

RA2021-1-I

# **RAILWAY ACCIDENT INVESTIGATION REPORT**

**Railway accident with casualty in the premises of Shin-Sugita station,  
Kanazawa Seaside Line, the Yokohama Seaside Line Co., Ltd.**

**February 18, 2021**



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

TAKEDA Nobuo  
Chairperson  
Japan Transport Safety Board

Note:

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

《Reference》

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

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

# Railway Accident Investigation Report

Railway operator           Yokohama Seaside Line Co. Ltd.  
Accident type               Railway accident with casualty  
Date and time               About 20:15, June 1, 2019  
Location                     In the premises of Shin-Sugita station, Kanazawa Seaside Line,  
                                  City of Yokohama, Kanagawa Prefecture

January 25, 2021

Adopted by the Japan Transport Safety Board

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## SYNOPSIS

### <SUMMARY>

On Saturday, June 1, 2019, the outbound 2009B train, composed of five vehicles and started from Shin-Sugita station bound for Namiki-Chuo station of Kanazawa Seaside Line of the Yokohama Seaside Line Co., Ltd., departed from the starting station, Shin-Sugita station, on schedule at 20:15, by the unmanned automatic operation. However, the train moved to the inbound direction opposite to the direction of travel *i.e.*, the outbound direction, and collided with the car stop at the end terminal of the track.

There were 25 passengers boarded on the train, the 17 passengers among them were injured.

### <PROBABLE CAUSES>

The Japan Transport Safety Board concludes that the probable cause of this accident was certain that this accident occurred because this train started to run in the inbound direction, *i.e.*, the outbound direction opposite to the direction of travel, when turned back in Shin-Sugita station, and collided with the car stop at the end terminal of the track.

It is highly probable that this train started to move by power running in the direction opposite to

the designated running direction without intention, because the motor control device of the 2000 series vehicle drove the motors in the inbound direction that had been preserved in the memory function, as the F cable, which is the command cable to transmit the signal on the running direction of the train to the motor control device, became in the de-energized status due to be broken in the 1st vehicle. Furthermore, it is probable that the measures such as the emergency stop procedures could not be implemented, because the station ATO ground unit recognized that the running direction of the train had been set normally, as the station ATO onboard unit had transmitted the status of the running direction based on the energized status of the command line to select the driving desk, which is different to the input signal to the motor control device, and also there was no function to detect the backward running or the function to detect by the other methods backward moving such as in this accident.

It is probable that the F cable had broken as that the insulator of the F cable wore gradually by the friction with the upper surface of the end rail due to the vibration while the vehicle was running, and fault grounded to the end rail, as the results of that the bundle of cables including the F cable in the device room were wired without attaching the protecting materials for the electric wires sufficiently, and had been contacted with the end rail made of the stainless steel, but the inspection had not been implemented after finished the wiring works.

It is likely that the existence of the latent causes for such dangerous incident and the insufficient security of the safety against the abnormal status such as the backward running, etc., were not noticed, because the confirmation and the arrangement on the understandings for the designing organization, the basic concept, and the specifications, etc., among the Company, the vehicle manufacturer and the device manufacturer, and the extraction of the safety factors before designing were not implemented sufficiently, in the designing and manufacturing process of the 2000 series vehicle, the latent causes of the dangerous incident for the occurrence of the backward running was generated, in addition, also the verification of the safety was insufficient, in the back ground of this accident.

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# 1. PROCESS AND PROGRESS OF THE RAILWAY ACCIDENT INVESTIGATION

## 1.1. Summary of the Railway Accident

On Saturday, June 1, 2019, the outbound 2009B train, composed of 5 vehicles and started from Shin-Sugita station bound for Namiki-Chuo station of Kanazawa Seaside Line of the Yokohama Seaside Line Co., Ltd., departed from Shin-Sugita station, *i.e.*, the starting station, on schedule at 20:15, in the unmanned automatic operation, but the train moved to the inbound direction opposite to the direction of travel *i.e.*, the outbound direction, and collided with the car stop at the end terminal of the track.

There were 25 passengers boarded on the train, the 17 passengers among them were injured.

## 1.2. Summary of the Railway Accident Investigation

### 1.2.1. Organization of the Investigation

As this accident falls into the railway accident with casualties stipulated in Article 3, paragraph (1), item (vi) of the Ordinance on Reporting on Railway Accidents (the Ordinance of Ministry of Transport No.8 of 1987, applied by the provision of Article 6 of the Ordinance on Reporting on Tramway Accidents Notification of the Ministry of Transport and the Ministry of Construction No. 1 of 1987), and at the same time, the train operated by the unmanned automatic operating system<sup>\*1</sup> moved in the power running to the direction opposite to the preset direction of travel against the intention, *hereinafter referred to as "running in wrong direction"*, the Japan Transport Safety Board, *hereinafter referred to as "the JTSB"*, decided this accident investigated as the "accident particularly rare and exceptional" stipulated in the Article 1, item (iii) of the Ordinance for Enforcement of the Act for Establishment of the Japan Transport Safety Board (Ordinance of Ministry of Land, Infrastructure, Transport and Tourism No. 1 of 2001).

The JTSB designated an investigator-in-charge and the other three railway accident investigators to investigate this accident, on June 1, 2019. After that, the JTSB designated another railway accident investigator, and dispatched the board members to the accident site, etc.

The Kanto District Transport Bureau dispatched its staffs to support the investigation of this accident.

The analysis on the mechanism, etc., to cause the breaking of electric wire of the command cable transmitting the running direction of the train were entrusted to the Japan Electric Cable Technology Center, *hereinafter referred to as "the professional organization on electric cables"*, to investigate this accident.

In addition, as it is likely that the automatic operating system related to this accident, the JTSB appointed the Expert Adviser engaged in this accident investigation on September 9, 2019, and designated the analysis on the verifying method of the automatic operating system and on its safety as the area of specialization to be investigated. [*Refer to Table 1*]



Table 1. The Expert Adviser and the area of specialization to be investigated

Affiliation	Title	Name	Area of specialization to be investigated
National University Corporation, Nagaoka University of Technology	Professor Emeritus	HIRAO Yuji	Verifying method of automatic operating system and its safety

*\*1 "Automatic operating system" in this context is the operation control of the train, that a part or the all of the operations to drive trains, are automated. The operations to drive the train such as the departing procedures, the velocity control, the stopping at the station, i.e., the stopping control at the determined position, the braking in an emergency, etc., were implemented automatically, in the situation protected by the ATC<sup>#</sup>. # Refer to the foot note 4.*

### 1.2.2. Implementation of the Investigation

June 1 to 3, 2019	On-site investigation, vehicle investigation, hearing statements
June 5 to 6, 2019	Vehicle investigation, hearing statements
June 12, 2019	Hearing statements
June 17, 2019	Reenacting test, hearing statements
July 10 to August 8, 2019	Hearing statements
August 29 to November 15, 2019	Entrusted investigation
September 2, 2019	Reenacting test
September 6, 2019 to July 13, 2020	Hearing statements

### 1.2.3. Provision of the Factual Information

On June 14, 2019, the JTSB provided the information on the broken command cables transmitting the signal of the running direction of the train, the operated records of the devices, the specification of the motor control devices, etc., to the Railway Bureau of the Ministry of the Land, Infrastructure, Transport and Tourism, *hereinafter referred to as "the MLIT"*, based on the results of the investigation up to that time.

### 1.2.4. Interim Report

On February 27, 2020, the JTSB issued the interim report on the results of the investigation and the analysis on the broken cables and the running in the wrong direction that were confirmed by that moment, and published on the measures to prevent the breaking of cables, the measures to prevent the running in the wrong direction of the vehicles<sup>\*2</sup> in the route, etc.

*\*2 In this report, the "vehicle" means the structure body composed of the vehicle body, the running gear, etc., and the "train" means the set of vehicles named by the train number and running in the main line.*

### 1.2.5. Comments from Parties Relevant

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

## 2. FACTUAL INFORMATION

### 2.1. Process of the Train Operation

#### 2.1.1. Operating Status of the Train

*[Refer to Attached Figure 1]*

The Kanazawa Seaside Line of the Yokohama Seaside Line Co. Ltd., *hereinafter referred to as "the Route" and "the Company"*, respectively, is the new transit system<sup>\*3</sup> operating by the unmanned automatic operating system in the 10.8 km long double track section between Shin-Sugita station and Kanazawa-Hakkei station.

According to the Company, the vehicle operated in this accident started the operation in the day of this accident, as the first inbound train bound for Shin-Sugita station, departed from Namiki-Chuo station at 04:52, after that, shuttled between Shin-Sugita station and Kanazawa-Hakkei station 15 times till the occurrence of this accident. The vehicle had been scheduled as the outbound 1905 train departed from Shin-Sugita station at 19:15 bound for Kanazawa-Hakkei station, the inbound 1910 train departed from Kanazawa-Hakkei station at 19:43 bound for Shin-Sugita station, the outbound 2009B train, *hereinafter referred to as "the Train"*, depart from Shin-Sugita station at 20:15 bound for Namiki-Chuo station, after that, operated from Namiki-Chuo station to the vehicle depot. The Train had been operated without delay, the detection of abnormality, etc., after departed from the vehicle depot till the occurrence of this accident, in the accident day.

When the Train departed from the track No.1 of Shin-Sugita station on schedule at 20:15, the Train departed to the inbound direction, opposite to the direction of travel of the Train, *i.e.*, outbound direction, and collided with the car stop in the terminal end of the track.

<sup>\*3</sup> *"New transit system" is the general name of the transit system operated in the track adopted new system as to use the automatic operating system among the urban transit system. Mainly used for the transit system that a few vehicles suspended by rubber tires and about 8 m long each are coupled each other and operated on the concrete track. There are the guideway system, the monorail, the mini subway, the linear motor car, etc., and there are the types that vehicles are operated by the manned operation and the unmanned operation.*

#### 2.1.2. Statements of the Dispatchers and the Station Staffs

Based on the statements of the 2 dispatchers who were monitoring the train operation in the dispatcher's office and the 3 station staffs of Shin-Sugita station, the summaries of the status of the occurrence of the accident were as follows.

##### (1) Dispatchers

On the accident day, while watching the monitor displays in front of the command desk, the information that the emergency brake acted in the Train, was indicated.

There was the report from the passenger using the cabin reporting button that the train ran in reverse direction and some passengers seemed to be injured. Furthermore, there was the communication from the staff of Shin-Sugita station that there were many injuries. When confirmed the status of the platform No.1 of Shin-Sugita station in the monitors, it was found that the Train had been stopped as collided with the car stop in the end terminal of the track, then, operated the suspension of all operating trains, immediately.

According to the report from the passenger, the Train collided just after departed in the reverse direction at 20:15.

There was no alarm showing the existence of the abnormality in the Train before departed.

## (2) Station staffs

A few station staffs were in the place where the Train could not be sighted, but they heard the sound that could not be distinguished the motor or the running wheels, never heard in the usual operation, just after that, they heard the breaking sound as crashed. They thought that the breaking sound was heard at about 20:15, because they had the consciousness that the train bound for Namiki-Chuo station would depart at 20:15, in the back of their mind.

### 2.1.3. Records of the Operating Status of the Train

The event recorder was equipped on the Train.

According to the operating data recorded before and after this accident in the above onboard event recorder and the ground device, the Train started moving at 20:14:57, after set the running direction "outbound" at 20:14:41, in Shin-Sugita station. At 20:15:05, the velocity reached to the maximum velocity 25 km/h accompanied with the operation of the emergency brake, and the velocity became to almost 0 km/h at 1 second after that. In addition, there was the record in the event recorder that the side door in the 3rd vehicle opened when the emergency brake was operated. Here, there was no record showing the abnormal situation on the setting running direction in the onboard and the ground event recorders. [Refer to Table 2]

Table 2. Major operating data of the Train

Recorded time	Recorded device	Recorded data	Remarks
20:14:40	Ground	Command of running direction, outbound	Transmit from ground to vehicle
20:14:41	Ground	Status of running direction, inbound to outbound	Transmit from vehicle to ground
20:14:55	Ground	Command to depart	Transmit from ground to vehicle
20:14:56	Onboard	Release the brake	
20:14:57	Onboard	Start moving	Notch ON, powering command
20:15:05	Onboard	Velocity 25 km/h, Emergency brake	Maximum velocity, start deceleration
20:15:06	Onboard	Velocity 0 km/h	Stopped

\* The time data in the onboard event recorder were revised corresponded to the ground system.

According to the data in the event recorder, the notch had been set in the "ON" status, the motor current was about 400 A, and the brake pressure was 0 kPa, till the maximum velocity, but the motor current decreased and the brake pressure rose a little late after the emergency brake command became "ON" and the notch became in the "Off " status. [Refer to Table 3]

Table 3. Major data in the event recorder at the accident

Recorded time	Velocity [km/h]	ATC* <sup>4</sup> signal	Emergency brake command OFF : 0, ON : 1	Notch OFF : 0, ON : 1	Motor current [A]	Brake pressure [kPa]
20:15:04.4	22	40 signal* <sup>5</sup>	0	1	392	0
20:15:04.6	22.5	40 signal	0	1	392	0
20:15:04.8	23.5	40 signal	0	1	396	0
20:15:05.0	24	40 signal	0	1	396	0
20:15:05.2	25	40 signal	0	1	396	0
20:15:05.4	23.5	40 signal	0	1	428	0
20:15:05.6	16	40 signal	1	0	428	0
20:15:05.8	4.5	-	1	0	176	148
20:15:06.0	1.5	ORP signal* <sup>6</sup>	1	0	0	264

\* The time data in the onboard event recorder were revised corresponded to the ground system.

Additionally, it was recorded that the F cable which is the command cable to transmit the signal on the running direction of the train to the motor control device, etc., *hereinafter referred to simply as "the F cable"*, described in the following paragraph 2.3.2, changed from the energized status to the de-energized status, when running in the section between Sachiura station and Sangyo-Shinko-Center station, while the vehicle of the Train was operating as the outbound 1905 train.

\*<sup>4</sup> "ATC" is the abbreviation of the automatic train control, and the system to control the velocity of the train continuously less than the limited velocity when the velocity of the train exceeded the limited velocity, by checking the train velocity continuously based on the speed control signal instructed continuously responding to the position of the foregoing train and the conditions of the track.

\*<sup>5</sup> "40 signal" is the ATC signal indicated as the signal showing the allowable operating velocity indicated in the cabin signal indicator device in the driving desk in the train operated by the ATC. The "40 signal" indication means that the allowable operating velocity is 40 km/h.

\*<sup>6</sup> "ORP signal" is the signal to implement the overrun protection control in order to prevent the overrun in the terminal station, and the emergency stop procedure will act when the train velocity becomes to 7.5 km/h or above, at 1 second after the train velocity was 5 km/h or lower in the protecting section for overrun described in the later.

## 2.2. Human Death, Missing and Injury

### 2.2.1. Boarded Stratus and the Injured Status of the Passengers

There were 25 passengers boarded on the Train, among them, 17 passengers were injured, including the seriously injured\*<sup>7</sup> 12 persons. The boarded status of the passengers in the 1st vehicle to the 5th vehicle was shown in Figure 1, and the status of the injuries of the passengers was shown in Table 4. *Hereinafter the words "front", "rear", "left", "right" are defined based on the running direction of the outbound train bound for Kanazawa-Hakkei station, and the vehicles are counted from the front.*

\*<sup>7</sup> Based on the Notification to Stipulate the Format of the Report on Railway Accidents, etc., the Notice No.1387, Ministry of Land Infrastructure, Transport and Tourism, 2001, "seriously injured person" is the injured person required the treatment by the physician for over 30 days, and "slightly injured person" is the injured person except for the seriously injured person.

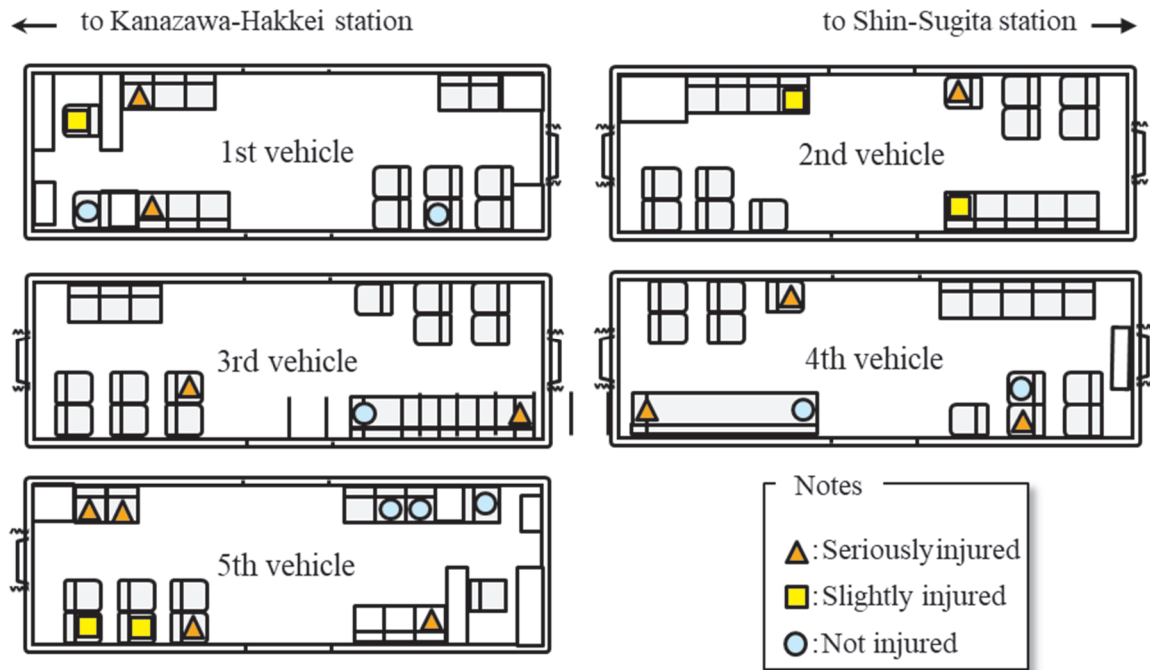


Figure 1. Boarded positions of the passengers

Table 4. Injured status of the passengers

Vehicle	Number of passengers	Injured status [Persons]
1st vehicle	5 persons	2 serious, including 2 broke bone, 1 slight, 2 were not injured.
2nd vehicle	3 persons	1 serious, 2 slight.
3rd vehicle	3 persons	2 serious, include 1 broke bone, 1 was not injured.
4th vehicle	5 persons	3 serious, include 1 broke bone, 2 were not injured.
5th vehicle	9 persons	4 serious, including 2 broke bones, 2 slight, 3 were not injured.
Total	25 persons	17 injured, including 12 serious and 5 slight, 8 were not injured.

#### 2.2.2. Information on the Rescue Activities

*[Refer to Attached Figure 2]*

After the occurrence of this accident, the Company started the rescue activities of the passengers by the station staffs of Shin-Sugita station, etc. According to the records of the Company, the dispatcher office communicated to Shin-Sugita station to arrange the ambulance, at 20:17.

In addition, according to the image data of the security video cameras equipped in each vehicle of the Train, the staffs of Shin-Sugita station got on the Train from the door for train crews in the 1st vehicle at 20:18, and started to check the status of the passengers and the rescue activities for the passengers from the vehicles, etc. The ambulance squad arrived at 20:30, and completed to rescue all injured passengers at 20:56. Additionally, according to the statement of the staff of Shin-Sugita station, as the platform gates had been installed in Shin-Sugita station, the station staffs opened the platform gate of the 4th vehicle which had just faced to the side door of the 1st vehicle after collided, and let the passengers get off the train through the side door in the 1st vehicle.

## 2.3. Information on the Vehicles and the Railway Facilities

### 2.3.1. Major Specification of the Vehicles

The major specification of the vehicles in the Train was as follows.

Vehicle category	DC electric railcar, DC 750 V
Vehicle type	The 2000 series vehicle
Vehicles in the trainset	5 vehicles
Trainset	No. 41 trainset
Newly manufactured date	March, 2013
Accumulated running distance	About 522,000 km, from put into service to the occurrence of this accident
Total length of the train set	42,000 mm
Length of the vehicle body	8,000 m, for each vehicle
Weight of the train set	52,880 kg, when completed manufacturing

The first trainset composed of the 2000 series vehicles was delivered to the Company on October 2010, and put into the commercial operation from February 2011, after implemented the test running, etc. After that, the 16 trainsets were manufactured by 2014, in addition the 2 trainsets were added in 2019. [Refer to Figure 2]

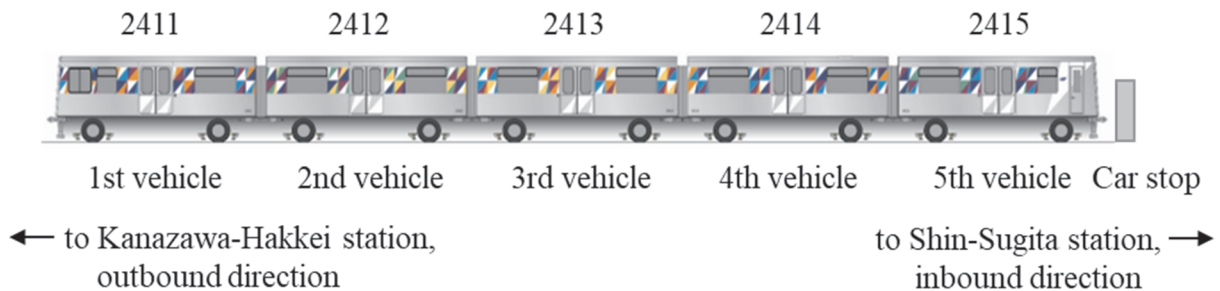


Figure 2. Trainset of the Train

### 2.3.2. Summary of the Operation Control System in the Route

The trains running in the Route are operated by the unmanned automatic operation system, *i.e.*, the train crews such as the driver or the conductor is not boarded, by transmitting information required to the train operation mutually between the onboard devices and the ground devices.

The instruction for operation control and monitoring the operated status are implemented by the central unit of the centralized traffic control system<sup>\*8</sup>, the ATO ground unit<sup>\*9</sup> in the dispatcher's office, and the ATC ground unit<sup>\*10</sup> in each station, etc.

The platform gates are installed in the platforms in all station, and open and close automatically together with the side doors for getting on and off of the passengers of the vehicles, when the train stopped at the predetermined position. While the train is stopping in the station, the information such as the setting up of the running direction, the door control of the vehicles, etc., are transmitted between the station ATO ground unit<sup>\*11</sup> installed in each station and the station ATO onboard unit<sup>\*12</sup> equipped in the vehicle, and the train after departed from the station runs following the

running pattern produced by the ATO onboard unit<sup>\*13</sup> of the vehicle.

The loop coils for the ATC and the train detecting device<sup>\*14</sup>, *hereinafter abbreviated as "the TD", "for the ATC/TD", respectively*, are laid in the center, in the direction of width, of the running track. The onboard antennas for the ATC/TD are mounted in the 1st vehicle and the 5th vehicle, and the limited velocity signal as the ATC signal is transmitted from the ground to the onboard unit, the signal for the train detection is transmitted from the onboard unit to the ground<sup>\*15</sup>. The ATC onboard unit<sup>\*16</sup> monitors the exceeded velocity by comparing the ATC signal with the velocity, and decelerate or stop the train if the abnormal running<sup>\*17</sup> occurred.

The control method to set up the running direction of the train implemented in the turn-back station, *i.e.*, Shin-Sugita station or Kanazawa-Hakkei station, when the train is operated by the automatic operation, was as follows.

At first, while the train is stopping in the turn-back station, the station ATO ground unit transmit the instruction on the running direction to forward or backward, *hereinafter referred to as "the instruction on running direction"*, to the station ATO onboard unit on the vehicle, after confirmed the stopping status of the vehicle in the predetermined area<sup>\*18</sup> or the clearance of the route for the departing train, etc., as shown in Attached Figure 4 (1).

Next, the station ATO onboard unit, received the instruction on running direction from the station ATO ground unit, and energize<sup>\*19</sup> the 194E cable or the 195E cable if the running direction is outbound or inbound, respectively, as shown in Attached Figure 4 (2). The front relay board<sup>\*20</sup> mounted on the 1st and the 5th vehicles, set up the 1st vehicle or the 5th vehicle as the front vehicle, when the 194E cable or the 195E cable is energized, respectively, furthermore, energize the 194G cable, which is the command cable to change over the driving desk<sup>\*21</sup> wired through in the trainset, and the F cable, which is the command cable to transmit the running direction of the train to the motor control device and the function to detect backing operation in the ATC onboard unit when the running direction is outbound, or energize the 195G cable and the R cable when the running direction is inbound, as shown in Attached Figure 4 (3) and (4). Here, as described in 2.8.1, the command on the running direction by the F cable and the R cable were the command on the running direction of the vehicle, then there is the case as different from the actual running direction of the train.

