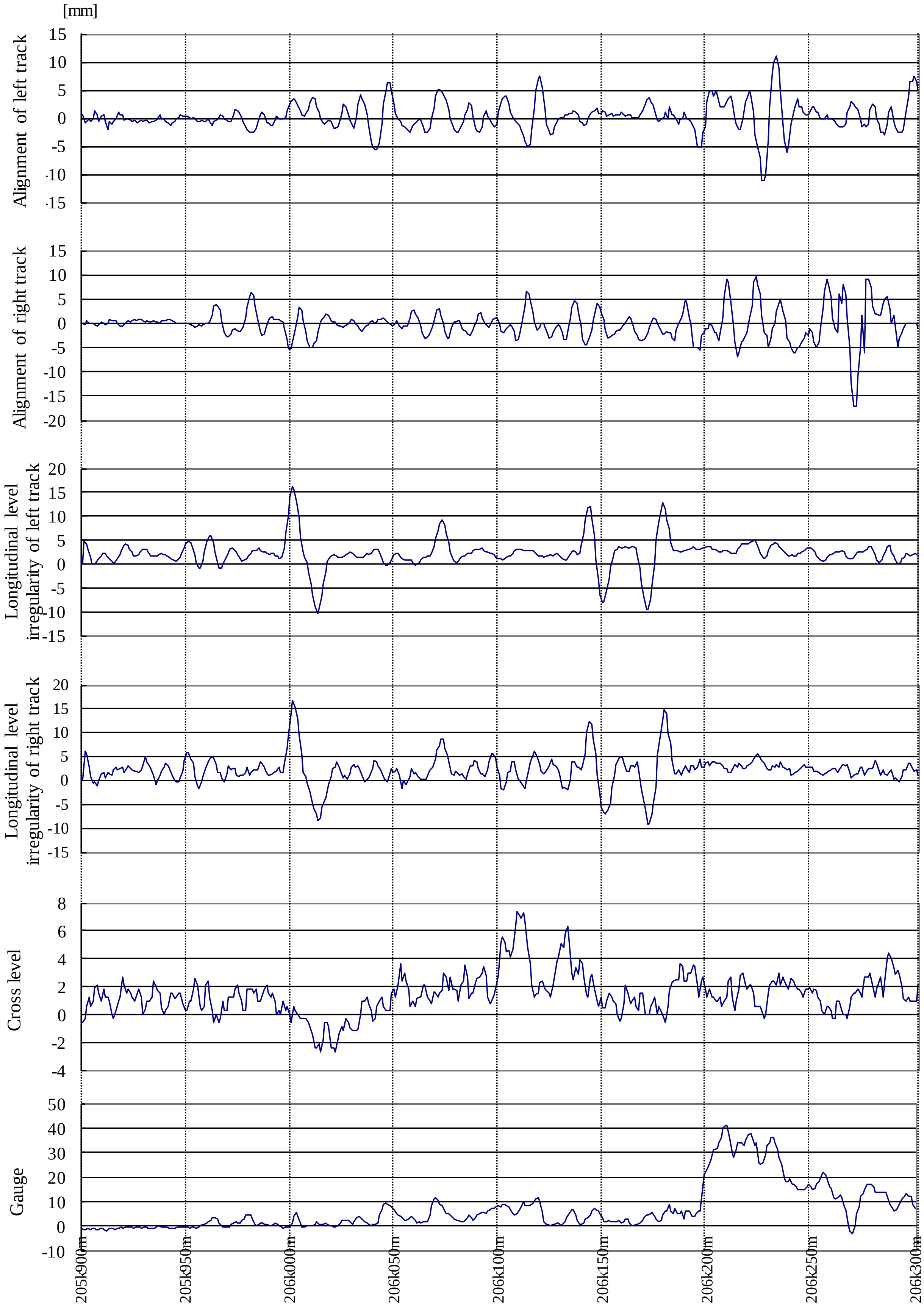
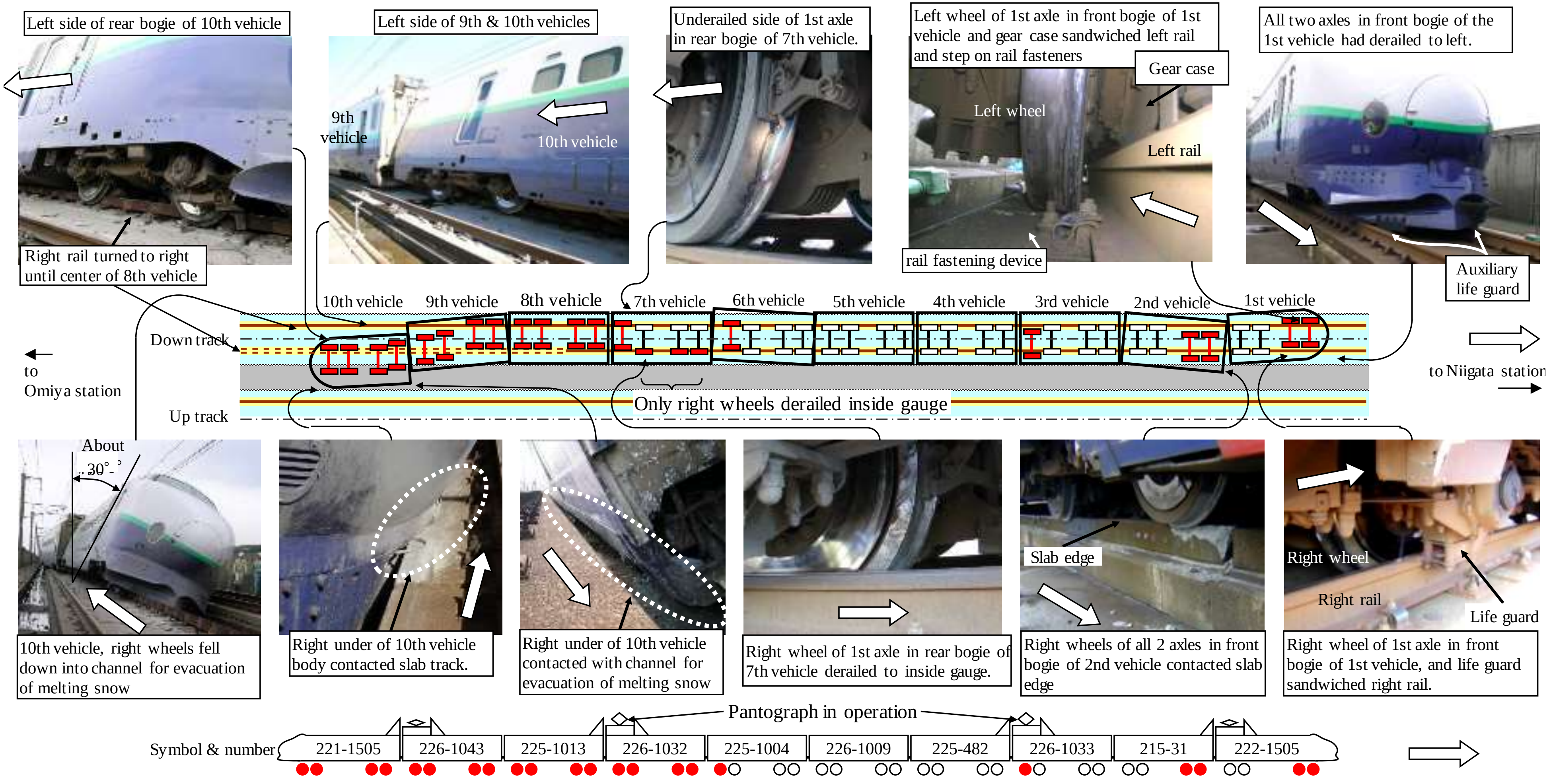


Figure 3. Status of the Derailment of the Vehicle



Derailed direction & deviation from rail [cm]

	221-1505	226-1043	225-1013	226-1032	225-1004	226-1009	225-482	226-1033	215-31	222-1505
Front bogie 1st axle	R 100	L 5	L 10	R *	—	—	—	—	R 50	L 20
Front bogie 2nd axle	R 140	L 5	L 10	R *	—	—	—	—	R 50	L 20
Rear bogie 1st axle	R 140	R 80	L 10	R *	—	—	—	—	—	—
Rear bogie 2nd axle	R 140	R 90	L 10	L 5	L 5	—	—	R 10	—	—

● : Derailed axle

* Only right wheel was derailed

⇨ : Train direction

Figure 4. Status of the Major Damages of the Vehicles I (The 1st Vehicle)

