

RI2019-1-I

**RAILWAY SERIOUS INCIDENT
INVESTIGATION REPORT**

**Vehicle damage of West Japan Railway Company
In the premises of Nagoya station, Tokaido Shinkansen**

March 28, 2019

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.

Kazuhiro Nakahashi
Chairman
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.

Railway Serious Incident Investigation Report

Railway operator : West Japan Railway Company
Serious incident type : Vehicle damage, railway serious incident related with "the situation that malfunction, damage, destruction, etc., hindering the safety of the train operation in the running gears, brake gears, electric devices, coupling devices, train protection system, etc., of the vehicle occurred" prescribed in Item 8, Paragraph 1, Article 4 of the Ordinance on Report on Railway Accidents, etc.
Date and time : About 23:40, December 11, 2017, when the crack in the bogie was found.
Location : In the premises of Nagoya station, Tokaido Shinkansen, Nagoya City, Aichi Prefecture, where the crack in the bogie was found.

March 11, 2019

Adopted by the Railway Committee, the Japan Transport Safety Board

Chairman	Kazuhiro Nakahashi
Member, Chair	Fuminao Okumura
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SYNOPSIS

SUMMARY

On December 11, 2017, the inbound 34A train, "Nozomi 34", of West Japan Railway Company, composed of 16 vehicles started from Hakata station bound for Tokyo station, departed from Hakata station of Sanyo Shinkansen on schedule at about 13:33. The train crews, etc., had been noticed unusual smell in the cabin and unusual noise from underfloor of the vehicle, from just after departed from Hakata station, but the train was operated until to Shin-Osaka station, and the subsequent train operation was handed over to Central Japan Railway Company.

When the 34A train arrived at Nagoya station of Tokaido Shinkansen at about 16:53, the vehicle maintenance staffs, dispatched to Nagoya station obeying the instruction of the operation dispatcher of Central Japan Railway Company, noticed unusual sound from the 4th vehicle, and implemented the underfloor inspection in Nagoya station at about 17:03.

As the results of the inspection, the leaked oil was found in around the gear box in the front bogie of the 4th vehicle, then the further operation of the 34A train was cancelled.

After that, when the works to move the concerned vehicle to the train depot, *i.e.*, Nagoya Rolling Stock Depot, was implemented, the crack was found in the side beam in left side of the bogie frame of the front bogie in the 4th vehicle, at about 23:40.

There were about 1,000 passengers, 4 train crews, *i.e.*, the driver and 3 conductors, and 3 pursers engaging in the cabin sales, etc., boarded on the train when the train had arrived at Nagoya station, but there was no injured person.

Here, the vehicles operated as the 34A train were owned by West Japan Railway Company.

PROBABLE CAUSES

It is highly probable that the concerned serious incident occurred because the gear type flexible shaft coupling displaced exceeding the allowable range and damaged due to deformation of the bogie frame caused by the crack which had generated in the side beam of the bogie frame of the vehicle and had expanded by fatigue.

The crack had generated in the side beam of the bogie frame of the vehicle because it is somewhat likely that the split had generated in around the back boundary of the slot welded part where the crack had originated when the welding work had implemented. In addition, it is highly probable that the crack had generated related with the followings.

- (1) The residual stress was generated in around the slot welded part due to the implementation of the overlay welding on the bottom surface of the axle spring seat after annealed.
- (2) The thickness of the bottom plate of the side beam had become thinner than the designed standard value, because the bottom surface of the side beam had been grinded excessively when attached the axle spring seat to the bottom plate of the side beam.

In addition, it is highly probable that the crack had expanded in the period shorter than the vehicle life, *i.e.*, the usable period of the bogie, because the expanding speed of the crack became faster as the thickness of the bottom plate of the side beam became thinner due to the excessive grinding works implemented in the bottom plate of the side beam.

Here, it is highly probable that the bottom plate of the side beam was grinded excessively related with that the problem, that the machining work was required to attach the axle spring seat due to the swell in the bottom surface of the side beam generated in the manufacturing process of the bogie frame, was dealt without studying the essential causes and counter measures, and the manufacturing works had implemented without well understandings on the instructions for the work related to the strength of the bogie frame.

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1. PROCESS AND PROGRESS OF THE RAILWAY SERIOUS INCIDENT INVESTIGATION

1.1. Summary of the Railway Serious Incident

On Monday, December 11, 2017, the inbound 34A train, "Nozomi 34", of West Japan Railway Company, composed of 16 vehicles started from Hakata station bound for Tokyo station, departed from Hakata station of Sanyo Shinkansen, on schedule at about 13:33. The train crews, etc., had been noticed unusual smell in the cabin and unusual noise from underfloor of the vehicle, from just after departed from Hakata station, but the train was operated until to Shin-Osaka station, and the subsequent train operation was handed over to Central Japan Railway Company.

When the 34A train arrived at Nagoya station, Tokaido Shinkansen at about 16:53, the vehicle maintenance staffs, dispatched to Nagoya station obeying the instruction of the operation dispatcher of Central Japan Railway Company, noticed unusual sound from the 4th vehicle, and implemented the underfloor inspection in Nagoya station at about 17:03. *Hereinafter, the direction "front", "rear", "left" and "right" were defined based on the running direction of the train, and the vehicles were numbered from the front of the train.*

As the results of the inspection, the leaked oil was found in around the gear box in the front bogie of the 4th vehicle, then the further operation of the 34A train was cancelled.

After that, when the works to move the concerned vehicle to the train depot, *i.e.*, Nagoya Rolling Stock Depot, was implemented, the crack was found in the side beam in left side of the bogie frame of the front bogie in the 4th vehicle, at about 23:40.

There were about 1,000 passengers, 4 train crews, *i.e.*, the driver and 3 conductors, and 3 pursers engaging in the cabin sales, etc., boarded on the train when the train arrived at Nagoya station, but there was no injured person.

Here, the vehicles operated as the 34A train were owned by West Japan Railway Company.

1.2. Outline of the Railway Serious Incident Investigation

1.2.1. Organization of the Investigation

The concerned serious incident corresponded with "the vehicle damage" in "the situation that malfunction, damage, destruction, etc., hindering the safety of the train operation in the running gears, brake gears, electric devices, coupling devices, train protection system, etc., of the vehicle occurred" prescribed in Item 8, Paragraph 1, Article 4, of the Ordinance on Report on Railway Accidents, etc., the Ministerial Ordinance No. 8, Ministry of Transportation, 1987, and the plural abnormal situations were found in the running gear, *i.e.* the bogie, of the Shinkansen vehicle. Then the Japan Transport Safety Board, *hereinafter referred to as "the JTSB"*, determined the concerned serious incident as the subject of the investigation which was the "Incidents that are particularly rare and exceptional" subscribed in Item 6, Article 2, of the Ordinance for Enforcement of the Act for Establishment of the Japan Transport Safety Board, the Ministerial Ordinance No.124, Ministry of Land, Infrastructure, Transport and Tourism, *hereinafter referred to as "the MLIT"*, 2001.

The JTSB designated the chief investigator and two railway accident investigators to engage in the investigation of the concerned railway serious incident, on December 12, 2017. After that, the JTSB designated an additional railway accident investigator on April 1, 2018.

The Chubu District Transport Bureau and the Kyushu District Transport Bureau dispatched their staffs to the incident site, etc., to support the investigation of the concerned serious incident.

On December 19, 2017, the JTSB dispatched the Board Members to the rolling stock depot of the West Japan Railway Company, *i.e.*, Hakata General Rolling Stock Depot, to investigate the damaged bogie.

1.2.2. Implemented Period of the Investigation

Investigated items	Implemented date
Investigation on damaged status of the vehicle at the incident site	December 12, 13, 2017
Investigation on the bogie, etc.	December 17-19, 26, 27, 2017, January 11, 16, 17, February 2, 16, 21, March 16, 26, April 26, May 31, August 7, 2018
Investigation on status of the vehicle inspections	January 30, February 15, 2018
Hearing statements on the process of the train operation	December 13, 14, 27, 2017, January 29, July 25, 2018

1.2.3. Interim Report of the Investigation and Opinions Pursuant to Article 28 of the Act for Establishment of the Japan Transport Safety Board

On June 28, 2018, the JTSB reported the interim report on the process and progress of the investigation of the concerned railway serious incident to the Minister of Land, Infrastructure, Transport and Tourism, based on the results of the investigation on the factual information and the analysis up to that moment, and expressed its opinions on the measures to be implemented to prevent accident, etc., pursuant to Article 28 of the Act for Establishment of the Japan Transport Safety Board.

1.2.4. Comments from Parties Relevant to the Causes

Comments from parties relevant to the causes were invited.

2. FACTUAL INFORMATION

2.1. Process of the Train Operation

The summary of the process to the concerned serious incident was as follows, based on the statements of the relevant staffs of the West Japan Railway Company and the Central Japan Railway Company, *hereinafter referred to as "the JR West" and "the JR Central", respectively. Information on the relevant staffs were described in the following paragraph 2.8.2.*

Here, the inbound 34A train, composed of 16 vehicles started from Hakata station bound for Tokyo station, *hereinafter referred to as "the concerned train"*, was scheduled to stop at Kokura station, Hiroshima station, Fukuyama station, Okayama station, Shin-Kobe station, Shin-Osaka station, and Kyoto station, from the departure from Hakata station to the arrival at Nagoya station. The operation of the concerned train was implemented by the train crews, etc., of the JR West between Hakata station and Shin-Osaka station, and by the train crews, etc., of the JR Central between Shin-Osaka station and Nagoya station.

(1) Between Hakata station and Okayama station

On the day of the occurrence of the concerned serious incident, the train driver A, the conductors A and B, the cabin attendant^{*1} A, the pursers A, B and C, of the JR West were boarded on the concerned train from Hakata station.

The cabin attendant A and the pursers A and B noticed the unusual sound and nasty smells in plural vehicles of the concerned train, from just after the concerned train departed from Hakata station, and reported to the conductor A. Then the conductor A reported about generation of the nasty smells to the operation dispatcher B in the traffic control office of the JR West using the train radio. The operation dispatcher B, as received the report from the conductor A, arranged to let the vehicle maintenance staffs to get on the concerned train at Okayama station to implement check and inspection of the vehicles.

After that, while the concerned train was running in the section between Fukuyama station and Okayama station, the cabin attendant A and the purser B noticed that it was hazy by the thin mist in the cabin of the No.13 vehicle, *i.e.*, the 4th vehicle from the front of the concerned train, *hereinafter referred to as "the concerned vehicle"*, as it was pointed out by the passengers, and reported it to the conductor A. Then, the conductor A reported the status of haze in the cabin to the passenger service dispatcher A, just before the concerned train arrived at Okayama station.

^{*1} *The company staff engaged in sales, guidance, etc., in the cabin were called as the cabin attendant, in the JR West. Here, the cabin attendant was not charged in handling operation such as handling of the door operation, etc.*

(2) Between Okayama station and Shin-Osaka station

Three vehicle maintenance staffs A, B and C, of the JR West boarded on the concerned train from Okayama station. The vehicle maintenance staff B worried about noise heard from around the bogie of the concerned vehicle rather than the nasty smell and hazy mist, then he reported to the operation dispatcher B as "I felt little smell but the noise was severe, I would like to implement the underfloor inspection as my opinion, but isn't there any time for that?". However, for the inquiry from the operation dispatcher B as "Is there the hindrance in the train operation?", the vehicle maintenance staff B replied as "I think it would not in such situation, but I could not determine the phenomena because I did not inspect underfloor".

After that, as the abnormal sound was so large, the vehicle maintenance staff B reported to the operation dispatcher B that "There was a possibility that the motor related devices generated large noise. Shall we implement the underfloor inspection at Shin-Osaka station to secure safety?". However, the operation dispatcher B could not listen the report from the vehicle maintenance staff B, because he took off the receiver of the telephone from his ear at that moment. After that,

the operation dispatcher B replied to the inquiry from the vehicle maintenance staff B as to wait one moment. After a while, the operation dispatcher B was reported from the vehicle maintenance staff B that "I think that the open motor circuit^{*2} for the concerned vehicle seemed as the good measure, but I will investigate again and report afterward."

After a while, the operation dispatcher A received a proposal from the vehicle maintenance staff A that the situation might be improved by implementing the measure of the open motor circuit for the concerned vehicle, then decided to implement the open motor circuit and instructed the vehicle maintenance staff A to confirm the change of the sound.

The operation dispatcher B instructed the train driver A to implement the open motor circuit procedure for the concerned vehicle. At this moment, the operation dispatcher C and E of the JR Central heard the conversation as the operation dispatcher of the JR West in the traffic control office instructed to implement the open motor circuit, then they confirmed the contents of the conversation. The operation dispatcher A of the JR West communicated to the operation dispatcher E of the JR Central that there was the nasty smell in the concerned train but the smell faded away at present, the measure of the open motor circuit of the concerned vehicle had implemented as the abnormal sound has still existed, and received the report from the vehicle maintenance staff boarded on the concerned train that there was no hindrance for train operation.

When the concerned train arrived at Shin-Kobe station, the vehicle maintenance staffs B and C got off the concerned train once and checked the concerned vehicle from the platform, but they did not feel abnormal situation.

After the concerned train departed from Shin-Kobe station, the vehicle maintenance staff A reported to the operation dispatcher B that "The abnormal sound did not change after implemented the measure of the open motor circuit of the concerned vehicle. It is difficult to determine the position generating abnormal sound as it is considered as in around the bogie."

The operation dispatcher A, who received the above report, instructed the train driver A to restore the open motor circuit operation of the concerned vehicle.

The operation dispatcher B asked the vehicle maintenance staff A that "As we had asked many times, are you sure that there is no hindrance in the train operation at present?" The vehicle maintenance staff replied that "I cannot judge the situation, I cannot say that there was no abnormal situation for the train running, but I am sure that the status was different from as usual".

The concerned train arrived at Shin-Osaka station on schedule. The train driver, the conductor and the cabin attendant of the JR West handed over the train driver and conductor of the JR Central, respectively, that the nasty smell had generated in the concerned vehicle, and the inspection had been implemented by the vehicle maintenance staffs, and the train operation was continued as there was no hindrance for train running. Three vehicle maintenance staffs got off the concerned train at Shin-Osaka station.

^{*2} *"Open motor circuit" is the measure to enable the electric motor rotate freely so as not to generate driving or braking forces by the motor, by disconnecting the main electric circuit of the concerned vehicle to prevent expansion of abnormal situation when some abnormal situation existed in the traction motor or the main electric circuit.*

(3) Between Shin-Osaka station and Nagoya station

The vehicle maintenance staff B, who got off the concerned train to the platform of Shin-Osaka station, noticed the sound as scraping from the concerned vehicle when the concerned train departed from Shin-Osaka station. The vehicle maintenance staff A, who listened the sound together with the vehicle maintenance staff B, reported the situation to the operation dispatcher A, and the operation dispatcher A communicated it to the operation dispatcher E of the JR Central. After that, the operation dispatcher E instructed the conductor E of the JR Central, who got on the concerned train from Shin-Osaka station, to confirm the existence of smells from the 8th to 14th vehicles and to confirm the existence of abnormal situation in the concerned vehicle in the arrival at and the departure from Kyoto station. In addition, the operation dispatcher D of the JR Central sounded the Nagoya Train Depot on the possibility to let the vehicle maintenance staffs to get on the concerned train to implement the inspection. The inspection and repair staff on duty A in the Nagoya Train Depot instructed three vehicle maintenance staffs D, E, etc., to leave toward Nagoya station, and reported it to the operation dispatcher D.

The conductor E felt the nasty smell and noticed the ping sound as howling wind in the concerned vehicle, then he reported it to the operation dispatcher D.