The station ATO onboard unit judges that the running direction was set up in the vehicles by checking the energized status of the 194G cable or the 195G cable, and transmit the signal on the running direction in forward or backward, *hereinafter referred to as "the status of running direction"*, to the station ATO ground unit on the ground, as shown in Figure 4 (5).

In addition, the F cable and the R cable are wired through in the trainset from the DC power source bus cable<sup>\*22</sup> and connected to the motor control devices mounted on the 1st, the 3rd and the 5th vehicles, via the circuit breakers for the wired cables installed in the 1st and the 5th vehicles, *hereinafter referred to as "the control circuit breaker"*, and the front relay board. Additionally, the energized status of the F cable of the vehicle running in outbound direction or the R cable of the vehicle running in the inbound direction is held by the front relay board. When the instruction on running direction from the station ATO ground unit changed in the next turn-back station, the

station ATO onboard unit switches the energizing statuses of the 194E cable and the 195E cable, as the results, the energized statuses of the F cable and the R cable are reversed. Furthermore, the signal of the onboard antenna for the ATC/TD switches according to the energized status of the 194G cable and the 195G cable, as to activate the 1st vehicle when the running direction of the train is outbound or to activate the 5th vehicle when the running direction of the vehicle is inbound. When the side doors of the vehicles and the platform gates are in the closed status in the scheduled departure time, the station ATO ground unit transmits the departure instruction to the station ATO onboard unit, as shown in Attached Figure 4 (6), then the train start running. [Refer to Attached Figure 3 and 4]

- \*8 *"Center unit of the centralized traffic control system" is the automatic remote-control device by concentrating the functions to handle the switches and the signals in each station to a certain place.*
- \*9 *"ATO ground unit" in the Route implement automatically, the starting control from station, the constant speed operation control, the stopping control at the predetermined position in the station, etc. Here, the "ATO" is the abbreviation of the Automatic Train Operation that is the system to implement automatically, the starting control, the on-schedule operation control, the stopping control at the predetermined position, etc.*
- \*10 *"ATC ground unit" in the Route is the device to supply the high frequency signal current superposing the modulated signal current corresponding to the allowable velocity, to the loop coils for the ATC and the train detection in each block section installed on the ground.*
- \*11 *"Station ATO ground unit" in the Route is the device to control in the station area, to transmit and receive the information between the dispatcher's office and the trains in the whole route, and between the traffic dispatcher's office and the devices in the station facilities in each station, in the automatic train operation.*
- \*12 *"Station ATO onboard unit" in the Route is the device to receive the information to implement the automatic train operation from the ground and send the information to the control circuit and the devices on the vehicle, and to transmit the information such as the status of the vehicles, the failures, etc., to the ground.*
- \*13 *The "ATO onboard unit" of the vehicles in the Route control the train running between stations automatically and output the proper notch, etc., to control train operation to stop at the predetermined position in the stations, based on the control information from the ground, such as the allowable velocity, the control instructions in the station, the information on the position, the control instructions, etc.*
- \*14 *"Train detecting device" in this text, is the device to detect the position of the running train. In the Route, the check-in signal and the check-out signal are transmitted from the onboard antennas in the front end vehicle and the rear end vehicle, respectively, when the train entered the block section, the loop coil on the ground in the block section received the check-in signal, and when the train went out of the block section, the ground loop coil in the next block section in ahead received the check-out signal. Here, "TD" is the abbreviation of the train detection.*
- \*15 *In the usual railways, the transmission of the ATC signal or the train detection are implemented by sending the signal currents in the rails.*
- \*16 *"ATC onboard unit" of the vehicles in the Route is the device to receive the high frequency signal current flowing in the loop coil of each block section by the onboard antenna in the front vehicle, and to compare this output signal with the output signal of the tachometer generator attached to the traction motor, then control the train velocity or stop the train automatically when the train runs exceeding the limited velocity.*
- \*17 *"Abnormal running" in this context is the abnormal on the running status such as the exceeding velocity, the running in wrong direction, etc. In addition, the abnormal status occurred in the vehicles such as the abnormal status of the devices, the abnormally closed status of the side doors, etc., added to the abnormal running are called as "the abnormal status".*
- \*18 *"Predetermined area" in the Route means the area where the open and close control of the platform gates in the station can be implemented.*



- \*19 *"Energize" in this context means to connect the electric wire electrified by the DC 100V to the 194E cable or the 195E cable to supply the DC 100V to these command cables, in the station ATO onboard unit.*
- \*20 *"Front relay board" of the vehicles in the Route, is the device installed in the head vehicles in both ends of the train, and composed of the signal relays, etc., related to the switching of the running direction, switching of the automatic or the manual operation, the inching operation, etc. Here, the "inching operation" is the running method to fit the stopped position to the predetermined position again by the automatic operation, when the train had stopped in forward or backward position against the predetermined position in the station, due to some reasons.*
- \*21 *"Driving desk" in this text is the device to implement the handling operation equipped in the front vehicles. The driving desk in the 5th vehicle or the 1st vehicle is selected to be used when the running direction is inbound or outbound, respectively.*
- \*22 *"DC power source bus cable" in this context is the electric wire supplying the DC 100 V electric power, supplied from the batteries, etc., in the 2nd and the 4th vehicles, to the bus cable wired through in the whole trainset.*

### 2.3.3. Facilities in Shin-Sugita Station

*[Refer to Attached Figure 2 and 5]*

The loop coils for the ATC/TD were installed in the overrun protection signal section to prevent overrunning of the inbound train that could not stop at the predetermined position, and in the starting signal section, that is the arriving signal section for the inbound train, continued toward Kanazawa-Hakkei station, respectively.

When the train stopped at the predetermined position in Shin-Sugita station, the position of the onboard antenna for the ATC/TD in the 1st vehicle was in the starting signal section, 24,586 mm apart in the direction to Kanazawa-Hakkei station from the boundary between the overrun protection signal section and the starting signal section, *hereinafter referred to as "the signal section boundary"*.

As Shin-Sugita station is the turn-back station and the track was dead ended, the safety margin for overrunning was constructed for about 24,500 mm from the predetermined stop position, if the train cannot stop there, the train collides with the car stop at the end edge of the track. The car stop was equipped with the hydraulic buffering device with 1,000 mm stroke which is supposed the overrunning of the train, and designed to stop the train in cooperation with the braking force of the train even if the train collided in the maximum velocity 10 km/h.

### 2.3.4. Monitoring System in the Dispatcher's Office

The surveillance monitors which displays the status on the platform in all stations, the operating status indication displays which indicates the position and the train number of each train, the monitoring board to monitor the trouble, etc., of the electric power, the disaster prevention system, the vehicle depot, the facilities in the stations, are installed in the dispatcher's office, and total 3 dispatchers, *i.e.*, one dispatcher monitors the facilities such as the electric power system and the other 2 dispatchers monitor the status of all trains and all stations by the monitor displays, etc. Shin-Sugita station, Namiki-Chuo station and Kanazawa-Hakkei station are the manned stations and the other stations are the unmanned stations, but the dispatcher's office comprehensively implements the operation management and the security of the safety, such as to implement remote operation of the platform gates, the public announcing devices, the facilities managing disaster

prevention, etc., and to implement the emergency stop procedures for all trainset or the designated train individually in an emergency, effectively using the surveillance cameras and the monitor displays.

## 2.4. Information on Damages and Traces of the Vehicles and the Railway Facilities

### 2.4.1. Status of the Vehicle just after the Occurrence of this Accident

The status of the Train just after the occurrence of this accident was as follows.

- (1) The headlight in the 1st vehicle had been lighting.
- (2) The tail light marker in the 5th vehicle had been lighting.
- (3) The control circuit breakers in the 1st and the 5th vehicles were in the turned on status.
- (4) The F cables and the R cables in the 1st vehicle to the 5th vehicle were all in the status de-energized, *i.e.*, 0 V.

### 2.4.2. Status of Damages and Traces of the Vehicles

*[Refer to Attached Figure 6]*

There were the damages mainly in the coupler parts and the vehicle ends from the 2nd to the 5th vehicles, and the bending of the intermediate couplers, the deformation of the end plate, the deformation of the ceiling panels and the floor boards, the deformation of the gangway footplates, were found. Here, there was no significant damage in the coupled part between the 1st and the 2nd vehicles.

### 2.4.3. Status of the Railway Facilities after this Accident

*[Refer to Figure 3]*

The hydraulic buffering device of the car stop in the track No.1 of Shin-Sugita station, described in 2.3.3, struck the guide end and stopped after lengthened about 1,000 mm by the collision of the Train. However, there was no significant damage in the other facilities in the station, even though the oil leaked from the hydraulic machinery.



Figure 3. Status of the hydraulic buffering device after this accident

## 2.5. Information on the Breaking of the Command Cable for the Running Direction

### 2.5.1. Status of the Broken Command Cable for the Running Direction

In the investigation on the status of the vehicles implemented after this accident, it was found that the F cable, which is the command cable transmitting the running direction of the train to the motor control device, etc., described in 2.3.2, was broken in the device room in the rear left of the

cabin of the 1st vehicle, hereinafter referred to as "*the Device Room*" and sometimes referred to as "*the Vehicle*", respectively, and the other side of the broken part was melted and adhered to the part of the end structure\*<sup>23</sup> attached to near floor board of the vehicle body, hereinafter referred to as "*the end rail*"\*<sup>24</sup>. [Refer to Figure 4]

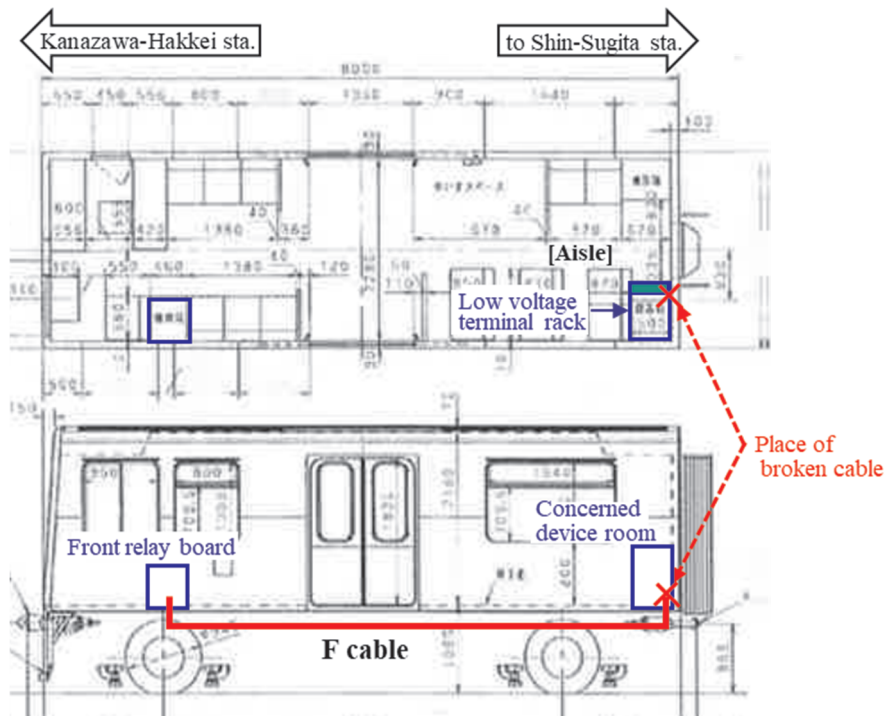
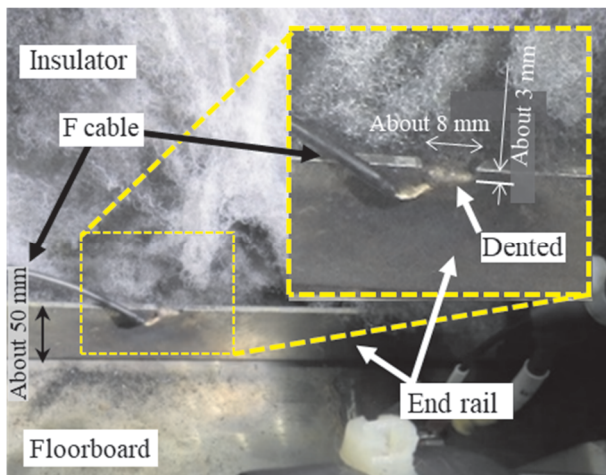


Figure 4. Route of the F cable and the broken place in the Vehicle

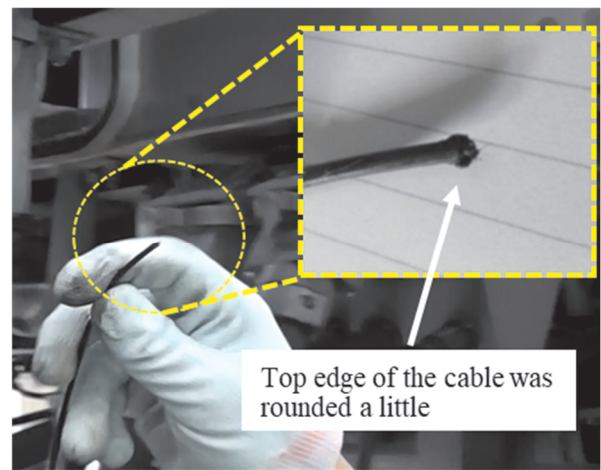
The F cable, which is wired from the front relay board, via under floor, lifted to above the floor through the wiring hole in the floorboard of the Device Room and connected to the low voltage terminal base installed in aisle side in the Device Room, was broken at the upper part of the end rail in the Device Room, and the broken electric wire in the side to be connected to the low voltage terminal base, was melted and adhered to the end rail. On the other hand, the tip of the broken electric wire in the side to be connected to front side was in the status as a little round. In addition, the broken electric wire connected to front side was the side to be connected to the control circuit breaker and the front relay board, and the melted and adhered electric wire in the low voltage terminal base side was the cable connected to the motor control device and to the 2nd vehicle.

In addition, the adhered part in the end rail was dented in about 8 mm wide and about 3 mm depth, and the black materials were adhered in the both surfaces of the parts in its peripherals.

Furthermore, the black materials were adhered in around the melted and adhered place in the bundle of cables\*<sup>25</sup> wired in the nearest place to the end rail, and the sheath of the outer most cable was torn. [Refer to Figure 5]



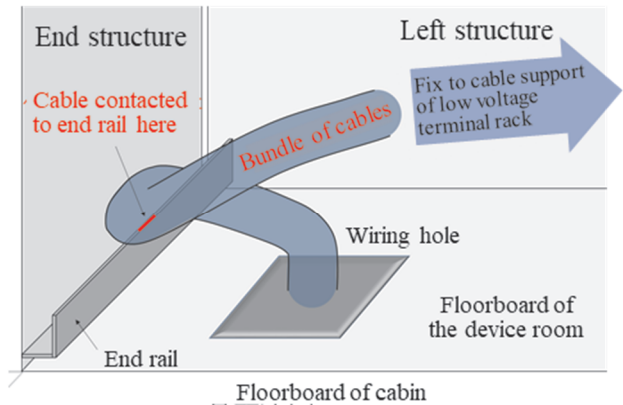
Status of electric wire, in low voltage terminal side, melted and adhered to the vehicle material.



Broken status of electric wire in front side



Status of bundle of cables in around the place where cable was melted and adhered



Status of bundle of cables in the Device Room

Figure 5. Status of the neighborhood of the broken electric wire

The electric wire of the light weight specification, which is lighter than the electric wire of the standard specification, *hereinafter referred to as "the lightened electric wire"*, had been used for the F cable. According to the company, as the vehicles of the Route are operated by the rubber tires, the vehicles are required to make light in weight from the viewpoint of the load weight of the structures of the track, etc., the passenger capacity, the tolerance of the rubber tires, etc., therefore, the lightened electric wires, which are about 20 % lighter than the standard specification electric wires, were used in a part. The specifications of the electric wires used for the F cable are shown in Table 5.

In additionHere, the "general rules for electric wires and cables, rolling stock", J1000, the Japan Association of Rolling Stock Industries Standard, the JRIS, prescribed on the matters to be attended to treat the lightened electric wires as follows.

*10 Matters to be attended*

*The electric wires for the vehicles should be treated carefully considering the following matters.*

- a) *The electric wires should be treated carefully not to be damaged, because there is the case to cause the dielectric breakdown by the decreased insulating characteristics due to the*

damages of the insulators. Particularly, the lightened electric wires using the thin covering materials and the halogen free electric wires which used the soft surface insulators required the following attentions.

1) [Omitted]

2) Considering the used environment as received the vibration, it is necessary to endeavor to secure the wiring route and the proper remaining length as to avoid the contact between electric wires and metal pieces, and to implement thoroughly the covering process in order not to damage the covers of the electric wires.

According to the vehicle manufacturer, at the time when manufactured the 2000 series vehicles, the lightened electric wires were used occasionally for the vehicles of the conventional railways for the private railways, hereinafter referred to as "*the ordinary railway vehicles*", and there was the recognitions that the special attention was needed for the treatment compared to the standard electric wires.

Table 5. Characteristics of the electric wires used for the F cable

Material of insulator	Fluorine resin ETFE : Ethylene Tetra Fluoro Ethylene
Nominal cross-section	1.25 mm <sup>2</sup>
Nominal thickness of insulator	0.4 mm
Roughly estimated mass	16 kg/km
Insulation resistance	32,000 MΩ-km
Cut-through characteristics <sup>*26</sup>	120 to 137 N
Abrasion characteristics <sup>*27</sup>	767 to 975 times

<sup>\*23</sup> "Structure" means the structure of the vehicle body, "end structure" is the structure of the end part of the vehicle body, "side structure" is the structure of side surface of the vehicle body. Here the "end" is a part of the vehicle body, that is the part composed of both ends of the vehicle body connecting the roof and the underframe, i.e., framework as the base of vehicle body, in general.

<sup>\*24</sup> "End rail" is the horizontal materials in the direction of sleepers in the lowest part to support the vertical material, i.e., the end post, among the parts composed of the end structure.

<sup>\*25</sup> In this report, the "electric wire" indicates the single conductor cable, the "cable" indicates the multicore cable, the "electric wires, etc." indicates the electric wires and the cables, the "bundle of cables" indicates the bundled plural electric wires, etc.

<sup>\*26</sup> "Cut-through characteristics" is one of the worn characteristics by the external flaw of the electric wires, and is the tolerance against the strong pressure in the edge part, and estimated as the load weight when the electric wire was short circuited while the jig having the 90 degrees sharp edge was applied in the ratio of 5 mm/min.

<sup>\*27</sup> "Abrasion characteristics" is one of the worn characteristics by the external flaw of the electric wires, and is the tolerance against abrasion in the metal edge part when wired cables in the outfitting procedures. It is estimated by the repeated number of the reciprocating operation as pushing the electric wire by the sharp edge tool with the force of 2 pounds, i.e., 907 g, until to be short circuited.

### 2.5.2. Status of the Cable Wiring, etc., in the Device Room

In the Device Room, two main air reservoirs <sup>\*28</sup> and the low voltage terminal base in the aisle side are installed, and the total about 340 electric wires and cables, hereinafter referred to as "*the*

*electric wires, etc.*", lifted through the wiring hole to above the floor, are divided into the groups for each connecting object in around the wiring hole. Among these, the electric wires, etc., wired in the aisle side via the neighborhood of the end structure in the Device Room, were gathered in 4 bundles of cables using the protecting materials using the rubber bands and fastening bands, respectively, and piled up vertically and fastened into a large bundle of cables, and fixed to the cable support in the rack to attach the low voltage terminal base, *hereinafter referred to as "the low voltage terminal rack"*. After this accident, the wired route of the F cable which had been connected to the low voltage terminal rack was investigated after this accident by removing from the bundle of cables toward the wiring hole and found that the F cable had been in the lowest bundle of cables among four bundles of cables, near to the end rail. [Refer to Figure 6 and 7]

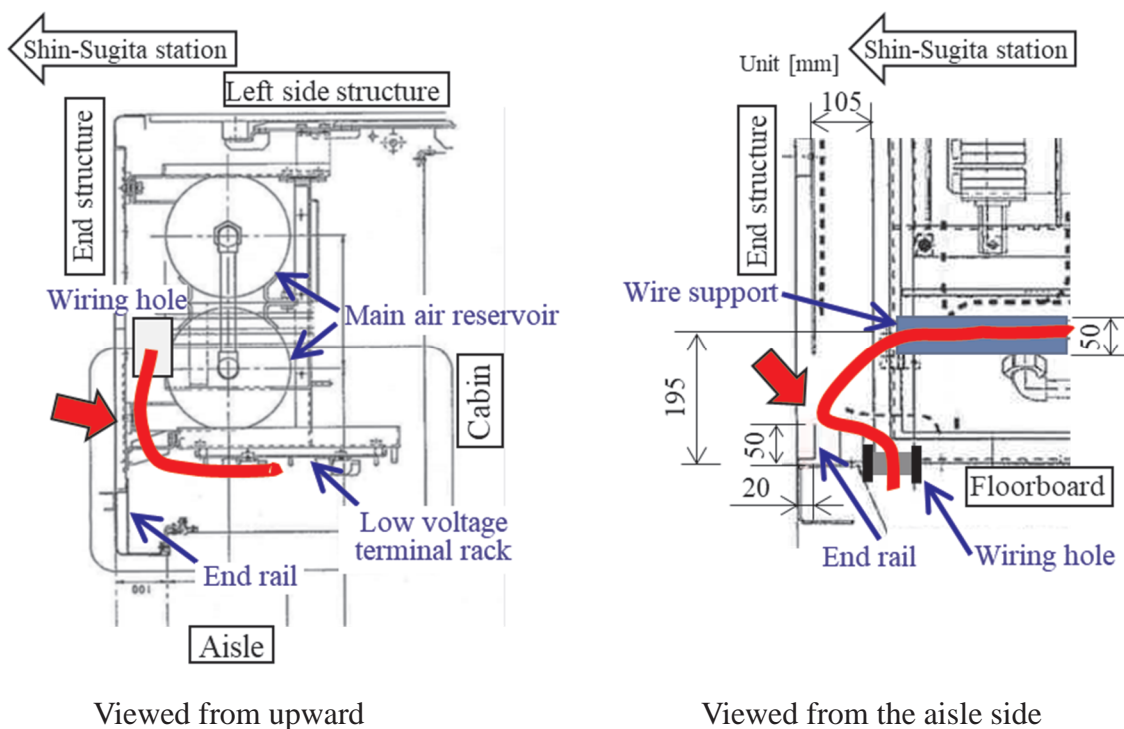


Figure 6. Device layout and wired route of bundle of cables in the Device Room

In addition, Figure 7 shows the status that the electric wires, etc., connected to the low voltage terminal base, were removed and the belt to fasten the lowest bundle of cables was removed, in order to investigate the route of the F cable.

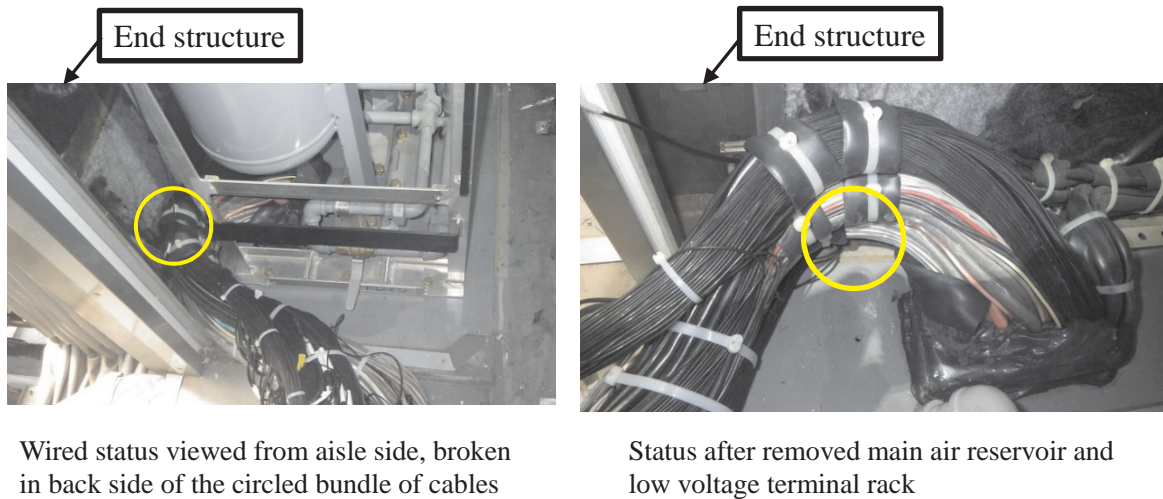


Figure 7. Status of inside of the Device Room, when investigated

The end rail is the 1.5 mm thick stainless steel plate, attached in the Device Room as its upper surface is about 50 mm apart from the floor board, about 20 mm apart to inside from the end structure.