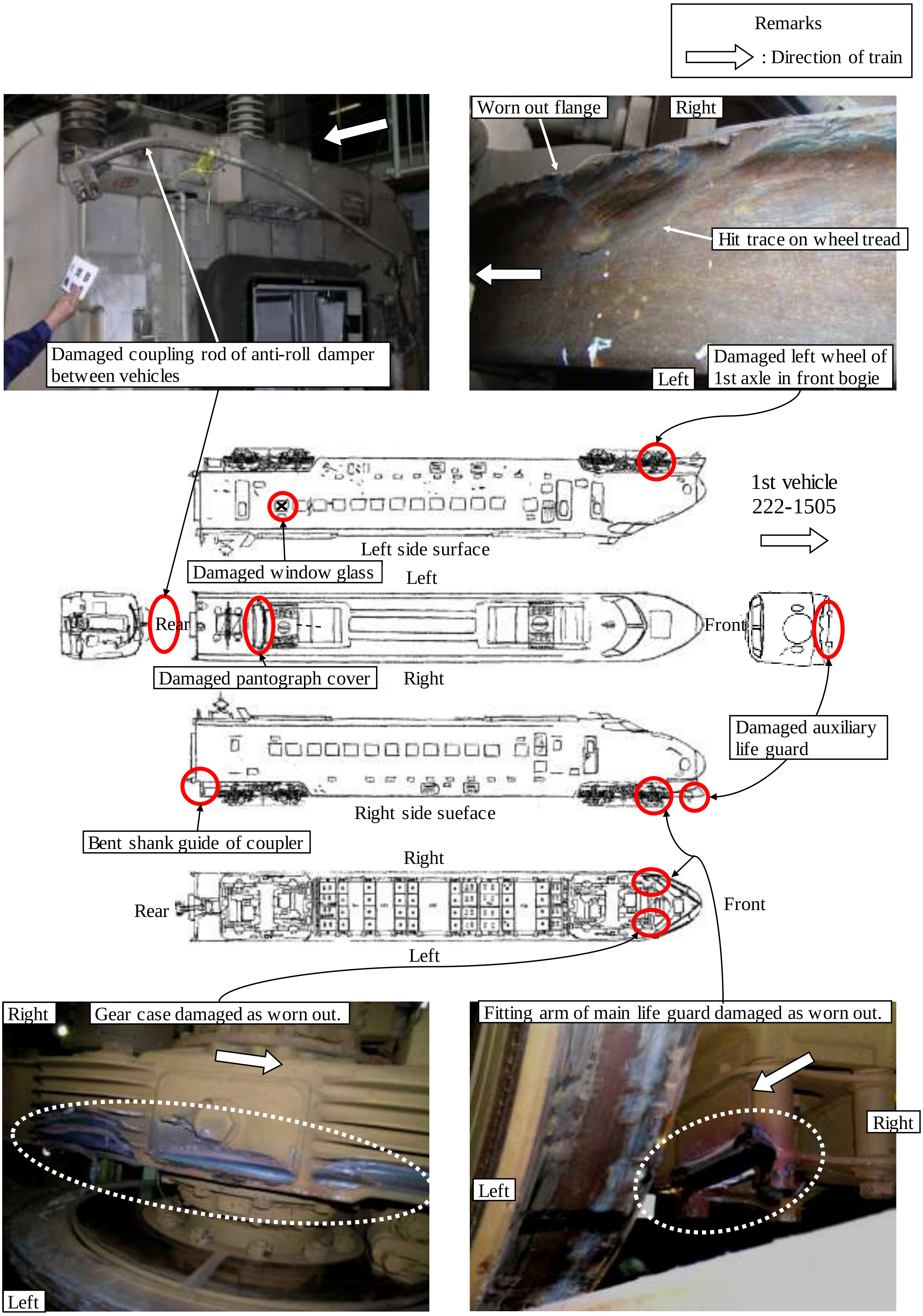


Figure 4. Status of the Major Damages of the Vehicles II (The 2nd Vehicle)

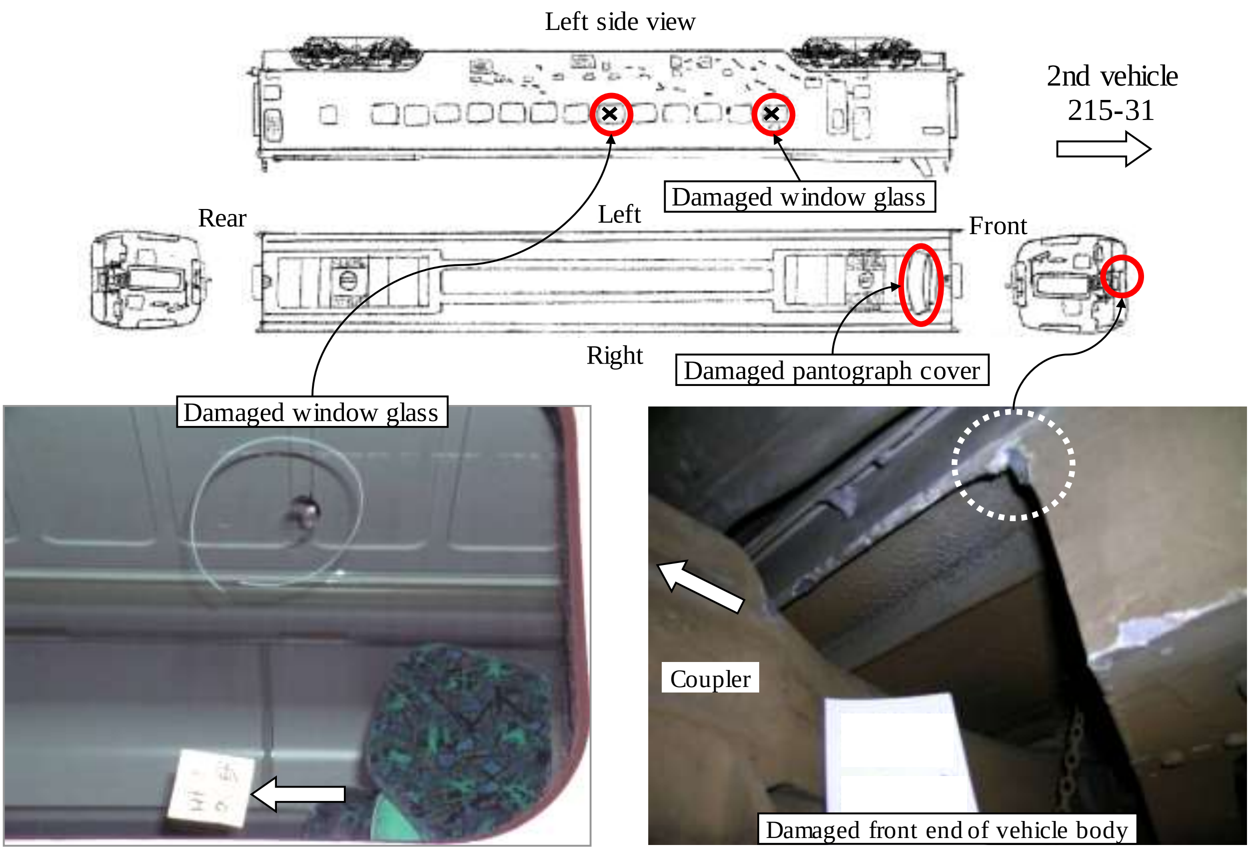


Figure 4. Status of the Major Damages of the Vehicles III (The 3rd Vehicle)

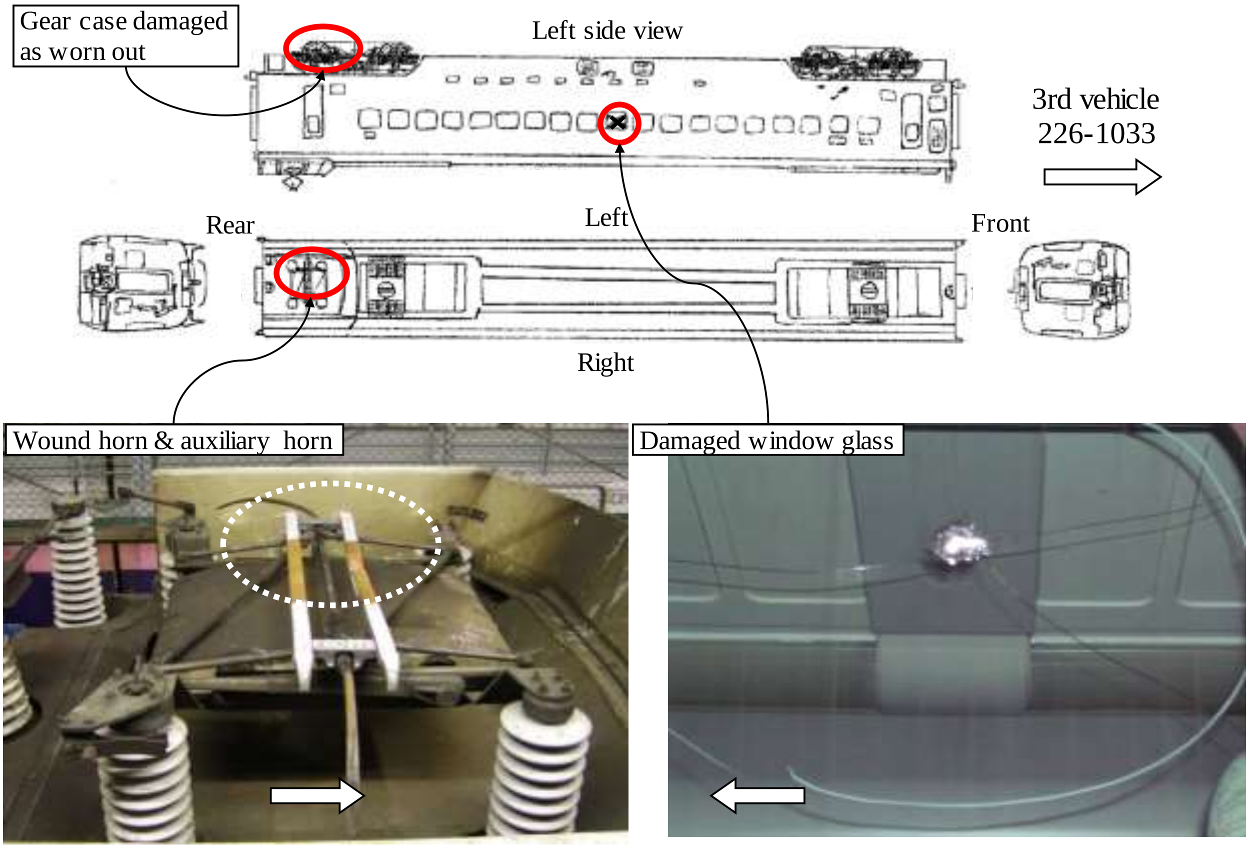


Figure 4. Status of the Major Damages of the Vehicles IV (The 4th Vehicle)