(4) Nagoya station

When the concerned train arrived at Nagoya station, the vehicle maintenance staffs D and E, who were dispatched to Nagoya station and waiting for arrival of the concerned train on the platform, noticed the rattling sound from the concerned vehicle. After the concerned train stopped, the vehicle maintenance staffs D and E entered the cabin from the front door of the concerned vehicle and felt faint smell as something burnt.

The vehicle maintenance staff D reported the situation to the technical staff in the office A in Nagoya Train Depot. The technical staff A immediately asked the operation dispatcher D to arrange the underfloor inspection. The operation dispatcher D, as received this request, immediately communicated to stop departure from Nagoya station of the concerned train as to being transmitted to the traffic dispatchers. The doors of the concerned train had already closed because it was the scheduled departure time, but the train driver B suspended departure of the concerned train as he received the instruction from the traffic dispatcher A that the concerned train is prohibited to move for the inspection of the bogies.

After that, the underfloor inspection was implemented at Nagoya station, and the vehicle maintenance staff D found the leaked oil in around the gear box of the front bogie of the concerned vehicle, *hereinafter referred to as "the concerned bogie"*, then he reported to the operation dispatcher D that the concerned train was impossible to be operated, and the concerned train was cancelled further operation at Nagoya station.

While the works to move the concerned vehicle to the Nagoya Train Depot was implemented, the company staff of the JR Central found the crack in the side beam in left side of the bogie frame, *hereinafter referred as "the concerned crack", "the concerned side beam" and "the concerned bogie frame", respectively*, of the concerned bogie, at about 23:40.

2.2. Information on the Railway Facilities

[Refer to Attached Figure 1]

The summary of the route of Sanyo Shinkansen and Tokaido Shinkansen were as follows.

(1) Sanyo Shinkansen

Sanyo Shinkansen of the JR West originated from Shin-Osaka station and terminated at Hakata station, the business mile was 644.0 km, with 1,435 mm gauge, double track. The driving power was electricity of AC 25,000 V.

(2) Tokaido Shinkansen

Tokaido Shinkansen of the JR Central originated from Tokyo station and terminated at Shin-Osaka station, the business mile was 552.6 km, with 1,435 mm gauge, double track. The driving power was electricity of AC 25,000 V.

2.3. Information on the Vehicles

2.3.1. Outline of the Vehicles

The outline of the concerned train was shown in Figure 1. The major specification of the vehicles were as follows.

Category of vehicles	AC electric railcars electrified by AC 25,000 V, 60 Hz
Type of vehicles	N700 series, numbered in 5000's
Trainset	16 vehicle trainset
Capacity of the trainset	1,323 persons
Maximum operating velocity	285 km/h in Tokaido Shinkansen section 300 km/h in Sanyo Shinkansen section
Symbol & number of the concerned vehicle	785-5505
Tare of the concerned vehicle	40.1 t ^{*3}
Completion of the concerned vehicle	November 2007
Type of the concerned bogie	WDT209A
Type of the axle box suspension	Wing type spring ^{*4}
Manufactured date of the concerned bogie	April 2007

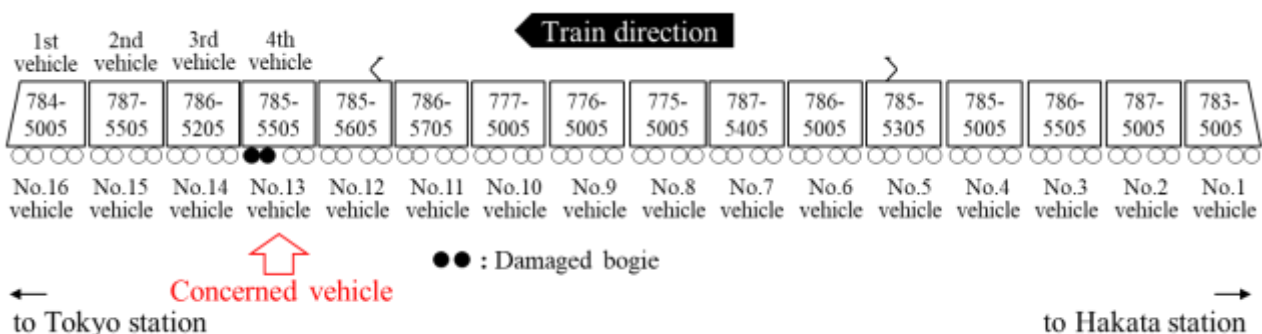


Figure 1. Outline of the concerned train

The cumulative running distance of the concerned vehicle from the start of commercial operation to the occurrence of the concerned serious incident was about 6,923,000 km. The cumulative running distance of the concerned bogie was about 6,222,000 km, different from that of the

concerned vehicle because the bogies were replaced with the other bogies, which had completed the maintenance works, in the general inspection, etc., described in the following paragraph 2.3.3.1.

*3 "t" is the unit of weight. $1[t] = 1,000 [kgw]$, $1[kgw] = 9.8 [N]$.

*4 "Wing type spring" is the form that the axle springs were attached to the both front and rear sides of the axle box.

2.3.2. Outline of the Bogie Structures, etc.

[Refer to Attached Figure 2]

The concerned bogie was mainly composed of the front and the rear wheel axles, the bogie frame in the above, the driving equipment including the traction motor, the brake gear including calipers^{*5}, etc. The bogie frame was mainly composed of right and left side beams suspending vehicle weight and load weight in front/rear and lateral directions and the cross beams connecting these side beams.

The structure of the side beam was as follows. The rolled steel for welding structure of 8 mm thick, which is the nominal thickness in the Japanese Industrial Standard, *hereinafter referred as "the JIS standard"*, was bent into U-shape cross section parts by the press machining and being attached the reinforce plate to inside of the U-shape by welding. Then, the two U-shape cross section parts were assembled as to face each other and unified by welding to make the side beam having the rectangular shaped cross section.

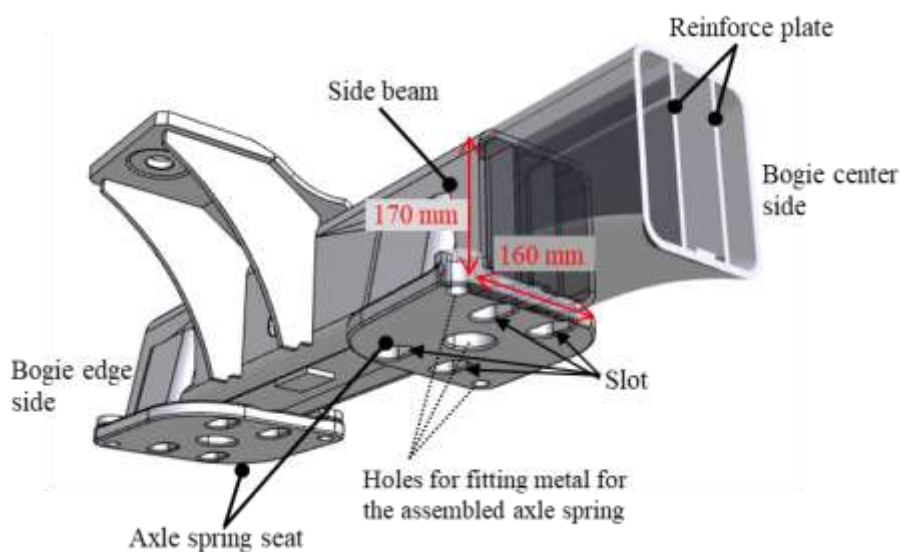


Figure 2. Appearance of a Part of the Side Beam

The size of the cross section of the side beam was 170 mm in height, *i.e.*, vertical direction, and 160 mm in width, *i.e.*, direction of sleepers, at the place where the crack had generated. The axle spring seats to attach the assembled axle springs were attached in 8 points for each bogie frame, by the fillet welding^{*6} to the bottom surface of the side beam in the circular part of the slotted holes of 55 mm long and 30 mm width, *hereinafter referred to as "the slot"*, in 4 points in each axle spring seat, *Hereinafter the welding method of this type was referred as "the slot welding"*.

The axle spring seats received the load weight in vertical, lateral and front/rear directions in the status of sitting on the axle box containing the bearings in the edges of wheel axle, through the

spring mechanisms called as the axle box suspension devices in its bottom.

The device for driving in the concerned bogie was mainly composed of the gear device attached to the wheel axle, the traction motor attached to the bogie frame, and the gear type flexible shaft coupling, *hereinafter referred as "the WN coupling"*, which transmit the torque of the traction motor to the gear device permitting relative displacements in vertical, lateral and front/rear directions generated between the traction motor and the gear box, caused by the train running. Here, the permitted relative displacement of the same type WN coupling was about 10 mm.

In addition, the structure of the brake gear in the concerned bogie was that the brake lining at the tip of caliper attached to the bogie frame sandwiched the brake disk attached to both sides of the wheels.

Here, the air springs were attached to the air spring supports mounted on the side surface of the side beam to support vertical load weight mainly permitting displacements between the vehicle body and the bogie by the air springs equipped 2 sets for each bogie, *i.e.*, total 4 sets for a vehicle.

**5 "Caliper" is one of the parts composing the disk brake, which is the device to press the brake shoes directly to the disk by the piston.*

**6 "Fillet welding" is the welding with the triangular cross section between the welded materials.*

2.3.3. Status of Maintenance, etc., of the Vehicles

2.3.3.1. Implemented Dates, etc., of the Inspection of the Concerned Vehicle

The maintenance works of the vehicles for Shinkansen of the JR West have been implemented based on the "Regulations for Implementing Standards for Maintenance of Shinkansen Electric Railcars", *hereinafter referred to as "the Regulation for Implementing Maintenance"*, one of the implementing standards reported by the JR West to the Minister of Land, Infrastructure, Transport and Tourism, based on the "Ministerial Ordinance to Provide Technical Regulatory Standards on Railways", Ministerial Ordinance No.151 prescribed by the MLIT, 2001, *hereinafter referred to as "the Technical Standard"*, and the related documents, *i.e.*, "Rules for Maintenance of Shinkansen Electric Railcars" and "Rules for Maintenance of N700 Series Shinkansen Electric Railcars", *hereinafter referred to as "the Maintenance Rules, etc."*

The latest inspections for the concerned vehicle, *i.e.*, the general inspection^{*7}, the regular inspection^{*8} and the daily inspection^{*9}, implemented before the concerned serious incident were as shown in Table 1.

There was no record to show the existence of the abnormal situation in the concerned bogie frame in all inspections listed in Table 1.

The details of the periodic inspections for the concerned bogie frame were described in the following paragraph 2.5.3.

**7 "General inspection" is the inspection implemented for the components of the whole vehicle after dismantled entirely. The inspection period is prescribed as not exceed 36 months, or 48 months for the newly manufactured vehicle, or 1,200,000 km running distance.*

**8 "Regular inspection" is the inspection for the status, operation and function for current collectors, running gears, electric devices, brake gears, vehicle bodies, etc., in the on-condition status. The inspection period is prescribed as not exceeded 45 days or not exceeded 60,000 km running distance.*

**9 "Daily inspection" is the inspection for the status and operation for current collectors, running gears,*

electric devices, brake gears, vehicle bodies, etc., from the outside, and to supply and replace the consumables. The operation period of the train is prescribed as until to the end of one continuing operation allotted from completion of the inspection to the next day.

Table 1. Implemented Status of the Inspections

Category of the inspection ^{#2}	Implemented date and running distance ^{#1}	Department implemented inspection
General inspection	February 21, 2017, 570,437.9 km	Hakata General Train Depot, the JR West
Regular inspection	November 30, 2017, 27,231.1 km	Okayama Branch of Hakata General Train Depot, the JR West
Daily inspection ^{#3}	December 10, 2017, 1,806.8 km	Tokyo Daily Inspection Train Depot, the JR Central

^{#1} *Running distance in the table is the running distance after implemented each inspection until to the occurrence of the concerned serious incident.*

^{#2} *The other inspection, i.e., the bogie inspection^{*10} was not listed in the table because it was not scheduled before the occurrence of the serious incident as the running distance was shorter than the inspection period.*

^{#3} *The JR West and the JR Central had been exchanged the agreement on the inspection and repair of the vehicles of the Shinkansen electric railcars to implement inspection and repair works etc., efficiently and rationally, and the JR Central had been implemented the inspection for the same contents as being implemented in the JR West.*

^{*10} *"Bogie inspection" is the inspection implemented for the major components of the traction motor, the power transmission devices, the running gears and the brake gears. The inspection period is prescribed as not exceeded 18 months, or 30 months for the newly manufactured electric railcars, or not exceeded 600,000 km running distance.*

2.3.3.2. Inspection of the Concerned Train at Hakata Station

The abnormal sound and the nasty smell were not noticed in the turn-back inspection implemented at Hakata station while the outbound 15A train, Nozomi 15, operated just before the concerned train, turned back to became to the concerned train, on the day of the occurrence of the concerned serious incident, i.e., December 11, 2017

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

2.4.1. The Damaged Status, etc., of the Concerned Bogie [Refer to Attached Figure 2]

According to the results of the vehicle inspection implemented at Nagoya station of the JR Central where the concerned serious incident had occurred, the situation of the concerned bogie was as follows.

- (1) The concerned crack was found in the front part of left side beam of the concerned bogie frame. The concerned crack continued from the bottom plate to both sides of the side beam. The length of the concerned crack was 146 mm in height from the bottom surface of the side beam, and the width of the opening in the direction of rail was 16 mm at around the bottom surface of the side beam, in the side surface in outside of the bogie of the concerned side beam where the measurement could be implemented. As for the broken surface of the crack, there was the rust from the bottom surface of the side beam to about 40 mm in height direction, and it was metallic shine without rust in the above.

- (2) The oil and fats were scattered in around the traction motor, gear box, the WN coupling connecting them, *hereinafter referred to as "the concerned WN coupling"*, in the 1st axle of the concerned bogie, and the bottom surface of the vehicle body. The paint on the surface of the concerned WN coupling had come off.
- (3) The left axle box of the 1st axle in the concerned bogie had shifted forward and tilted accompanied with the deformation of the bogie frame due to the crack. The distance in the direction of rail, from the bogie center to the center of the left axle box of the 1st axle, was about 30 mm longer than the distance in the direction of rail from bogie center to the center of the left axle box of the 2nd axle which was considered as in the normal status.

Here, when measured the above distance from bogie center to the center of the axle boxes, the measurement was implemented to raise up the bottom plate of the bogie frame a little and inserted the support to secure the safety in the measuring works. In this situation, the opening of the crack in the direction of rail at around the bottom surface of the side beam had changed from 16 mm to 13 mm, then, there was a possibility that the position of the axle box also changed from the status before inserted the support under the bogie frame.

2.4.2. Damaged Status, etc., of the Concerned Bogie Frame

2.4.2.1. Status of Broken Surface of the Crack

[Refer to Attached Figure 3]

The concerned bogie was transported to Hakata General Train Depot of the JR West, and was disassembled to the bogie frame and the other components. After that, the precise inspection was implemented by opening the concerned crack forcibly. The damaged status of the concerned crack found in the inspection were as follows.