The upper surface of the end rail is made as square shape cut by the laser cutting, but the resin protecting material, *hereinafter referred to as "the vehicle material side protectors"*, to prevent damage of the electric wires, etc., attached to the materials of vehicle such as the body structure, the racks for devices or the interior finishing materials, etc., *hereinafter referred to as "the vehicle materials"*, was not attached. Furthermore, the adhesive for insulating material pasted to inside of the end structure were adhered on its surface. The shape of the corner part was almost rectangular, without chamfered nor grinder finishing, then the surface felt rough when touched by hand. [Refer to Figure 8]

\*28 "Main air reservoir" is the air tank to reserve the compressed air to supply air to all pneumatic devices in the pneumatic circuit.

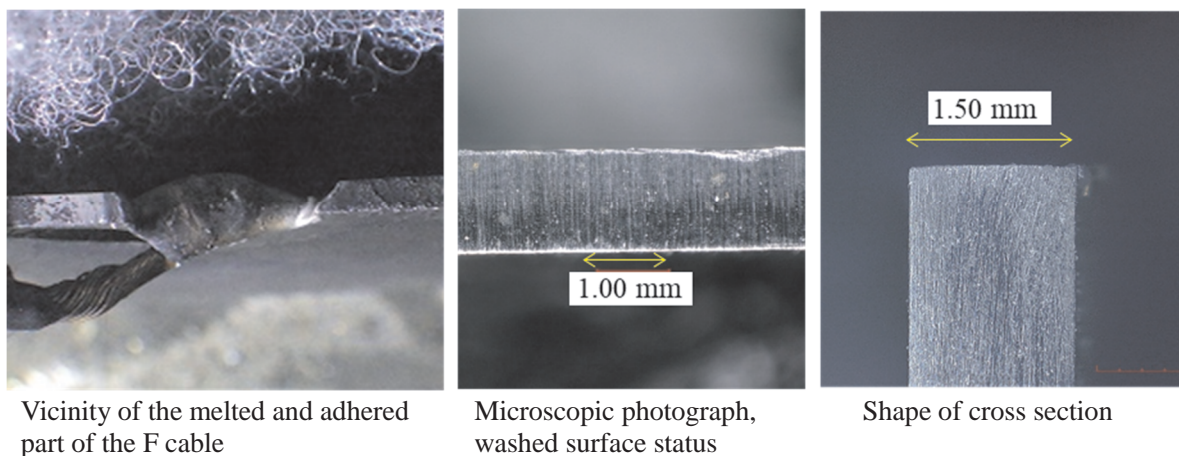


Figure 8. Shape of the top surface of the end rail

## 2.6. Information on the Wiring Works, etc., in the Vehicle Manufacturer

### 2.6.1. Wiring and Connecting Works When Vehicles are Manufactured

The vehicle manufacturer provided the "Manual for wiring in around the end plate" as the manual for the wiring works in the Device Room, and showed the wiring route, etc., from the wiring hole to the low voltage terminal base.

According to the vehicle manufacturer, the procedures of the wiring cables in the Device Room are as follows.

- [1] Divide the electric wires, etc., lifted from the wiring hole into each route, fasten the electric wires, etc., after arranged in each route, and integrate as the bundle of cables.
- [2] Attach the main air reservoir, the low voltage terminal rack, the main body of the low voltage terminal board, etc.
- [3] Fix the bundle of cables made in the above [1] to the cable support in the aisle side of the low voltage terminal rack finally, after that, connect each electric wire, etc., to the low voltage terminal board, etc.

In addition, the works [1] were implemented by the wiring workers mainly charged in the laying electric wires, the works [2] were implemented by the workers mainly charged in the outfitting<sup>\*29</sup> to attach the devices, etc., and the works [3] were implemented by the connecting wire workers mainly charged in the connecting work of the electric wires to the terminal board, etc.

As the route and the grouping method of the bundle of cables in the wiring works are entrusted to the engaged wiring workers, but, in the place such as the concerned bundle of cables, the cables are bundled in two stages, *i.e.*, fasten cables preliminary after decided the wiring route, in addition, fasten by the protecting materials for the electric wires side and the bundling band, etc.

When implement the wiring works, the wiring route is decided as the electric wires, etc., keep the spacing with the vehicle materials, in order not to contact each other, and attach the protecting materials in the electric wire side or the vehicle materials side or in the both sides, as the fundamentals, when there is a possibility to contact with each other.

Here, the "Manual for outfitting" has been provided for each vehicle, and "the vinyl horse and the flexible bush" are prescribed as the processing procedure for the "protection of the contacting part" in the driver's cab, the cabin, and the ceiling.

According to the vehicle manufacturer, the "manual for outfitting" and "manual for wiring in around the end plate" describe the general points required attention and the rough instructions such as the protection of cables in the narrow space, etc., and they were not the manuals to promote individual attentions when implementing the wiring works.

*\*29 "Outfitting" is the process to attach the various devices, wiring cables, laying pipes, etc., to the vehicles, in the process of manufacture vehicles.*

#### 2.6.2. Confirmation after the Wiring and Bundling Works are Finished

According to the vehicle manufacturer, the wiring workers, etc., is requested to check the electric wires, etc., after finished the wiring works, visually and touched by hands whether the electric wires contacted with the vehicle materials, etc., or the bundled status of the electric wires, etc. The finally wired status in around the end rail from the wiring hole to the low voltage terminal board in the Device Room, should be checked by the connecting wire workers in the work [3]



described in 2.6.1, but it was difficult to check visually or to touch by hand, by the reasons such as the narrow gap between the end structure and the low voltage terminal rack, etc. In addition, there was no checking item to confirm the wired status from the wiring hole to the low voltage terminal board, even though there was the check sheet for the connecting works of the low voltage terminal board.

### 2.6.3. The Inspection of the Vehicles When Completed Manufacturing

The inspection of the vehicle when completed manufacturing has been implemented by the other section different from the section charge in the wiring works.

The "check sheet for the inspecting items in the completed vehicle" of the 2000 series vehicle was checked, but there is no checking item on the wired status.

According to the vehicle manufacturer, there is no checking item on the wired status because "the conductivity test" implemented in the "Inspection before applying electricity to prepare the functional test" in the check sheet, is combined with the confirmation of the wired status. In addition, there is no chance to inspect the wired status, etc., in the Device Room, after finished the wiring works till the completion of manufacturing the vehicle.

## 2.7. Information on the Periodic Inspection, etc., in the Company

### 2.7.1. History of the Periodic Inspection, etc., of the Vehicle

The periodic inspection for the vehicles in the Company is stipulated in the "Rules on the vehicle maintenance" notified by the Company to the Kanto District Transport Bureau.

The rule on the vehicle maintenance stipulates the groups for each category of the inspection, and the inspection of the items related with wiring cables are stipulated to implement in the "relays, electromagnetic valves, wiring cables, etc." of the "general electric devices" in the monthly inspection, the critical parts inspection and the general inspection, and the inspecting items are stipulated as the "damages and attached status of electric wires, connecting box, the other accessories" and to implement mainly by the visual inspection.

In the critical parts inspection and the general inspection, the "insulation characteristics" is added to the inspecting items and the inspection method is stipulated as "the insulating resistance test and the dielectric strength test". Furthermore, it is prescribed that the general tests should be implemented in the critical parts inspection and the general inspection, and designated the inspecting items as "the functions to control and protect the devices in the control circuit", and the inspecting method was stipulated as "the measurement".

The results of the monthly inspection and the critical parts inspection of the Vehicle, implemented just before this accident, were checked and found that there was the record as "good" in the column "damages and attached status". Furthermore, in the critical parts inspection, the insulating resistance measurement and the dielectric strength test between the DC power source bus cable and the vehicle body, were conducted and there was no problem in the records of the results.

In addition, it was confirmed that there was no problem in the control and function using the F

cable in "the function to control and protect the device in the control circuit" in the general inspection. [Refer to Table 6]

Table 6. Period and conducted date of the inspection, etc., of the Vehicle

Category of inspection, etc.	Inspection period	Conducted date
Inspection for newly manufactured	-	March 22, 2013
Critical parts inspection	4 years	March 30, 2017
Monthly inspection	Every period not exceed 3 months	May 21, 2019
Train inspection	Every period not exceed 3 days	May 30, 2019
General inspection	8 years	Not conducted yet, scheduled to conduct by March, 2021.

2.7.2. History of the Remodeling of the Vehicle

The confirmation of the remodeled history of the Vehicle was implemented and found that there was no record on the remodeling of the Device Room.

2.8. Information on the Running in Wrong Direction

2.8.1. Setting the Running Direction

As described in 3.1.2, the train received the instruction on the running direction of the train from the station ATO ground unit, and set the forefront vehicle and the running direction in each device, etc., to the opposite direction, based on the energized status of the 194G cable or the 195G cable, while stopping in the turn-back station.

According to the vehicle manufacturer, in the backward inching operation<sup>\*30</sup>, etc., of the train stopping in the station, the front relay board had been set as to move the train backward, *i.e.*, the motor control device drive the motors in the opposite direction, by only change the energized status of the F cable and the R cable, while the energized status of the 194G cable and the 195G cable did not change, in order to avoid the errors that the command on the running direction from the station ATO ground unit to the vehicles disagree with the information on the status of the running direction sent from the vehicle. Originally, the station ATO onboard unit was set to transmit the energized status of the F cable and the R cable, as the status of running direction of the vehicle, to the station ATO ground unit, but changed in the meeting for design review, etc., consisted of the Company and the vehicle manufacturer described in 2.9.2 and 2.9.3, to the system to transmit the energized status of the 194G cable and the 195G cable same as in the 1000 series vehicles based on the above reasons.

Furthermore, in the 2000 series vehicles, separately from the command of the running direction by the F cable and the R cable, the powering command is inputted to the motor control device from the ATO onboard unit and the master controller in the driving desk in the forefront vehicle by the P cable, and the P cable becomes in the energized status when the conditions for the

powering operation was established, and the powering command is inputted to the motor control device.

*\*30 The "backward inching operation" in this context is one of the inching operation, to move the vehicle backward in order to adjust the stopping position to the designated position again, by the automatic operation, when the vehicle had stopped in the position ahead of the designated position.*

## 2.8.2. Motor Control

[Refer to Table 7]

The memory function to store the running direction of the vehicle, *hereinafter referred to as "the function to memorize running direction" or simply as "the memory function"*, was equipped in the motor control device. The information on the running direction was set to the memory function by the energized status of the F cable and the R cable, and drives the motors in the outbound direction or the inbound direction according to the memorized running direction. In the 2000 series vehicles, one of the F cable and the R cable is always in the energized status while the vehicle is running, and renewed the running direction in the memory function when the running direction of the train changed in the turn back station, etc., and the energized status of the F cable and the R cable is changed. The specifications of the functions for the motor control device prescribed the information on the memory function as that the memory function should keep the previous running direction when both the F cable and the R cable become to in the de-energized status. Further, the specification of the functions prescribed that the vehicle should not be operated in the powering operation when both the F cable and the R cable become to the energized status by some reasons, however, there is no description on the operation in the case that the powering command is inputted when both the F cable and the R cable become in the de-energized status.

Table 7. Relation between energized status of the F and R cables and the driven direction of the motors by the motor control device

Status of F cable	Status of R cable	Direction that the motor control device drives the motors
De-energized	De-energized	Keep the previous direction
Energized	De-energized	Set to outbound direction, <i>i.e.</i> , from Shin-Sugita station to Kanazawa-Hakkei station.
De-energized	Energized	Set to inbound direction, <i>i.e.</i> , from Kanazawa-Hakkei station to Shin-Sugita station.
Energized	Energized	Operate the train protection

In the 2000 series vehicles, when the running direction of the train is outbound direction, the energized status of both the F cable and the R cable, which are inputted to all motor control devices installed in the 1st, the 3rd and the 5th vehicles, become in the de-energized status if the F cable is broken in the device room, etc., in the 1st vehicle, same as in this accident, and the information in the memory function is not renewed and keep the information of the previous running direction. When the train is going to operate in the outbound direction after turned back in Shin-Sugita station, and received the powering command from the ATO onboard unit, all motors are driven in the inbound direction opposite to the direction of travel, because both the F cable and the R cable are in the de-energized status and the motor control devices had been set to drive the motors in the

inbound direction, which is the previous running direction kept in the memory function.

Here, according to the device manufacturer of the motor control device, *hereinafter referred to as "the device manufacturer A"*, it is considered as an assumption that the function to memorize running direction is used to recognize the rotating direction of the wheels in the regenerating operation when the regenerating brake is operated, and the powering command is inputted to the motor control devices after adjusted the consistency with the statuses of the F cable and the R cable in the forward and backward switching circuit, in the ordinary railway vehicles.

### 2.8.3. Function to Detect Abnormal Running

The 2000 series vehicle is decelerated or operated the emergency brake by the ATC onboard unit, etc., when the exceeded velocity, the abnormal closed status of the side doors, the no ATC signal status, the decrease of main air pressure, the backward moving, etc., were detected.

The ATC onboard unit is equipped with the function to detect backward running as one of the functions, and detecting the backward running of the train. According to the device manufacturer of the ATC onboard unit, *hereinafter referred to as "the device manufacturer B"*, the function to detect backward running in the 2000 series vehicles assumed the case such that the vehicle moved backward slowly when the vehicles started in the upgrade track, same as for the ordinary railway vehicles. The function to detect the backward running acts in the following conditions.

- [1] There is the running direction signal inputted based on the energized status of the F cable or the R cable, at the same time, there is the phase detection<sup>\*31</sup>.
- [2] The velocity is in the range from 3 to 20 km/h.
- [3] The above conditions [1] and [2] continue for over 1 second.

According to the statements of the device manufacturer B, the function to detect backward running assumed that the information on the running direction, etc., was inputted correctly, and judge that the vehicle run in the backward direction, when the above all conditions [1] to [3] were satisfied and the vehicle moved in the direction opposite to the direction of travel, and then apply the emergency brake.

Additionally, the function to detect backward running use the F cable and the R cable as the command of the running direction, in order to make the function detect backward running effective, against actual running direction of the vehicle, in the backward running by the manual operation and the back inching running, described in 2.8.1.

<sup>\*31</sup> *"Phase detection" in this context is to detect the signal on the phase difference between two sinusoidal signals obtained from the tachometer generator. The velocity and the direction of the rotating wheel are detected from these signals.*

### 2.8.4. Operating Status of the Train Protection System

*[Refer to Attached Figure 5]*

The ATC onboard unit and the train detection device are equipped as the train protection system in the 2000 series vehicles.

As described in 2.3.3, the station ATO onboard unit in the Train received the running direction command "outbound" from the station ATO ground unit, after arrived as Shin-Sugita station, and set the 1st vehicle as the forefront vehicle, therefore, the signal of the onboard antenna for the

ATC/TD in the 1st vehicle becomes as valid.

When the Train moved to backward, the emergency brake did not act because the onboard antenna for the ATC/TD in the 1st vehicle, which already became to valid, was in the departure signal section and the ATC signal at that time was the "40 signal", as described in Table 3, then the 5th vehicle of the Train collided with the car stop after it ran for 24,500 mm from the predetermined position before started toward the terminal end of the track. The onboard antenna entered the overrun protection signal section when it ran for 86 mm after that, and the Train stopped after it ran pushing the car stop for 914 mm toward the terminal end of the track. Here, the ATC onboard unit recognized the ORP signal when the Train had almost stopped, then, the emergency brake did not act even in the protection section for overrunning.

As described in 2.1.3, according to the data recorded in the event recorder, the ATC onboard unit recognized the 40 signal when the Train started, and the ORP signal after it collided, as the ATC signal. In addition, the time element <sup>\*32</sup> about 0.5 second has been set to switch the recognition of the ATC signal in the ATC receiver. Although the ATC onboard unit detects the abnormality of input signals of the ATC signal or the velocity signal, and the troubles in the arithmetic circuit, the abnormal status had not been detected while running.

*\*32 "Time element" in this context is the time required to recognize the change of the signal when the signal had changed and continued its status.*

#### 2.8.5. Setting Methods of the Running Direction in the Other New Transit System

According to the materials of the the 3rd study meeting on the prevention of accident in railways and tramways operated by unmanned automatic operation, held by the Ministry of Land, Infrastructure, Transport and Tourism, and the hearing investigation implemented by the Japan Transport Safety Board, the setting method of the running direction in the other six railway and tramway operators, who operated the unmanned automatic operation, had been such systems that the onboard device and the ground device compares plural information, *i.e.*, the running direction commands from the ground, the recognition on the running direction by the motor control devices, and the recognition on the running direction by the ATC device, and did not move the train if they were inconsistent, in all routes. However, in the concerned Route, different from the other 6 operators, the comparison of the running direction command from the ground device and the running direction command to the motor control device had not been implemented as the system.

### 2.9. Information on the Design of the 2000 Series Vehicle

#### 2.9.1. Procedures, etc., when the 2000 Series Vehicle were introduced [*Refer to Attached Figure 7*]

The Route started the commercial operation in 1989, and the 1000 series vehicles, designed and manufactured by the other vehicle manufacturer, were operated by the manned manual operation, started the automatic operation boarded by the train crew from 1992, and started the unmanned automatic operation from 1994.

According to the Company, due to the deterioration of the 1000 series vehicles, etc., the company decided to introduce the new type vehicles basically to be operated by the unmanned

automatic operation, and selected 5 major vehicle manufacturers in the country in order to implement the synthetic evaluation including not only the cost but the technologies, etc. by the synthetically evaluating method<sup>\*33</sup>. After evaluated synthetically the received technological proposals from 5 vehicle manufacturers, the Company made the contract on the manufacturing of the 2000 series vehicles with the vehicle manufacturer in December 2008. This was the first time for the contracted vehicle manufacturer, to design the vehicle of the new transit system, *hereinafter referred to as "the new transit system vehicle"*, even though the vehicle manufacturer had the experience to manufacture the vehicle body of the 1000 series vehicle as one of the joint venture. The Company applied the changed design of the vehicles to the Governor of Kanagawa Prefecture on October 2009, based on the Tram Law, and was approved in December 2009. The first set of the 2000 series vehicles were delivered to the Company in October 2010.

<sup>\*33</sup> *"Synthetically evaluating method" in this context is, the bidding system to evaluate synthetically the "cost" and the "factors except for the cost, for example, conservation of the initial performance, safety construction, effects to the environment", different from the conventional automatic contract system which decide only by the cost, concretely, the bidding system that determined the successful bidder by evaluating synthetically the cost and the contents of the technological proposals submitted from the bidder.*

#### 2.9.2. Process to Design the 2000 Series Vehicles

According to the examples of the process to design and manufacture the vehicles shown by the vehicle manufacturer, the vehicle manufacturer studied the contents of the proposals based on the specifications presented to the vehicle manufacturer from the operator, and submitted the proposal of technical matters to the operator. After the contracts were concluded, through the plural meetings between the railway operator and the vehicle manufacturer, the meetings for the design review were held and the design was examined based on the drawings and the materials, etc. At the time when the vehicle manufacturer completed the precise design, the design examination, etc., were conducted, and discussed on the validity and the safety of the design. After that, the vehicles were proceeded to the manufacturing process, and after going through the interim inspection and the completion inspection, etc., by the operator, the vehicles were delivered to the operator and put into the operation.

According to the vehicle manufacturer, the 2000 series vehicles were designed and manufactured in almost the same process, *hereinafter referred to as "the designing and manufacturing process of the 2000 series vehicles"*. [Refer to Figure 9]

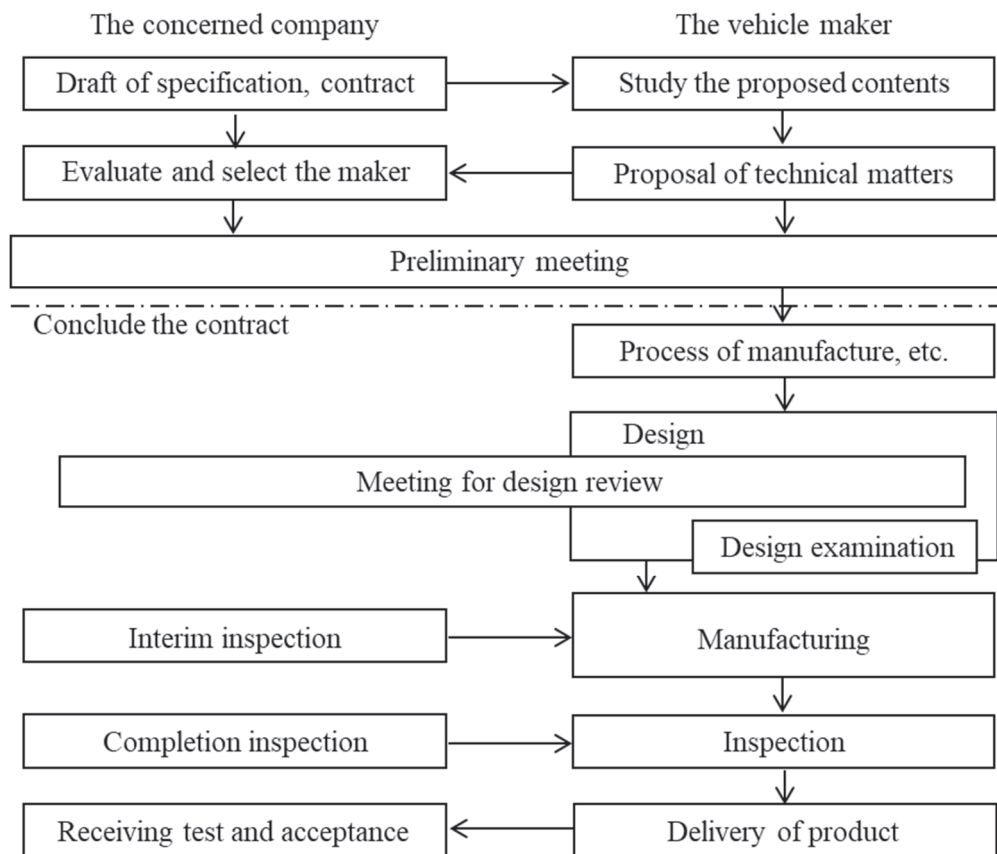


Figure 9. Designing and manufacturing process of the 2000 series vehicles

### 2.9.3. Studied Subjects in the Meeting for Design Review

Usually, when design the new vehicle, the meetings for design review by the operator and the vehicle manufacturer, etc., are held, and a variety of the subjects are studied. According to the Company and the vehicle manufacturer, the Company and the vehicle manufacturer held the meetings for design review total 32 times from December 2008 to June 2010, in addition, the arrangements on the design by the Company, the vehicle manufacturer and the device manufacturer were held total 31 times from December 2008 to July 2010.

According to the minutes of the first meeting for design review held in December 2, 2008 and the second meeting for design review held in December 19, 2008, the vehicle manufacturer submitted the materials such as the plan of the manufacturing process and the list of the onboard devices, etc., and implemented the study works on the manufacturing process, the layout of the onboard devices, the selection of the device manufacturer, etc. In the following meetings, the drawings and the materials on the body structure, the outfitting, the systems, etc., which had been designed up to that moment, were submitted mainly from the vehicle manufacturer. In addition, a variety of items on the design and manufacturing of the 2000 series vehicles, such as the designing and the manufacturing process, the selection of the device manufacturer of the ATC onboard unit and the motor control device, etc., were the studied subjects. The Company and the vehicle manufacturer agreed these studied subjects when there was no special problem, and discussed each other if there was the problem or the matters to be confirmed, and the precise subjects were studied gradually as repeating the meetings.