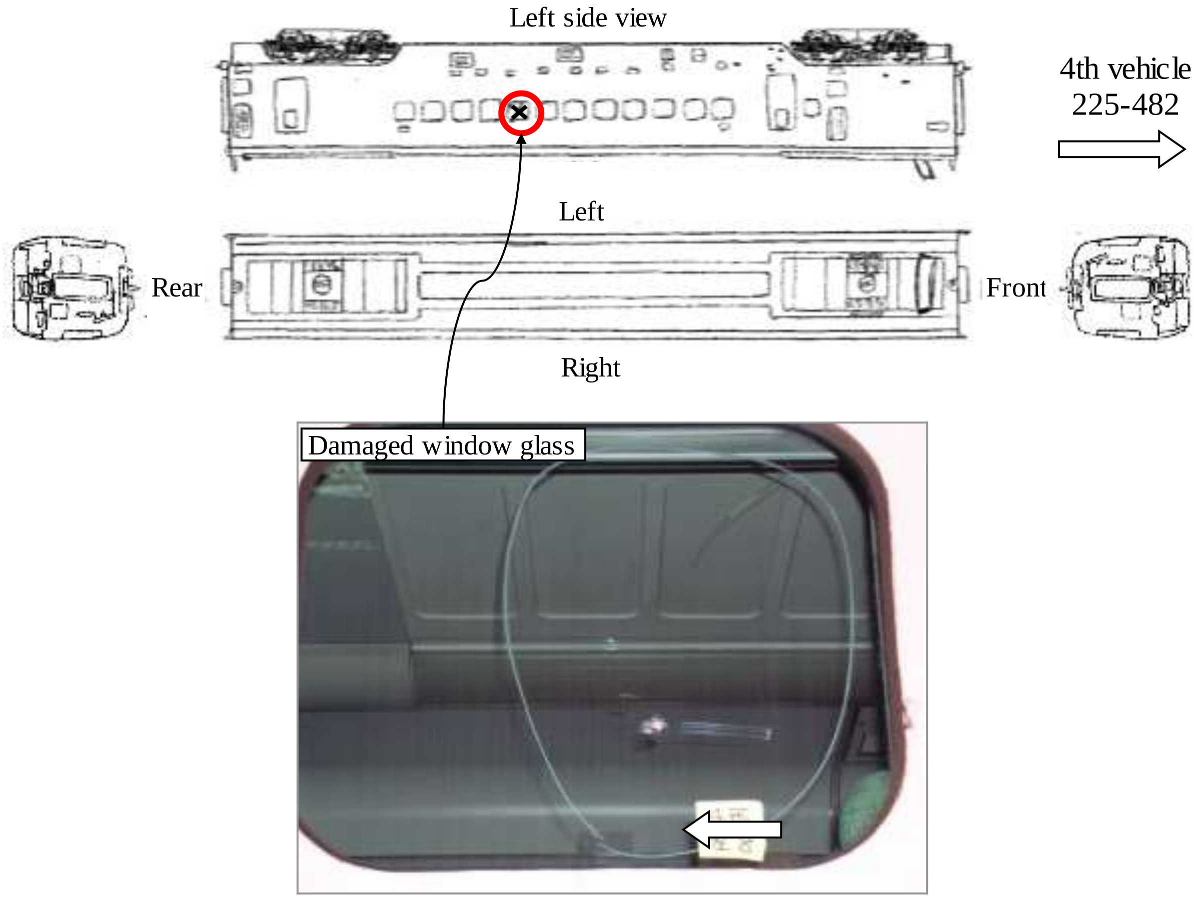


Figure 4. Status of the Major Damages of the Vehicles V (The 5th Vehicle)

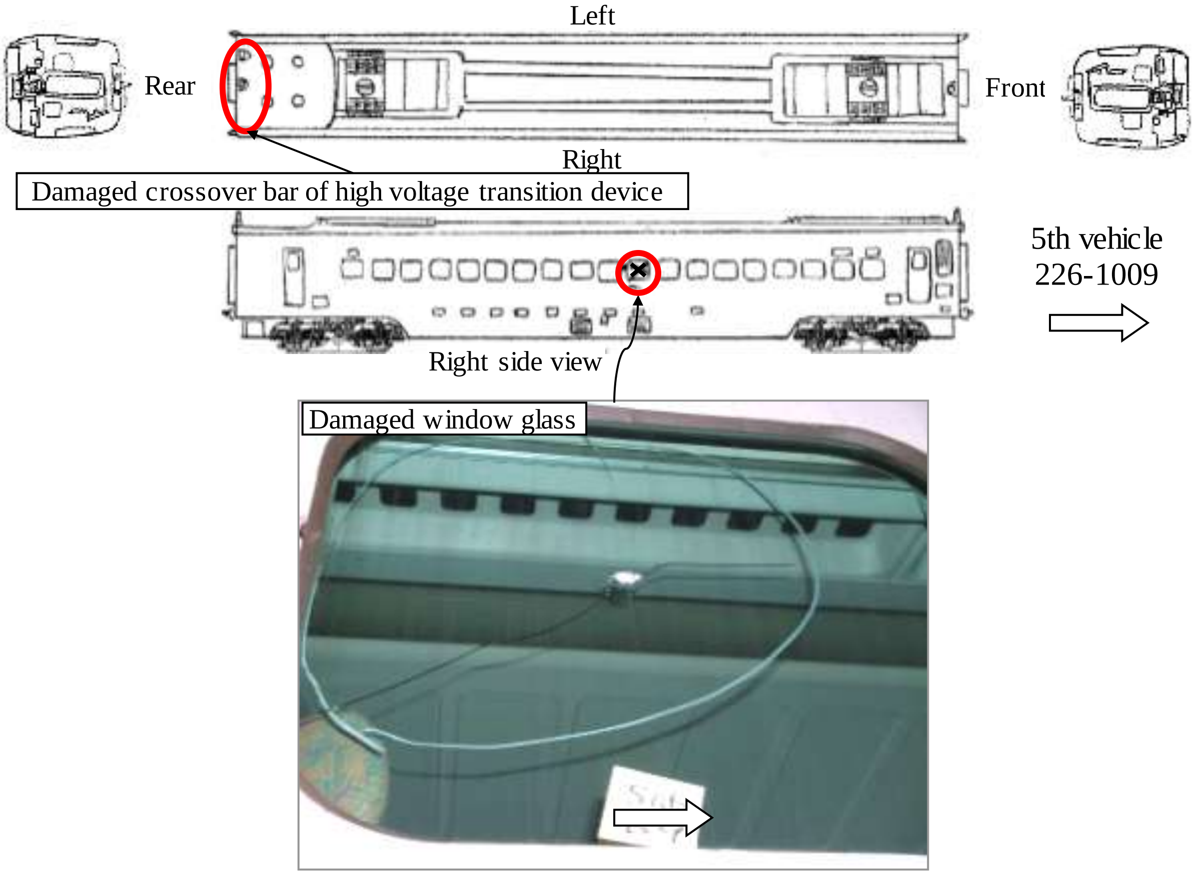


Figure 4. Status of the Major Damages of the Vehicles VI (The 6th Vehicle)

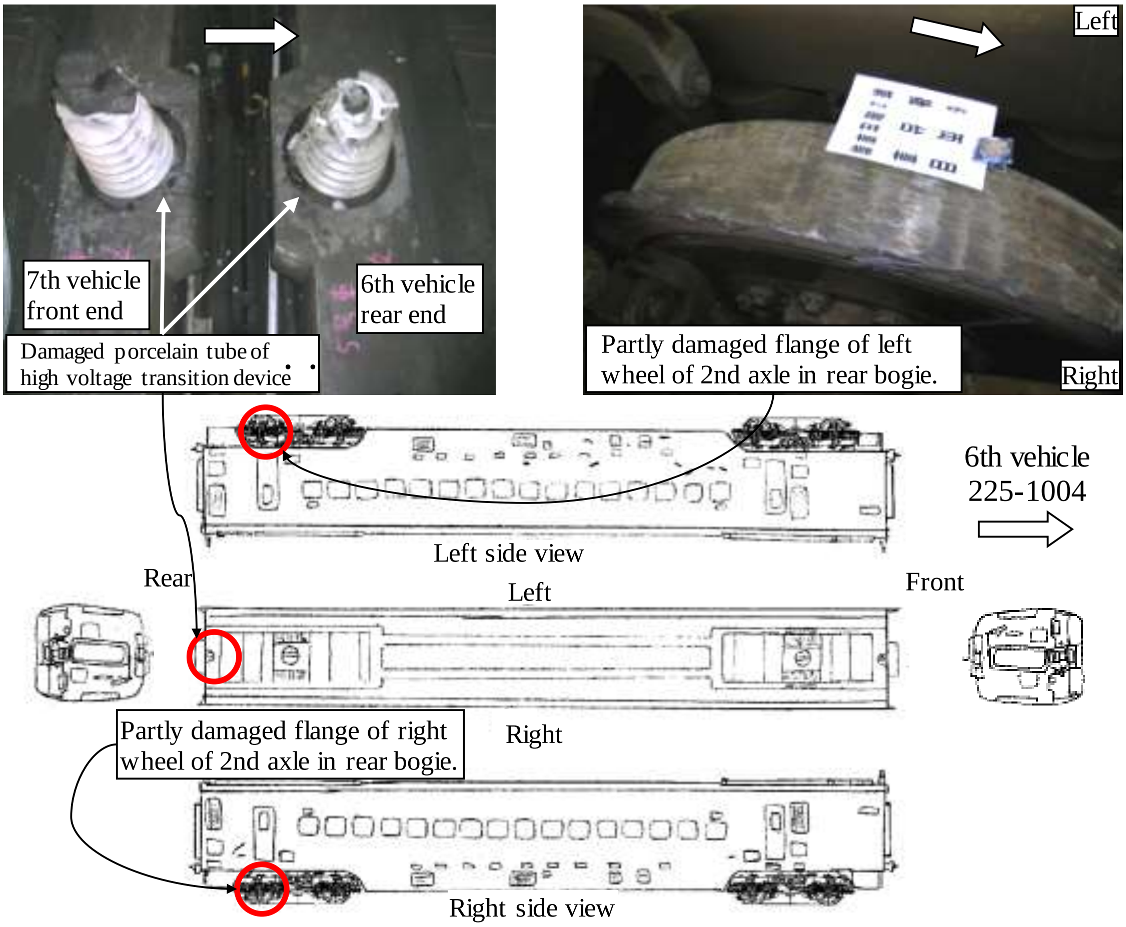


Figure 4. Status of the Major Damages of the Vehicles VII (The 7th Vehicle)