- (1) The lengths of the concerned crack in the side beam were 146 mm in the side plate in outside of the bogie, 141 mm in the side plate in inside of the bogie, 117 mm in the reinforce plate in outside of the bogie, 108 mm in the reinforce plate in inside of the bogie, and 160 mm in the bottom plate of the side beam.
- (2) The beach mark^{*11} pattern was found from the R-part^{*12} in the bottom plate of the side beam to the side plate and the reinforce plate, in the observation of the broken surface of the concerned crack. The height and the pitch of the unevenness of this pattern became larger toward the higher part in the both sides of the side plate and the reinforce plate.
- (3) There was the beach mark pattern in the broken surfaces in around the center of the bottom plate of the side beam and the backing metal located in the above.
- (4) The broken surface in around the slot welded part in the bottom plate of the side beam was smoothed as the corrosion and abrasion due to contact between broken surfaces each other, compared to the broken surface in around the side plate, the reinforce plate and around the center of the bottom plate.
- (5) In the broken surface in the side plate of the side beam, the striation^{*13} pattern could not be found in the place where corrosion and abrasion due to the contact between broken surfaces each other had deteriorated to around the R-part, but the striation pattern was found in the upper part of the R-part to around the tip of the concerned crack.
- (6) According to the analysis of the material adhered to the broken surface of the concerned

crack in around the slot welded part by the EDX analysis ^{*14}, the titanium was detected in a part of the broken surface in the bottom plate of the side beam in around the slot welded part in outside of the bogie. Here, the titanium was used as the raw material of the paint used for painting the bogie frame.

According to the above situations, it is highly probable that the originated point of the concerned crack was around the two slot welded parts in inside and outside of the bogie where the axle spring seats were attached to the bottom plate of the side beam, based on the analysis described in the following paragraph 3.1.1.

**11 "R-part" in this report is the part where the steel plate was bent by machining.*

**12 "Beach mark" is the peculiar stripe pattern in the broken surface when the fatigue crack had deteriorated, which is large as can be found visually as usually.*

**13 "Striation" is the peculiar stripe pattern in the broken surface when the fatigue crack had deteriorated, which is small as being observed only by the electron microscope usually.*

**14 "EDX analysis" is the abbreviation of the Energy Dispersive X-ray spectrometry, used to detect an alien substance on the surface of the material and to identify its composing elements. Here, the EDX analysis was used to detect the components of the paints, etc.*

2.4.2.2. Status of Thickness of the Bottom Plate of the Side Beam

The designed thickness of the side beams was prescribed as to use 8 mm nominal thick steel plate and above 7 mm thick after bent by the machining works.

The thickness of the bottom plate of the side beam measured at the broken surface of the concerned crack was 4.7 mm in the thinnest place, indicated as (Z) in the Attached Figure 3.

2.4.2.3. Status of the Cross Section of the Concerned Crack

The originated point of the concerned crack was estimated as in around the slot welded part where the axle spring seats were attached to the bottom plate of the side beam, as described in 2.4.2.1. Therefore, the composition of the cross section of the concerned crack was observed by cutting the side beam and the axle spring seats at the central positions of the slot welded parts in inside and outside of the bogie in the direction of rail at the position shown in Figure 3

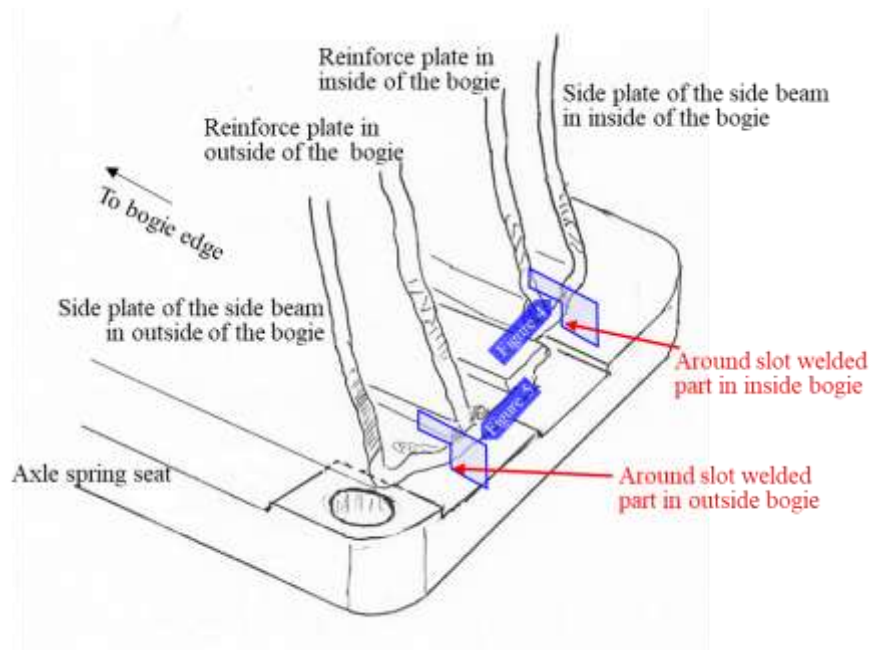


Figure 3. Cutting Positions of the Side Beam and the Axle Spring Seats

(1) Cross section of the slot welded part in inside of the bogie

The results of the observation of the slot welded part in inside of the bogie were as follows.

- (i) The thickness of the bottom plate of the side beam in the position estimated as the originated point of the concerned crack, indicated as (A) in Figure 4, was 5.9 mm.
- (ii) There was the gap of 0.4 mm in the direction of rail between the estimated surface to be machined holes for the axle spring seat, *i.e.*, the reference line, and the axle spring seat in beneath the back boundary^{*15} in the welded part, indicated as (B) in Figure 4.
- (iii) There was the aspect different from the materials composed of the axle spring seat in the bottom surface of the axle spring seat indicated as (C) in Figure 4. Here, it is somewhat likely that the aspect was the trace of implementation of the overlay welding^{*16}, based on the analysis described in the following paragraph 3.3.4.
- (iv) There was the imperfect welded part such as incomplete penetration^{*17}, incomplete fusion^{*18}, etc., in around the boundary between the axle spring seat and the welded metal, indicated as "D" in Figure 4.
- (v) There were the plural microscopic slits involved in the place thermally effected by the welding works of the axle spring seat in around the back boundary, indicated as (E) in Figure 4.
- (vi) There was unevenness due to plastic deformation in the broken surface of the concerned crack in around the slot welded part in inside of the bogie as indicated as (F) in Figure 4, but the size of the unevenness was larger than that observed in the general fatigue crack^{*19}.

^{*15} "Back boundary" is the boundary between the welded metal and the base materials in upward and downward in the back side of the slot welded part.

^{*16} "Overlay welding" in this text is to compliment by the welding material when the size of the material was lacked.

^{*17} "Incomplete penetration" indicates the status as lack of the actual penetration compared to the

designed penetration.

- *18 "Incomplete fusion" indicates the status that the surfaces of the welded boundary did not fuse each other sufficiently.
- *19 "Fatigue crack" is the crack expanded when the load was acted repeatedly.

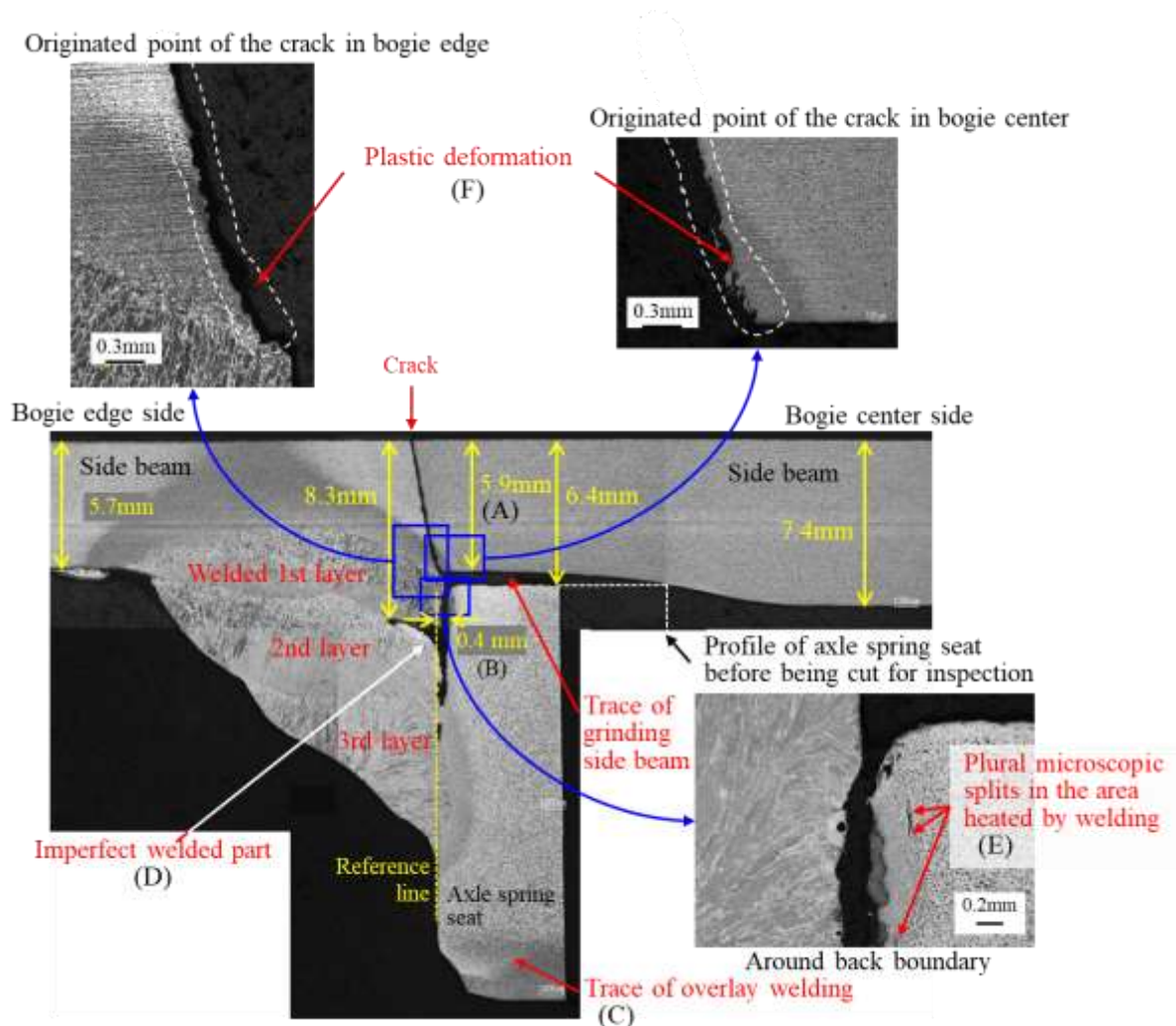


Figure 4. Status of the cross section of the crack in the slot welded part in inside of the bogie

(2) Cross section of the slot welded part in outside of the bogie

The results of the observation of the slot welded part in outside of the bogie were as follows.

- (i) The thickness of the bottom plate of the side beam at the point where estimated as the originated point of the concerned crack was 5.5 mm, as indicated as (G) in Figure 5.
- (ii) There were microscopic gap in the boundary of the 2nd and the 3rd layers of welding, as indicated as (H) in Figure 5, but there was no incomplete penetration as found in the slot welded part in inside of the bogie, indicated as (I) in Figure 5.
- (iii) There was the aspect different from the material of the axle spring seats in the bottom surface of the axle spring seat. It is highly probable that the aspect was the trace of implementation of the overlay welding, as same as found in the cross section of the inside slot welded part, as indicated as (J) in Figure 5.
- (iv) The definite slits, etc., as found in the cross section of the slot welded part in inside of the bogie, were not found.

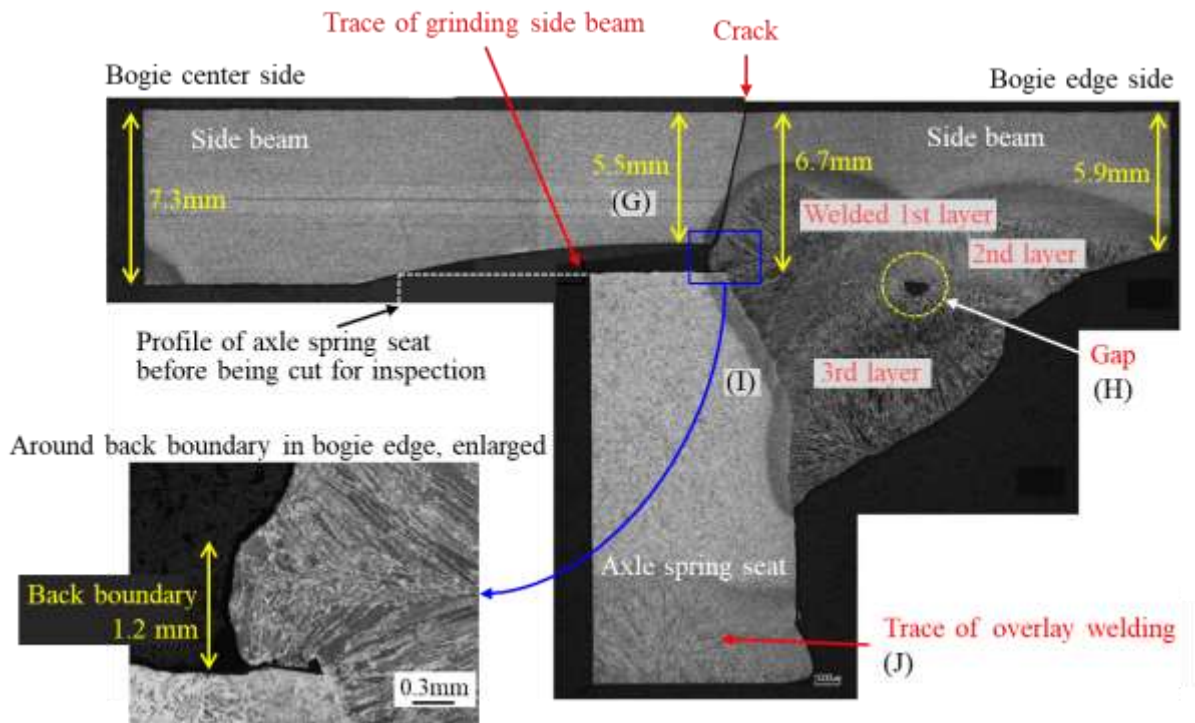


Figure 5. Status of the cross section of the crack in the slot welded part in outside bogie

2.4.2.4 Inspection of the Slot Welded Part Except for the Place of the Concerned Crack

In the slot welded parts of each axle spring seat located on front right, rear left and rear right, except for the place where the concerned crack was generated, in the position of the bogie center side of the concerned bogie frame, the side beam and the axle spring seats were cut at the center of each slot welded part in inside and outside of the bogie, in the direction of rail as same as in the part where the concerned crack was generated, and the status of the cross sections were observed.

Here, in the slot welded part in outside of the bogie in rear left of the concerned bogie frame, the side beam and the axle spring seats were cut in the direction of rail at three points except for the central position of the slot welded part, and the cross sections were observed. In addition, the broken surface was observed by opening forcibly the slits which was found in the slot welded part.

The results of the observation were shown in Table 2.

Table 2. Observed results for the slot welded parts except for the place of the concerned crack

	Slot welded part in inside of the bogie	Slot welded part in outside of the bogie
Front right of bogie frame	- Welded status was good	- Welded status was good
Rear left of bogie frame	- Welded status was good	<ul style="list-style-type: none"> - There was a slit from around back boundary to bottom plate of side beam, in the place where affected thermally by welding. - A part of tip of the slit showed the aspect of broken forms different from other areas, and the ratchet mark^{*20} pattern, which was usually observed in the fatigue crack, was observed - Titanium existed in the whole broken surface. - There was incompletely welded part such as incomplete penetration, incomplete fusion, etc.
Rear right of bogie frame	<ul style="list-style-type: none"> - There was incompletely welded part such as incomplete penetration, incomplete fusion, etc., in the boundary part between the axle spring seat and the welded metal. - There were microscopic slits in around the incompletely welded part. 	- There was incompletely welded part such as incomplete penetration, incomplete fusion, etc., in the welded part.