#### 2.9.4. Recognition on the Designing System, etc., of the Company and the Vehicle Manufacturer

The confirmation was implemented, on the designing system of the Company and the Vehicle Manufacturer, the basic concept, and the integration with the existing facilities of the Route when the 2000 series vehicle was designed, and it was found that there was some difference in the recognition between the Company and the vehicle manufacturer.

On the "designing system", the Company thought that "the vehicle manufacturer is in charge of the design including the onboard devices, and is responsible for the design and the manufacturing of the entire vehicle, based on the contract on the manufacturing", but the vehicle manufacturer thought that "the vehicle manufacturer stands in the position to design the attaching mechanism and the interface, etc., of the body structure and each device, and to setup as the vehicle. The vehicle manufacturer thought that the device manufacturer takes responsibility to design and manufacture each device including the safety. Furthermore, the 2000 series vehicle was designed in the meeting for design review".

On the "basic design philosophy", the Company thought that "the company does not care for the new design, it is needless to worry too much about the 1000 series vehicle", but the vehicle manufacturer said that "the vehicle manufacturer designed the 2000 series vehicle to utilize partly the parts that had shown the performance and the high reliability in the 1000 series vehicles and the ordinary railway vehicles, because the 2000 series vehicles will operate together with the 1000 series vehicles, and the railway vehicles in the country are usually designed by utilizing the knowhow and the experiences based on the performances up to that time".

On the "integration with the existing facilities of the Route", the Company said that "it was the condition of the contract that the Company asked the vehicle manufacturer to lead the designing studies because the Company had no design knowhow naturally and a few manpower as it was the first case to renew the vehicles. The Company entered in the specification that, basically, the vehicle manufacturer was expected to study accurately, to keep the interface with the existing ground devices, so that the trouble in the vehicle did not affect to the whole system, by having thorough knowledge of the status and the ground facilities of the Route". However, the vehicle manufacturer said that "for example, as for the function of the ATO, the ATO is the highly specialized system composed complexly related with the ground unit, the onboard unit, the ATC device, etc., and therefore the vehicle manufacturer could not comprehend the functions of each device and all data exchanged between the devices, implemented the design based on the information obtained in the meetings for design review, etc., and received the approval from the Company. In addition, there were the information on the highly specialized device such as the control devices, etc., which were not provided due to the company secret of the device manufacturer, and the area of the closed information is in the trend to enlarge according to the progress of the electronics in recent years".

It was said that these designing system and the basic concept had been confirmed and arranged in the preliminary meetings, etc. implemented before contracts.

*[Refer to Table 8]*



Table 8. Recognitions on designing system, etc., in the Company and the vehicle manufacturer

	The Company	The vehicle manufacturer
Designing system	<p>The vehicle manufacturer is in charge of the design including the onboard devices, and is responsible for the design and the manufacturing of the entire vehicle, based on the contract of the manufacturing.</p> <p>In addition, the meeting for design review was held promoted by the vehicle manufacturer substantially, and asked the confirmation and the correction for the design of the vehicle manufacturer.</p>	<p>The vehicle manufacturer stands in the position to design the attaching mechanism and the interface of the body structure, each device, etc., and to finish setting up as the vehicle.</p> <p>The device manufacturer takes responsibility to design and manufacture each device including the safety.</p> <p>In addition, the meeting for design review was promoted by the Company, and the 2000 series vehicle was designed in the meeting for design review.</p>
Basic design philosophy	<p>The Company does not care the new design, it is needless to worry too much about the 1000 series vehicle, although provided the information on the 1000 series vehicle.</p>	<p>The vehicle manufacturer designed the 2000 series vehicle based on the performance of the 1000 series vehicles and the ordinary railway vehicles, because it was the first time to design the new transit system vehicle.</p>
Integration to existing facility of the Route	<p>It was the condition of the contract that the vehicle manufacturer was asked to lead the designing studies. The Company entered in the specification that, basically, the vehicle manufacturer study accurately on the status of the Route and the ground facilities.</p>	<p>For example, the function of the ATO is the highly specialized system composed complexly by the ground unit, the onboard unit, the ATC device, etc., and the functions of each device and all data exchanged between the devices could not be comprehend, therefore, designed based on the information obtained in the meetings for design review, etc., and received the approval from the Company.</p>

#### 2.9.5. Recognitions on the Specification, etc., of Each Device in the Vehicle Manufacturer and the Device Manufacturer

When the vehicle manufacturer and the device manufacturer confirmed on the specifications of the motor control device and the function to detect backward moving equipped in the 2000 series vehicle, it was found that there were differences of the recognitions between the vehicle manufacturer and the device manufacturer. On the "function to memorize running direction in the motor control device", the vehicle manufacturer recognized as "it could not be recognized that the information in the memory function is used in the powering operation as the specification", "it is considered that it is used only in the braking operation, generally". However, the device

manufacturer A said that "the information of the memory function established in the same conditions in order to confirm compatibility on the running directions, are used in the both cases of the powering operation and the regenerating brake operation, and this is the standard specification in the device manufacturer A and applied to the ordinary railway vehicles. In addition, the powering command is considered to be inputted to the motor control device after checked the compatibility with the established F cable or the R cable in the forward and backward switching circuit, as the assumption".

On the function to detect backward moving, the vehicle manufacturer said that "the function to detect backward moving, is the important function to secure the operation in order to prevent the train collision, etc., due to the backward moving, and to operate the emergency brake in all cases except for the intended backward moving, *i.e.*, when the reverse handle is set to the reverse position, in the ordinary railway vehicles. This idea has been recognized in the majority of the railway operators. In addition, the function to detect the backward moving was written clearly as one of the functions of the ATC device in the ordering specifications of the vehicle manufacturer". However, the device manufacturer B said that "the function to detect the backward moving is the subsidiary function of the ATC onboard unit and is not the train protection system. To receive the running direction command and detect the backward moving against the received direction, is the general specification".

Additionally, on the specifications on the direction that the motor control device drive the motor described in 2.8.2, and the operating condition, etc., of the function to detect the backward moving described in 2.8.3, the vehicle manufacturer said that the "the specifications of the functions of the both devices were submitted from the device manufacturer in the final stage of a series of the design works. But there was no description on the characteristic parts in the contents and no concrete explanation and question". *[Refer to Table 9]*

Table 9. Recognition on the specification of each device in the vehicle manufacturer and the device manufacturer

	The vehicle manufacturer	The device manufacturer
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<p>The function to memorize running direction in the motor control device</p>	<p>Considered that it is used only in the braking operation, generally. The main principle of powering control of the ordinary railway vehicles is not to drive motors unless the command cable indicated the direction to be running is energized.</p>	<p>The device manufacturer A : Using the information of the memory function established in the same conditions to confirm compatibility on the running directions, in the both cases of the powering operation and the regenerating brake operation. The motor control device equipped with the function to memorize running direction was applied to the ordinary railway vehicles and the standard specification of our company. Considered that the powering command is inputted the motor control device after confirmed compatibility on the establishments of the F cable of the R cable in the forward and backward switching circuit, as the assumption.</p>
<p>Function to detect backward moving</p>	<p>Function to detect backward moving is the important train protection system in order to prevent the train collision, etc., due to the backward moving, and to operate the emergency brake in all cases except for the intended backward moving, <i>i.e.</i>, when set the reverse handle to the reverse position, in the ordinary railway vehicles.  This concept is recognized in most railway operators. In addition, the function to detect backward moving was written clearly as one of the functions of the ATC device in the ordering specifications of the vehicle manufacturer.</p>	<p>The device manufacturer B : Function to detect backward moving is the subsidiary function of the ATC onboard unit and is not the train protection system. To detect the backward moving against the command, after received the running direction command, is the general specification, used in the ordinary railway vehicles.</p>

#### 2.9.6. Verification of the Safety

All of the Company, the vehicle manufacturer, and the device manufacturers, stated that they had not been supposed the occurrence of the incident such as the backward running as in this accident. According to the Company and the vehicle manufacturer, the safety of the 2000 series vehicles was verified in the meeting for design review described in 2.9.3, and the abnormal status as the breaking of the command cables was studied and implemented the measures for a part of control circuit in the meeting for design review, but the abnormal status in the command cable of the running direction in the forward and backward switching circuit was not studied. [Refer to Table 10]

Table 10. Recognition on the study against abnormal status between the Company and the

vehicle manufacturer

	The Company	The vehicle manufacturer
Study on abnormal status	Recognized that studied using a certain period on the actions and the alarms to the ground assumed the occurrence of abnormal status, checked the contents of the design proposed based on the above studies, and instructed the design to the vehicle manufacturer, etc., therefore, do not consider that the recognition was unconditionally insufficient.	Studied in the meeting for design review, as assumed the case that moved in the direction not to be instructed by some reasons, the function to detect backward moving is equipped in the ATC onboard unit to back up the abnormal status.

In addition, it was written in the proposals submitted from the vehicle manufacturer to the Company that the vehicle manufacturer implements the meeting for quality control in the designing section, *i.e.*, the mini design review, *hereinafter referred to as "the MDR"*, and the design examination, etc., by the designing, the manufacturing and the quality control sections, etc., as the measures to improve quality of the products. The MDR was implemented on the car body and the equipment, and for the matters related with the system, the MDR was implemented focused on the brake circuit by the plural related staffs. In addition, in the design examination, the car body, the outfitting and the system were examined together by the planning department, the production management department, the quality control department, the sales department, the production technology department, the manufacturing department, etc., and the examined result on the "consideration for the safety and the environment", one of the examined items, was "no finding".

## 2.10. Meteorological Information

The weather in the occurred date of this accident was clear.

## 2.11. Information on the Verification Test

### 2.11.1. Confirmation on the Status of the Wiring Works for the Bundle of Cables

The status of the wiring works to fix the bundle of cables from the wiring hole to the cable support in the low voltage terminal rack were investigated in the Device Room.

As the results, it was found that the whole bundle of cables was in the status which is easy to close to the end structure when the bundle of cables were wired through outside of the low voltage terminal rack. In addition, center of the cable support in the low voltage terminal rack was in the height of 195 mm from the floor board, as shown in Figure 6. Therefore, the bottom of bundle of cables are in the status contacted with the upper surface of the end rail, unless the whole bundle of cables is fixed to the cable support being raised.

Furthermore, it was confirmed that the end rail was in the status not visible from the working position of the wiring worker, because the end rail was in backside of the bundle of cables, and the status of the end rail standing inside the end structure was difficult to be comprehended by the

insulating material pasted to the end structure described in Figure 5, when the wiring works of the bundle of cable are implemented.

### 2.11.2. Investigation on the Broken Part of the F Cable and the Bundle of Cables

The investigation, on the broken part of the F cable and the bundle of cables, was implemented in the professional organization on electric cables.

As the results, there were 107 electric wires, etc., in the bundle of cables, and the broken wires, etc., was not found except for the F cable, but there was the cable having the askew flaw in its insulator, and the black material adhered to the surface was the soot. In addition, as the results of the analysis on the surface of the end rail, where the F cable had melted and adhered, the surface of the melted and adhered portion was the alloy of the stainless steel and the copper. As the melting point of the stainless steel is over 1,400 °C, it is confirmed that the temperature when short circuit was in high temperature. [Refer to Figures 10 and 11]



Figure 10. Flaws in the other cables

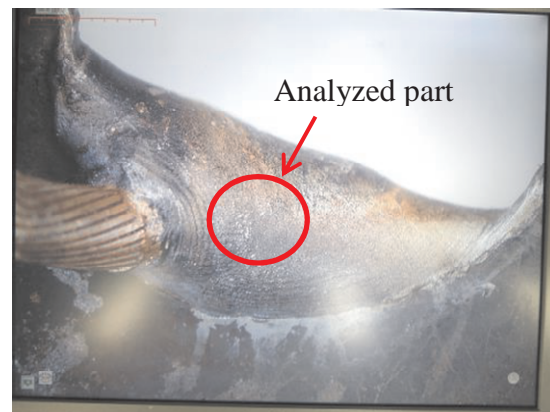


Figure 11. Analyzed surface of the melted and adhered place

### 2.11.3. Test to Reenact Fault Grounding

It was considered as possible that the DC 100 V in the DC power source bus cable had fault grounded<sup>\*34</sup> to the end rail through the F cable, from the broken status of the F cable described in 2.5.1. Then, the reproduction test to comprehend the status when the cable was broken, using the vehicle in the other set composed of the 2000 series vehicles different from the Vehicle, *hereinafter referred to as "the test set"*, was implemented by installing the wires of the same kind as the F cable, and applying DC 100 V to let fault grounded to the material attached to the vehicle.

In the reproduction test, the temporarily wired electric wire was wired through the circuit breakers and the signal relays, which are same kind as the control circuit breaker, temporary installed in the 1st vehicle and the 5th vehicle in the test set, *herein after referred to as "the temporary circuit breaker" and "the temporary signal relay"*, respectively, and the currents were measured at three points, *i.e.*, each temporary circuit breaker and in around the grounded place. [Refer to Figure 12]

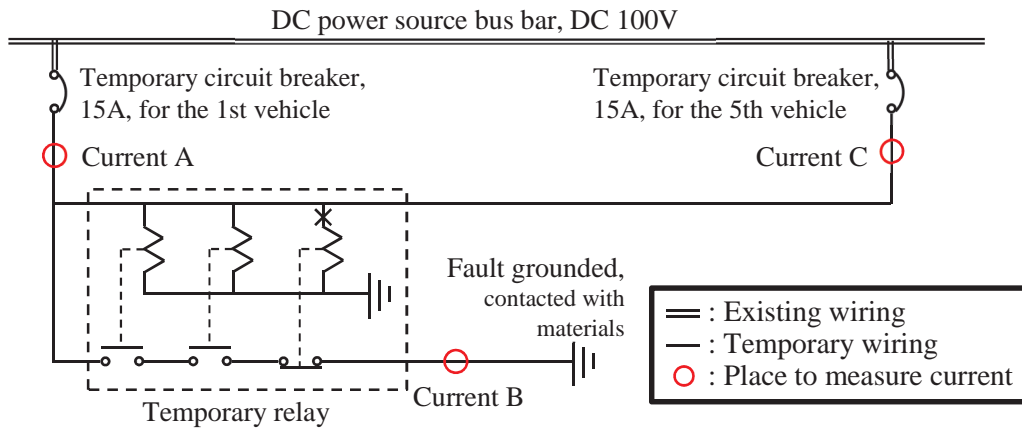


Figure 12. Connection diagram in the test to reenact the ground fault

When the temporary electric wire covered by the flawed insulator was made to contact with the parts made of the same material and thickness as the end rail fixed to the body structure, the spark was generated and the temporary electric wire was broken. The tip of the broken temporary electric wire was discolored a little as same as the F cable in the Vehicle, and the part corresponding to the end rail was melted and damaged in the place contacted with the temporary electric wire. [Refer to Figure 13]

*\*34 "Fault grounding" in this context indicates that the DC power source bus cable supplied by DC 100 V from the power source device, such as the storage batteries, etc., contact directly to the vehicle body that is in the ground level, without through any load.*

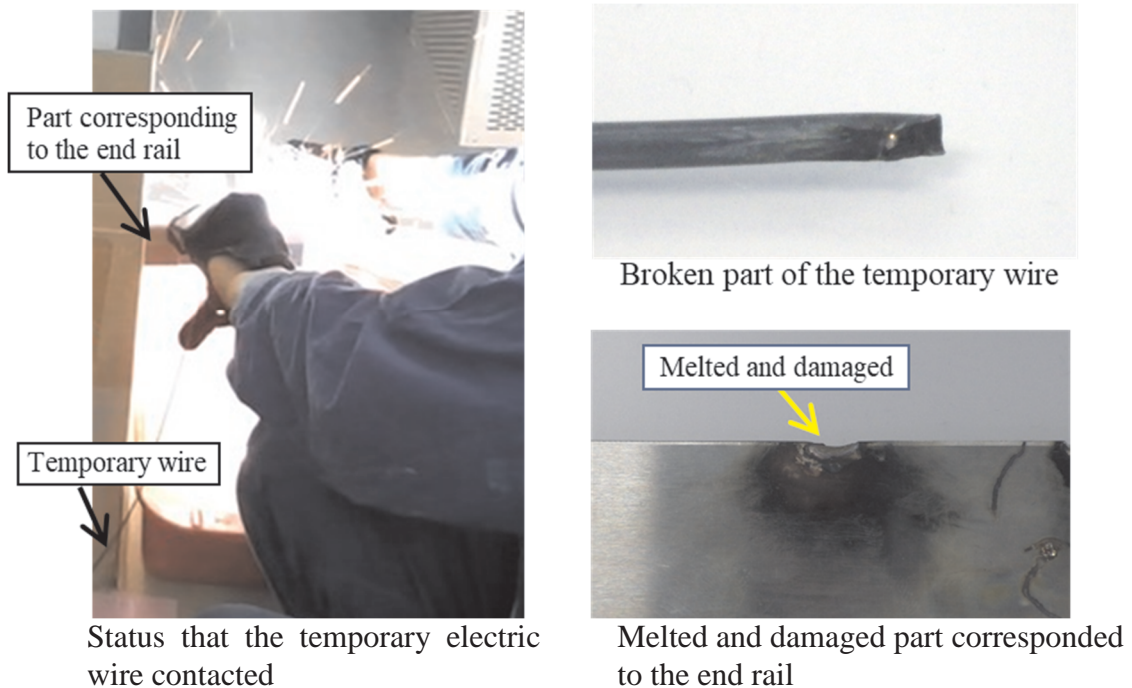


Figure 13. Status of the reenacting test of the ground faults

#### 2.11.4. Measurement of Load Weight Acting on the Bundle of Cables

As it is confirmed that the bottom part of the lowest bundle of cables in the Device Room contacts with the end rail depending on the fixed status by the cable support in the low voltage

terminal rack, as described in 2.11.1, the load weights acting on the bundle of cables were measured in the two places using the jigs.

As the results, the load weight acting on the bundle of cables varies depending on the height or the status of the bundle of cables fixed to the cable support to the low voltage terminal rack, and about 6.4 N in the status reenacted being fixed as possible, and was about 12 N in the status to remove a part of the fixed fastening cable support and laid the bundle of cables on the end rail as possible. Here, the load weight was 0 N when the bundle of cables was fixed in high position.

[Refer to Figure 14]

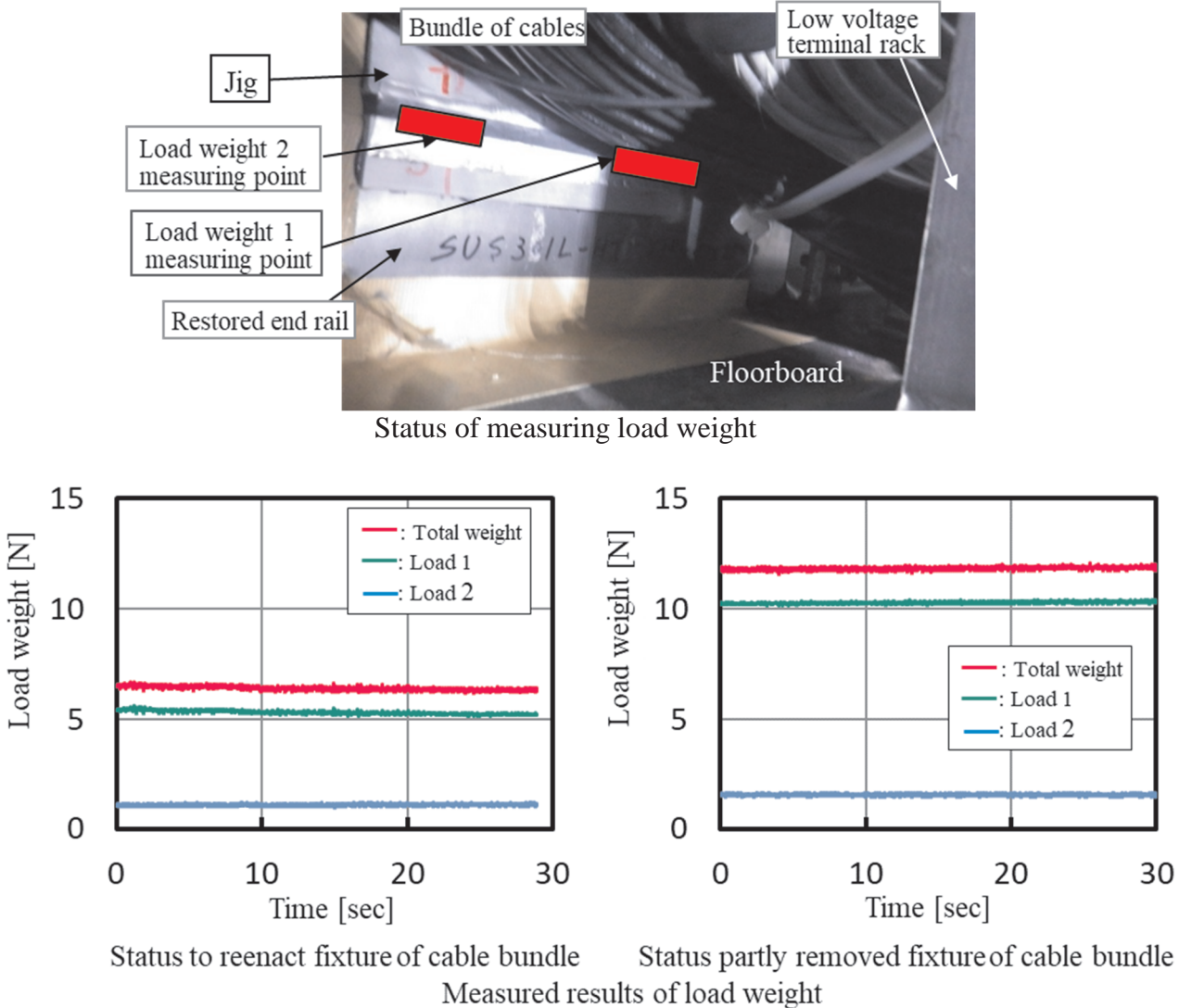


Figure 14. Measurement of load weight of bundle of cables

2.11.5. Investigation on the Breaking Operation of the Control Circuit Breaker

The F cable was wired from the DC power source bus cable via the control circuit breaker and the front relay board of the rated current 15 A, as described in 2.3.2. The control circuit breakers in the Vehicle and the 5th vehicle had been in the "on" status and had not been breaking, at the time of this accident.

The power source cable for three motor control devices in the trainset and the control circuits,

such as the F cable and the R cable, were connected to the load side of the control circuit breaker. Considered the rating current of the control power source of the motor control device 3.5 A, and the current in the control circuit such as the F cable, etc., about 1 A, the rating current of the control circuit breaker was selected as 15 A, *i.e.*, estimated as  $3.5[A] \times 3[set] + 1[A] = 11.5[A]$ . Therefore, if one of the control circuit breaker became to the "off" status, the electric power was supplied from the other control circuit breaker.

In the reenacting test of the fault grounding described in 2.11.3, the temporary electric wire covered with the defected insulator was forced to fault grounded. In this case, the temporary circuit breakers in the 1st and the 5th vehicles had been in the "on" status and did not act the breaking operation. The current B flew in the fault grounded place was 100 A in the maximum, the current A and C flew in the temporary circuit breakers in the 1st and the 5th vehicles were 84 A, and 15 A in the maximum, respectively, and the energized time was 0.27 sec in all cases. [Refer to Figure 15]

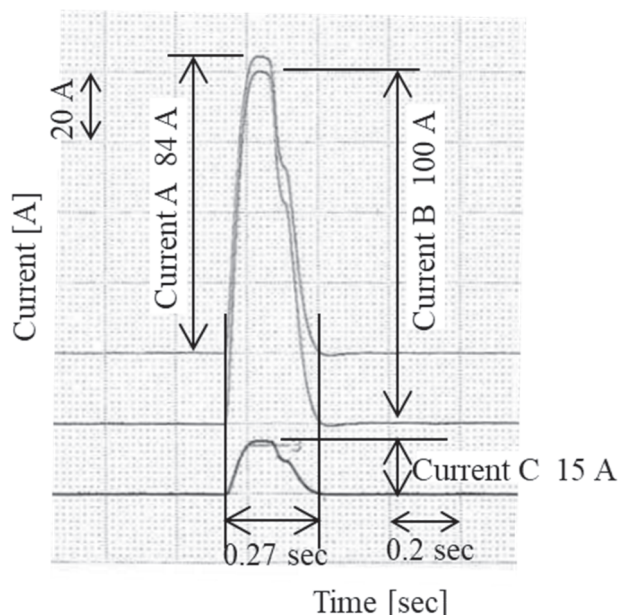


Figure 15. Measured results of the fault grounding current

#### 2.11.6. Vibration Test of the Electric Wires

The vibration test of the electric wires was conducted in the professional organization on electric cables, in order to clarify the anti-abrasion characteristics of the electric wires used in the Vehicle against the end rail and the effects to prevent to flaw the electric wires by the vehicle material side protectors. The vibration test was implemented as the electric wires of the same kind as the F cable in the Vehicle, *hereinafter referred to as "the vibration testing electric wire"*, is contacted with the edge surface of the jig manufactured by the same material and thickness as the end rail, and vibrating the whole test stand by the vibration test machine while applying the load weight. The jig was cut by the laser cutting as the status of the edge part becomes to the same status as the upper surface of the end rail. In addition, in order to verify the effects to prevent flawing electric wires of the vehicle material side protectors, the test was also conducted for the



status that the protecting material, which is the same kind protector as that used to attach to the end rail, was attached to the jig.