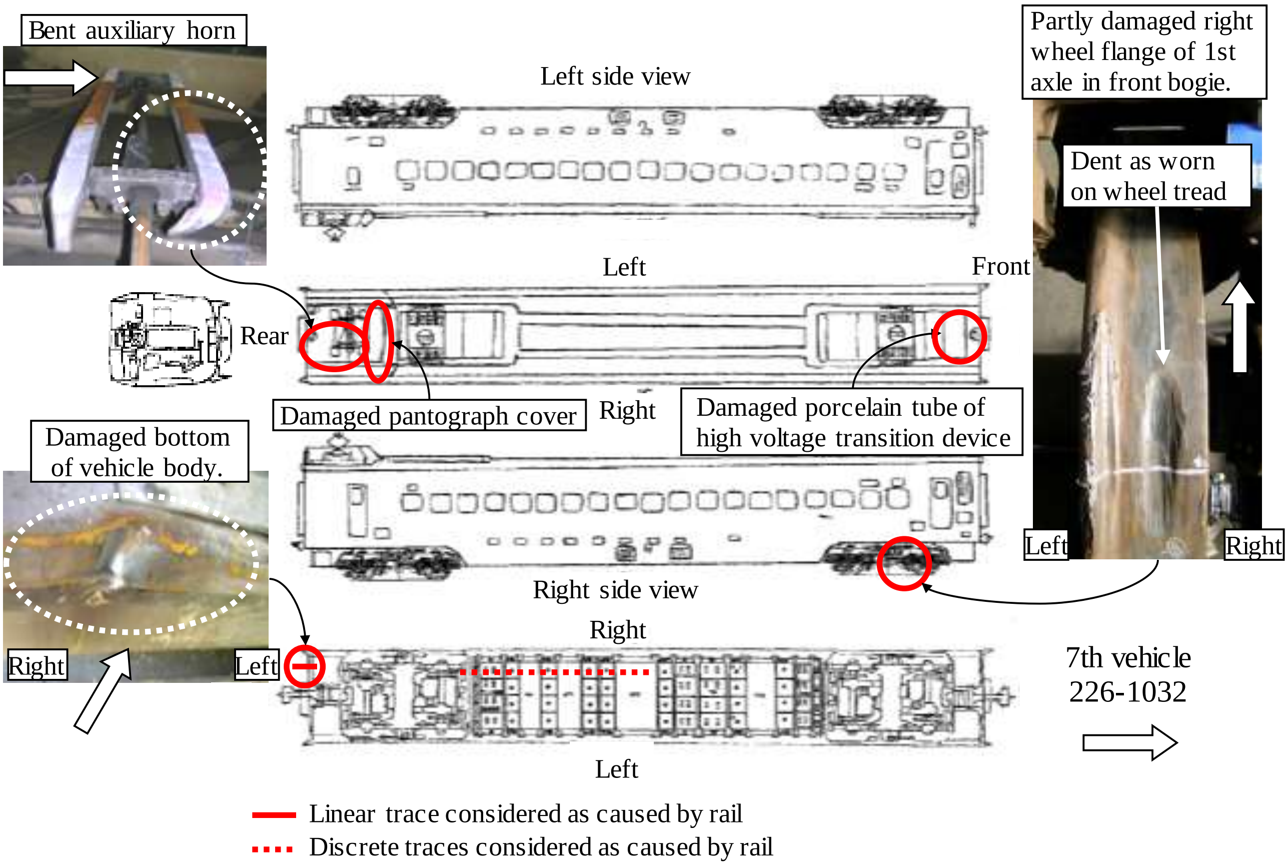


Figure 4. Status of the Major Damages of the Vehicles VIII (The 8th Vehicle)

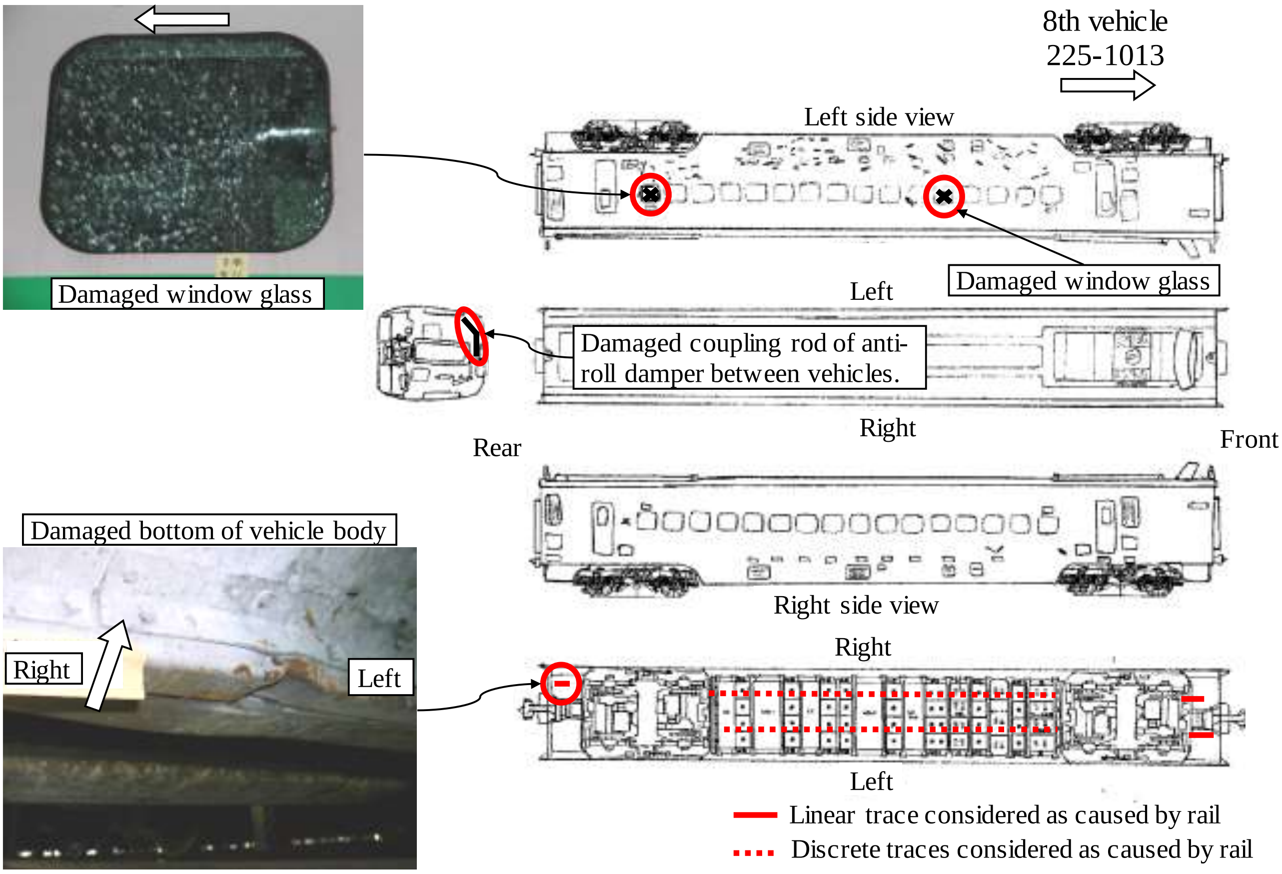


Figure 4. Status of the Major Damages of the Vehicles IX (The 9th Vehicle)

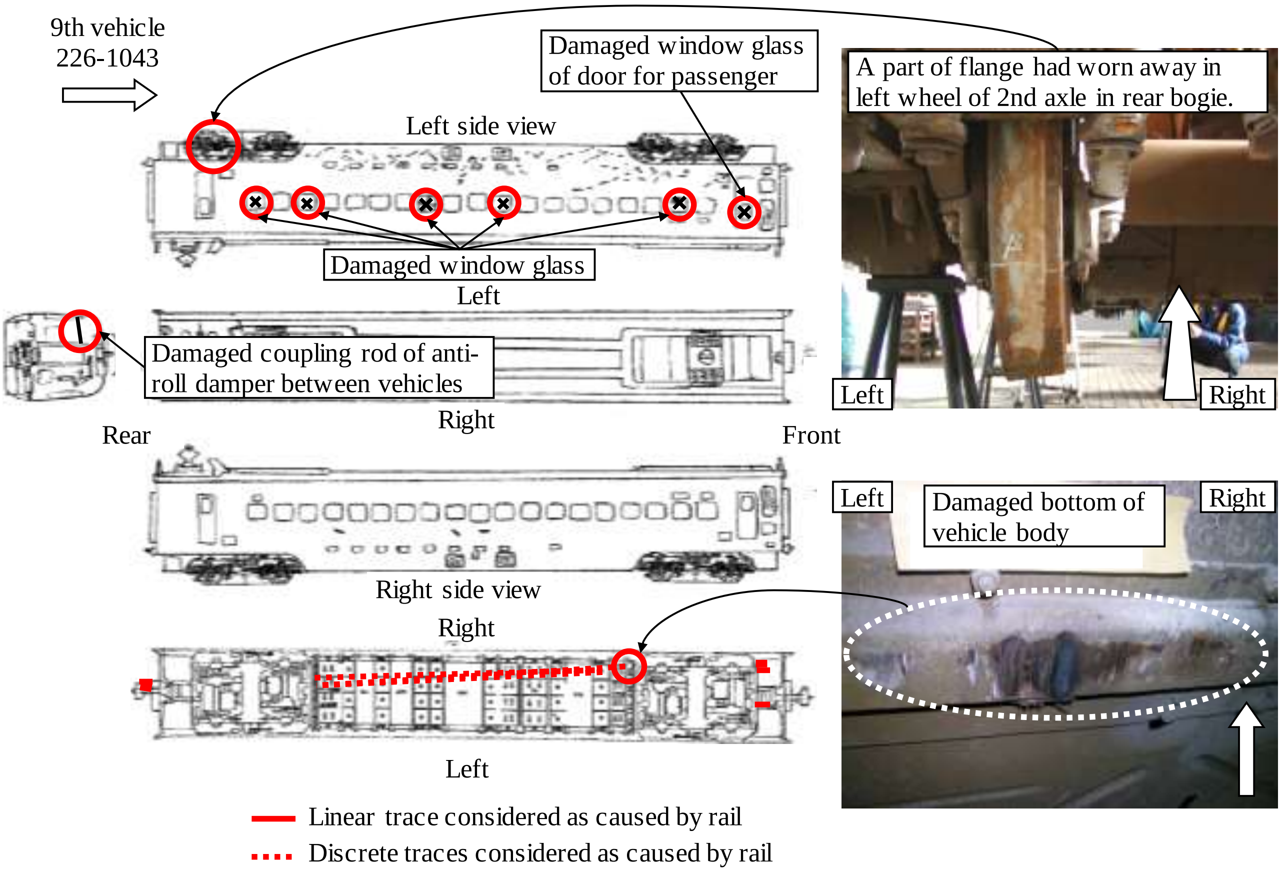


Figure 4. Status of the Major Damages of the Vehicles X (The 10th Vehicle)