*20 "Ratchet mark" is the stepwise traces caused by unifying broken surfaces of cracks generated in plural originated points, and mainly observed in the broken surface caused by fatigue. It is also called as the step pattern.

2.4.2.5. Status of the Cross Section of the Axle Spring Seat

The aspect, which was different from the material of the axle spring seat, found in the bottom surface of the axle spring seat described in 2.4.2.3 (1) (iii) and 2.4.2.3 (2) (iii), was observed in the whole bottom surfaces of "the axle spring seat in beneath the place where the concerned crack originated", hereinafter referred to as "the concerned axle spring seat", and the axle spring seat neighboring in the direction to the bogie edge, and was not observed in the other axle spring seats.

The status of the cross section of the concerned axle spring seat is shown in Figure 6.

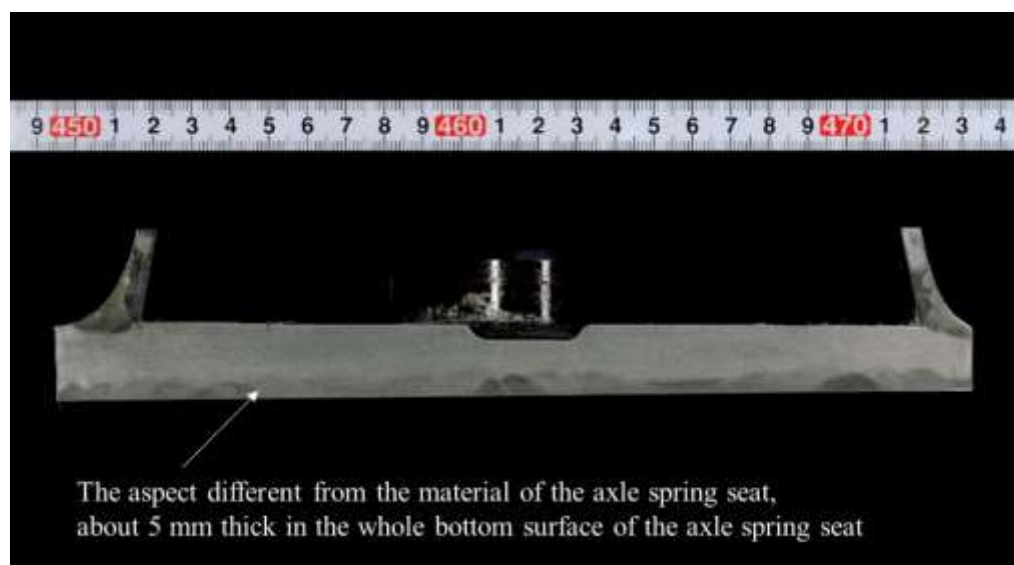


Figure 6. Status of cross section of the concerned axle spring seat

The thickness of the axle spring seat in around the concerned place, before cutting the bottom plate of the axle spring seat by machine tools, *hereinafter this process is referred to as "the machining process"*, was 20 mm as the designed value.

The bottom surface of the axle spring seat was anticipated to being cut about 5 mm by the machining process after assembled to the bogie frame, and the designed remaining thickness after the machining process was about 15 mm. The thickness of the concerned axle spring seat measured at the cross section was 17 mm to 20 mm.

The thickness of the place of the aspect, different from the material of the axle spring seat, was about 5 mm from the bottom surface of the axle spring seat where the machining process had implemented.

The measurement of hardness of the cross section of the concerned axle spring seat was implemented and compared with the measured hardness of the cross section for the samples manufactured as to recreate the status to be annealed, *i.e.*, removed the residual stress^{*21} by the strain in inside of the materials caused by welding works, etc., after welded, and the samples recreated the status that the annealing was not implemented after welded. As the result, the hardness in the place, where the aspect was different from the material of the axle spring seat, was the same level as in the part of the welded material in the sample recreated the situation that the annealing process was not implemented after welded.

Here, the hardness measured for the welded part in the reinforced side plate of the concerned axle spring seat was compared with the measured hardness for the sample being annealed, the results was that both measured hardness were in the same level.

^{*21} *"Stress" is the internal force per unit area.*

2.4.3. Damaged Status, etc., of the Bogie Components Except for the Concerned Bogie Frame

[Refer to Attached Figures 4, 5, 6 and 7]

The bogie components, except for the bogie frame which was removed from the concerned bogie in Hakata General Train Depot of the JR West, were disassembled and inspected. In addition, the important components were inspected including existence of damages, by the manufacturers of the concerned components.

The summary of the status of damages, etc., in the components considered as related with the concerned serious incident was as follows. Here, the inspection was implemented for the components of the 1st and the 2nd axles in the concerned bogie, but there was no abnormal situation in the components of the 2nd axle. Then, the following descriptions without specific comment were for the components of the 1st axle.

(1) The WN coupling

The status of the concerned WN coupling were as follows.

- (i) The paint on the outer cylinder had come off and the metal surface was exposed and discolored to blue. When the carbon steel equally composed as the outer cylinder was heated at about 300 °C, it becomes blue as observed in the concerned WN coupling.
- (ii) There were traces that the inner gear and the oil thrower contacted each other, and the

deformation of the oil thrower. The fastening torque of some bolts fixing the oil thrower had decreased.

- (iii) The rubber O-ring preventing leakage of grease to outward between the outer cylinder and the oil thrower had been lost. There was the linear trace which was black as rubber in the groove and the opposing flat surface where the O-ring had to exist.
- (iv) The teeth surface of the inner gear was abnormally worn away.
- (v) The grease used to rubricate between the teeth of the inner gears was discolored and hardened. But the WN coupling was not got stiff^{*22} even in this situation.

Here, the recreating experiment to heat the new grease used for inside WN coupling and the grease sampled from the WN coupling in the 2nd axle to 300 °C, was implemented. The smell and smoke as oil was warmed were confirmed from just after to start heating, and the grease had discolored and hardened to become the similar status as the grease sampled from inside of the concerned WN coupling which the damage was found, after heating for about 2 hours at about 300 °C.

(2) The traction motor and the gear device

- (i) There was no abnormal situation in the traction motor.
- (ii) There was no abnormal situation in the inner parts such as the gears, etc., and the gear oil.
- (iii) The inspection of the ingredient of the oil and fats adhered to the surfaces of the traction motor and the gear device was implemented, and the results showed that the ingredient was almost consistent with the ingredient of the grease used in inside of the WN coupling.

(3) The wheels

- (i) The results of the measurement of the tread profile of the wheels showed that the flange of the right wheels of the 1st and the 2nd axles had relatively worn compared with the left wheels in the same axles, and the abrasion in the right wheel flange of the 1st axle was remarkable.
- (ii) There were the traces considered as contacted with the brake pads which would not contact in the normal status, in the internal circumference of inner and outer surfaces of the rim of the left wheel in the 1st axle.
- (iii) The movement of the left wheel of the 1st axle from the regular position to the bogie edge calculated based on the trace in the outer rim surface, was about 34 mm at the position of the outer rim surface.

(4) The wheel tread cleaner in left wheel of the 1st axle

There was the fretting trace in the rack shaped components mounted inside to keep the proper gap between the wheel tread and the abrasive device to wheel tread. The wheel tread cleaner was designed to move toward the wheel side, according to the abrasion of the wheel and the abrasive device to wheel tread contacting with wheel tread in the tip of the wheel tread cleaner, but it was not designed as to return automatically.

There was no damage and abrasion, etc., considered as related to the concerned serious incident in the other components of the concerned bogie.

*22 "Get stiff" is the status that the rotating parts, etc. was disturbed to move smoothly due to being adhered.

2.4.4. The Damaged Status, etc., of the Railway Facilities

According to the JR West, there was no abnormal situation related with the concerned serious incident in the railway facilities such as the railway track, in the periodic inspection such as the on-foot track patrol in Sanyo Shinkansen section implemented after the occurrence of the concerned serious incident.

According to the JR Central, there was no report on any abnormal situation from the other train and the train crews. In addition, there was no abnormal situation in the results of the inspection of the ground facilities using the confirmation car in the nighttime work implemented after the occurrence of the concerned serious incident.

2.5. Information on the Bogie Frame

2.5.1. Status of the Strength Design and Verification of the Bogie Frame

According to the results of investigation for the JR West, the JR Central and the manufacturer who made the concerned bogie, *hereinafter referred as "the concerned bogie maker"*, the summary of the strength design and its verification of the bogie frame for the N700 series vehicles were as follows.

- (1) The verification of the strength in the strength design of the concerned bogie was implemented based on the method prescribed in the Japanese Industrial Standard "JIS E 4207, General Rule on Designing Bogie Frame, Bogie, Railway Vehicle", 2004, *hereinafter referred to as "the JIS E 4207"*. The calculated stress obtained by implementing the strength analysis using computers, *i.e.*, FEM^{*23} analysis, and the measured stress obtained by implementing the static loading test prescribed in the "JIS E 4208, Method of loading test for bogies and railway vehicles", 2004, *hereinafter referred to as "the JIS E 4208"*, were used as the stress generated in each part of the bogie frame in the verification. Here, the positions to measure the stress in the static loading test were determined as the typical positions in the bogie frame such as the center of the bottom surface of the side beam, etc., and the position where relatively high stress was obtained in the results of the FEM analysis.
- (2) After that, the maximum value and the minimum value of the actual stresses, *i.e.*, the tensile stress and the compressive stress, respectively, obtained by implementing the running test using the commercial vehicles in Tokaido and Sanyo Shinkansen section, using the N700 series vehicles including bogies manufactured prior to mass production, were estimated based on the method prescribed in the JIS E 4207. The positions to measure the stress in the running test using the commercial vehicles were determined as the position of relatively high stress and the typical positions of the bogie frame, in the places where the stress was measured in the static loading test.
- (3) Furthermore, based on the actual stress obtained in the running test using the commercial vehicles, the fatigue tests loading the vertical load corresponded to 9,000,000 km train running and loading the vertical vibration of the traction motor and the caliper corresponded to the

same running distance, were implemented. It was confirmed that the crack was not generated by the magnetic particle test^{*24}, implemented after the fatigue tests.

The fatigue life was confirmed based on the stress measured in around the concerned welded part, 130 mm apart from the edge of the slot welded part toward the bogie center, in the running test using the mass produced N700A commercial vehicles, after the occurrence of the concerned serious incident. In addition, the fatigue life was confirmed based on the stress in around the slot welded part, under the supposition that the vehicle was always operated in fully loaded by the passenger capacity. The prediction of these fatigue lives were implemented based on the method of the judging curve for the weld toe, etc., class E, described in the "Fatigue Strength of the Steel Welded Structure Bogie Frame"^{*25}, and the results was that the predicted fatigue lives remarkably exceeded the vehicle life, *i.e.* usable period of the bogie.

^{*23} *"FEM" is the abbreviation of the Finite Element Method, which is the method of numerical analysis to estimate strain, stress, etc., generated in the position of the element, by dividing the structure, etc., into the fine simple shaped elements and analyze the equation for each element.*

^{*24} *"Magnetic particle test" is the nondestructive test to detect defects on the surface and in the neighborhood of the surface visualized by the leakage magnetic field using the proper test medium including magnetic particles.*

^{*25} *T. Nagase, "Fatigue Strength of Steel Welded Structure Bogie Frame", pp.92-119, Kenyusha, 2000.*

2.5.1.1. Modeling of the Bogie Frame and Results of the Analysis

Status of the strength analysis, when the bogie of the same structure as the concerned bogie was designed, were as follows. The model of the bogie frame used in the FEM analysis in the designing stage of the N700 series vehicle, *hereinafter referred to as "the model when designed"*, and the results of the analysis were shown in Figure 7.

- (1) The model when designed was mainly composed of the plate elements, *i.e.*, the shell elements^{*26}, which is the popular modelling method for the bogie frame also using at present.
- (2) In the model when designed, the area where the axle spring seat was attached to the bottom surface of the side beam, was the single plate of 23 mm thick, which was the total of the designed thickness of the bottom plate of the side beam, *i.e.*, 8 mm, and the designed thickness of the axle spring seat, *i.e.*, 15 mm.
- (3) According to the calculated results of the FEM analysis using the model when designed, the large stress was not generated in the position corresponded to the concerned slot welded part for all loading conditions considering the loads in vertical, lateral, front and rear directions generated during train running.

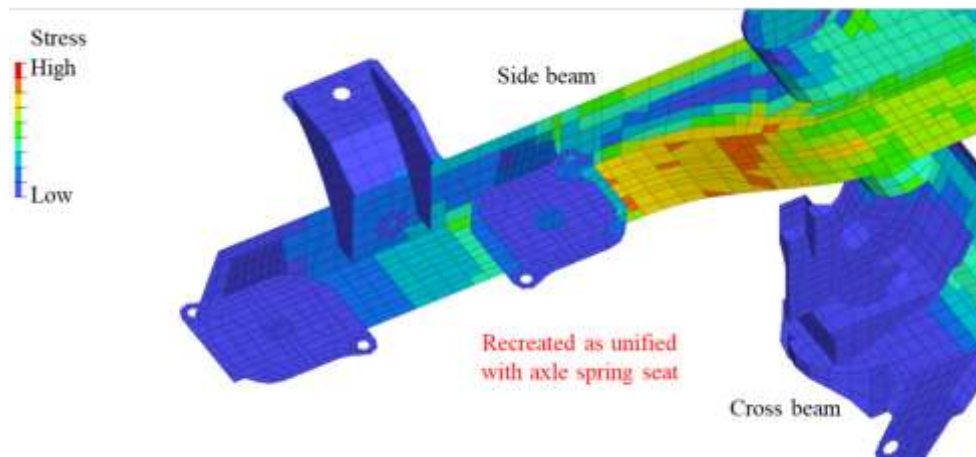


Figure 7. The model of the FEM analysis in the design stage and the results

After the occurrence of the serious incident, in order to implement the simulation to estimate the expanding status of the fatigue crack, described in the following paragraph 2.6.2, the axle spring seat, the peripheral side beam and the slot welded part joining them each other, were modeled using the three dimensional elements, *i.e.*, the solid elements ^{*27}, to compose as the two plates were fixed at the slot welded part, same as the actual bogie. The calculated results by the FEM analysis using this model showed that the stress was generated as to concentrate to the back boundary of the slot welded part and the generated stress was higher compared to its periphery as shown in Figure 8.

^{*26} "Shell element" is one of the elements used in the analysis by the FEM, having the rigidity corresponded to the thickness of the plate in the calculation, although it has no visual thickness.

^{*27} "Solid element" is the solid shaped element, one of the elements used in the FEM analysis. The higher performance computer is needed for the FEM analysis based on the solid model due to the increased number of the nodes per element compared with the shell model.