As the vibration in three directions, *i.e.*, up and down, left and right, back and forth, are acted to the vibration testing electric wires in the running vehicle, the vibration test was conducted as to act the load weight and the vibration obliquely, by tilted the whole jig by 45 degrees.

The vibrating data used in the vibration test was created using the vibrating acceleration data acted on the floor board near the Device Room, measured by the Company in the test run in the general inspection, and the load weight was set as 7 N and 14 N in the vertical direction, referred to the load weight measured in 2.11.4. [Refer to Figure 16]

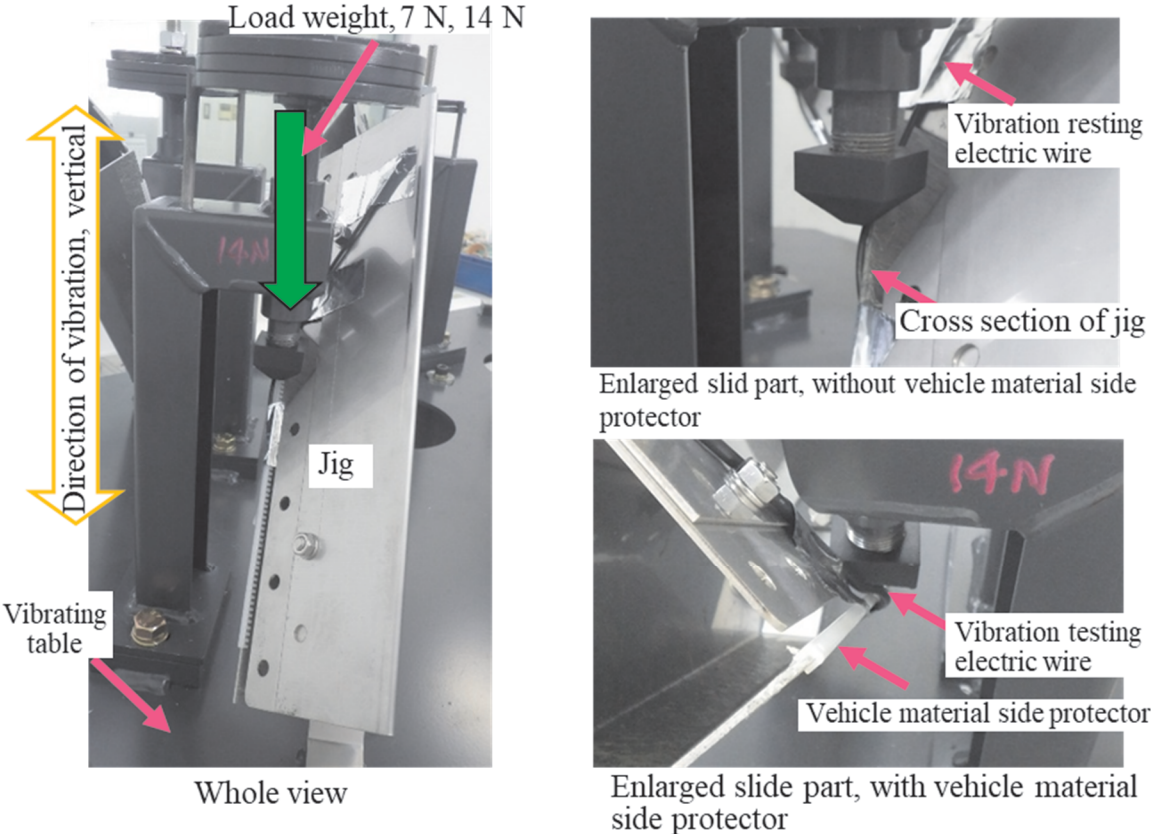


Figure 16. Status of the Vibration Test

After vibrating 5 days or 14 days, the maximum depth of the faults in the insulator of the vibration testing electric wires were measured, individually. As the results, the major results as the followings were obtained in the above test conditions.

- It was confirmed that the insulators flawed in both cases of the load weights 7 N and 14 N.
- The thickness of the insulators reduced over 10 % by the 14 days vibration test.
- The insulator of the vibration testing electric wires flawed even in the case that the vehicle material side protectors was attached to the jig, and the maximum depth of the flaw was in around the same level when the protector was not attached. [Refer to Figure 17]

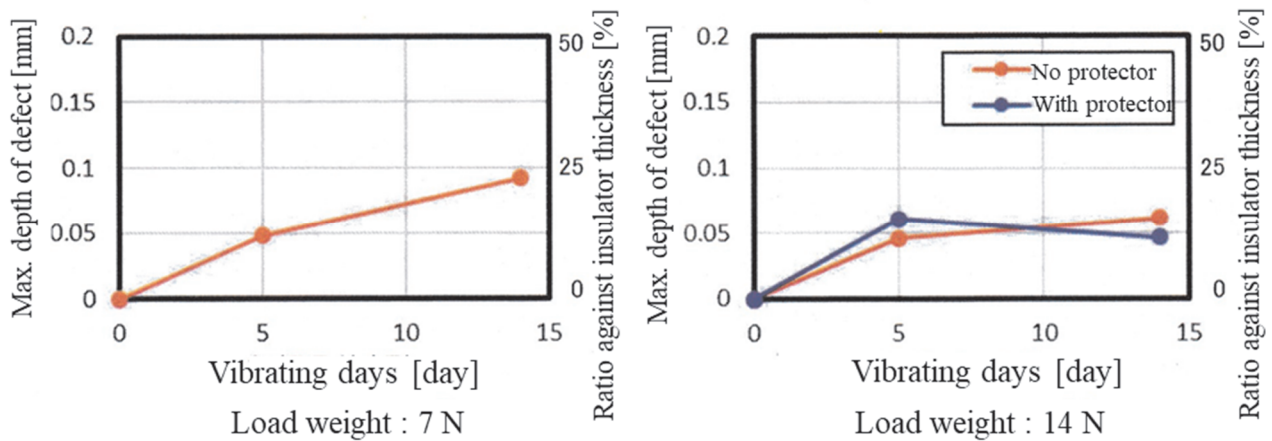


Figure 17. The maximum fault test of the vibration testing electric wires by the vibration test

#### 2.11.7. Reenacting Test on the Backward Running

In order to confirm the running status, etc., of the vehicle when the F cable was broken in the Device Room, the reenacting test on the incident of the backward running in this accident using the other vehicle different from the Vehicle, in the test track in the vehicle depot of the Company. The major procedures of the reenacting test were as follows.

- (1) Set the running direction of the train as the inbound direction in the automatic operation, and stopped after running.
- (2) Break the F cable in the low voltage terminal rack in the Device Room.
- (3) Set the running direction of the train in the outbound direction.
- (4) Departed by the automatic operation.

As the results, the vehicle started to run in the inbound direction although the running direction was set in the outbound direction in the above procedure (3). Thus, it was confirmed that the vehicle moved in the direction opposite to the scheduled running direction if the F cable was broken.

### 3. ANALYSIS

#### 3.1. Analysis on the Process to the Occurrence of this Accident

In this accident, the vehicle collided with the car stop in Shin-Sugita station, as the motor control devices in the Vehicle drive the motors in the direction opposite to the original running direction of the Train. It is probable that the process to the occurrence of this accident was as follows.

As described in 2.5.1, it was found in the investigation conducted after the accident that the F cable, which is the command cable of the running direction to the motor control device in the device room of the 1st vehicle of the Train, had been broken. Therefore, it is highly probable that the F cable had short circuited to the end rail in the device room of the 1st vehicle and broken, based on the record that the F cable of the Train changed from the energized status to the de-energized status while the Train had been operated as the outbound 1905 train, *i.e.*, the train two cycle round

operation before the Train, between Sachiura station and Sangyo-Shinko-Center station, as described in 2.1.3. The outbound 1905 train could be operated to Kanazawa-Hakkei station as the motor control device drove the motor in the outbound direction which was the direction of travel of the Train, because the memory function of the motor control device was in the status as to keep the previous running direction, as described in Table 7 in 2.8.2, although both the F cable and the R cable became in the status as nor energized, as the control circuit breaker did not operate breaking action when the F cable was grounded as described in 2.4.1.

When the Train was going to operate as the inbound 1910 train after turned-back at Kanazawa-Hakkei station, the R cable became to the energized status when the running direction of the train was switched to the inbound direction, therefore, the motor control device switched the running direction to the inbound direction unless to be affected by the breakage of the F cable, and the train operated to Shin-Sugita station.

In addition, when operated as the outbound 2009B train after turned back at Shin-Sugita station, both the F cable and the R cable became to the de-energized status again due to the breakage of the F cable when the running direction of the train switched to the outbound direction, then the motor control device drove the motors in the inbound direction, which was kept in the function to memorize running direction, after that, the train collided with the car stop in the end edge of the track at the velocity of about 25 km/h, at about 20:15, *i.e.*, just after departed, based on the data in the event recorder described in 2.1.3. In addition, it is highly probable that the Train stopped in the status that the hydraulic buffer device of the car stop lengthened by about 1,000 mm and hit guide end as described in 2.4.3, as the emergency brake acted because the side door in the 3rd vehicle opened instantly due to the shock of the collision of the Train and the car stop.

## 3.2. Analysis on the Breakage of Wires

### 3.2.1. Process to the Breakage of Wires

It is probable that the F cable had been in the status as being contacted with the surface of the end rail from the time when the vehicle had manufactured, based on the results of the investigation described in 2.4 to 2.7. In addition, because the upper surface of the end rail was cut by the laser in almost rectangular cross section, it is highly probable that the insulator of the F cable had been wearing gradually due to the vibration accompanied to the running operation of the vehicle, and fault grounded to the end rail while the vehicles were running as the outbound train operated two trains before the Train. Furthermore, it is highly probable that the electric wire in the side connected to forward broken in a short time by the heat generated in the place contacted with the end rail when the F cable was fault grounded, then the electric wire in the side connected to the low voltage terminal base had melted and adhered to the end rail, based on the status that the F cable had melted and adhered to the end rail and the soot had been adhered in around the place where the bundle of cables wired in the neighborhood had melted and adhered, as described in 2.11.2.

### 3.2.2. Wired Status in the Device Room

It was obliged to install the main air reservoir, etc., in the Device Room on the floorboard as described in 2.5.2, because the length of each vehicle body of the 2000 series vehicle was 8 m then the space for loading the underfloor equipment was small, as described in 2.3.1. In these situations, the bundle of cables including the F cable had been wired from the wiring hole to the aisle side, via outside of the main air reservoir and the low voltage terminal rack, and the neighborhood of the end structure. Therefore, it is probable that the bundle of cables including the F cable became close to the end rail. Furthermore, it was confirmed that load weight acting on the end rail was in the status to change depending on the fixed status of the bundle of cables to the cable support of the low voltage terminal rack, as described in 2.11.4.

Based on the above discussion, it is probable that the F cable and a part of the cables finally existed in the outermost of the bundle of cables or its neighborhood contacted with the end rail, because the bundle of cables had been fixed in low height, etc., in the wiring works of the Vehicle.

In addition, as for the status of the F cable in the bundle of cables, the investigation was conducted on the procedures of the works in the vehicle manufacturer described in 2.6.1, and the wiring status, etc., in the same bundle of cables in the other vehicles. As the results, it is highly probable that the F cable was tied in bundle together with the other electric wires and a part of the whole bundle of cables including the F cable had been contacted with the end rail.

### 3.2.3. Wiring Works, etc., when Manufactured Vehicles

It is likely that the consciousness of the wiring workers was lacked against the contact between bundle of cables and the end rail, considering that the worker could not see the end rail as it is hidden by the bundle of cables in the wiring works of the bundle of cables as described in 2.11.1, although the workers usually pay attention to the electric wires, etc., not to contact with the vehicle materials as described in 2.6.1. In addition, the vehicle manufacturer had been provided the manual for outfitting process and the manual for wiring in the end structure for each vehicle category, however these manuals described only the general matters that required general attention and the rough instructions and there was no description to call attention to the individual items in the wiring works such as the contact with the end rail in the Device Room.

As the results, it is likely that the attachment of the protecting materials for the electric wires and the vehicle material side protectors to the bundle of cables and the end rail were insufficient, in the work to arrange the bundle of cables, described in 2.6.1 (1), furthermore, the status, that the bundle of cables had been contacted with the end rail, was not noticed even in the final fixing works of the bundle of cables, as described in 2.6.1 (3).

As described in 2.6.3, the wired status in the Device Room was not inspected after the wiring workers finished the wiring works by the section in charge of inspection, and had been in the status that the inspection could not be conducted easily after completed manufacturing of the vehicle. Therefore, it is probable that the contacted status of the bundle of cables and the end rail could not be found. In addition, it is likely that the status of the concerned bundle of cable contacted with the end rail was found, if the wired status of the concerned bundle of cables were inspected after the wiring works by the visual inspection, the touching inspection, or the inspection using the

mirror or the fiber scope, etc., considering that the concerned space was narrow, although the handling of the lightened electric wires should be treated more carefully not to damage the insulators, etc., than the standard electric wires.

#### 3.2.4. The Periodic Inspection, etc.

The inspecting contents for the electric wires, etc., in the Vehicle in the periodic inspection of the Company were the insulation resistance measurement, the dielectric strength test, etc., in addition to the visual inspection.

Generally, many electric wires are installed in the railway vehicles, and the insulation resistance measurement and the dielectric strength test are conducted by applying high voltages for the power source bus cable after made in the independent status, but the inspection for the individual electric wire should be conducted by taking off many fastened parts, therefore there is the fear to induce troubles in each device.

Therefore, usually, the confirmation of the wired status was conducted by confirming the operation of each device in the last step of the inspection, unless to inspect individual electric wires, etc.

Therefore, it is probable that it is hard to comprehend the status of the F cable and to foresight the breakage of cable in the periodic inspection of the Company.

#### 3.2.5. Braking Operation of the Control Circuit Breaker

As described in 2.11.3, based on the reenacting test of the fault grounding, it is highly probable that the ground faulting current in the same level as the current A described in 2.11.5 flew additionally to the steady current for the control power source of the control circuit and the motor control device, in the control circuit breaker of the Vehicle. It is probable that the current flew in the control circuit breaker, 65 A, corresponds to about 433 % of the rated current of the circuit breaker 15 A, because the steady current was about 5.6 A, and the effective value of the current A was about 59.4 A. The energizing time, 0.27 sec, was almost in the area that the circuit breaker did not operate, as shown in Figure 18.

Generally, the circuit breaker was equipped in order to connect or disconnect the connected electric circuits or to prevent damages, etc., in the electric wires, etc., or the devices by the circuit break operation when the exceeding current flows continuously for a certain time, and the circuit related to the emergency brake was included in the forward and backward switching circuit in the 2000 series vehicle. The rated current of the control circuit breaker in the Vehicle was the value that can supply the control power source, of the motor control device, about 10.5 A, together with the control circuit of the command cables, etc., about 1 A. Therefore, it is probable that the concerned circuit breaker did not act to break circuit for the current characteristics when the F cable was fault grounded in this accident.

When the control circuit breaker of the rated current 5 A, is connected to only the command cable for the forward and backward switching circuit such as the F cable or the R cable, the current of about 1,300 % of the rated current of the control circuit breaker will flow if one of the F cable

and the R cable was fault grounded, therefore, the control circuit breaker will act to break circuit in high possibility. It is probable that this accident would not occur, if the circuit breaker acts to break electric circuit, because the vehicle becomes impossible to run as the emergency brake will operate. [Refer to Figure 18]

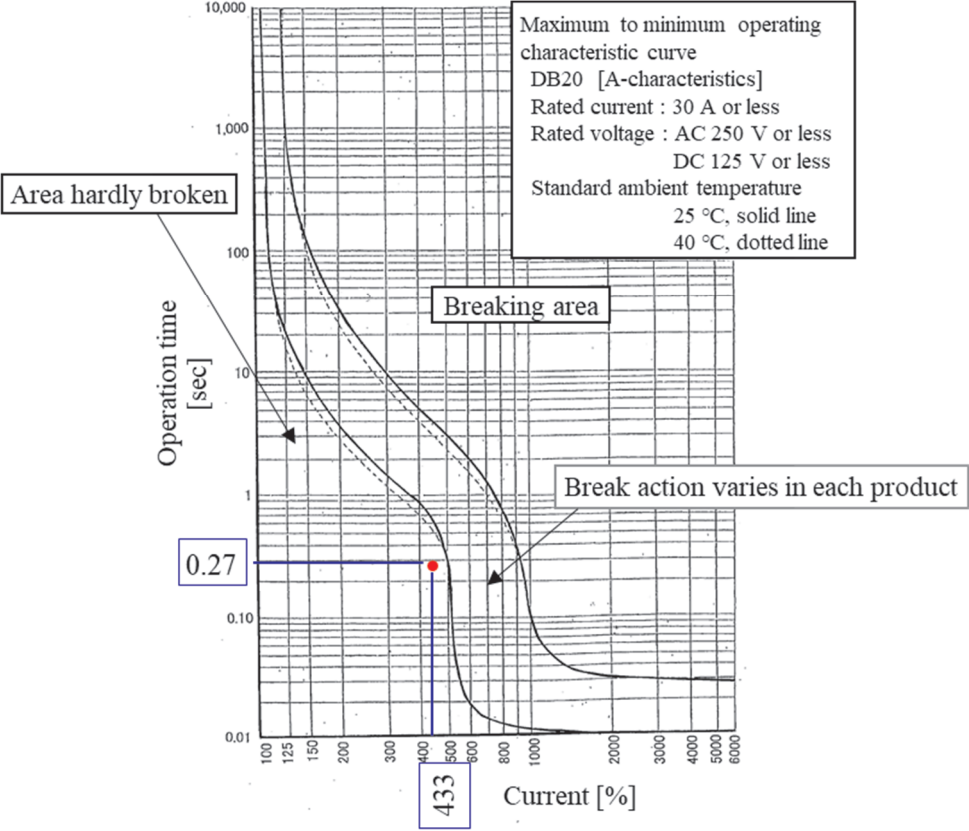


Figure 18. Characteristics of the operation of the control circuit breaker

3.2.6. Protection of the Electric Wires

As described in 2.5.1, the particular attention not to flaw the insulator was required for the lightened electric wires used in a part of the vehicle. Furthermore, it is confirmed in the vibrating test of the electric wires described in 2.11.6, that the vibration testing electric wire of the same kind as the F cable contacts with the material corresponded to the end rail in the status being applied with a certain load weight, and its protecting material flawed when applied the vibration, and the maximum depth of the flaw in the insulator was almost the same level as the case that the vehicle material side protectors was not attached, when the vehicle material side protector was attached.

Based on the above analysis, the protecting material for the electric wires by the rubber band, etc., described in 2.5.2, are expected as the measure to prevent the insulators, from abrading the insulators of the electric wires due to the contact with the vehicle material. However, as described in 2.11.6, there is the case that the vehicle material side protectors could not prevent the flaws in the insulators completely. The protection for the vehicle material side should be implemented at first, when it is difficult to secure the space between the electric wires, etc., and the vehicle material,

and there is the possibility to be contacted with each other. Furthermore, when the vehicle material side protectors are attached, the attention should be paid not to damage the electric wires, etc., by the protecting materials such as to use the protecting material with round shaped edges or to use the different materials, etc. In addition, it is considered as necessary to study on the chamfering edges of the vehicle material side, considering the place where the inspection after the wiring works could not be conducted easily and the blind place such as the backside of the interior panels, etc., becomes to the status that the inspection could not be implemented for a long period.

### 3.3. Analysis on the Occurrence of the Backward Running

#### 3.3.1. The Signal Transmission, etc., at the Occurrence of this Accident

It is probable that the signals were transmitted in the ground and the onboard as followings, by the occurrence of the breakage of the F cable described in 2.5.1, in this accident.

[1] The station ATO onboard unit, that received the running direction command to outbound direction from the station ATO ground unit, transmitted the status of the running direction as outbound, to the station ATO ground unit. As the result, the station ATO ground unit judged that the running direction command to the vehicle and the status of the running direction of the vehicle agreed as the outbound.

[2] As the motor control device was in the status as to drive the motor in the inbound direction which was the running direction preserved in the memory function, the motor control device drove the motors in the inbound direction, opposite to the direction of travel of the Train, due to receive the powering signal from the ATO onboard unit.

[3] As the train started in the reverse direction by the process described in [2], the abnormal running was not detected by the function to detect backward running in the ATC onboard unit and the other methods, and the brake did not act until the train collided with the car stop.

*[Refer to Figure 19]*

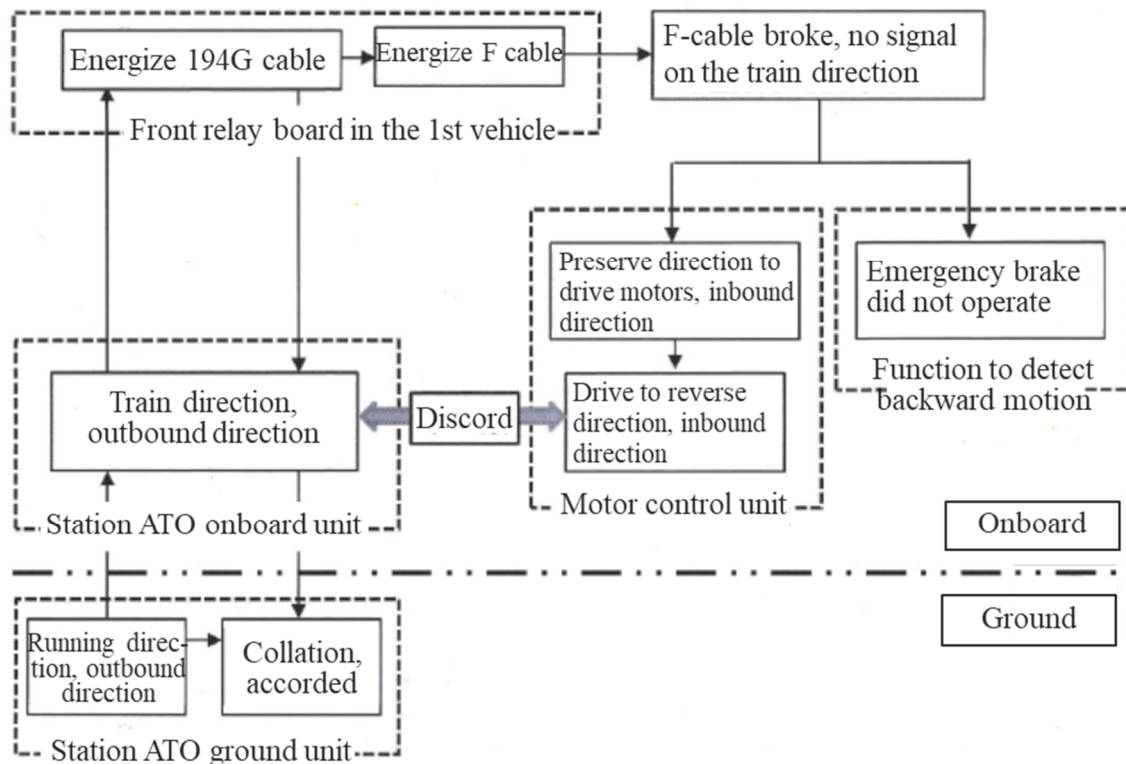


Figure 19. Signal transmission and the recognition in each device in this accident

### 3.3.2. The Forward and Backward Switching Circuit and Setting of the Running Direction

As described in 2.3.2, the F cable and the R cable were used for the command of the running direction to the motor control device in the forward and backward switching circuit in the 2000 series vehicles, as described in 2.3.2, but the station ATO onboard unit had been transmitted the status of the running direction based on the energized status of the 194G cable and the 195G cable which are the command cable to select the driving desk, to the ground unit.