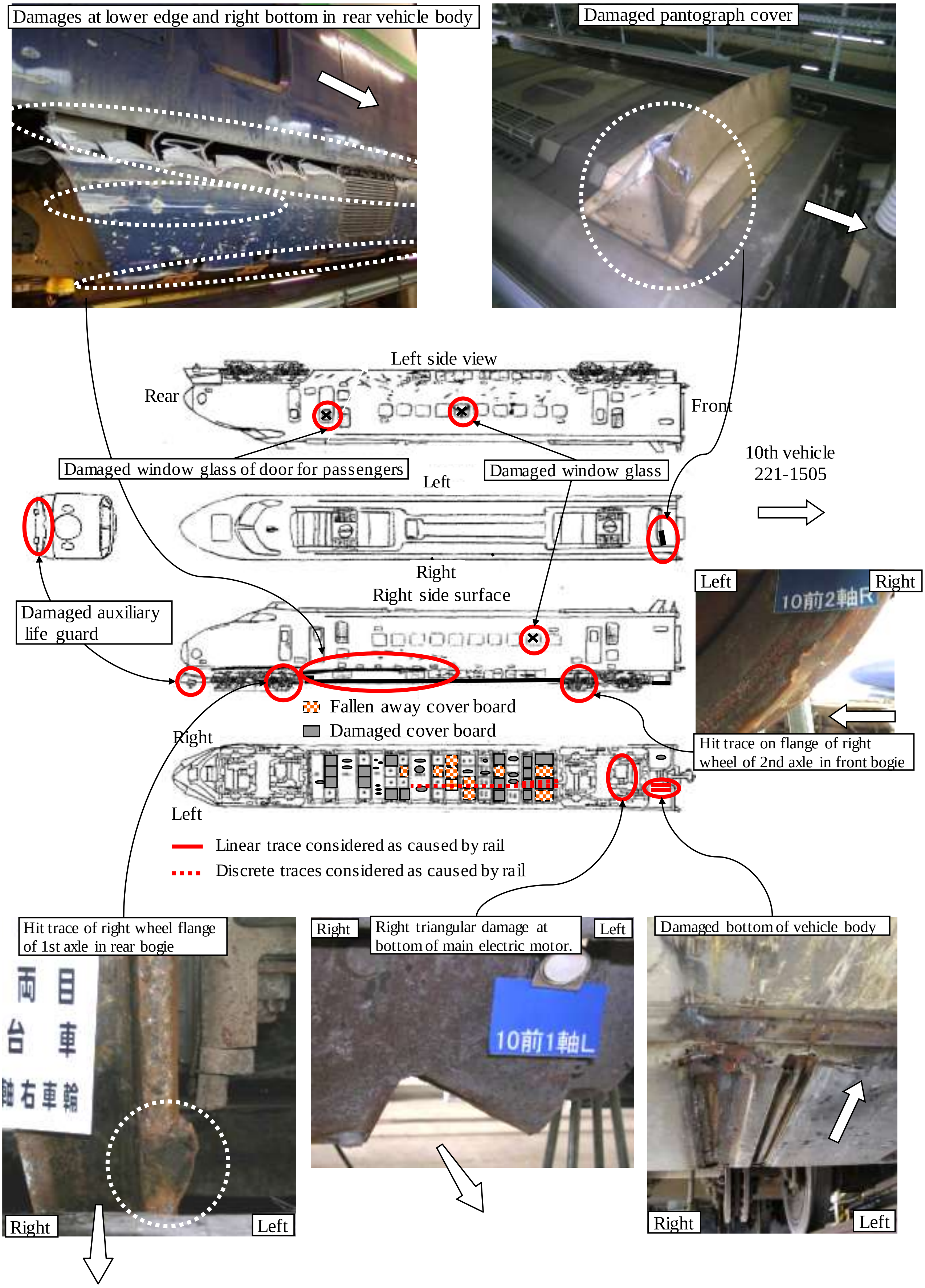


Figure 5. The Maximum Acceleration of the Niigata Prefecture Chuetsu Earthquake Observed in around the Accident Site

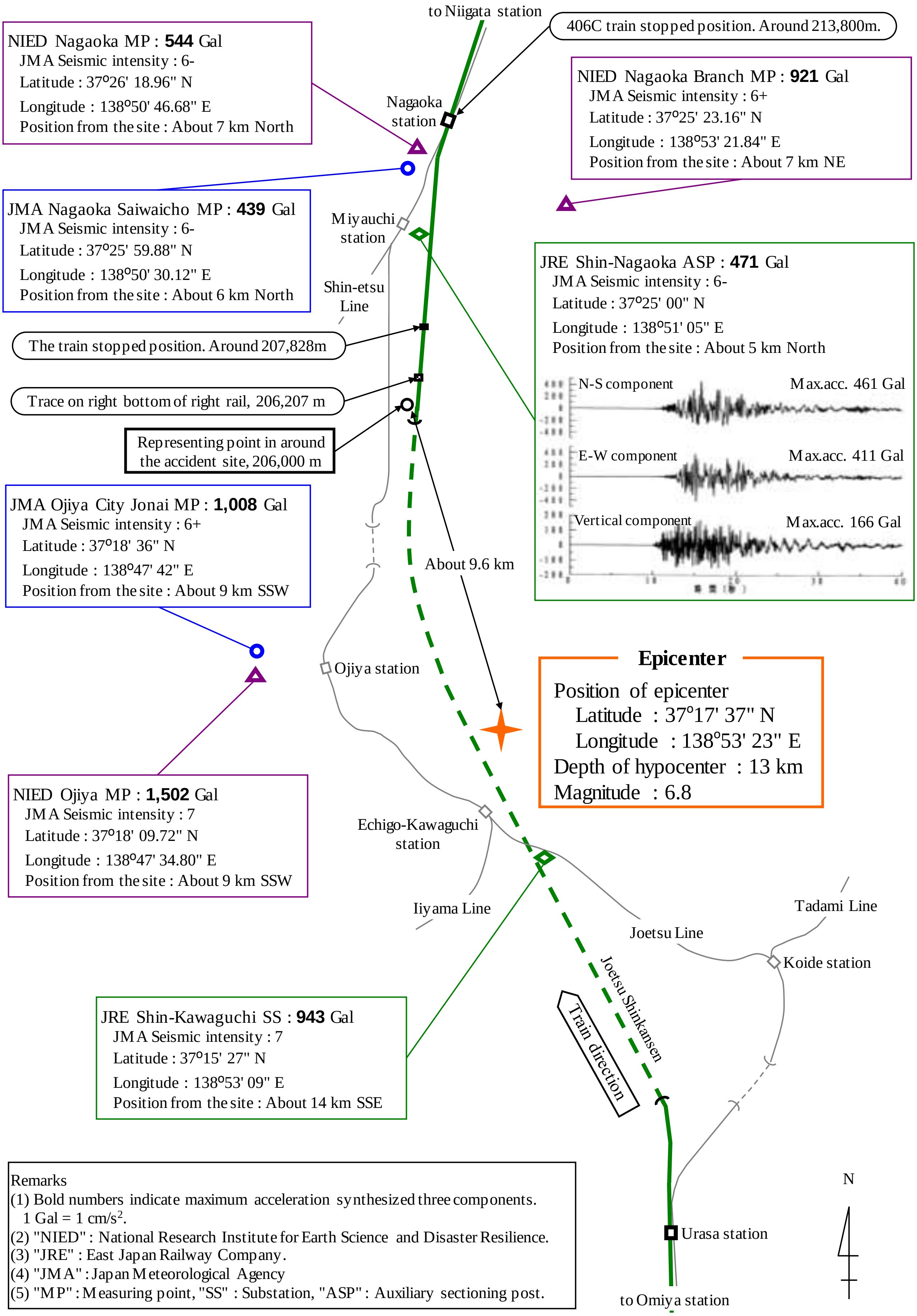
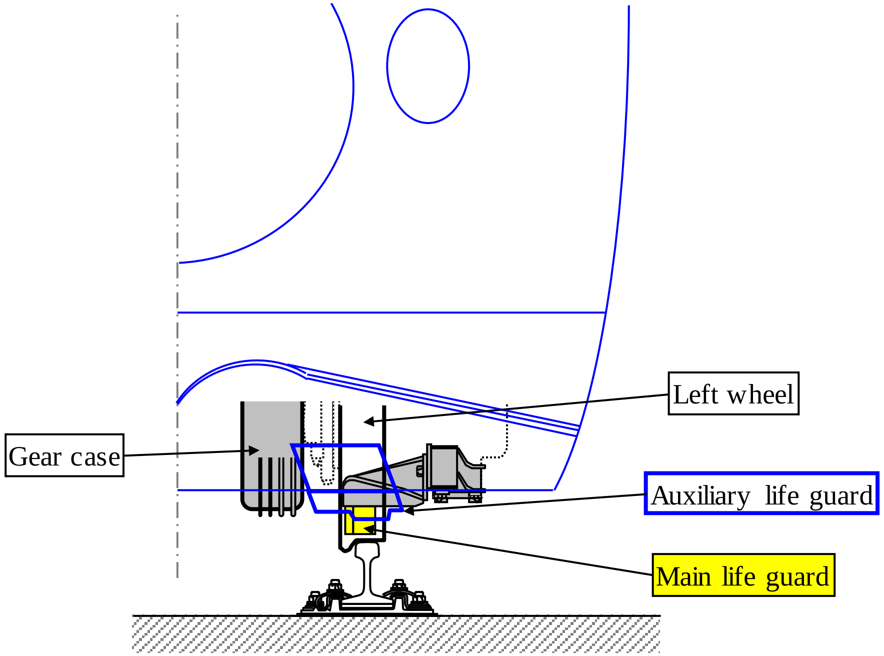
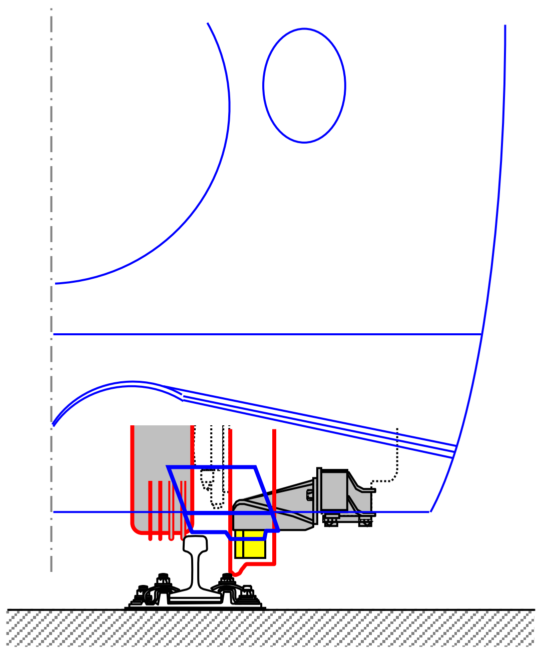


Figure 6. Positional Relationship between Life Guard and Wheels, and Status of the Left Rail Sandwiched by the Left Wheel and the Gear Case

(a-1) Positional relationship between lifeguard and wheel.