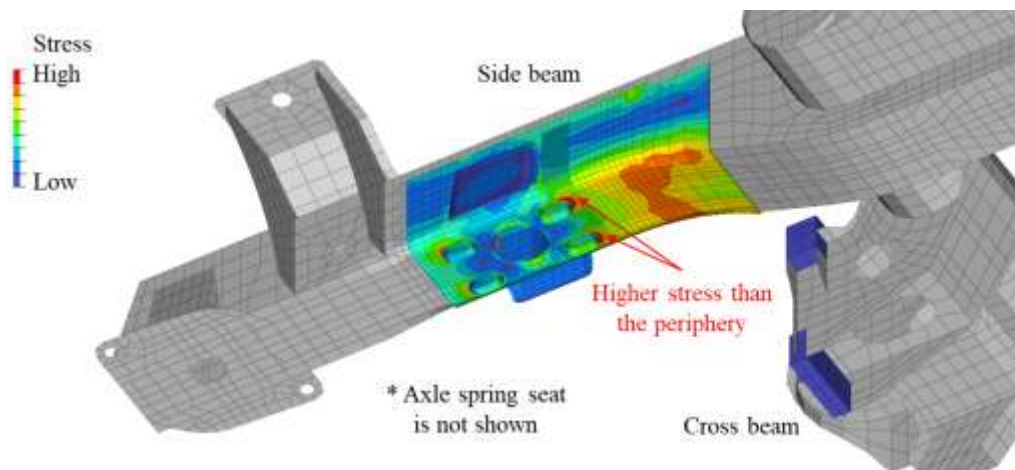


Figure 8. Model and results of the FEM analysis recreating the slot welded part

2.5.1.2. Modeling of the Axle Box Suspension Device

The inspection, on the analytical model of the axle box suspension device used in the strength analysis when it was designed, showed that the positions suspending the horizontal forces considering the loads in lateral and front/rear directions generated in the train running, had differed from the actual device.

2.5.2. Status of Manufacturing the Concerned Bogie Frame *[Refer to Attached Figure 8]*

The situation, when the concerned bogie frame was manufactured, was investigated by implementing the hearing statements from the concerned bogie maker, after the occurrence of the concerned serious incident. The results were as follows.

Here, the outline of the process of manufacturing bogie frame were, the process to assemble the parts manufactured as bending steel plates by the press machine, *hereinafter referred to as "the pressed material for side beam"*, and the inner reinforce plates, etc., by welding, the process to attach the accessories such as the axle spring seat, etc., to the assembled side beam by welding, the process to assemble to the bogie frame with the cross beam by welding, the process of the annealing to remove the stress, the painting and the machining process.

2.5.2.1. The Pressed Material for Side Beam

(1) Materials

The steel material used in the pressed material for side beam in the concerned bogie frame, *hereinafter referred to as "the concerned pressed material for side beam"*, had been inspected to measure the ratio of chemical ingredients such as carbon, etc., contained in the material and the tensile stress, etc., by the steel maker. According to the concerned bogie maker, the record of the inspection for the steels in the lot when the concerned side beam was manufactured could not be found, because their preserved period of the records had already expired. Then the investigation on the inspected records for the next lot of the concerned side beam was implemented as the reference, and the result showed that there was no abnormal situation because the results of the inspection records were within the standard values required to the steel material designated in the drawings.

In addition, after the occurrence of the serious incident, the chemical ingredients and the tensile strength, etc., of the steel material were measured for the test piece being cut from a part of the concerned bogie frame, and confirmed that the measured values were within the standard values required to the specified materials.

(2) Method of the bend machining

The process bending the steel material to the shape of the pressed material for side beam, had been outsourced to the cooperate company of the concerned bogie maker.

At the time when the concerned bogie frame was manufactured, the cooperate company who had been engaged in the bend machining of the pressed material for side beam of the bogie frame for the former type 700 series vehicles, *hereinafter referred as "the former cooperate company"*, withdrew from manufacturing the components of railway vehicles. Then, the bend machining of the pressed material for side beam was outsourced to the other cooperation company who had the achievements on the bend machining of the press materials for the other type bogies, *hereinafter referred to as "the new cooperate company"*.

In the former cooperate company, the bend machining was implemented by the "hot press machining", *i.e.*, the steel plate was heated and bend machined by the press machine in the status that the steel plate was softened in a certain level.

As for the hot press machining of the long material as the concerned pressed material for side beam, the large press machine and special facilities such as the large heating furnace, etc., are required, and it is difficult to control temperatures from heating to the bend machining due to large size of the material. Then, only the limited cooperate company could implement these jobs. Therefore, the concerned bogie maker judged that there was a problem to manufacture many press materials for side beam including materials for the other types by the limited cooperating company from the viewpoint of the steady provision, and decided to change the bend machining process in the new cooperating company, to the "cold press machining", that implement the bend machining by a large press machine in the normal temperature without heating materials.

The concerned bogie maker held the meeting on the quality of the products to possess jointly the information in the company on the summary of specification, the changed specification, etc., before starting the manufacturing works of the bogie frames for the N700 series mass production vehicles, however the information on the change of the outsourcing company of the pressed material for side beam and the change of the method of the bend machining, were not possessed jointly in the related sections in the company, and the effects of these change were not studied.

The workers in the new cooperate company implemented the cold press machining under the technical guidance, etc., from the former cooperate company who had experiences of the cold press machining of the pressed material for side beam of the other type bogies.

Here, according to the new cooperate company, they already had the technologies and the facilities for the bend machining by the hot press machining, as they had been manufactured the pressed material for side beam of the bogie frames for the N700 series mass production vehicles by the hot press machining, and had delivered to the other vehicle maker in the same period of the manufacturing works of the concerned pressed material for side beam.

(3) Inspections

The new cooperate company had been implemented the sampling inspection in the ratio of one for each ten products of the press materials for side beam after implemented the bend machining, on the existence of the defects as the slit caused by the bend machining, *hereinafter referred as "the pressed defects"*, and the sizes of the completed materials. The inspected records for the pressed material for side beam in the same lot of the concerned pressed material for side beam were investigated. There was no record on the existence of the pressed defects, and no abnormal situation in the sizes of the completed material, including the size in the direction of the opening in the part being bend machined, where to become the upper plate or the bottom plate after completed as the side beam, the sizes of the completed materials were in the range of the prescribed values, *hereinafter referred as "the tolerance"*, in the drawings of the concerned bogie maker. Here, the tolerance of the opening in the part being bend machined was, less than 1 mm in the tip of the opening compared to the status as bent in right angle, and less than 2 mm in the curved part.

The summary of the hearing investigation for the new cooperate company, on the

manufacturing process and the status of inspection of the sizes at the time of manufacturing the concerned pressed material for side beam, implemented after the occurrence of the serious incident, was as follows.

- (i) It is the normal process to check the sizes, etc., of the trial product manufactured prior to the mass production. Then the company considered that the confirmation of the sizes by the trial manufacturing was also implemented at that time, even though there was no record including the opening size of the side beam.
- (ii) The new cooperate company considered that the measurement of the sizes had been implemented for all products, because all products were corrected their sizes using the small press machine that was implemented as checking sizes of the product certainly, after the cold press machining by the large press machine, even for the products having no inspected record, although the inspected records were filed only in the sampling inspections implemented one for each ten products in the mass production.

2.5.2.2. Assembling Works of the Side Beam and the Axle Spring Seat

The press materials for side beam delivered to the concerned bogie maker were assembled in the following process, these were, cutting the materials into the designated sizes, groove machining^{*28} for welding, welding the inner reinforce plates, etc., putting together the parts of the side beam for inside and outside of the bogie, then unified to a side beam by welding, *hereinafter referred as "the hold welding"*. After that, the axle spring seats were attached to the bottom surface of the hold welded side beam by the slot welding.

Here, the welding works were implemented in two processes, these were, the process to fix the parts by the spot welding after corrected sizes as to fix the parts in the normal position to be attached using fixtures, etc., *hereinafter referred to as "the temporary welding" and the worker engaged in the assembling work to the temporary welding was referred to as "the assembling worker"*, and the process to implement welding obeying the instructions in the drawings, *hereinafter referred to as "the finish welding" and the worker engaged in the finish welding was referred as "the welding worker"*. The welding workers hold the technical license of welding based on the company's regulation of the concerned bogie maker.

To summarize the statements obtained in the hearing investigation for the assembling workers who was charged in the temporary welding work of the concerned side beam, *hereinafter referred to as "the concerned worker"*, the on-site manager of the assembling works, and the welding worker, the situation at that time of manufacturing the concerned side beam were as follows.

^{*28} *"Groove machining" is to cut and spread the edge of the object of welding into the proper shape in order to make the welding works easy.*

(1) Information on the staffs related with the assembling works

The ages and the years of experiences of the staffs engaged in the assembling work at the time of assembling the concerned bogie frame were as follows.

The on-site manager was 35 years old male experienced for about 16 years and 3 months.

The concerned worker was 20 years old male experienced for about 2 years and 11 months.

(2) Statements of the assembling workers, etc.

- (i) In the concerned bogie maker, the allowable gap between materials was prescribed in the Instruction on the allowable gap between material parts in the assembling works of the bogie frames commonly applied to all vehicle categories, *hereinafter referred to as "the common instruction for allowable gap"*, as follows.

*The gap between materials in the structures to pile up materials should be less than 0.5 mm in all surfaces of the piled materials after welded, removed strains^{*29} and annealed. [Omitted] Implement works carefully not to make a gap exceeding 0.5 mm, by removing the strain, finishing by grinder^{*30}, and removing the alien substances and the burr^{*31}.*

The on-site manager had instructed the assembling workers to implement assembling works by checking the gap width by inserting the 0.5 mm thick metal scale to the gap, and to fix the gap as the scale could not be inserted.

**29 "Removing strain" in this context is the work to adjust the sizes of all parts of the materials to the normal values by heating steel plate locally by the burners, etc., then cooling rapidly by sprinkling water to shrink its size.*

**30 "Finishing by grinder" is to grind a part of material by the tool having rotating whetstone, i.e. the grinder.*

**31 "Burr" in this context is the part remaining as protruded from the cut surface when cutting the steel materials, etc.*

- (ii) When the concerned worker started the temporary welding work to attach the axle spring seat to the side beam in the same lot as the concerned side beam, here the works for the first side beam was implemented on about January 25, 2007, the concerned worker immediately noticed that the bottom surface of the side beam after implemented the hold welding process had swelled as convex, which would become in rattling status because the gap would be generated when assembled with the flat surface axle spring seat. Then the concerned worker consulted to the on-site manager on the correcting method against rattling status, because it was the first time for him to treat the side beam which was assembled from two U-shaped press materials for side beam into the rectangular shaped side beam same as the concerned side beam.

- (iii) The on-site manager had the experiences to correct the rattling status of the bottom surface of the side beam by grinding work using the grinder to fit the flat upper surface of the axle spring seat, *hereinafter referred to as "the fitting by grinding"*, for the side beam against the rattled status considered as caused by the unevenness between bottom surface of the side beam in the hold welding process, *hereinafter referred to as "the joint stagger"*, when assembled the side beam of the bogie frame for the former 700 series vehicles engaged as an assembling worker.

The on-site manager instructed the concerned worker to implement the fitting by grinding works for the place in the bottom surface of the side beam where contacted with the axle spring seat until to eliminate rattling without confirming the actual object by himself, as considered that the rattling status in the side beam of the bogie frame for the N700 series mass produced vehicle was as same as that in the bogie frame for the 700 series

vehicle, based on his experience at that time.

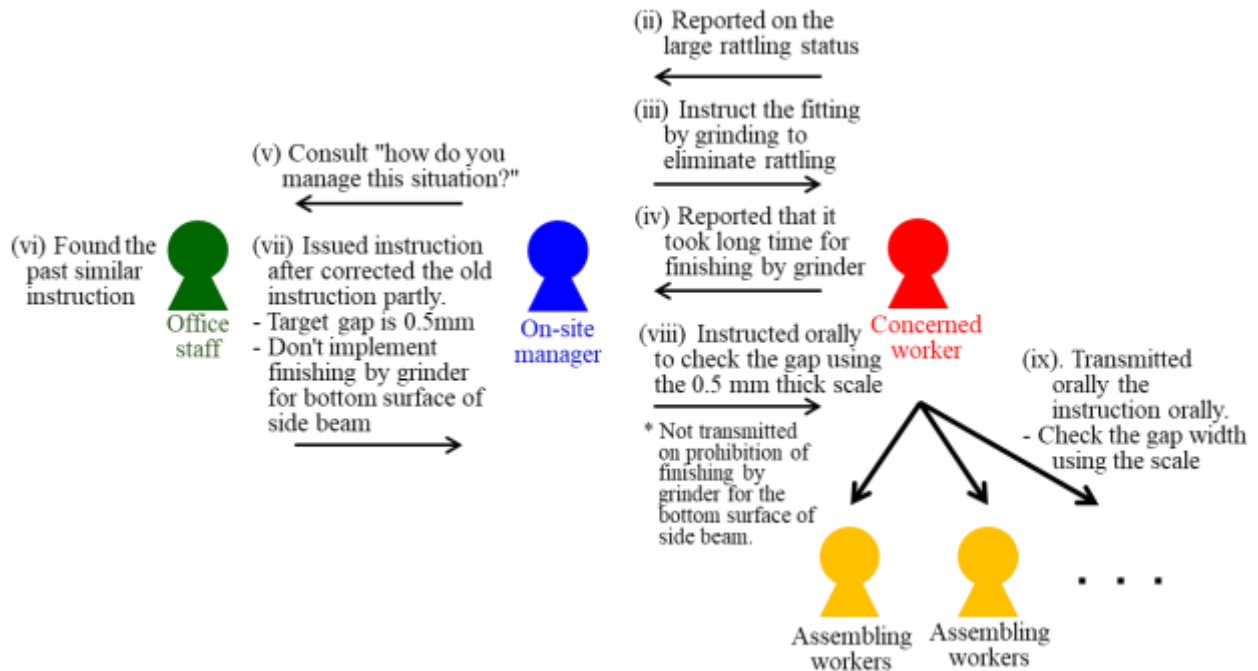
The on-site manager did not instruct the limit value of the thickness to be grinded at that time, because he thought that the slight grinding would be enough as same as in the case of his experience to assemble the side beams of the bogies for the 700 series vehicles.

- (iv) After the concerned worker restarted the assembling work, he could not implement his work on schedule because it took long time due to large amount of grinding volume required for the fitting by grinding, then he consulted the on-site manager again.
- (v) The on-site manager checked the actual object and found that the gap due to rattling was larger than the value as he had been experienced in the past, then he consulted the staff in the office of the bogie plant as "How do you manage this situation?".
- (vi) The staff in the office of the bogie plant found the record to issue the instruction for work prescribed as the gap between the bottom plate of side beam and the axle spring seat in the side beam should be "less than 0.5 mm as the target value, but allowed to 1 mm in the maximum", in order to abolish the fitting by grinding works for the concerned place, in the files at the time for manufacturing the bogie frames of the past Shinkansen 300 series vehicles.
- (vii) The staff in the office of the bogie plant corrected a part of the context of the above instruction, and draw up as the corrected instruction of the gap management for the works of the side beam of the bogie frames for the N700 series mass production vehicles, *hereinafter referred as "the instruction of gap management for N700 series vehicle"*, and distributed it in the plant.

Here, it was prescribed in the instruction of gap management for N700 series vehicle, that the grinder finishing works for the bottom plate of side beam should not be implemented.

- (viii) As the gap management was relaxed from "less than 0.5 mm" to "0.5 mm as the target" in new instruction, the on-site manager instructed the concerned worker to implement the fitting by grinding work as to check the gap by inserting the 0.5 mm thick metal scale and to consider as the gap is less than 1 mm if the gap width was in the level whether the metal scale could be inserted or not. Here, the on-site manager had focused the relaxation to the "0.5 mm as the target", and did not inform the concerned worker on the prescription that "the grinder finishing of the bottom plate of side beam should not be implemented."
- (ix) The concerned worker transmitted the above instruction to the coworkers engaged in the same assembling works of the side beam in the morning meeting.
- (x) Here, the instruction of gap management for N700 series vehicle was drawn up on January 29, 2007 and expected to be distributed in the whole plant in the same day in the fastest, after the approval procedures in the office of the bogie plant. However, the date of the final approval of the instruction, and the date of distribution in the whole plant were not clear. In addition, at that time, the instructions had been distributed up to the on-site managers, and the on-side manager had been transmitted the essence of the instructions to the concerned workers orally.