Therefore, because the motor control device drive the motors in the direction to the previous running direction preserved in the memory function, when the running direction command did not transmitted correctly from the station ATO onboard unit to the motor control device, there was the possibility that the direction of the status of the running direction transmitted from the station ATO onboard unit to the ground unit did not consistent with the direction of the running vehicle driven by the motors controlled by the motor control device.

The running direction command to the motor control device was in the status not to be transmitted correctly due to the breakage of the F cable in this accident, but the station ATO ground unit had recognized the status of the running direction based on the energized status of the 194G cable and the 195G cable transmitted from the station ATO onboard unit, as the direction of trouble of the vehicle. As described in 2.1.3, the data recorded in the ground and the onboard units at the time of this accident were checked and found that there was no record to show the abnormality in the setting, etc., of the running direction before the Train started moving. Therefore, it is highly probable that the station ATO ground unit recognized that the direction of travel of the train had been set normally, and could not detect that the vehicle actually run in the reverse direction.



In addition, as described in 2.8.1 and Table 11, the powering command and the running direction command are inputted to the motor control device by the different command cables, and the motor control device preserve the running direction in the memory function. Therefore, even if the abnormal situation occurred in the running direction command, the condition to drive the motors to the previous running direction is established when the powering command was inputted. However, in the forward and backward switching circuit of the ordinary railway vehicles, the powering command is inputted to the motor control device in the condition that the running direction command had been inputted, generally. Therefore, the vehicle has the fail-safe system such that it cannot be operated in the powering operation because the powering command also was not inputted if the command cable of the running direction was broken. In addition, it is presumed that the backward running incident such as this accident had not occurred in the 1000 series vehicles, because the running direction was not set when the command cable of the running direction was broken, because the function to memory the running direction in the motor control device was not equipped, although the powering command and the running direction command were inputted to the motor control device by the different command cables same as in the 2000 series vehicles. Therefore, it is probable that the consideration against the occurrence of abnormal status in the running direction command, in the forward and backward switching circuit including the motor control device of the 2000 series vehicle, had been insufficient compared to the ordinary railway vehicles. [Refer to Table 11]

Table 11. Difference of the input of powering command and running direction command to the motor control device in each vehicle category

Vehicle category	The ordinary railway vehicles	The 1000 series vehicle	The 2000 series vehicle
Command flow to motor control device			
	Powering command was inputted in the condition that the running direction command was inputted beforehand.	Powering command and running direction command were inputted by the different command cables.	Powering command and running direction command were inputted by the different command cables.
#	Motor control device cannot drive motors because powering command and running direction command did not inputted.	Motor control device cannot drive motors because the running direction of travel could not be recognized.	Motor control device drive motors in the previous running direction preserved in the memory function.

# Operation of the motor control device when the command cable of running direction was broken

### 3.3.3. Motor Control

As described in 2.8.2, the motor control device of the 2000 series vehicles had been set to drive the motors in the direction which was preserved when both the F cable and the R cable, which are the command cables on the running direction, were de-energized, because the memory function reserves the previous running direction.

In this accident, it is highly probable that the motor control devices in all vehicles drove the motors in the inbound direction, opposite to the direction of travel of the Train because the F cable had broken in the Device Room, and both the F cable and the R cable inputted to all motor control devices installed in the 3rd vehicle and the 5th vehicle of the concerned Vehicle, became to the de-energized status.

As described in 2.3.2, the energized status of the F cable and the R cable were preserved in the onboard front relay board until it received the signal to switch the running direction of the train from the ground unit in the turn-back stations, *i.e.*, Shin-Sugita station and Kanazawa-Hakkei station, and the motor control device always receive the command on the running direction. Therefore, it had been possible to drive the trains without problem even though the memory function was not equipped in the motor control device. However, in the meeting for design review described in 2.9.3, the study on the abnormal status in the forward and backward switching circuit described in 2.9.6 was not implemented, and the effect of the function to memorize running direction in the motor control device when both the F cable and the R cable became to the de-energized status, was not studied although it was necessary to be comprehended as prescribed in the specifications of the functions described in 2.8.2. The preservation of the running direction in the memory function of the motor control device is not the special problem in the forward and backward switching circuit of the 2000 series vehicle, because the running direction can be set correctly when there is no abnormal status in the forward and backward switching circuit, however, it is probable it became the latent cause of the dangerous incident which is able to generate the running in wrong direction when the powering command is inputted if there was the abnormal status in the running direction command, as in this accident, or the improper renewal, etc., had generated by the trouble in the memory itself.

Additionally, as described in 3.3.2, it is highly probable that the incident of running in wrong direction in the Route was occurred only in the 2000 series vehicles, because the 1000 series vehicles of the company, manufactured by the manufacturer different from the device manufacturer A, were not equipped with the function to memory the running direction in the motor control device and then it was presumed that the incident of running in wrong direction is not occurred as in this accident even when the command cable of the running direction was broken.

### 3.3.4. Securing Safety in the Abnormal Status

As described in 2.9.5, according to the device manufacturer B, the function to detect backward moving in the 2000 series vehicles is the general specification based on the ordinary railway vehicles, assumed to detect backward moving of the vehicle in the upgrade section, and one of the operating conditions was that the running direction command had been inputted, therefore, it is

highly probable that the backward running of the Train could not be detected. Generally, it is the abnormal running that the train ran in the status while the running direction had not been established, therefore, it is probable that the abnormal running of the train could be detected when implemented the phase detection, if there is the case when the running direction command was not inputted as one of the operating condition of the function to detect backward running described in 2.8.3. Additionally, in this condition, the detection of the wheel rolling<sup>\*35</sup> as running in forward or backward without the intention becomes possible when the running direction had not been established in the train. In addition, it is highly probable that the signal in the onboard antenna for the ATC/TD in the Train had been switched to the 1st vehicle normally, based on the record in the event recorder, etc., described in 2.1.3, therefore it is probable that the Train entered the overrun protecting section just after collided with the car stop. However, as described in 2.8.4, it is highly probable that the emergency brake had not operated even in the overrun protecting section because the time element of 0.5 sec had been set for switching the recognition of the ATC signal.

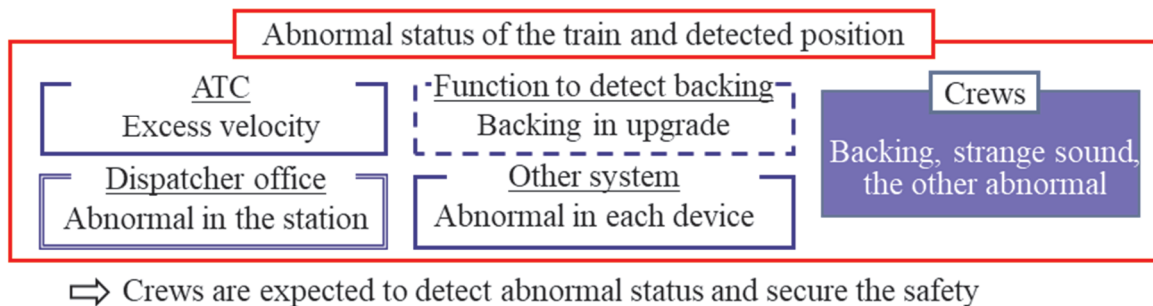
Considering to secure the safety against the occurrence of abnormal status in the train which is operated by the manned or the unmanned operation, the places to detect the abnormal status differs each other, *i.e.*, it is expected that the train crew detects the abnormal status including the backward running as in this accident and implement the emergency stop procedures in the train operated by the manned operation. On the other hand, it is necessary for the train operated by the unmanned operation to secure the safety by detecting the abnormal status in the whole system. For example, when the backward running as in this accident or the wheel rolling happened, it is necessary to detect them by the function to detect backward moving or the other method, and stopped the train immediately. *[Refer to Figure 20]*

However, the function to detect backward moving of the 2000 series vehicles cannot detect the backward movement when the running direction command has not been inputted as described in 2.8.3, although the 2000 series vehicles are operating by the unmanned operation, and the abnormal status could not be detected in the other system. It is necessary to secure the safety to detect the abnormal status by the function to detect the abnormal status such as the running in wrong direction as in this accident, but it is probable that the function to secure the safety had been insufficient to detect the abnormal status such as the backward running as in this accident. *[Refer to Figure 21]*

<sup>\*35</sup> "Wheel rolling" in this context means that the vehicle started to move forward or backward without intention while the train is halting. The wheel rolling occurred when the braking force had reduced while the vehicle had been halting in the grade section.

—: Train by manned operation    —: Train by unmanned operation  
 Detection by a device     Detection by a function     Detection by human

Example of the train by manned operation



Example of the train by unmanned operation

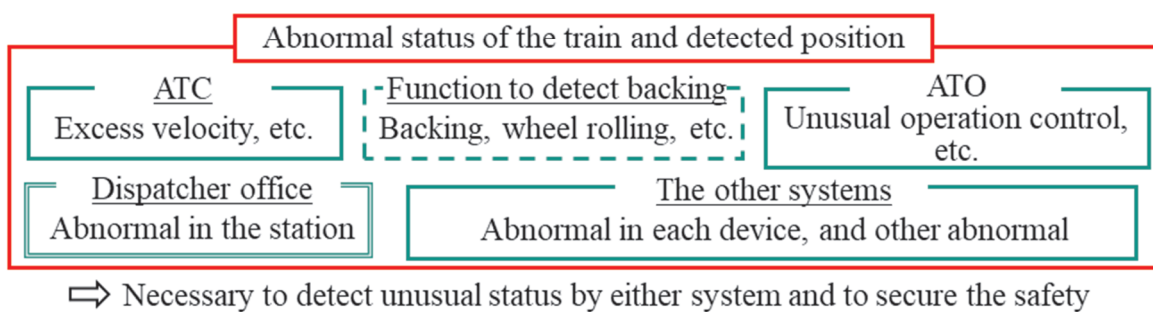


Figure 20. Composition to secure the safety in the trains operates by manned or unmanned

— : Train by manned operation    — : Train by unmanned operation  
 : Detection by a device     : Detection by a function     : Detection by human

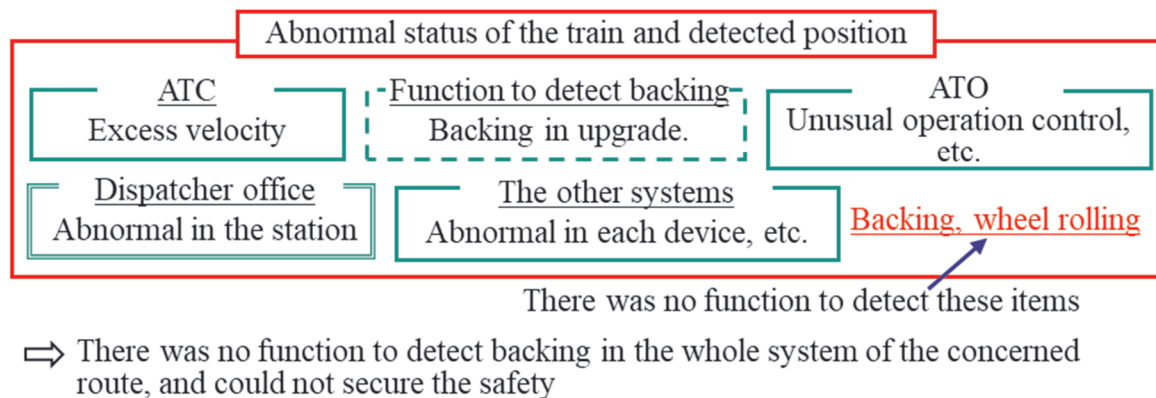


Figure 21. Composition to secure the safety of the 2000 series vehicles

### 3.4. Analysis on the Designing of the Vehicles

#### 3.4.1. Designing and Manufacturing Process of the 2000 Series Vehicles

In the designing and manufacturing process of the 2000 series vehicles described in 2.9.2, the designing phase started immediately after it concluded the contract on the manufacturing.

Referring to the "Life cycle<sup>\*36</sup> of the system required the safety", etc., prescribed in the comments of the Article 63 of the Ministerial Ordinance Providing the Technological Standard for Railways, Ministerial Ordinance No.151 prescribed by the Ministry of Land, Infrastructure,

Transport and Tourism, 2001, presented in order to realize the safety of the train protection devices, it is considered as necessary to prepare the phases to confirm and coordinate the basic concept and to clarify the sections of responsibility of the related parties, and the phase to adjust the requirements, etc., necessary to secure the safety before implemented the design works, *hereinafter referred to as "the phase to confirm and arrange designing organization", "the phase to extract safety factors", respectively*, and implement the individual phases sufficiently, in the designing and manufacturing processes of the railway and the tramway system. Furthermore, in the final design stage, it is required to prepare the phase to verify the safety of the designed contents, based on the specifications from the customer and the safety factors, etc., coordinated in the phase to extract safety factors, *hereinafter referred to as "the phase to verify safety"*, and implement sufficiently. To summarize the above discussions, a designing and manufacturing process which can be applied to various systems including the vehicles can be imagined, *hereinafter referred to as "the imaginable designing and manufacturing process"*. [Refer to Figure 22]

As confirmed the minute of the meeting for design review for the 2000 series vehicle described in 2.9.3, the manufacturing process, the layout of the onboard devices, the selection of the device manufacturers, etc., were studied in the 1st meeting for design review, and a various matters on the designing and manufacturing of the 2000 series vehicle, such as the body structure, the outfitting, the systems, the layout of the onboard devices, the selection of the device manufacturers, etc., were studied in the following meetings. However, there was no record on the designing organization, such as to clarify the responsible organization to conduct designing between the Company, the vehicle manufacturer and the device manufacturer, and on the confirmation and the coordination of the specification which are considered as the standard, or recognized as general for each device in each company. In addition, in the meetings, etc., held before the design works of the 2000 series vehicles were started, the matters required the attention in the designing and manufacturing works were not adjusted sufficiently. That is, it is probable that the concrete design works had started without confirmation and coordination of the designing organization and sufficient extraction of the safety factors.

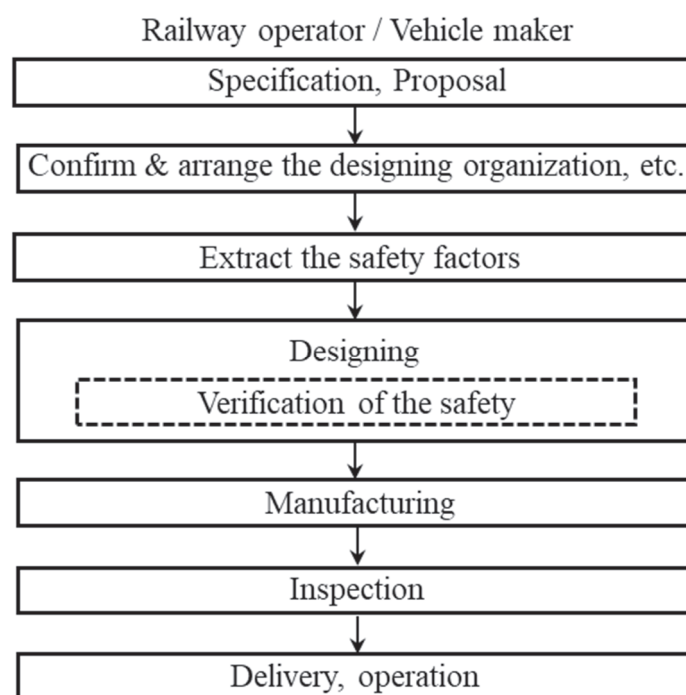


Figure 22. Imaginable design and manufacturing process

As described in 2.3.2, the ground system and the onboard system operating the train cooperate with each other in the Route. In addition, as described in 3.3.4, since the 2000 series vehicles are operated in the unmanned operation, it is necessary to secure the safety by detecting all abnormal statuses by the systems. Considering these situations, the new transit system by the unmanned operation becomes more complex system compared with the ordinary railway system operated by the manned operation. On the contrary, as described in 2.9.4, as for the integration with the existing facilities of the Route, the Company said that "the vehicle manufacturer was asked to be the leader of the design studies as the condition of the contract", but the vehicle manufacturer said that "the vehicle manufacturer could not comprehend, for instance, the whole functions of the ATO because it was highly specialized". In addition, the vehicle manufacturer said that "Regarding the extremely specialized device, such as the control device, the information was not provided partly because of the company's secrets of the device manufacturer".

Recent years, the control system by the software became popular according to the progress of the digitization of the onboard devices in the vehicle, but it is probable that the importance of the system integration is increasing in the design of the vehicles which becomes more complex. The system integration of the vehicles in this context is defined as to overlook the whole system including the ground facilities, under the recognition unified by the relevant staffs based on the purposes, the specifications and the characteristics of each device, suppose the various situations that the trouble may occur, and construct the vehicle of the high safety. Consequently, it is considered as important to clarify the designing and sharing the responsibility between the operator, the vehicle manufacturer and the device manufacturer including before contract, at first. However, in the design of the 2000 series vehicle, the recognition on the organization responsible for implementing the system integration of the Vehicle whether the Company, or the vehicle

manufacturer implement it, or they implement in cooperation with each other, differed in the Company and the vehicle manufacturer, as described in 2.9.4.

In the design of the vehicle, etc., the occurrence of the incident as to generate the new problem as the whole system is considered, although each device functioned without any problem individually. In order to detect such incident in advance and implement the measures, it is important to extract and evaluate the conditions which caused the dangerous incident without lack before designing, in the designing organization, etc., confirmed and coordinated by the relevant parties, and reflect these measures as the matters of the safety factor. Furthermore, the safety management for the whole life cycle including the manufacturing and the operation is necessary. However, the 2000 series vehicle was the first time to renew in the Company, in addition, the 2000 series vehicle was the first time to design the new transit system vehicle for the vehicle manufacturer. Therefore, it is probable that the confirmation and the arrangement of the designing organization, and the extraction of the safety factors, should be conducted more carefully, and the verification of the safety after designed, etc., should be sufficiently implemented after designing, etc.

*\*36 "Life cycle" in this context indicate the flow of the activities required from the concept design of the product to the disposal after the usage, generally.*

#### 3.4.2. Recognition, etc., of the Company, the Vehicle Manufacturer and the Device Manufacturer

As described in 2.9.4 and 2.9.5, there were the differences of the recognition against the designing organization and the basic concept or the integration with the existing facilities of the Route between the Company and the vehicle manufacturer, and the recognition against the specifications of the motor control device and the function to detect the backward moving between the vehicle manufacturer and the device manufacturer. It is probable that these situations occurred by the lack of the confirmation and the coordination on the designing organization and the basic concept, etc., between the Company and the vehicle manufacturer, and on each specification, etc., between the vehicle manufacturer and the device manufacturer, as described in 3.4.1.

As described in 2.9.4, the vehicle manufacturer conducted the designing works emphasizing the achievements, etc., in the 1000 series vehicles and the ordinary railway vehicles, and thought that the device manufacturer takes responsibility to design each device including the safety. Because the device proposed by the device manufacturer was judged as applicable to the 2000 series vehicles considering the achievements of the device in the ordinary railway vehicles, it is likely that the specifications submitted from the device manufacturer was adopted although the sufficient confirmation for the precise specification after the submitted from the device manufacturer had been lacked.

As the results, the forward and backward switching circuit in the 2000 series vehicle became to be composed the motor control circuit equipped with the function to memorize running direction for the ordinary railway vehicles described in 3.3.3, in the forward and backward switching circuit based on the 1000 series vehicles described in 3.3.2. It is probable that the latent cause against the backward running, that the motor control device preserved the running direction in the memory

function, was generated because the composition became different from the ordinary railway vehicles and the 1000 series vehicles. That is, it is probable that the new dangerous factors had generated caused by the combination of the forward and backward switching circuits and the motor control device, although these devices had the achievements in the 1000 series vehicles and the ordinary railway vehicles, respectively. It is considered as necessary to comprehend sufficiently, not only for the achievements until that time, but also on the difference with the design of the ordinary railway vehicles, when the devices used in the ordinary railway vehicles was installed in the new transit system vehicle, in the designing works of the 2000 series vehicle.

Additionally, although the specifications of the functions of the motor control device prescribed to preserve the running direction in the memory function described in Table 7, there was no description on the operation for the case that the powering command was inputted while both the F cable and the R cable are in the de-energized statuses.

It was necessary not only to confirm the contents of the descriptions in the specifications, but to study combining with the possibilities of the occurrence of a various malfunctions, in order to be noticed that the concerned memory function was used in the powering operation not only in the braking operation, furthermore becomes the cause of the dangerous incident toward the backward running when the powering command was inputted in the turn back station when the command cable for the running direction was broken. However, the studies on the existence of the memory function and its effects had not been implemented in the meetings for design review and coordination for design together with the device manufacturer, therefore, it is probable that the understandings on the precise functions of the motor control device were lacked in the Company and the vehicle manufacturer. That is, the designing and manufacturing process of the 2000 series vehicle described in 2.9.2, had not been implemented by the organization considered the system integration sufficiently, and the understandings of the precise functions of the motor control device were lacked in the Company and the vehicle manufacturer, therefore, it is probable that the studies supposing the various situations that have the possibility to cause the malfunctions had not been implemented.

In addition, there were the differences in the understandings on the function to detect the backward running between the vehicle manufacturer and the device manufacturer B, but the confirmation and coordination of the designing organization, described in 3.4.1, were not implemented sufficiently, and the devices were installed in the status that the confirmation and the coordination on the understandings of each specifications had been lacked. As the results, it is probable that the composition to secure the safety of the 2000 series vehicle described in 3.3.4, became in the status that the function to detect the abnormal running of the backward running, by the function to detect backward moving or the other method, were not existed.

#### 3.4.3. Verification of the Safety

According to the Company and the vehicle manufacturer, the verification on the safety of the 2000 series vehicle was implemented in the meeting for design review, the MDR and the design examination in the vehicle manufacturer, as described in 2.9.6.



However, the occurrence of the incident of the backward running such as this accident had not been supposed, because the confirmation and the coordination of the designing organization and the extraction of the safety causes described in the designing and manufacturing process, shown in Figure 22 in 3.4.1, were not implemented sufficiently, in the designing and manufacturing process of the 2000 series vehicle, and therefore the design works was implemented in the status where the confirmation and the coordination of the designing organization as described in 3.4.2 are insufficient, and furthermore there was no precedent that the train in the unmanned operation was running in reverse direction in the past.

It is likely that the verification of the safety against the system such as the forward and backward switching circuit could not be implemented sufficiently in the meeting for design review and the MDR and the design examination, etc., in the vehicle manufacturer, because the matters to be paid attention in the designing and manufacturing of the 2000 series vehicle were not put in order. As the results, it is probable that the motor control device in the forward and backward switching circuit of the 2000 series vehicle preserved the running direction in the memory function, described in 3.4.2, could not be extracted and was not noticed as the latent cause of the dangerous incident that can cause the backward running.

It is probable that the more precise study was required on the differences with the train operated by the manned operation in the security of safety in the trains operated by the unmanned operation, as described in 3.3.4. As it is necessary to secure the safety by detecting the abnormal status of the train operated by the unmanned operation by the function to detect the backward moving or the other methods, but the confirmation and the coordination of the purpose and the specifications, etc., which had been understood as general in each company, on the function to detect the backward moving, etc., had been lacked. It is probable that it was not realized to secure the safety by the function to detect backward moving and the other methods supposing the possibilities of the backward moving as in this accident because of the lack of the above confirmation and the coordination.

Many railway vehicles in the country have been usually designed by using the best of knowhow and experiences of the person in charge of design based on the achievements up to that time. It is considered as necessary to study carefully and precisely comprehending sufficiently the difference with the design of the ordinary railway vehicles up to that time based on the purposes and the characteristics of the vehicle and the onboard devices for the newly designed vehicles such as the vehicles for the unmanned operation, etc., although the existence of the achievements up to that time was the important standard for judgement. Although the safety was studied from various angles in the meeting for design review, etc., it is possible to generate the lack in the studied matters, in addition, there is risk not to aware the lack of the studied matters even though studied many times and in the long times. These designing procedures are the method based on the conventional experiences, however, it is probable that there is the case that the comprehensive study for the whole contents becomes close to a limit, in the design of the vehicle system which becomes complicated more and more.