(b) Status of the left rail sandwiched by left wheel and gear case



(a-2) Positional relationship between life guard and wheel.

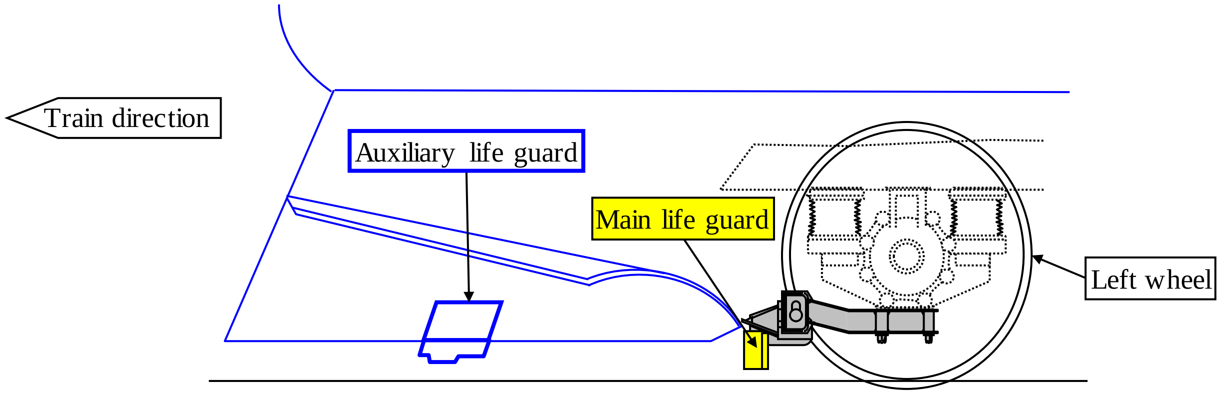


Figure 7. Vehicle Running Simulation during the Earthquake I
(a) Conceptual Diagram to Estimate Waveforms of the Seismic Ground Motion

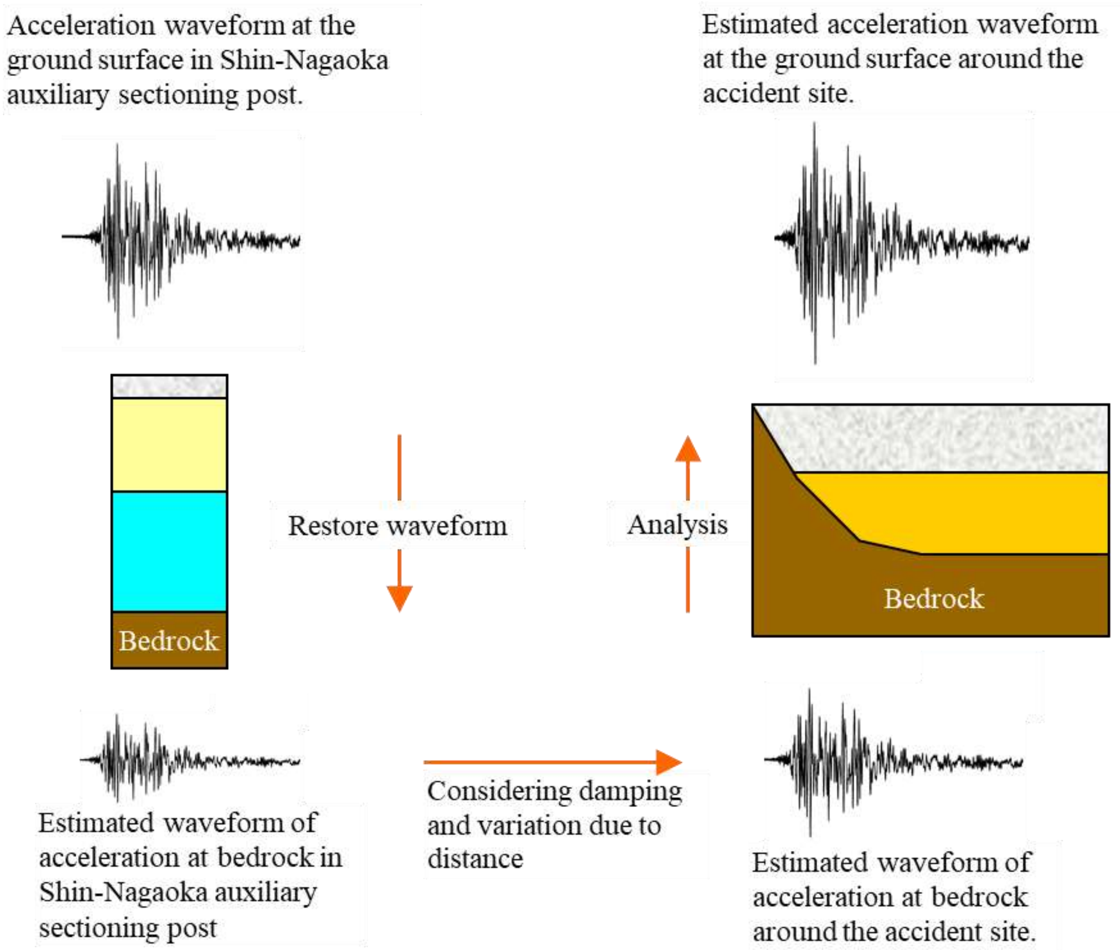
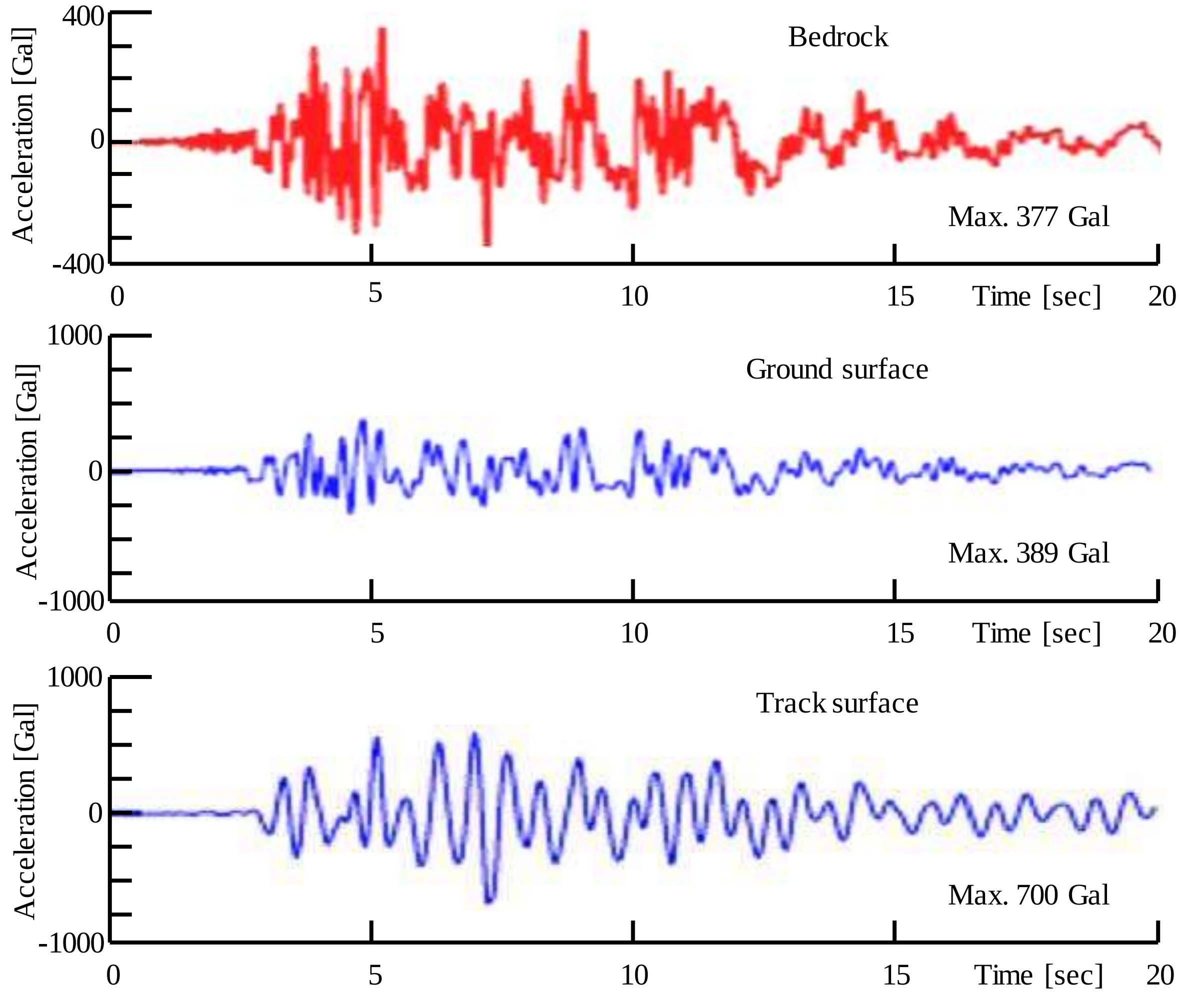


Figure 7. Vehicle Running Simulation during the Earthquake II

(b) Estimated Lateral Acceleration Waveforms in Tokamachi Viaduct R3



(c) Estimated Absolute Displacement Waveform on the Track Surface in Tokamachi Viaduct R3