The assembling workers for the side beam except for the concerned worker who could be identified by the hearing investigation at that time, stated that they had never see the instruction of gap management for N700 series vehicle. Only the concerned worker had a memory to see something as drawing inserted in the instruction of gap management for N700 series vehicle, in the paper put in the shelf for the distributed instruction sheet for the on-site manager, but he did not check its context and did not know that it was the instruction related to the fitting by grinding works.



* Roman numbers in the figure corresponded with the texts in 2.5.2.2 (2)

Figure 9. The routes to transmit instruction for handling works and reporting

(xi) The allowable volume to be grinded in the direction of thickness of the base material by the grinder was prescribed in the company's standard "Regulation on Grinding Works". As for the grinder finishing for the bead ^{*32} toe in the butt weld part was prescribed as that the grinding depth was limited to 0.5 mm. However, these contents were not made well known to the assembling workers in the education program, etc., in the company.

The on-site manager had been understanding that the finishing by grinder was allowed up to 0.5 mm in the maximum, for the cases not limited to the finishing of the bead toe of the welded part in the education, etc., by the experienced coworkers. The assembling workers did not care about the limit of the grinding depth.

**32 "Bead" is the one stroke welding operation implemented along the guide line for welding. "Toe" is the cross point of surfaces of the base material and the weld bead.*

(xii) The on-site manager checked the process before attached the axle spring seat to the bottom surface of the side beam, after confirmed the status of the swell in the bottom surface of the side beam. Almost all the side beams in the same lot of the concerned side beam had already finished the hold welding process by that moment, because the process up to the hold welding process had been implemented in the front-loaded schedule

supposing that the manufacturing of side beams would become busy at that time.

The correction of the joint stagger had not been implemented in the hold welding process when the concerned side beam was manufactured. In addition, the bent angle of the pressed material for side beam was not corrected to right angle accurately in the process to attach the inner reinforce plates.

The swells in the bottom plate of the side beam was considered as in the status as impossible to correct swells by the methods such as the removing strain, etc., in this stage, related with the existence of the reinforce plates vertically fixed to inside of the pressed material for side beam.

Here, the fitting by grinding process had been still implemented even though the grinding depth of the bottom plate of the side beam was decreased in the successive lots, by the method to push the axle spring seat to the side beam using press machine in the process of the temporary attachment of the axle spring seat, the method to correct the joint stagger using press machine in the process of the hold welding process, the method to correct using press machine in the process to attach the inner reinforce plates that is the prior process to the hold welding process, etc.

(3) Date of the inspection on the related works

According to the "Inspection Records of Welding Side Beam, etc.", issued from the management section in the concerned bogie maker when the concerned side beam was manufactured, the inspection after the hold welding process, the inspection after attachment of the components including the axle spring seats by the temporary welding, the inspection after finished the welding work of the components, were implemented as shown in Table 3. Each inspection had been implemented just after finished each working process, usually.

Here, the work of the temporary attachment of the components for the concerned axle spring seat was implemented by the concerned worker.

Table 3. Date of the inspection for the related works written in the inspection records

Contents of the works	Date of inspection
The hold welding	February 7, 2007
Attachment of the components	February 24, 2007
Welding of the components	February 26, 2007

2.5.2.3. Status of the Slot Welding

As for the slot welding of the axle spring seat, the structure that the axle spring seat was attached to the bottom plate of the side beam by welding in the slot hole, was not particularly difficult place for welding work, because it was the same method and the same slotted hole size used in the bogie frame of the former Shinkansen vehicles such as the 700 series vehicles, etc., based on the hearing from the concerned bogie maker.

The experiment of welding works^{*33} simulated the status of the concerned slot welding was not implemented in the concerned bogie maker, because it was considered as the existing company's regulations could be applied.

After the occurrence of the concerned serious incident, the experiment of welding works using the material manufactured to simulate the slot welding was implemented. There was no defect such as the incomplete penetration in the part where the temporary welding to fix the axle spring seat before the finish welding was not implemented. However, there were the microscopic incomplete penetration in some test pieces, in the place where the temporary welding and the following finish welding were implemented for the comparison obeyed to the guideline for welding works at that moment.

**33 "Experiment of welding works" is the experiment to test whether the expected welded joint could be obtained by the planned method of welding works. The validity of welding conditions, such as the material shapes before welding and the magnitude of the current while welding, etc., were confirmed by checking the status of the cross section, etc., of the welded part after implemented the welding works actually for the test piece of the similar material and shapes manufactured prior to the welding works of the commercial products.*

2.5.2.4. Status of the Annealing and Machining of the Bogie Frame

The side beams assembled by welding and the cross beams assembled by welding separately were assembled as the bogie frame by welding, after that the bogie frame was annealed. The annealing was implemented as to put the whole bogie frame into the furnace, heated and kept in the constant temperature for several hours, after that, the bogie frame was cooled gradually.

Before annealing, the existence of the enough margins for machining required to the machining works in the following process was checked. When there is a possibility that the unmachined surface remained in the surface to be machined due to lack of margin for machining, there is the case to implement the overlay welding to heap up the welding material by welding until to get enough margin for machining. The overlay welding is a popular repairing method even prescribed in the JIS standards.

In the overlay welding, there is a possibility to increase quantity of the heat input to the material by welding, although it depends on the thickness and area being heaped. Then, there was the fear to cause the residual stress due to the heat input and the rapid cooling again, when overlay welding was implemented to the bogie frame which the residual stress had been removed by annealing. Therefore, the concerned bogie maker also understood that the overlay welding should be implemented before annealing.

The machining works, to correct the surface to attach the other bogie components including the axle spring and to correct the sizes of the holes, etc., for the bolts to the designated values, were implemented to the annealed bogie frame after painted. In the concerned bogie maker, the machining works had been implemented in turns, from the bottom surface of the axle spring seat in bogie edge side of the concerned axle spring seat, after that, the bottom surface of the concerned axle spring seat. The above machining works for the axle spring seat had been implemented by the method being controlled based on the numerical data which were set in the computer in advance.

In the concerned axle spring seat, there was the aspect different from the material of the axle spring seat, as described in 2.4.2.3. It is considered that the overlay welding had been implemented in the bottom plate of the axle spring seat after annealed in the part of the concerned

aspect, as analyzed in the following paragraph 3.3.4. However, the information, that someone remembered to implement the overlay welding in the entire bottom plate of the axle spring seat, could not be obtained in the hearing investigation implemented for the workers who were engaged in the welding works and the machining process of the bogie frames when the concerned bogie frame was manufactured, in the concerned bogie maker.

Here, in the inspection record, the machining process for the bottom surface of the concerned bogie frame including the axle spring seat was implemented on March 29 to 30, 2007, but there was no record in the machining device.

2.5.2.5. Information on the Side Beams Manufactured after the Concerned Serious Incident

In order to prevent the recurrence of the situation in the concerned side beam and to improve quality of the products for the bogie frame manufactured for the exchange use, the concerned bogie maker implemented the following revisions, after the occurrence of the concerned serious incident.

- (1) The bend machining method of the pressed material for side beam was changed to the method by the hot press machining.
- (2) The works in each process from the reception of the pressed material for side beam in the concerned bogie maker to the process to attach the axle spring seat by welding, were implemented as measuring sizes including the status of opening of the parts to become to the upper and the bottom plates of the side beam.
- (3) The assembling work was implemented as correcting the bent angle of the parts to become to upper and bottom plate of the side beam by added the process to remove the strain, as the parts to become to upper and bottom plate of the side beam slanted a little due to the slight strain generated when welded the inner reinforce plates and the backing metal.
- (4) In addition, the problem of the joint stagger in the surface, where the axle spring seat was attached, was dissolved by setting the bottom surface of side beam as the reference in the hold welding process.

According to the concerned bogie maker, the fitting by grinding process was not needed when attached the axle spring seat to the bottom plate of the side beam, because the axle spring seat did not wobble due to the swell or the joint stagger in the attached plate, as the result of the above revisions.

In addition, the difference in the works of each worker were dissolved by determined the positions of the temporary attachment and the order of welding works for the slot welded part.

2.5.3. Status of the Inspection of the Concerned Bogie Frame

2.5.3.1. Regulations on the Standard for Bogie Frame Inspection *[Refer to Attached Material 1]*

The bogies of the railway vehicles are a part of the running gears which are important to secure the running safety and the stability of the vehicles. Therefore, the Technical Standard regulated as follows.

(Running gear, etc.)

Article 67. The running gear shall conform to the following standards.

(i) to (iv) [Omitted]

(v). [Omitted] , the running gear, etc., shall be strong, have sufficient strength and be able to secure the safe and stable running of the vehicles.

In addition, the periodic inspections of the vehicles were prescribed in the above Technical Standard as follows.

(Periodic inspection of the facilities and vehicles)

Article 90. The periodic inspection of the facilities and the vehicles shall be implemented by the inspection period, place to be inspected and method of the inspection determined according to the category, the structure and the operated status of the facilities and the vehicles.

2. When the Minister of Land, Infrastructure, Transport and Tourism issues a public notice on the items related with the periodic inspection in the above paragraph, the periodic inspection shall be implemented conforming to the public notice.

In addition, the inspection periods for the important parts inspection and the general inspection, etc., were prescribed in the "Article 5. Periodic inspection of vehicles" of the "Notice on the Periodic Inspection of Facilities and Vehicles", Ministerial Notice No.1786 issued by the Ministry of Land, Infrastructure, Transport and Tourism, on December 25, 2001. In addition, the precise inspecting items such as deformation, crack, corrosion, etc., and the precise inspection methods such as the flaw detection, measurement, etc., for the bogie frame were prescribed in the "Interpreting standards of the Ministerial Ordinance to Provide Technical Regulatory Standards on Railways, etc.", Official Notice from the Director-General of the Railway Bureau of the MLIT, issued on March 8, 2002, *hereinafter referred as "the Interpreting Standards"*. The inspection method for the bogie frame was prescribed as to be implemented conforming the Attached Material 1 "Inspection Manual of the Bogie Frame", in the Interpreting Standards.

In the JR West, the inspection of bogie frames was prescribed to implement the visual inspection or the flaw detecting inspection based on the "Standard for Inspection of the Bogie Frame", in the "Maintenance Rules, etc.", and the place to be inspected, the method of inspection and the period of inspection were prescribed in the attached material of the above Inspection Standard, "Inspection Standard of Bogie Frames for the Shinkansen Electric Railcars".

"Inspection Standard of Bogie Frames for the Shinkansen Electric Railcars", extracted

2. Place to be inspected, inspection method and inspection period for the bogie frame

- The place to be inspected should be designated based on the data of crack generation in the past, etc.

*- Inspection should be implemented by the flaw detection, i.e., the magnetic particle test or the penetrate test^{*34}, fundamentally.*

- The visual inspection should be implemented for the designated place where the special attention is required, and should be implemented after removed the dirt in the inspected

- place well using brushes, etc.*
- *The visual inspection should be implemented for the entire bogie frame including the places other than the designated place.*
 - *Place to be inspected, inspection method and inspection period for each vehicle and bogie type should be as shown in the following table.*
 - *The visual inspection for the entire bogie frame should be implemented in the periodic inspection implemented in the period different from the designated period.*

(3) The 700 series, N700 series - WDT207, 209, 209A, TDT204 bogies

<i>Place to be inspected</i>	<i>Inspection method</i>	<i>Inspection period</i>
<i>Place where side beam and cross beam were welded</i>	<i>Magnetic particle test or penetrant test</i>	<i>At the time of the general inspection</i>
<i>Place where traction motor support and cross beam were welded</i>		
<i>Place where gear box hanger support and cross beam were welded</i>	<i>Visual inspection</i>	
<i>Place where the inside of traction motor support and cross beam were welded</i>		

According to the JR West, there was no precedent of crack generation in the past in the bogie frames for the Shinkansen vehicles of the company, then the places to be implemented the flaw detection were designated referring the past instances of crack generation in the bogie frames for the vehicles of the conventional lines of the company, and the vehicles of the conventional lines and the Shinkansen vehicles in the other railway operators.

The place where the concerned crack had generated was not designated as the place where the flaw detection should be implemented, because there was no precedent of crack generation in the place of the similar structure in the bogie frames of the vehicles for Shinkansen and conventional lines.

The periodic inspections for the concerned vehicle were implemented based on the "Regulation for Implementing Maintenance" and the "Maintenance Rules, etc." in the JR West, as described in 2.3.3.1.

**34 "Penetrate test" is the nondestructive test to detect the flaw opened in the surface as the indication pattern constituted by the penetrating process, removal process of the surplus penetrating liquid and the developing process in a part of the specimen.*

2.5.3.2. Records of the Size Inspection of the Concerned Bogie Frame

The size inspection of the detached bogie frame had been implemented in the general inspection to confirm the existence of the remarkable distortion in the major part of the bogie frame such as the side beam, etc., in the JR West.

There was no abnormal situation in the record of the measured sizes of the parts of the concerned bogie frame in the latest general inspection implemented before the concerned serious incident, as they were within the standard values determined in the JR West.

2.5.3.3. Inspection Records of the Wheel Load of the Concerned Vehicle

The wheel loads had been inspected in the general inspection in order to secure the running safety of the vehicles. The inspection of the wheel load was to confirm that the unbalance of the left and right wheel loads was within the standard value, by measuring the load weight acting on each wheel in the halting status, *i.e.*, the static wheel load. When the adjustment of the wheel loads is required, the load weight acting on the axle box is adjusted by adjusting the amount of the flexure in each axle spring by changing the number of the adjusting plates or the thickness of the adjusting plates inserted to the bottom of the axle spring.

The records of the measured wheel loads of the concerned vehicle in the latest general inspection implemented before the concerned serious incident were checked and it was found that the unbalance of wheel loads in left and right wheel was within the standard value determined in the JR West. In addition, the thickness of the adjusting plate inserted in total 8 points for all axle springs in the 4 axle box suspension devices in the concerned bogie to adjust the wheel loads, were checked and it was found that there was no distinctive difference in the 8 points.

2.6. Information on the Tests, etc., to Estimate Factors to Generate Cracks

2.6.1. Tests, etc., to Estimate the Effects by the Overlay Welding

The FEM analysis and the fatigue test were implemented in the concerned bogie maker, to comprehend the level of the effect by the overlay welding to the generation and expansion of the crack, as there was the aspects considered as the overlay welding in the bottom plate of the axle spring seat of the concerned bogie frame, as described in 2.4.2.3.

2.6.1.1. The FEM Analysis Recreating the Strain Caused by the Overlay Welding

In order to study the effects by the overlay welding, the FEM analysis was implemented after the concerned serious incident. The axle spring seat and the neighboring side beam were modeled by the three-dimensional elements, and the load weight in the direction to compress the axle spring seat was input to the model. In order to simulate the axle spring seat being implemented the overlay welding after annealed, the input condition for the FEM analysis were obtained by the following calculations.

- (1) To estimate the level of the stress acted in the place where the crack had generated, the status of being implemented the overlay welding after annealed was recreated by implemented the overlay welding of over 5 mm thick, after cutting the bottom plate of the axle spring seat 5 mm by the machining works, which was welded to the bottom plate of the side beam of the unused commercial bogie frame.
- (2) The deformation of the axle spring seat before and after implementing the overlay welding was measured using the three-dimensional scanner, and the strain in the direction to compress axle spring seat was calculated inversely so as to obtain the same level distortion in the FEM analysis.

The calculated result showed that the relatively high stress compared to the surrounding area

was generated in around the slot welded part.