Recent years, there is the case that the compatibility to the RAMS standard<sup>\*37</sup> is required to the

vehicles for foreign countries, however, the systematic safety analysis including the "hazard analysis", *i.e.*, the analysis on the occurrence of the dangerous incidents and their causes such as the FTA<sup>\*38</sup> and FMEA<sup>\*39</sup>, etc., has not been conducted so many times for the vehicles for the domestic operators. It is expected to extract and evaluate, without a lack, the conditions which caused the dangerous incidents by supposing the derailment, the fire, the collision, etc., as the dangerous incident, and analyzing the process to the occurrence and the causes to the occurrence, and comprehensively the effects of the breakage or the short circuit of electric wires, or the break or fell off of machine parts, etc. Therefore, it is considered as necessary to secure the sufficient designing period and conduct properly when introduce the new system to the running control or the train protection system.

Therefore, it is considered as necessary to secure the required designing period and confirm comprehensively whether the safety of the whole system was secured adequately or not, in the phase to verify safety, on the safety factors extracted by the systematic safety analysis in the phase to extract safety factors, in the designing and manufacturing process described in 3.4.1.

*\*37 "RAMS standard" is the IEC standard stipulated the implementing contents in a series of the processes and in each phase in the life cycle of the system, for the purpose to secure the safety and the transport quality, for the entire railway system such as the vehicles and the electric facilities represented by the railway signals. Here, the RAMS is the abbreviation of reliability, availability, maintainability and safety.*

*\*38 "FTA" is the abbreviation of the fault tree analysis, and the technique to analyze the process, the causes and the provability of the occurrence of the undesirable incidents.*

*\*39 "FMEA", is the abbreviation of the failure mode and effect analysis, and the technique to analyze the effects of the trouble mode of the components and the effects to the higher link items.*

### 3.5. Analysis on the Strength of the Vehicle and Ground Facilities

The "damages and attached status" was checked as good in the latest periodic inspection as described in 2.7.1, and the Train had been operated without particular problems from the departure from the train depot until the occurrence of the accident in the day of this accident, as described in 2.1.1. Therefore, it is probable that the damages of the intermediate coupler and the folded gangway footplate, described in 2.4.2, were caused as the Train collided with the car stop.

According to the 0.2 sec pitch data recorded in the event recorder shown in Table 3 in 2.1.3, the Train collided with the car stop in the maximum velocity of 25 km/h, the notch command turned off at 0.4 second after that, the brake command turned on 0.2 second after that. The motor current increased from 396 A to 428 A, within 0.4 second, from 0.2 second after the collision, therefore it is probable that the Train ran in the powering operation in this period. From 0.6 second after the collision, the brake pressure was established accompanied to the decrease of the motor current.

It is highly probable that the Train almost stopped in about 0.8 second after the collision, and the maximum deceleration in this period was  $37.5 \text{ km/h/s} = 10.4 \text{ m/s}^2$ .

As the mass of the Train was 52,880 kg, it is likely that the compressed load of about 550 kN had been acted from the coupler of the 5th vehicle which had collided with the car stop. It is probable that the body structure of the vehicle had the enough strength because it was partly damaged but

major damage was not found in the bogie frame.

Additionally, it is probable that the impact force of about 550 kN had acted to the ground facilities, but the major damage was not found except for the leaked oil caused by the hydraulic buffering device of the car stop, lengthened about 1000 mm, as described in 2.4.3, therefore, it is probable that the ground facilities including the station facilities had the tolerable strength against the collision.

## 4. CONCLUSIONS

### 4.1. Findings

#### 4.1.1. Occurrence of the Backward Running

The motor control device of the Train drove the motors in the direction opposed to the direction of travel of the Train, and the vehicle collided with the car stop, in this accident. It was found that the F cable, which is the command cable transmitted the signal of the running direction command of the train to the motor control device in the device room in the 1st vehicle of the Train, was broken in the investigation conducted after the accident. It is highly probable that the F cable broke while the Train had been operated as the outbound 1905 train, which was operated two trains before the Train, between Sachiura station and Sangyo-Shinko-Center station, based on the records in the event recorder of the vehicle. The motor control device was designed to preserve the previous running direction in the memory function, even in the case that both the F cable and the R cable became the de-energized status. It is highly probable that the motor control device drove the motors in the previous inbound direction, which was preserved in the function to memorize running direction when it received the powering command, and the train collided with the car stop in the terminal end of the track at about 25 km/h, because both the F cable and the R cable became the de-energized status due to the breakage of the F cable, when the direction of travel of the Train was switched from the inbound to the outbound, when the Train was operated as the turn back outbound train in Shin-Sugita station. [Refer to 3.1]

In this accident, the signals were transmitted in the ground and the onboard as follows.

- (1) The station ATO onboard unit transmitted the status of running direction as outbound to the station ATO ground unit, and the station ATO ground unit judged that the running direction command to the vehicle and the status of the running direction from the vehicle matched with each other.
- (2) The motor control device, as received the powering signal from the station ATO onboard unit, drove the motors in the inbound direction, *i.e.*, the direction opposite to the running direction of the Train preserved in the function to memorize running direction.
- (3) The abnormal running of the Train was not detected by the function to detect backward movement in the station ATO onboard unit and the other methods, and the brake did not act until to collide with the car stop.

[Refer to 3.3.1]

There was the possibility that the status of the running direction transmitted from the station ATO onboard unit to the ground unit did not match with the direction that the motor control device drive the motors, if the running direction command from the station ATO onboard unit to the motor control device had not been transmitted correctly because the station ATO onboard unit had transmitted the status of the running direction based on the energized status of the command line to select the driving desk, in the 2000 series vehicle. However, it is highly probable that the station ATO ground unit recognized that the running direction of the train was set normally, and the situation, that the vehicle actually move in the opposite direction, could not be detected in the Train.

In addition, the condition to drive motors in the powering operation will establish when the powering command is inputted even though the abnormal situation occurred in the running direction command, because the powering command is inputted to the motor control device by the command cable different from the running direction command, and the motor control device preserved the running direction in the memory function. [Refer to 3.3.2]

It was possible that the train could be operated without any problem if the memory function was not equipped in the motor control device, because the energized statuses of the F cable and the R cable are preserved in the onboard front relay board, and the motor control device always received the running direction command. It is probable that the preservation of the running direction in the memory function of the motor control device became the latent cause of the dangerous incident that can cause the backward moving when the powering command was inputted, if there was abnormal status in the running direction command, in the forward and backward switching circuit of the 2000 series vehicles. [Refer to 3.3.3]

The specifications of the function to detect the backward moving in the 2000 series vehicles were based on the ordinary railway vehicles and the other new transit system vehicles in the device manufacturer B. Considering to secure the safety against the occurrence of the abnormal situation, it is required to implement the measures such as that the train crew implement the emergency stop procedures in the train driven by the manned operation. On the other hand, it is required to secure the safety by detecting the abnormal situation by the system in the train driven by the unmanned operation. However, it is probable that the function to secure the safety against the abnormal status had been lacked in the 2000 series vehicle. [Refer to 3.3.4]

#### 4.1.2. Occurrence of the Breakage of Wires

It is probable that the F cable has been in the status as contacted with the upper surface of the end rail from the time when the vehicle was manufactured. It is highly probable that the insulator of the F cable wore gradually by the vibration of the running vehicle, and caused ground fault current to the end rail while running as the outbound train operated in two trains before the Train. [Refer to 3.2.1]

It is probable that the bundle of cables including the F cable got closer to the end rail because it had been wired from the wiring hole of the floor board, through outside of the main air reservoir and the low voltage terminal rack toward the aisle via the neighborhood of the end structure, in the

Device Room. Furthermore, it is probable that the F cable and a part of cables in outermost part of the bundle or its neighborhood had finally contacted with the end rail, resulted from that the height, to fix the bundle of cables to the cable support of the low voltage terminal rack, was low, etc. [Refer to 3.2.2]

It is likely that the attention against the contact of the bundle of cables and the end rail was insufficient, because the end rail could not be sighted from the workers as it was covered by the bundle of cables in the wiring work of the concerned bundle of cables, etc. There was no prescription as to stimulate attention for the individual wiring works, such as the contact to the end rail in the Device Room, etc., in the manual for the outfitting works and the manual for the wiring works in the end structure of the 2000 series vehicle. As the results, it is likely that the attachment of the protecting material to the bundle of cables and the vehicle material side protectors were insufficient, and the status that the bundle of cables contacted with the end rail had not been noticed even in the final works to fix the bundle of cables. In addition, the wired status in the concerned machine room was not inspected by the section in charge of inspection after implemented the wiring works, moreover, was in the status which could not be checked easily after completed manufacturing of the vehicle. Therefore, it is probable that the contacted status of the bundle of cables and the end rail could not be found. [Refer to 3.2.3]

It is probable that it was difficult to foresee the breakage of electric wires, etc., by comprehending the status of the F cable in the periodic inspection of the Company, although the insulation resistance measurement, the dielectric strength test, etc., had been implemented in addition to the visual inspection, as the inspecting items for the electric wires, etc., of the Vehicle in the periodic inspection of the Company. [Refer to 3.2.4]

It is highly probable that the fault grounding current flew in addition to the steady state current for the power source of the control circuit and the motor control device when the F cable had been grounded fault, because the control circuit of the command cables, etc., and the control power source of the motor control device had been connected to the control circuit breaker of the Vehicle. However, the fault grounding current in this case was in the level that would not break the circuit, based on the operation characteristics of the control circuit breaker. [Refer to 3.2.5]

In vibration testing of electric wire, the electric wire, which was the same kind as the F cable, contacted with the material equivalent to the end rail in the status as a certain load had been acted, and flawed in the insulator when applied the vibration. It is considered as necessary to protect the electric wires and the vehicle materials against the abrasion of the insulators of the electric wires due to the contact with the vehicle materials. [Refer to 3.2.6]

#### 4.1.3. Designing Vehicles

It is necessary to prepare the phase to confirm and coordinate the designing organization, the phase to extract the safety causes, before implemented the designing works, and prepare the phase to verify the safety of the designed contents in the final stage of the designing works, and implement them adequately in the designing and manufacturing processes of the railway and tramway systems. However, it is probable that the concrete design works had started without the

confirmation and arrangement of the designing organization and the extraction of the safety factors before started the design works when designed the 2000 series vehicle.

In the recent years, the design of the vehicle is complicating more and more, however it was unclear which organization was in charge of the system integration of the vehicle, in the designing works of the 2000 series vehicle. [Refer to 3.4.1]

It is probable that the confirmation and the coordination of the designing organization and the basic concept had been insufficient between the Company and the vehicle manufacturer, and the confirmation and the coordination of the understandings on the specifications of the motor control device and the function to detect the backward movement, etc., had been insufficient between the vehicle manufacturer and the device manufacturer. It is likely that the concrete specifications of the device proposed by the device manufacturer had adopted although the confirmation had been insufficient, while the designing works were implemented considering seriously the achievements, etc., in the 1000 series vehicle and the ordinary railway vehicles.

As the results, it is probable that the motor control device equipped with the function to memorize running direction used in the ordinary railway vehicles, had been incorporated into the forward and backward switching circuit based on the 1000 series vehicle, and the preservation of the running direction in the memory function of the motor control device became the latent cause of the dangerous incident against the occurrence of the backward running. [Refer to 3.4.2]

Because the matters to be paid attention in the designing and manufacturing process were not arranged in the designing and manufacturing process of the 2000 series vehicles, it is likely that the verification of the safety on the system such as the forward and backward switching circuit, etc., could not be conducted sufficiently in the meeting for design review and the MDR and the design examination in the vehicle manufacturer, etc. As the results, it is probable that the latent cause of the dangerous incident against the occurrence of the backward moving could not be extracted and had not been noticed.

In addition, it is probable that the safety had not been secured by supposing the possibility of the backward running same as this accident, because the study on the differences in the security of the safety between the vehicles operated by the manned operation and the unmanned operation were insufficient.

It is considered as necessary to study more carefully and concretely, after comprehending the differences with the conventional design of the ordinary railway vehicles, based on the purposes and the characteristics of the devices boarded on the vehicles in the vehicles which is newly designed, although the existing railway vehicles in the country are usually designed based on the achievements, etc., up to that moment.

It is considered as necessary to implement properly the systematic safety analysis including the so-called hazard analysis, such as the FTA or the FMTA, when the new system was introduced in the running control and the train protection system, because it is necessary to check comprehensively whether the safety was secured sufficiently in the whole system including the vehicles and the ground facilities. [Refer to 3.4.3]

## 4.2. Provable Causes

The JTSC concludes that the probable cause of this accident was certain that this accident occurred because the Train started to run in the inbound direction opposite to the outbound direction of the direction of travel, when turned back in Shin-Sugita station, and collided with the car stop at the end terminal of the track.

It is highly probable that the Train started to move by the power running in the direction opposite to the designated running direction without intention, because the motor control device of the 2000 series vehicle drove the motors in the inbound direction that had been preserved in the memory function, as the F cable, which is the command cable to transmit the signal on the running direction of the train to the motor control device, became in the de-energized status due to be broken in the 1st vehicle. Furthermore, it is probable that the measures such as the emergency stop procedures could not be implemented, because the station ATO ground unit recognized that the running direction of the train had been set normally, as the station ATO onboard unit had transmitted the status of the running direction based on the energized status of the command line to select the driving desk, which is different from the input signal to the motor control device, also there was no function to detect the backward running or the function to detect backward moving by the other methods such as in this accident.

It is probable that the F cable had broken because the insulator of the F cable wore gradually by the friction with the upper surface of the end rail due to the vibration while the vehicle was running, and F cable grounded fault to the end rail, as the results of that the bundle of cables including the F cable in the device room were wired without sufficient attachment of the protecting materials for the electric wires, and had been contacted with the end rail made of the stainless steel, but the inspection had not been implemented after the wiring works were finished.

It is likely that, in the back ground of this accident, the existence of the latent causes for such dangerous incident and the insufficient safety assurance against the abnormal status such as the backward running, etc., were not noticed, because the confirmation and the coordination on the understandings for the designing organization, the basic concept, and the specifications, etc., between the Company, the vehicle manufacturer and the device manufacturer, and the extraction of the safety factors before designing were not implemented sufficiently, in the designing and manufacturing process of the 2000 series vehicle, the latent causes of the dangerous incident for the occurrence of the backward running was generated, in addition, also the verification of the safety was insufficient.

## 5. SAFETY ACTIONS

### 5.1. Measures to Prevent the Recurrence Considered as Necessary

#### 5.1.1. Prevention of the Breakage of Electric Wires

It is necessary for the vehicle manufacturer to study the layout and the fixing methods, etc., of the electric wires, etc., and to keep sufficient spacing between the electric wires, etc., and the

vehicle materials, in order to demonstrate the required performances in the long term usable period. Furthermore, it is important to promote the workers to pay attention to the individual works by the manuals or drawings for the wiring works, such as to attach the protecting materials to the electric wires and the vehicle materials properly, to the places where there was a risk that the electric wires, etc., contact with the vehicle materials, such as the narrow portion. In addition, it is necessary to conduct inspections even during the manufacturing works, for the place where the implementation of the sufficient inspection for the wired status becomes difficult after completed manufacturing.

#### 5.1.2. Prevention of the Running in Wrong Direction

In order to prevent the running in wrong direction as in this accident, the following measures are considered as necessary for the 2000 series vehicles

- [1] It is necessary to use information of the command cable inputted to the motor control device in the vehicle, as the information on the status of running direction of the vehicle transmitted to the ground unit. In addition, it is desirable to make the system that supposed the occurrence of abnormal status in the transmitting route of the signals in the halfway in the trainset.
- [2] It is necessary to make the motor control device to drive the motor only in the case that the running direction command was inputted in the inbound or the outbound direction, and did not operate in powering even if received the powering command when the information on the running direction was indefinite.
- [3] It is necessary to stop the vehicles immediately not only when the wheel rotation was detected in the situation that there is no running direction command, but also in the case that the train ran in the reverse direction, opposite to the running direction set in the train, because the system is the unmanned automatic operation system.

#### 5.1.3. Designing Vehicles

When implementing the designing, manufacturing or remodeling of the automatic operation system, etc., of the train in the railway and tramway system, which neither the driver nor the staff operate the emergency stop procedures boarding on the forefront, in the situation that the vehicle design is advancing in complexity more and more in recent years, it is important to prepare the designing organization to conduct the system integration, and extract and evaluate the conditions caused to the dangerous incidents comprehensively without lack, and reflect these measures as the matters of the safety factors, also it is necessary to manage the safety for the whole life cycle including the manufacturing and the operation. Among them, it is probable that the railway and tramway operators, etc., and the vehicle manufacturers should prepare the phases to confirm and coordinate the designing organization, etc., to extract the safety factors carefully, and implement these phases sufficiently before the designing works are started, and implement the verification of the safety sufficiently after the designing works are finished.

##### (1) Implementation of the imaginable designing and manufacturing process

When manufacturing or remodeling of the system are designed for the automatic operation of



the train which the driver did not boarded, it is necessary to prepare the phase to "confirm and coordinate the designing organization, etc.", the phase to "extract safety factors", the phase to "verify the safety", and implement each phase sufficiently, referring the designing and manufacturing process shown in Figure 22.

(2) Implementation of confirmation and arrangement of the designing organization, etc.

It is necessary to prepare the designing organization to implement the system integration, and confirm and coordinate the roles and sharing of responsibility between individual companies, and the specifications of each device that each company considered as the standard or considered as general, in the phase to confirm and coordinate the designing organization, etc.

(3) Implementation of extraction of the safety factors

It is necessary to implement properly the systematic safety analysis by applying the analytical methods on the occurrence of the dangerous incident and their impacts such as the FTA and FMEA, etc., corresponding to the characteristics of the system, and arrange the required matters, etc., necessary to secure the safety, in order to be confirmed the safety comprehensively against the abnormal status supposed to happen, in the phase to extract the safety factors.

(4) Sufficient implementation of verification of the safety

It is required to verify the designed results whether the whole system is secured the sufficient safety or not, for the safety factors extracted in the above (3), in the phase to verify the safety.

## 5.2. Measures Implemented after this Accident

### 5.2.1. Measures Implemented by the Company

Safety actions of the running in wrong direction implemented by the Company after this accident were as follows.

[1] Changed the electric circuit to add the contact terminal of the relay to detect the energized status of the F cable and the R cable, in the condition of the operation of the departure condition relay in the ATO onboard unit.

In addition, for the purpose that the ground units comprehend correctly the recognition on the running direction of the vehicle, changed the command cable, which return the information on the status of running direction to the ground units via the station ATO onboard unit, from the conventional command cables to select the driving desk., the 194G cable and the 195G cable, to the F cable and the R cable, furthermore, set the F cable and the R cable as the loop circuit in the trainset to enable to obtain the information from the end terminal side.

[2] Changed the software of the motor control device to implement the powering operation and the regenerative braking control only when one of the F cable and the R cable was in the energized status.

[3] Changed the software in the ATC onboard unit, as to operate the emergency brake when detected vehicle running in the status that both the F cable and the R cable, which are the command cable for the running direction, are in the de-energized status due to the breakage of cables, etc.

[4] Abolished the relay to correct the stopped position backward<sup>\*40</sup>, in order to improve the reliability still more of the circuit to instruct running direction of the vehicle.

Besides, the Company implemented the following measures.

[5] The wired status in the device rooms in all trainset composed of the 2000 series vehicles were checked and attached the protecting materials to the electric wires and the vehicle materials for the electric wires, etc., close to the vehicle materials.

[6] Implemented the hazard analysis on the automatic operation system of the 2000 series vehicles, and implemented to check the existence of the part with the safety problem. As the results, it is confirmed that there was no part with the safety problem, except for the implemented measures in the above [1] to [4].

[7] It was difficult to investigate the personal information of the passengers and to comprehend the number of the transported injuries, etc., correctly, due to the small number of the station staffs who responded just after the accident against the number of the injured passengers in this accident. Therefore, created the "contact address card" to establish the system that enabled to be contacted from the passengers in the other day by distributing it to the injured passengers when the similar incident happened, and enabled to comprehend the number of the transferred persons, etc.

*\*40 "Relay to correct stopped position backward" in this context, is the relay used when corrected the stop position of the train if the train stopped after overran beyond the designated stop position in the station, in the automatic operation.*

### 5.2.2. Measures Implemented by the Vehicle Manufacturer

The vehicle manufacturer implemented the following measures against the wiring works after this accident.

[1] Revised the check sheet for the wiring works of the low voltage terminal rack, by adding the items on the wired status and the protected status of the electric wires. In addition, the vehicle manufacturer conducted the education and training on the revision to the company staffs thoroughly.

[2] Expressed clearly the concrete examples with the explanatory diagrams on the protection for the electric wires and the body structure, in the manual for wiring processing. In addition, added the confirmation of the distance between the electric wires and the body structure and the flaws of the electric wires, etc., in the manual drawn up instructions of the works.

[3] The procedures of the wiring and connecting works, implemented as the contract works, were made clear that the inspection of the first products is implemented by the relevant staffs, and receive after implemented the minor adjustment.

[4] Decided to manage and share the photographs recording the wired status in the unified format as the formal record.

[5] The actual vehicle implementing the wiring works were checked by the staffs relevant to the designing and manufacturing, and after the wired status and the protection of the wired cables are confirmed particularly in the narrow portion, they are added to the manual for

designing and the instruction for manufacturing. Furthermore, strengthen the instruction by brushing up the on-site confirmation, the drawings and the manuals, considering as necessary to check the omission of the instruction and the on-site confirmation in the designing work for the new vehicles.

[6] The vehicle manufacturer established the "working team to study on the manual for handling wiring works in the narrow space" composed of the relevant persons in the design section, manufacture section, etc., and implemented together with the "review of wiring in the narrow space" and the examination of wiring in narrow space in the actual vehicles, and decided to feedback to the design drawings and the manual for handling wiring works, etc.

In addition, the vehicle manufacturer implemented the following measures as the effort to improve the safety of the products.

[7] Revised the contents to be attended to the covering electric wires in the "10 admonitions", which was established in order to make lessons on the important works for the safety in the manufacturing process, and excite further attentions.

[8] Implemented the education to the workers, and known well again by the managers on the circumstances to establish the "10 admonitions" established in 2018 and on the important parts in the working site.

[9] On the "rules for safety products design, the 10 rules" established in 2018, decided to utilize in the "review of new standpoints", etc., that had been started before this accident to review on the risk of the safety when the design was changed, and aimed the improvement of the product safety.

### 5.3. Measures Taken by the MLIT after this Accident

[1] On June 2, 2019, the MLIT instructed the Company to implement the investigation on the probable causes and the safety actions to secure the safe railway transportation.

[2] On June 2, 2019, the MLIT issued "On the railway accident with casualties occurred in Kanazawa seaside Line of Yokohama Seaside Line Co. Ltd.", Railway Technology No.18, Railway Facility No.25, Railway Safety No.8, to the railway and tramway operators in the whole country, and issued the notification "On the railway accident with casualties occurred in Kanazawa Seaside Line, information provision" to the guide rail type railway operators, to let them well known the summary of this accident and instructed to endeavor to secure the safe and stable transportation by the railway and the tramway system consecutively.

[3] On June 3, 2019, the MLIT issued "On the railway accident with casualties occurred in Kanazawa Seaside Line of Yokohama Seaside Line Co. Ltd.", Railway Technology No.19, Railway Facility No.30, Railway Safety No.9, to the railway and tramway operators in the whole country to let them known well on the status of investigation reported from the Company, and instructed the six railway operators who are operating the vehicles by the unmanned automatic operation, to pay sufficient attention particularly to the train operation in the turn back station, until the probable causes are made clear.

[4] From the evening of June 3 to early morning of June 4, 2019, the staffs of the Railway Bureau

and the Kanto District Transport Bureau attended the confirmation test conducted to resume the operation by the manual operation of Kanazawa Seaside Line.