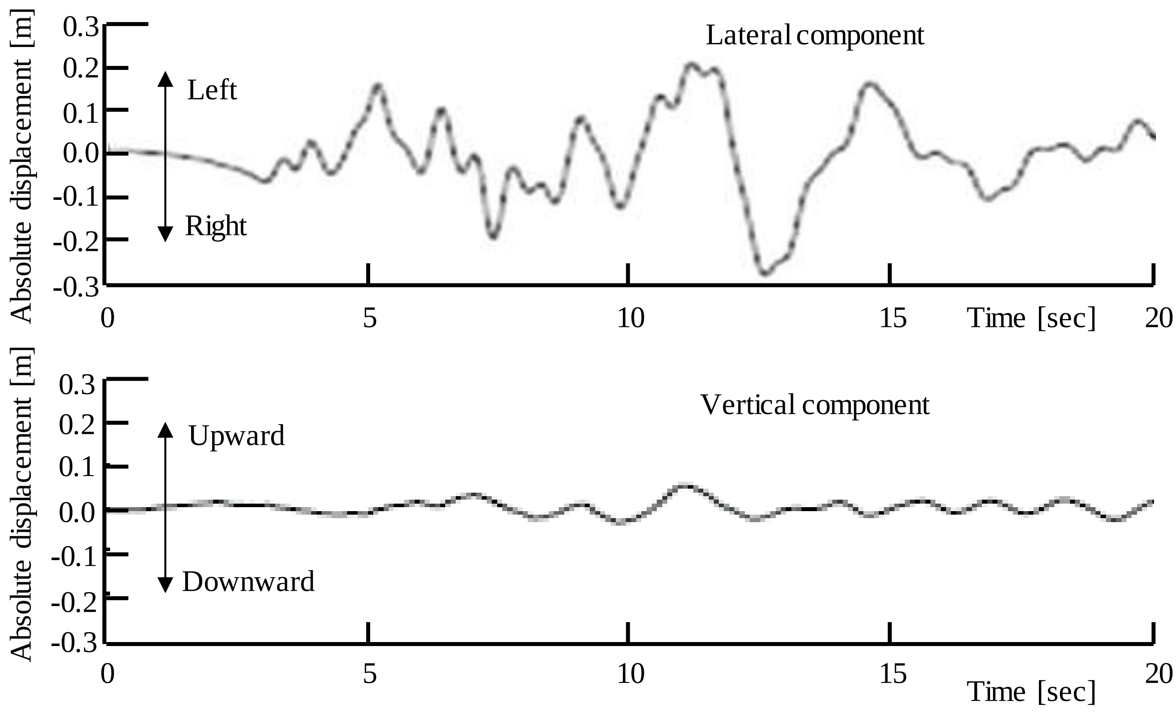
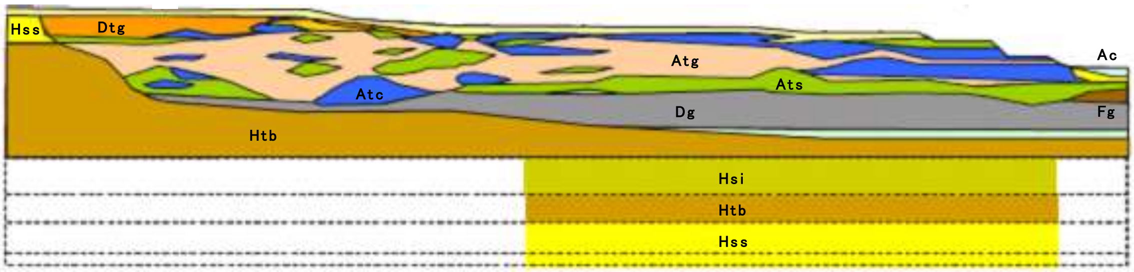


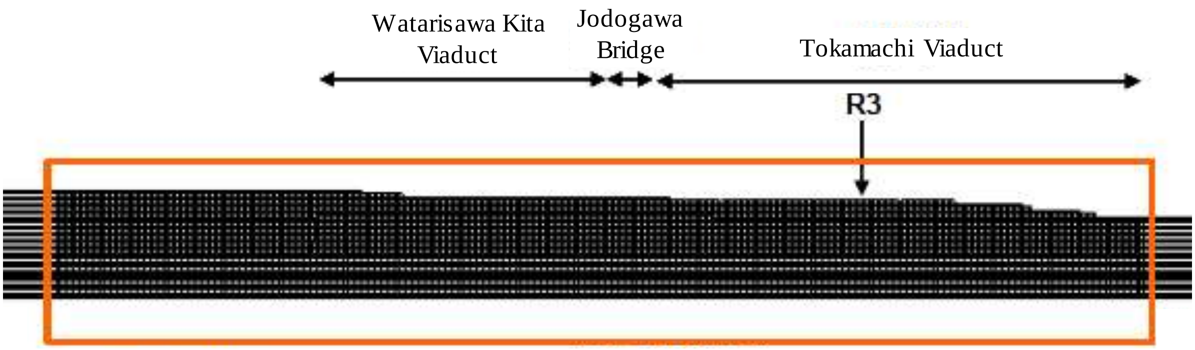
Figure 7. Vehicle Running Simulation during the Earthquake III

(d) Structural Model of the Ground around the Accident Site and Results of the Analysis

Remarks

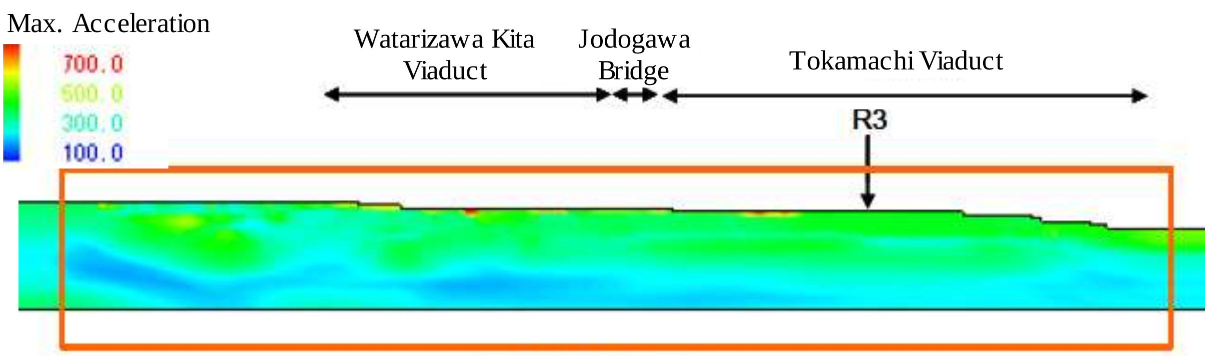
Surface soil	S	
Cliff sediment	Sand & gravel	Dtg
Alluvium	Clayey	Ac
Alluvium terrace sediment	Clayey	Atc
Alluvium terrace sediment	Sand & gravel	Atg
Alluvium terrace sediment	Sand	Ats
Diluvium sand & gravel layer	Sand & gravel	Dg
Old age alluvial fan sediment	Sand & gravel	Fg
Haizume foundation	Tuff breccia, andesite	Htb
Haizume foundation	Sandstone	Hss
Haizume foundation	Siltstone, mudstone	Hsi





Number of elements : about 9000

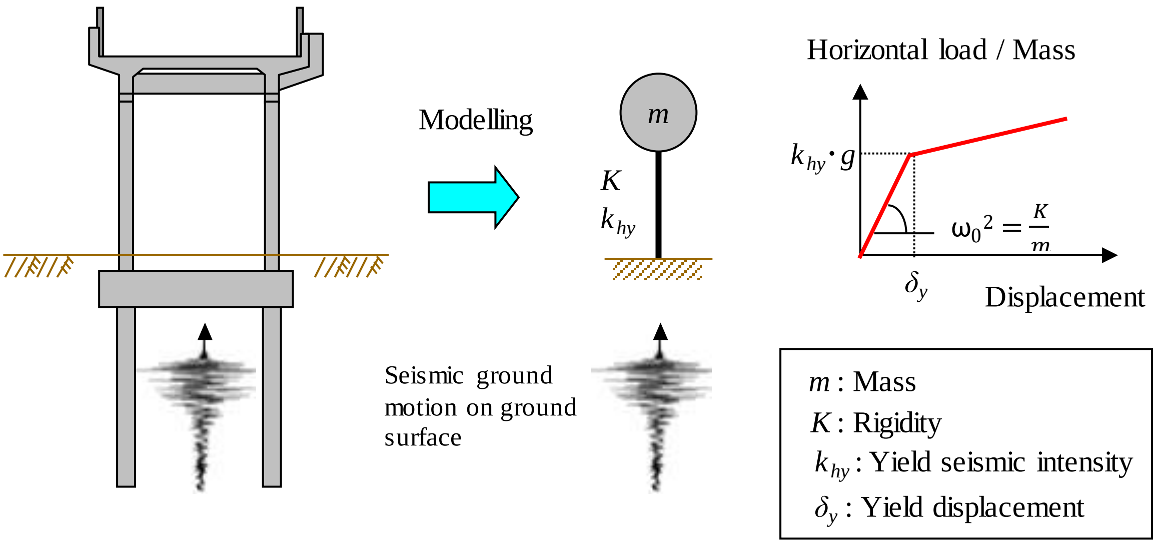
Effective calculation area



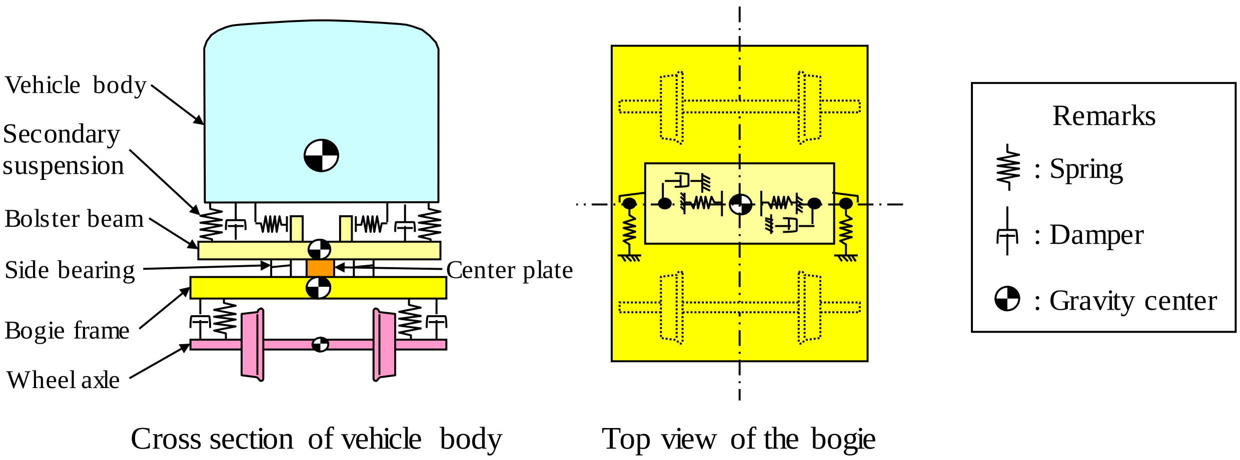
Maximum Acceleration

Figure 7. Vehicle Running Simulation during the Earthquake IV

(e) Conceptual Diagram of the Method of the Dynamic Analysis for the Structures



(f) Vehicle Model in the Simulation



(g) Conceptual Diagram of the Method to Input the Seismic Ground Motion in the Simulation