2.6.1.2. The Fatigue Test Recreated the Overlay Welding, etc. *[Refer to Attached Figures 9 and 10]*

The generation and the expanding degrees of the fatigue crack were compared in the fatigue test by preparing the normal product, the test piece recreated the overlay welding, the test piece of thin plate and the test piece having inner defects.

The unused bogie frame stored in the concerned bogie maker and the bogie frame, used for about 10 years, which was replaced due to thin thickness of the bottom plate of side beam after the serious incident, were used as the test piece of the fatigue test.

The status of the overlay welding after annealed was recreated by cutting the bottom surface of the axle spring seat 5 mm by the machining, implement the overlay welding of over 5 mm, and implemented the machining work again, in some test pieces. Here, there was no echo due to the defect in the ultrasonic test in the slot welded part after recreating the status being implemented the overlay welding.

As the rough trends of the test results, the test piece recreated the overlay welding after annealed showed the trend to generate fatigue crack by definitely small number of repetition of loading compared to the normal state test piece, and the test piece of insufficient thick plate showed the trend to generate fatigue crack by slightly small number of repetition of loading. The definite difference due to the existence of the inner defects could not be determined in these test results.

2.6.2. Transition of Expansion of the Fatigue Crack Based on the Simulation

[Refer to Attached Figures 11 and 12]

In order to estimate the expanding status of the fatigue crack, the simulation based on the numerical analysis was implemented by assuming that the initial fatigue crack had generated at the position on the center line of the slot welded part. The stress in the forward and backward direction at just close to the place where the crack had generated, which was measured in the running test using commercial vehicles implemented in Tokaido and Sanyo Shinkansen using the N700A mass produced vehicles, were converted to the load weight corresponding with the supposed passenger load factors, *i.e.*, empty load, loaded passenger capacity and fully loaded, and used as the input condition of the calculation.

The results of the simulation for the case that the thicknesses of the bottom plate, the side plate and the R-part between them were 7.0 mm, which was prescribed as the designed limited value, and the case that the thickness of the bottom plate was 4.3 mm, which was the thinnest of the bottom plate found in the inspection of the other bogie frame, were as follows. Here, the 4.3 mm was the measured value in a part of the bottom plate in the investigation, but the thickness of the bottom plate was set at 4.3 mm uniformly in the simulation in the latter case.

- (1) When the loading condition was assumed as loaded by the passenger capacity for all time, and the initial width and depth of the fatigue crack were assumed as 15 mm and 1 mm, respectively, as the initial condition of the simulation, the results of the simulation showed

that the time required for the supposed size fatigue crack expand to the R-part in the bottom plate, where there was a possibility to be found the tip of the crack by the magnetic particle test, etc., was about 35 years in addition to the period to expand to the supposed size from the generation of the crack, for the case of the 7.0 mm thick bottom plate of the side beam, on the contrary, it took about 5 years to expand to the same place for the case of the 4.3 mm thick bottom plate of the side beam.

(2) The tip of the crack reached to the center of the height of the side beam after the tip of the crack reached at the R-part in several months to shorter than one year, regardless of the thickness of the bottom plate.

(3) When the initial width and depth of the fatigue crack were 15 mm and 2 mm, respectively, the crack expanded in about half period compared to the case of the initial depth of 1 mm.

Here, in order to confirm the validity of the parameters, etc., used in the calculation of the simulation, the status of the expansion of the crack was investigated by the fatigue test using the actual side beam in the same conditions of the calculation and compared with the results of the calculation. The fatigue test was implemented for the test piece recreated the status after the fatigue crack had reached to the R-part by machining the simulated crack artificially in the bottom plate of the side beam prior to the fatigue test, in order to verify only the expanding status of the crack in the side plate of the side beam, As the results, it was confirmed that the simulation recreated the expanding status of the actual crack in good accuracy.

2.7. The Other Information on the Vehicles

2.7.1. The Air Conditioning Devices of the Vehicles

The device for air conditioning in the cabin was equipped in underfloor of each vehicle of the concerned train. The air conditioning device inhale the open air in around the center of the underfloor and supplied the air to inside vehicle, through the outlet located in the cabin and the deck.

2.7.2. Records of the Data of the Vehicles

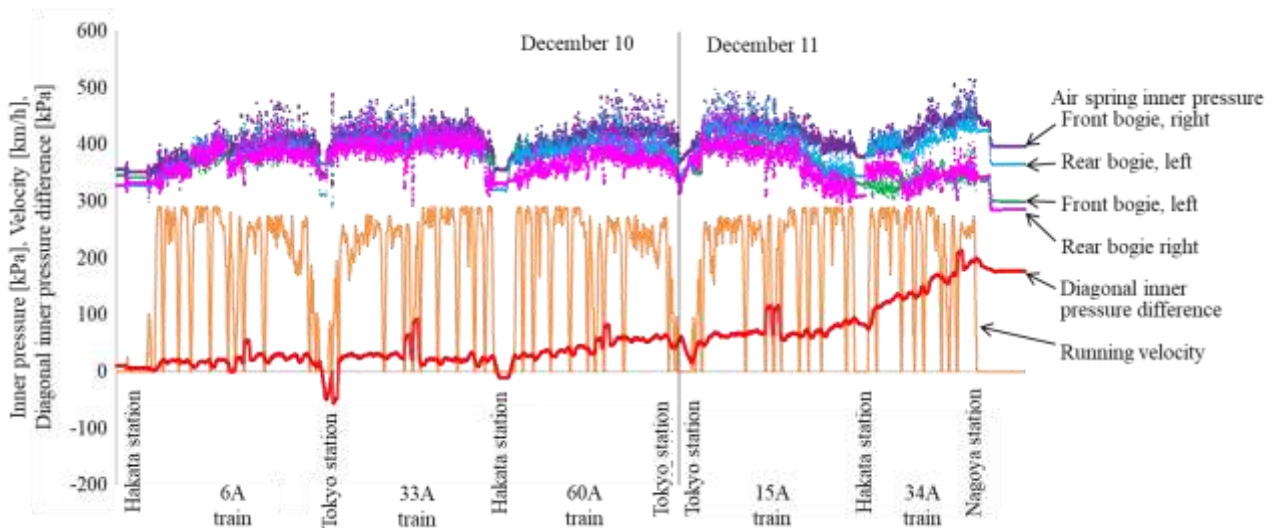
The concerned vehicle had equipped the function to adjust the accelerating force and the decelerating force of the vehicle corresponding to the gross weight of the vehicle body and the passengers, here, the gross weight of the vehicle body and the passengers was estimated by measuring the pneumatic pressure in the air spring suspending the vehicle body, *hereinafter referred as "the inner pressure"*.

The data recording device for monitoring main line in the concerned vehicle, *hereinafter referred as "the data recording device"*, had recorded the data of the inner pressures in the four air springs, *i.e.*, left and right air springs in each front and rear bogie of the concerned vehicle, for the trains operated from 12 days before the occurrence of the concerned serious incident including the concerned train.

When the components suspending the vehicle body vertically such as bogie frame, etc., had damaged and the suspension forces had decreased caused by the reduced rigidity of the suspension

force at that place, the inner pressure of the neighboring air spring would decrease. As the vehicle body was suspended by the air springs located in four points, it is supposed that the loads acting on the air spring nearest to the damaged place and the air spring in the diagonal place decreased and cause the decrease of their inner pressures, on the contrary, the load acting two air springs in the inverse side diagonal positions increased and their inner pressures also increased.

In order to confirm the above trends, using the records of inner pressure of the air spring in the data recording device of the concerned vehicle, the summation of the inner pressures of the air springs in left of the front bogie where the concerned crack had generated and in right of the rear bogie, *i.e.*, in diagonal position, was subtracted by the summation of the inner pressures of the air springs in the inversely diagonal positions, *i.e.*, in right of the front bogie and in left of the rear bogie, *hereinafter calculated value was referred to as "the diagonal inner pressure difference"*. The relationships of the operating status of the concerned vehicle and the inner pressures of the air springs, the diagonal inner pressure difference, which was the moving average for 10 minutes, and the running velocity, were shown in Figure 10.



Note : The diagonal inner pressure difference is the moving average for 10 minutes.

Figure 10. The diagonal inner pressure difference of air springs in the concerned vehicle

The same process was implemented for the record in the No.12 vehicle in the concerned train and compared with the trends of the diagonal inner pressure difference of the concerned vehicle. As there were large variation of the diagonal inner pressure difference considered as caused by the getting on and off of passengers while the train stopped at stations, and a little variation of the diagonal inner pressure difference considered as caused by the twist of the track, etc., during the train running in the records of the No.12 vehicle, but the both variations were restricted in short time and the average diagonal inner pressure difference became constant in around zero.

On the contrary, the diagonal inner pressure difference calculated from the recorded data in the concerned vehicle was in the trend to deflect to plus side, *i.e.*, in the direction to decrease the load in the diagonal air springs including the air spring just above the position where the crack had generated, in addition to the variation in short time same as in the No.12 vehicle, in the inbound 6A train, Nozomi 60, operated in the previous day of the occurrence of the concerned serious

incident. The same trend continued without change to the turned back outbound 33A train, Nozomi 33, but the diagonal inner pressure difference gradually increased from the inbound 60A train, Nozomi 60, and rapidly increased in the 15A train and the concerned train, *i.e.*, the 34A train, in the day of the occurrence of the concerned serious incident. Particularly, the diagonal inner pressure difference increased remarkably in the concerned train, and there was the remarkable difference between when departed from Hakata station and arrived at Nagoya station.

2.8. Information on the Process of the Operation on the Serious Incident Day

2.8.1. Information on the Formation

2.8.1.1. Formation of the Train Crews

The crews of the JR West were engaged in the train operation between Hakata station and Shin-Osaka station of Sanyo Shinkansen, and the crews engaged in the operation of the concerned train were the train driver, two conductors and a cabin attendant. In addition, three pursers were boarded. The conductor engaged in the on-train ticket examination was boarded additionally on the concerned train, between Hiroshima station and Shin-Osaka station on the day of the occurrence of the concerned serious incident.

The crews of the JR Central were engaged in the train operation between Shin-Osaka station and Tokyo station of Tokaido Shinkansen, and the crews engaged in the operation of the concerned train were the train driver and three conductors. In addition, three pursers were boarded on the concerned train.

2.8.1.2. Formation of the Dispatchers

The traffic control of Sanyo Shinkansen, from Hakata station to Shin-Osaka station, was implemented by the JR West, and the traffic control of Tokaido Shinkansen, from Shin-Osaka station to Tokyo station, was implemented by the JR Central, and the duties of the dispatcher were implemented in each company. Here, the duties of the dispatchers for Sanyo Shinkansen and Tokaido Shinkansen were implemented in the same place.

The dispatchers of the JR West consisted of the train dispatcher in charge of train operation, the train dispatcher in charge of passenger service, the operation dispatcher, the facility maintenance commander, the electric power dispatcher and the signal communication dispatcher, and the supervising train dispatcher supervised the commanding mission of the day. The duties of the supervising train dispatcher, the train dispatcher in charge of train operation, the train dispatcher in charge of passenger service, and the operation dispatcher were prescribed in the "Standard of Duties of Dispatchers Related Transportation, for Sanyo Shinkansen, Fundamental Volume", *hereinafter referred to as "the Fundamental Dispatching Standard"*, of the JR West, as shown in Table 4.

Three dispatchers were always assigned as the operation dispatcher in the JR West. The operation dispatchers were mainly consisted of the staffs having the experience as the train driver or the conductor. The staffs experienced the vehicle maintenance were also posted.

Three dispatchers were assigned as the operation dispatchers, in the JR Central.

Table 4. Duties and roles of the dispatchers

	Contents of the duties
Supervising train dispatcher	<ul style="list-style-type: none"> - The person in charge of commanding mission of the day - In abnormal situation, the missions are to judge the most safe and accurate judgment to resume train operation, to decide the proper transportation plan comprehending the operating status of the train, and to implement the arrangement, etc., with the affiliated companies related to resume train operation.
Train dispatcher in charge of train operation	<ul style="list-style-type: none"> - Always comprehend the operating status of the trains. When there is a fear to generate delay of train operation or the delay of train operation occurred, implement the railway traffic operation arrangement such as to set up the extra train or train service cancellation, etc., promptly to secure the normal operation.
Train dispatcher in charge of passenger service	<ul style="list-style-type: none"> - Implement the arrangement of transportation service as the occasion demanded such as to operate the extra train when crowded by comprehending the number of passengers every day. - When there was an obstruction or a fear of obstruction to the normal train operation due to the accident in operation, etc., implement rescue activities for the passengers by arranging with the related organizations, in addition to the prompt passenger treatment, the provision of the prompt and accurate information to the related organizations.
Operation dispatcher	<ul style="list-style-type: none"> - Always comprehend the operating status of the trains, and endeavor to secure the normal train operation, by implementing the arrangement on the operation of the vehicles and train crews, such as the change of operation schedules accompanied with the preparation of operation^{*35} and the railway traffic operation arrangement^{*36}, for the vehicles and the crews belonging to the area of the company and the vehicles running in the area of the company, including the vehicles of the other company.

^{*35} "Preparation of operation" is the operating train, train service cancellation, changing the time schedules, changing stopping station or classification of train velocity, addition or decoupling vehicles, changing works in the premises, changing the block system, stop feeding, etc., responding to the undulation of quantity of transportation or for the engineering works, etc.

^{*36} "Railway traffic operation arrangement" is the method to operate trains normally when there was the delay or the fear of the delay in train operation, such as train service cancellation, operation suspension, stop train operation, turn back operation, start new train operation from intermediate station, coupling of trainsets, split of trainset, change order of train operation, change time of operation, change the interchange point, change refuge bay, change the stopping station, change the operating route, change arrival and departure tracks, change classification of train velocity, etc.

2.8.1.3. Organization for Inspection by the Vehicle Maintenance Staffs when an Abnormal Status, etc., had Happened in the Running Train

The running inspection, when the inspection by the vehicle maintenance staffs was required due to the occurrence of an abnormal status in the running train, was prescribed in the "Implementing Standard for Maintenance", in the JR West, as described in the following paragraph 2.9.5. The similar regulation has been enacted in the JR Central. The staffs mainly

charged in these roles were called as the running management team, and posted as shown in Table 5. Here, they were implementing inspection boarding on the trains according to the schedule, usually.

Table 5. Posted status of the running management team

Company	Posted section	Staffs per day	Remarks
JR West	Hakata General Train Depot	4 persons	- Running management team was integrated to the other group in the reorganization in June 2017 - Implement inspection in an abnormal situation, continuously.
	Okayama Branch, Hakata General Train Depot	1 person	
JR Central	Nagoya Train Depot	2 persons	

2.8.2. Information on Persons Concerned

2.8.2.1. Persons Concerned of the JR West

Train driver A

Male 57 years old Experienced for about 31 years and 3 months
Got the driver's license of Shinkansen electric railcars, on June 30, 1987.