- [5] On June 6, 2019, the MLIT gathered 7 operators who are operating the vehicles by the unmanned automatic operation, and shared the information on this accident and exchanged opinions on the prevention of the accidents, etc.
- [6] On June 14, 2019, the MLIT established the "Study meeting on the prevention of the accident in the railway and tramway systems operated by the unmanned automatic operation system", and held the first meeting. In the study meeting, the information was shared and the study on the measures to prevent the recurrence, etc., was implemented among the relevant persons. The meetings were held 3 times.
- [7] On July 19, 2019, in the 3rd study meeting, the MLIT instructed to share the information on the analyzing method for the occurrence and the causes of the dangerous incidents such as the FTA, FMEA, etc., from the professionals on the risk analysis, and to implement the verification of the safety by the FTA, etc., on the malfunction of the brake which is one of the serious risks other than the backward running, because the analysis based on the FTA, etc., is considered as effective as the method to evaluate the safety, even though it was confirmed that there was no problem in the other method on the operation of the motor control device.
- [8] On the same day, the above-mentioned study meeting published the intermediate report<sup>\*41</sup>.
- [9] From the night time of August 23, 2019, to early morning in the next day, and from the night time of August 30, 2019, to the early morning in the next day, the staffs of the Railway Bureau and the Kanto District Railway Bureau attended in the confirmation test conducted to resume the automatic train operation after implemented the measures to prevent the recurrence of the Route.
- [10] On February 27, 2020, the MLIT gathered 7 operators who are operating the vehicles by the unmanned automatic operation and the vehicle manufacturers, etc., and implemented to exchange opinions on the interim report issued by the JTSCB, etc.

<sup>\*41</sup> *Intermediate report of the "Study meeting on the prevention of the accident in the railway and tramway systems operated by the unmanned automatic operation system", the MLIT, 2019, <http://www.mlit.go.jp/common/001300038.pdf>*

## 6. RECOMMENDATIONS

The direct cause of this accident was the breakage of the electric cable in the forward and backward switching circuit of the train, which resulted in start of running as the direction of the driving motors was in the inbound direction toward the terminal end of the track. It is probable that the situation, that the confirmation and the coordination of the designing organizations, etc., the extraction of the safety factors and the verification of the safety, had not been implemented sufficiently in the designing and manufacturing process of the vehicles, was the background of the situation that the dangerous incident in the occurrence of such troubles could not be excluded.

When designing, manufacturing or remodeling of the automatic operation system, etc., of the train, which the driver nor the staff to operate the emergency stop procedures boarding on the forefront of the train in the railway and tramway vehicle, in the situation that the vehicle design is advancing in complexity more and more in recent years, it is important to prepare the designing organization to implement the system integration, and extract and evaluate the conditions caused to the dangerous incidents without lack before designing, and reflect these measures as the matters of the safety factors, also it is necessary to manage the safety setting target for the whole life cycle including the manufacturing and the operation. Among them, it is probable that the railway and tramway operators, etc., should prepare the phases to confirm and coordinate the designing organization, etc., to extract the safety factors carefully, and implement these phases sufficiently, and implement the verification of the safety sufficiently after finished the designing works.

In the view of the result of this accident investigation, the Japan Transport Safety Board recommends the Minister of the Land, Infrastructure, Transport and Tourism pursuant to Article 26, paragraph (1) of the Act for Establishment of the Japan Transport Safety Board, to implement the following measures, in order to prevent the railway accident and to reduce damages when the railway accident had happened.

#### Notice

The Railway Bureau, MLIT, should enforce the instruction on the following matters to the railway and tramway operators and the manufacturers related to the designing and manufacturing of the railway vehicles in the whole country.

- [1] When conducting the design of manufacturing or remodeling of the system to implement the automatic operation of the train which the driver did not boarded, prepare the phases to confirm and coordinate the designing organization, etc., to extract safety factors, to verify the safety, and implement each phase sufficiently, referring the designing and manufacturing process shown in Figure 22.
- [2] In the phase to confirm and coordinate the designing organization, etc., prepare the designing organization to implement the system integration, and confirm and coordinate the roles and the division of responsibility between individual companies, and the specifications that each company considered as the standard or considered as general for each device.
- [3] In the phase to extract the safety factors, conduct the systematic safety analysis, etc., corresponding to the characteristics of the system, and arrange the required matters, etc., necessary to secure the safety, in order to be confirmed the safety comprehensively against the

abnormal status supposed to happen.

[4] In the phase to verify the safety, verify the designed results whether the whole system secured the sufficient safety or not, for the safety factors extracted in the above [3].

## 7. OPINIONS

When designing, manufacturing or remodeling of the automatic operation system and others, of the train, which the driver nor the staff to operate the emergency stopping procedures boarded on the forefront of the train in the railway and tramway vehicle, it is important to extract and evaluate the conditions to cause the dangerous incidents without lack before designing, and reflect these measures as the matters of the safety factors, also it is necessary to manage the safety setting target for the whole life cycle including the manufacturing and the operation.

Therefore, the JTSB expresses its opinions as follows to the Minister of the Land, Infrastructure, Transport and Tourism pursuant to Article 28 of the Act for Establishment of the Japan Transport Safety Board, accompanied with the recommendations described in Chapter 6, as the measures to be implemented in order to prevent the accident, etc., when the automatic operation system spread in the future.

### Notice

The Railway Bureau of the MLIT, preparing for the spread of the automatic operation system in the future, study on the institutionalization of individual matters described in Chapter 6, in the view point to prevent the occurrence of the latent causes for the dangerous incidents when designing, manufacturing or remodeling of the system are implemented.

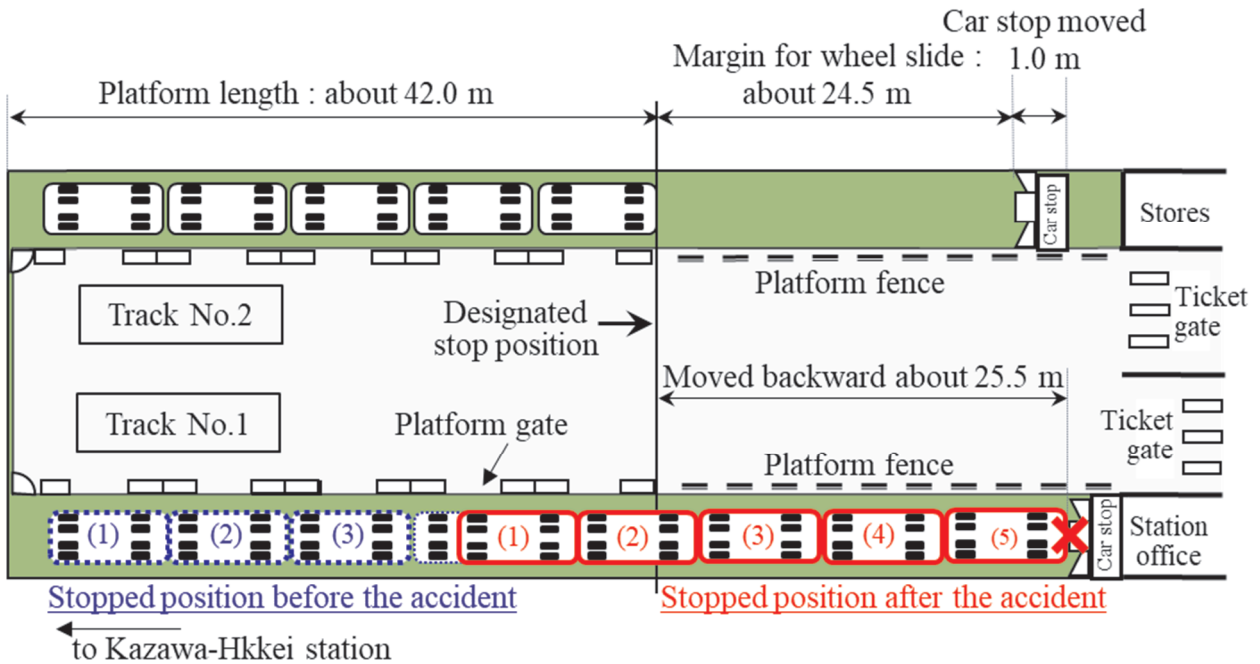
END

Attached Figure 1. Route Map of Kanazawa Seaside Line

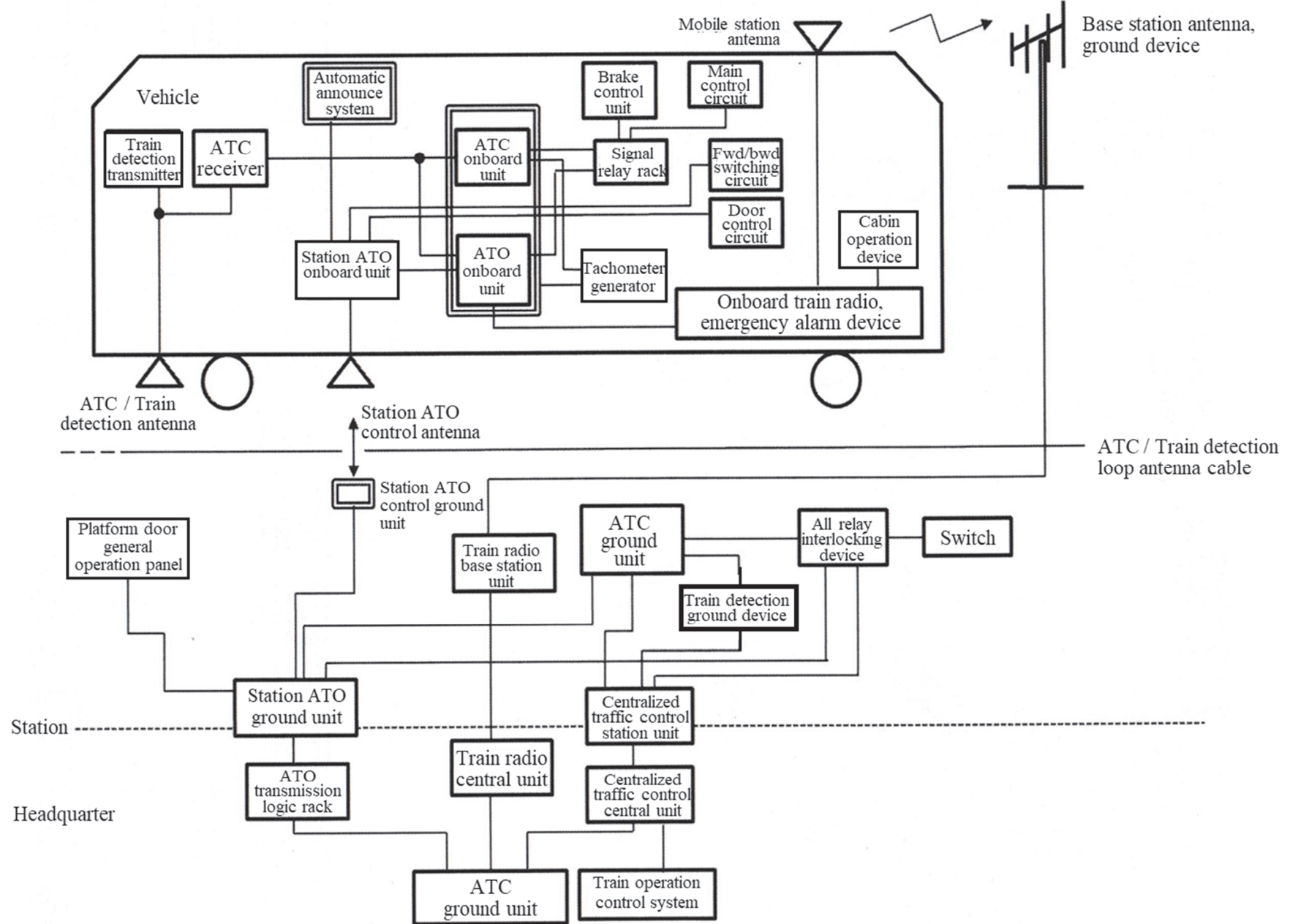


\* This figure was made using the Geographical Institute Map, Electrical Country Web, of the Geospatial Information Authority of Japan

Attached Figure 2. Rough Map of the Accident Site in Shin Sugita Station

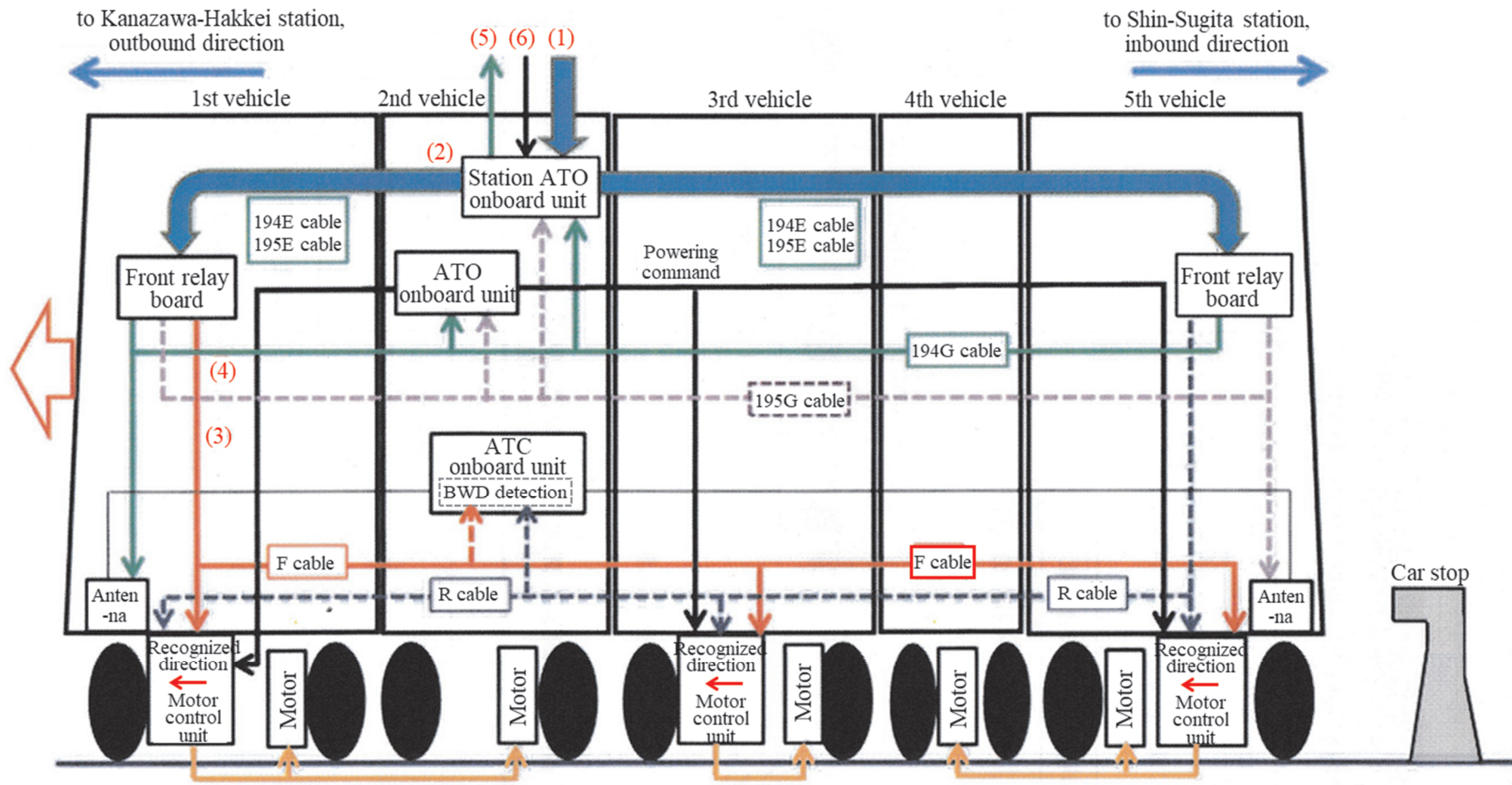


Attached Figure 3. Composition of the Ground and the Onboard Systems of the Route

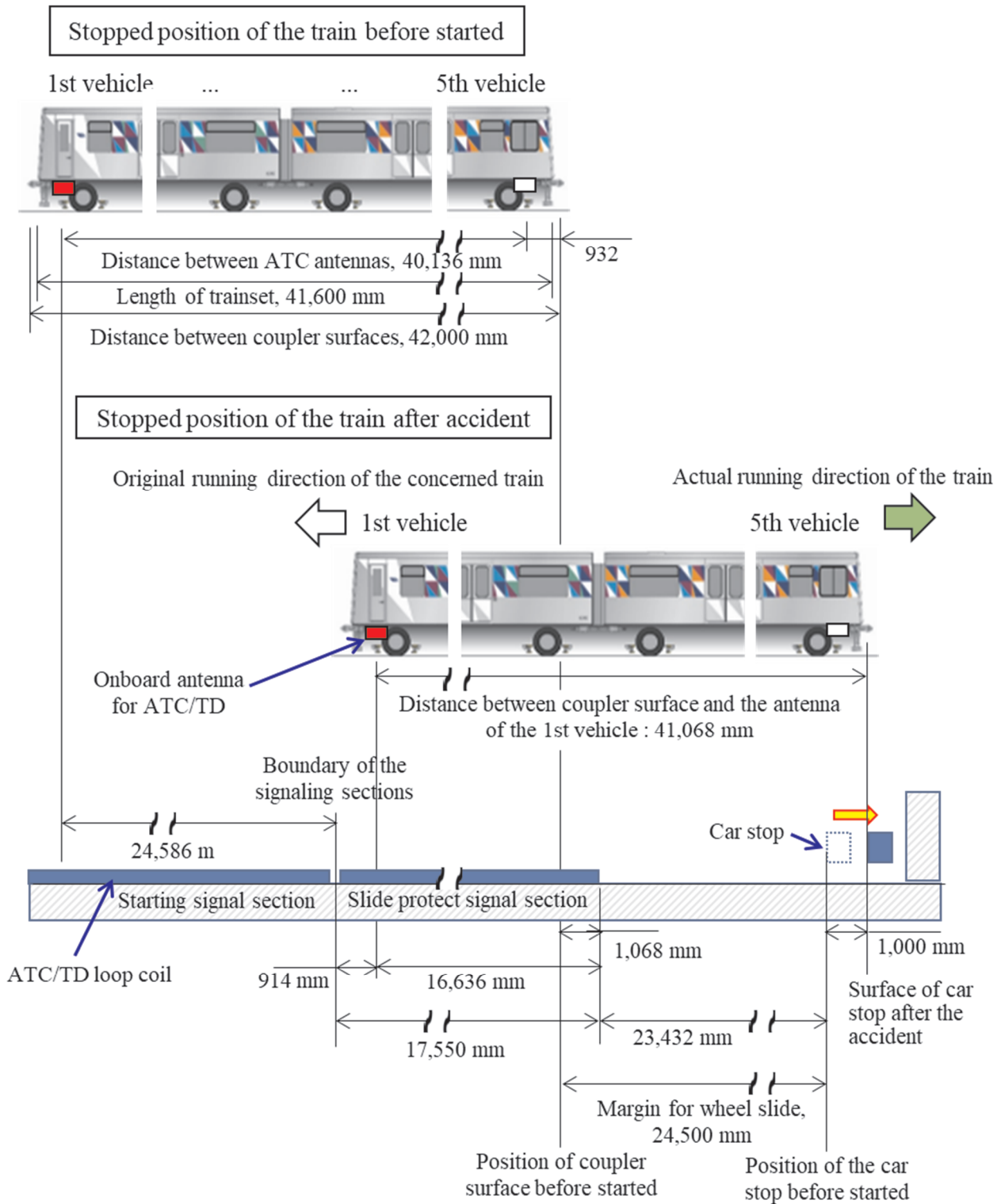




Attached Figure 4. Control Flow of the Onboard System When Changed the Running Direction



Attached Figure 5. Ground Facilities and the Stopped Position of the Train in Shin Sugita Station



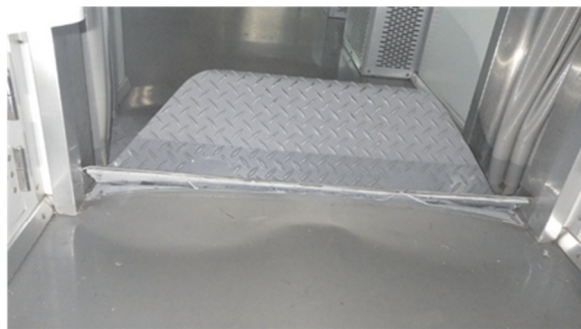
Attached Figure 6. Major Damaged Status of the Vehicles



Status of collision with the car stop, the 5th vehicle



Distortion of the ceiling panels in Shin-Sugita station side of the 4th vehicle



Inside cabin in the coupled part between the 4th and the 5th vehicles



Dent of the end plate, Shin-Sugita station side of the 2nd vehicle

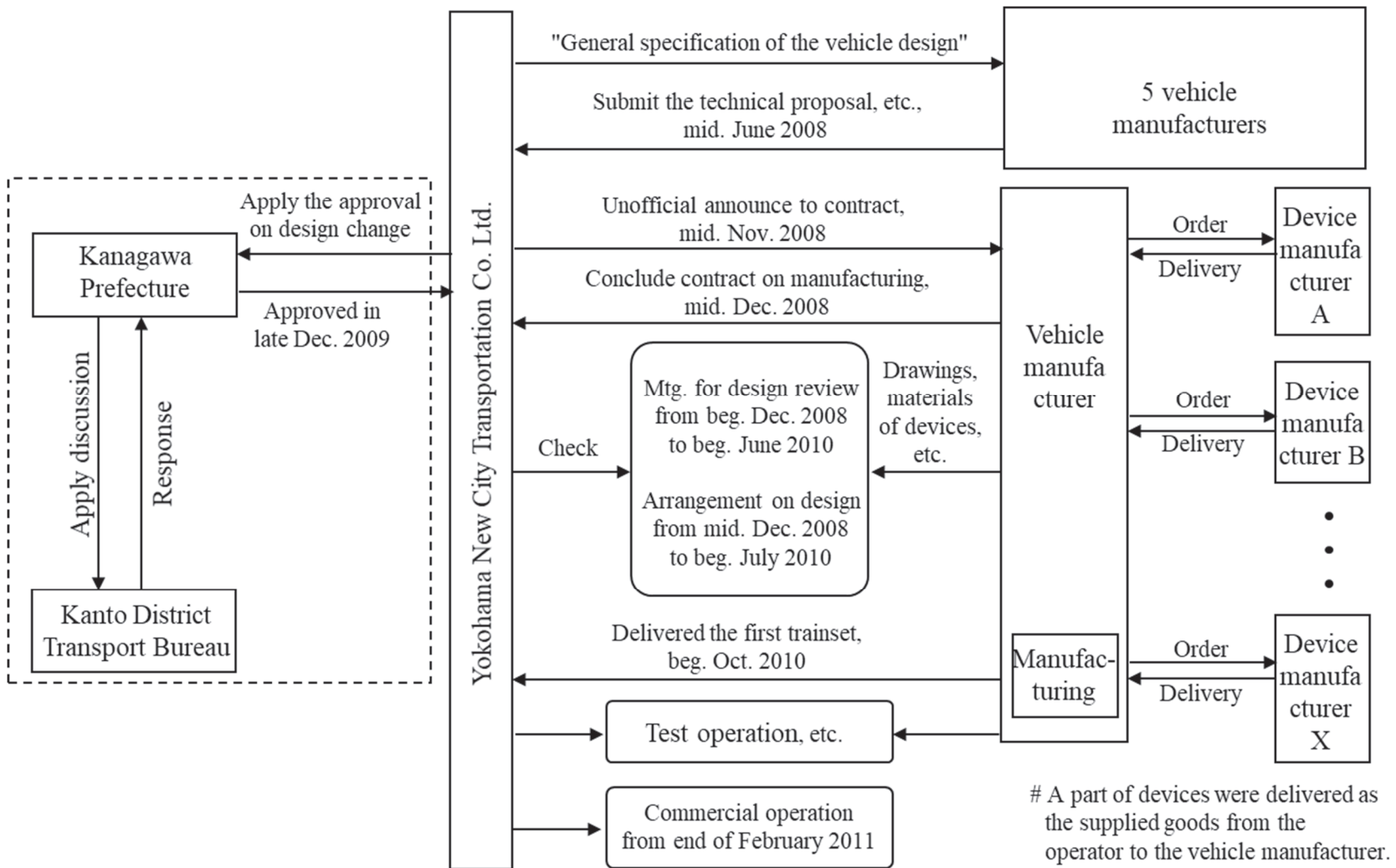


Inside cabin of the coupled part between the 2nd and the 3rd vehicles



Bent intermediate coupler, between the 4th and the 5th vehicles

Attached Figure 7. Process of Designing and Manufacturing of the 2000 Series Vehicles



# Yokohama New City Transportation Co. Ltd. was the company name when the 2000 type vehicles were designed and manufactured, and changed to Yokohama Seaside Line Co. Ltd., on October 1, 2013.