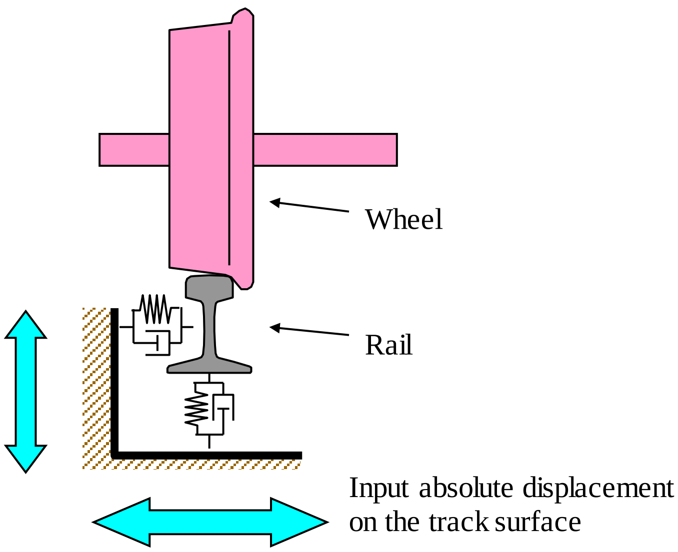
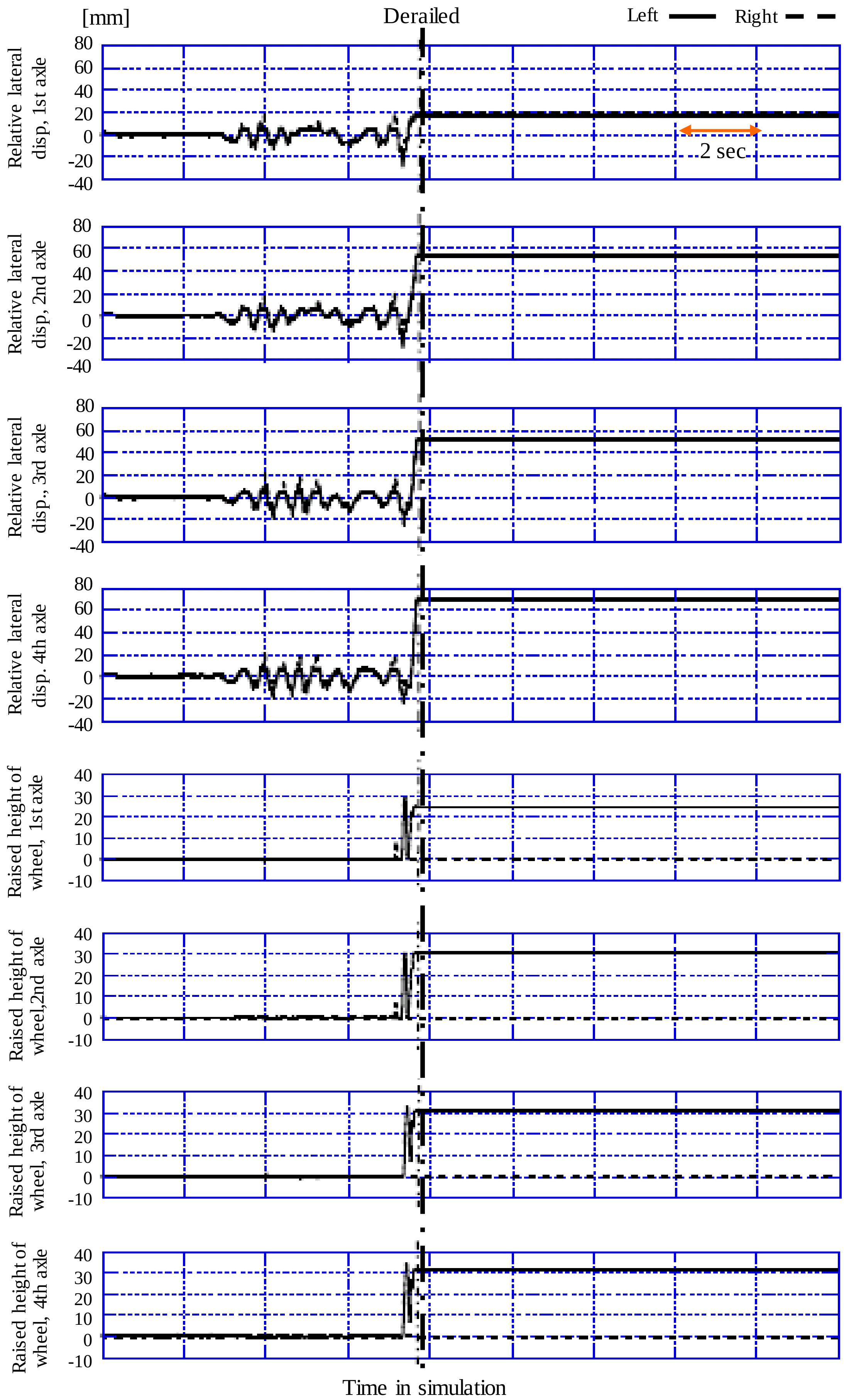
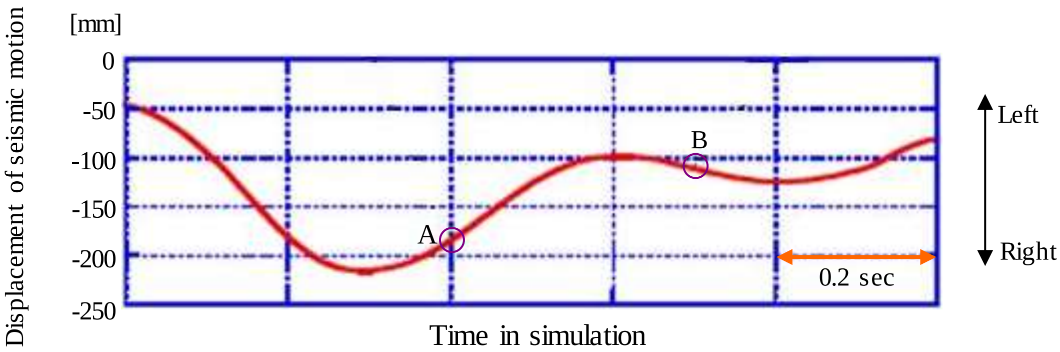


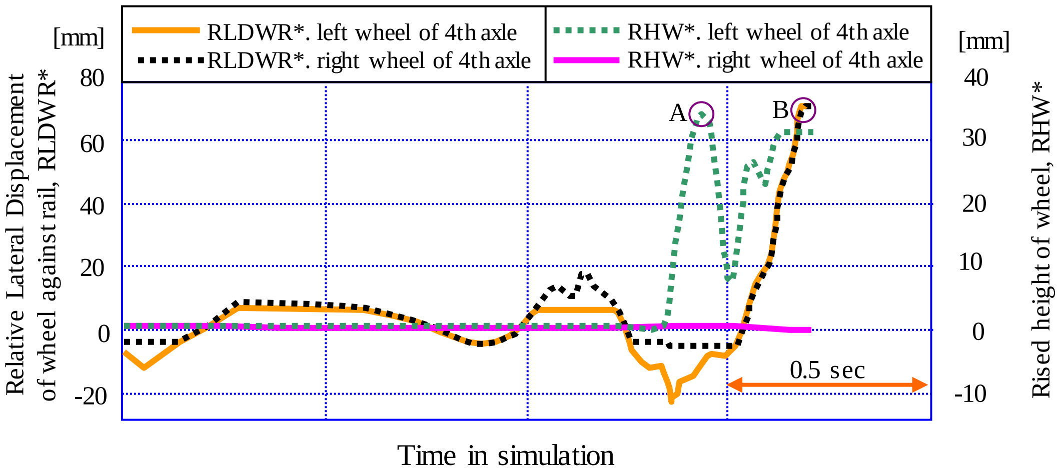
Figure 7. Vehicle Running Simulation during the Earthquake V
(h) Relative Lateral Displacement between Wheel and Rail and the Raised Height of Wheel

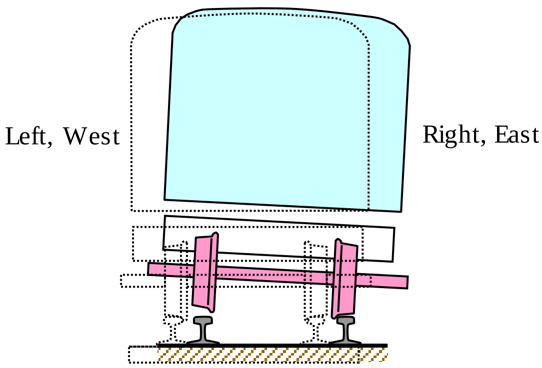


** Simulation was stopped when one of the axles became to the derailed status.*

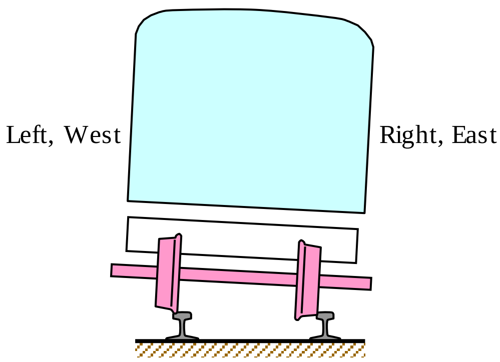
Figure 7. Vehicle Running Simulation during the Earthquake VI







Imaginary vehicle behavior at time A



Imaginary vehicle behavior at time B