Conductor A

Male 56 years old Experienced for about 17 years and 4 months

Conductor B

Male 36 years old Experienced for about 11 years and 0 month

Conductor C

Male 33 years old Experienced for about 3 years and 1 month

Cabin attendant A

Male 25 years old Experienced for about 3 years and 4 months

Purser A

Female 28 years old Experienced for about 6 years and 8 months

Purser B

Female 29 years old Experienced for about 9 years and 5 months

Purser C

Female 28 years old Experienced for about 9 years and 5 months

Vehicle maintenance staff A

Male 34 years old Experienced for about 0 year and 5 months

Vehicle maintenance staff B

Male 60 years old Experienced for about 24 years and 6 months

Vehicle maintenance staff C

Male 30 years old Experienced for about 6 years and 9 months

Supervising train dispatcher

Operation dispatcher A	Male	39 years old	Experienced for about 0 year and 6 months
Operation dispatcher B	Male	32 years old	Experienced for about 4 years and 3 months
Dispatcher for passenger services A	Male	34 years old	Experienced for about 4 years and 3 months
Dispatcher for passenger services B	Male	32 years old	Experienced for about 2 years and 3 months
	Female	30 years old	Experienced for about 0 year and 11 months

2.8.2.2. Persons Concerned of the JR Central

Train driver B

Male 36 years old Experienced for about 8 years and 2 months
Got the driver's license of Shinkansen electric railcars on Sept. 14, 2009

Conductor D

Male 61 years old Experienced for about 13 years 6 months

Conductor E

Male 24 years old Experienced for about 1 year 2 months

Purser D

Female 26 years old Experienced for about 6 years 8 months

Purser E

Female 30 years old Experienced for about 1 year 2 months

Purser F

Female 23 years old Experienced for about 1 year 9 months

Vehicle maintenance staff D

Male 32 years old Experienced for about 2 years 5 months

Vehicle maintenance staff E

Male 23 years old Experienced for about 0 year 4 months

Staff engaged in inspection and repair A

Male 57 years old Experienced for about 2 years 5 months

Staff engaged in engineering A

Male 46 years old Experienced for about 2 years 5 months

Operation dispatcher C

Male 57 years old Experienced for about 21 years 6 months

Operation dispatcher D

Male 36 years old Experienced for about 5 years 6 months

Operation dispatcher E

Male 31 years old Experienced for about 1 year 8 months

Traffic controller A

Male 30 years old Experienced for about 0 year 8 months

2.8.3. Information on the Action and Recognition of the Persons Concerned

[Refer to Attached Figure 13]

Based on the statements by the staffs concerned in the JR West and the JR Central, the summary of the actions and recognitions of the persons concerned until to the concerned serious incident was as follows.

(1) Actions and recognitions in the section between Hakata station and Kokura station

On the day of the occurrence of the concerned serious incident, the train driver A, the conductors A and B, the cabin attendant A, the pursers A, B and C were boarded on the concerned train from Hakata station.

The concerned train departed from Hakata station on schedule at about 13:33. While the concerned train was running between Hakata station and Kokura station, the cabin attendant A, who patrolled the cabins from the No.11 vehicle toward the No.16 vehicle, noticed the high-pitched sound "hoot" as whistle in the deck^{*37} in Tokyo station side of the concerned vehicle, *hereinafter referred to as "the concerned deck"*, and worried about it, but he continued patrol to the No.16 vehicle. The cabin attendant A also noticed the high-pitched sound in the concerned deck on his way returned from the No.16 vehicle, then he thought something strange, and communicated it to the conductor A. While the cabin attendant A was waiting for the arrival of the conductor A in the concerned deck, the sound became low as the concerned train began deceleration due to being approached to Kokura station.

The conductor A arrived at the concerned deck and checked the sound together with the cabin attendant A, but the conductor A felt that the sound was not so different as usual.

**37 "Deck" in this context is the entrance space for passengers separated from the cabin by the door.*

(2) Actions and recognitions in the section between Kokura station and Hiroshima station

After the concerned train departed from Kokura station at about 13:50, the cabin attendant A, while patrolled the cabins, heard the similar sound as he heard between Hakata station and Kokura station, in around the concerned deck, but he did not worry about it. The purser B felt the nasty smell something burnt in the No.8 vehicle and also heard the sound as "ting" different from as usual in the concerned deck.

After that, while the concerned train was passing around Shin-Yamaguchi station, the cabin attendant A was reported from the purser A, that she felt smell as something burnt in the preparation rooms for on-train sales in the No.8 and the No.7 vehicles, then went to check the situation together with the conductor A. At that time, the conductor A felt the nasty smell something burnt a little in the preparation room in the No.7 vehicle but became not to feel the nasty smell gradually. The conductor A reported to the operation dispatcher B using the train radio that the smell as something fumigated existed in the No.8 and the No.7 vehicles but there was no abnormal sound.

The other operation dispatcher reported to the supervising train dispatcher of the JR West that there was the nasty smell in the concerned train, and the supervising train dispatcher advised the operation dispatcher to let the vehicle maintenance staffs get on the concerned train and implement inspection if possible. Obeying this advice, the operation dispatcher B reported

the situation to the staff of the day in charge of inspection and repair in the Okayama Branch of Hakata General Train Depot, *hereinafter referred as "the Okayama Branch"*, and arranged to let the vehicle maintenance staffs get on the concerned train, at about 14:30.

The cabin attendant A was reported from the purser A that there was the nasty smell also in the preparation room for on-train sales in the No.11 vehicle, then he went to the No.11 vehicle and felt the nasty smell something burnt in the front aisle and inside of the preparation room for on-train sales. The cabin attendant A reported it to the conductor A.

(3) Actions and recognitions in the section between Hiroshima station and Fukuyama station

The conductor C boarded on the concerned train from Hiroshima station. After the concerned train departed from Hiroshima station on schedule at about 14:35, the conductor C received the report from the conductor A about the situation of the nasty smell, then he patrolled the cabins, but he could not feel the nasty smell. The cabin attendant A checked the status of the sound in the concerned deck, but the sound was in the same level as heard while the train was running between Hakata station and Kokura station, in addition, there was no report from passengers, then he thought that there was no problem.

The conductor A worried about the sound in the concerned vehicle reported from the cabin attendant A, then, he went to the concerned vehicle to check again but there was in the state not to be worried. In addition, he did not feel the nasty smell in the No.8 and the No.11 vehicles. The conductor A reported to the operation dispatcher B that the nasty smell in the cabins has vanished. At that time, he was transmitted from the operation dispatcher B that three vehicle maintenance staffs will get on the concerned train at Okayama station.

(4) Actions and recognitions in the section between Fukuyama station and Okayama station

After the concerned train departed from Fukuyama station at about 14:59, the cabin attendant A felt that the sound in the concerned deck became larger than he had heard while the train was running between Hakata station and Kokura station, then reported it to the conductor A.

The conductor C felt the slight nasty smell something burnt in the service compartment in the No.10 vehicle, at about 4 to 5 minutes after the concerned train departed from Fukuyama station. While he was going to report it to the conductor A, he was reported from the passenger that "As I was boarded on the No.13 vehicle, there was the smell something burnt and smokes broke out, please check it", then he went to the concerned vehicle together with the passenger.

On the other hand, the purser B, while working in service of on-train sales in the No.14 vehicle, was reported from the passenger in the concerned vehicle that the smoke broke out in the cabin of the No.13 vehicle. Then she went to the concerned vehicle and found that it was hazy in the entire cabin as she could not identify the smoke definitely in the cabin, but smelled smoky, then she turned the automatic door between cabin and deck to the manual handling mode and open it to try ventilation. The purser B communicated the situation to the cabin attendant A using the PHS^{*38} and reported to the conductor C who rushed to the concerned vehicle.

The conductor C arrived at the concerned vehicle and confirmed that the smell something burnt was not so serious but it was as the oily something had burnt different from as usual smell

in the cabins, and the Tokyo station side of the concerned vehicle was dim as haze.

The cabin attendant A, who received the reports, reported to the conductor A that something as smoke broke out in the concerned vehicle, and he was instructed to go to the concerned vehicle.

The cabin attendant A, who also arrived at the concerned vehicle and went into the cabin, confirmed the abnormal sound, the nasty smell and hazy, but no smoke broken out in the cabin. The cabin attendant A felt that the nasty smell became severe and abnormal sound also became larger and felt slight vibration as he moved toward the No.14 vehicle in the cabin.

The purser C felt the nasty smell as the rusted iron in the deck between the No.3 and the No.4 vehicles, then reported the situation to the conductor B who passed each other while working in the on-train sales. When the conductor B checked the status, he felt the nasty smell as rusty in the middle of the cabin of the No.4 vehicle. He felt the nasty smell were severe than that he had confirmed in the No.8 vehicle.

When the conductor A reported to the dispatcher for passenger services A that something as smoke broke out in the concerned vehicle, the concerned train arrived at Okayama station on schedule at about 15:15. The dispatcher for passenger services A did not think that the emergency occurred because the report from the conductor A was as something smoky rather than smoke, and the conductor was talking calmly. He had thought that the conductor would report that the fire broke out, if it was a fire.

The dispatcher for passenger services B transmitted to the operation dispatcher B that the conductor A reported about the nasty smell in the concerned vehicle. The operation dispatcher B had recognized the nasty smells in the No.7 and the No.8 vehicles but it was the first time for him to recognize the smell in the concerned vehicle.

**38 "PHS" in this context is the portable telephone which train crew could talk with the dispatchers and the other train crews each other.*

(5) Actions and recognitions at Okayama station

The Okayama Branch, who was asked for the onboard inspection for the concerned train by the operation dispatcher B, decided to dispatch the vehicle maintenance staffs A, B and C to the concerned train to respond the request, because the staffs in the running management team assigned in the serious incident day could not be charged in the inspection of the concerned train because they were out for the other on-board inspection jobs.

Three vehicle maintenance staffs were waiting for the arrival of the concerned train in around the place where the coupling part between the No.8 and the No.9 vehicles would stop when the concerned train stopped at the platform of Okayama station, as they were reported that the nasty smell broke out from around the No.8 vehicle.

Three vehicle maintenance staff did not feel the abnormal situation when the concerned train arrived at Okayama station. After the concerned train stopped, the vehicle maintenance staff B checked the nasty smell from the gap between platform and the vehicles and the appearance in the visible range through the gap. He did not feel the nasty smell and did not find the abnormal situation such as defects in the vehicle body, etc. The vehicle maintenance staff C also did not

feel the nasty smell from the platform. Three vehicle maintenance staffs felt a little nasty smell when they entered the cabin from the platform. However, they felt as the nasty smell had vanished as it was not sure that the nasty smell vanished or they might be acclimated to the nasty smell.

(6) Actions and recognitions in the section between Okayama station and Shin-Kobe station

The vehicle maintenance staffs A, B and C got on the concerned train at Okayama station. The concerned train departed from Okayama station on schedule at about 15:16.

After the concerned train departed from Okayama station, the conductor B reported to the conductor A that he felt the nasty smell in the No.4 vehicle while the concerned train was running between Fukuyama station and Okayama station.

The three vehicle maintenance staffs, boarded on the concerned train from Okayama station, went to the concerned vehicle together with the conductor A, as they were reported from the conductor A that he felt the nasty smell in the concerned vehicle and the No.14 vehicle. About 10 minutes after the concerned train had departed from Okayama station, they heard the large growl sound "whine" as something rotated when they arrived at the concerned deck. The vehicle maintenance staff A worried about the abnormal sound and his consciousness were concentrated to the sound even though he might felt nasty smell also a little. The vehicle maintenance staff C felt the vibration transferred as "bzzt" from the underfloor in around the washroom of the concerned vehicle.

The purser A went to the concerned vehicle, responding the report from the purser B, felt slightly shaded in the cabin, and heard the sound as "ting" from around the ceiling and the sound as "thump-thump" from the underfloor.

At about 15:31, the conductor A reported to the operation dispatcher B that he felt the nasty smell in the concerned deck and felt as something cloudy in the cabin through the ventilation system.

The vehicle maintenance staff B, who was handed over the train radio communicating with the dispatchers, was asked about the status of the vehicle by the operation dispatcher B. The vehicle maintenance staff B reported the status to the operation dispatcher B as "I felt few smells but felt the severe sound. There was the high-pitch sound as "ting" from the underfloor. I would like to inspect the underfloor, as my opinion, but isn't there any time to do it?". According to the vehicle maintenance staff B, he thought that he said in the meaning as "Is it difficult to stop the train in the main line between stations?" as his memory was not clear. On the other hand, the operation dispatcher B understood that the report from the vehicle maintenance staff B was not the request that he would like to implement inspection as it was required.

The operation dispatcher B asked the vehicle maintenance staff B that "Is there any hindrance in the train operation?", then the vehicle maintenance staff B replied as "I think it is not in such situation, but I could not understand the situation because I had not checked the underfloor of the vehicle". Then the operation dispatcher B thought that there was no hindrance in the train operation as the abnormal sound broke out from the underfloor, because he was reported from the vehicle maintenance staff B that he did not think that it was not in such situation. For the

inquiry from the operation dispatcher B as "Don't you feel that there is a hindrance in train operation?", the vehicle maintenance staff B replied as "There is a possibility that the sound was generated from the motor related devices because the sound became larger when the notch ^{*39} was shifted up. Shall we inspect underfloor of the vehicle at Shin-Osaka station to secure safety?".

At that moment, the operation dispatcher A was thinking that if there was any hindrance in the train operation he would stop the train even in between the stations, and asked the operation dispatcher B about the status at that moment. Then, the operation dispatcher B took off the receiver of the telephone from his ears in order to respond it. Therefore, the operation dispatcher B could not listen the contents of the report from the vehicle maintenance staff B, and replied once to the vehicle maintenance staff B as "Wait one moment, please".

The supervising dispatcher, who have been watching the communications using train radio between the operation dispatchers and the vehicle maintenance staffs, went to the operation dispatchers and instructed to stop the train and implement inspection if some abnormal status existed, and asked to report on the situation.

The operation dispatcher A received the report from the operation dispatcher B as "There was no nasty smell, and there was no hindrance in the train operation, even though the sound was generated from the underfloor", then reported it to the supervising dispatcher. The operation dispatcher A and the supervising dispatcher could not conclude to judge that there was the hindrance in train operation.

On the other hand, the vehicle maintenance staff A, listening the communications between the vehicle maintenance staff B and the operation dispatcher B, understood that the preparation of the underfloor inspection at Shin-Osaka station had been arranged, as he heard the reply from the operation dispatcher B.

After that, the vehicle maintenance staff B considered that the situation might be improved by implementing measures to open motor circuit in the concerned vehicle if the underfloor inspection could not be implemented, then, he proposed it to the operation dispatcher B. As the vehicle maintenance staff B was asked by the operation dispatcher B to confirm that the nasty smells in the No.7 and the No.8 vehicles were the problem or not, the vehicle maintenance staff B reported as "The nasty smell was almost vanished, but the high-pitch sound in the concerned vehicle still worry me, then I will report on it after inspected again", and, once, disconnected the conversation using the train radio. At that moment, the operation dispatcher B understood that the vehicle maintenance staffs would implement the measure to open motor circuit instead of the underfloor inspection. In addition, the operation dispatcher B thought that the vehicle maintenance staffs would request clearly as "I would like to inspect underfloor", if necessary.

After that, at about 15:38, the vehicle maintenance staff A reported to the operation dispatcher A that the high-pitch sound was generated from the underfloor in around the concerned deck and there was the slight vibration. Then, as the operation dispatcher A asked as "Is it all right to consider that there is no problem in the train running?", the vehicle maintenance staff A replied as "We could not judge it because we did not check the underfloors". For the

inquiry from the operation dispatcher A that the situation could be improved by the measure to open motor circuit or not, the vehicle maintenance staff A replied that "I could not say definitely, even though the situation might be improved by the measures, because I felt that the sound was generated when the motor was driven in the powering^{*40} operation". The operation dispatcher A decided to implement the measure to open motor circuit in the concerned vehicle, and instructed the vehicle maintenance staff A to confirm the change of the sound after implemented the measure to open motor circuit. The operation dispatcher B, listening these conversations in the next seat, instructed the train driver A to implement the measure to open motor circuit in the concerned vehicle at about 15:39. Here, there was no abnormal indication in the monitor display in the driver's desk.

On the other hand, the operation dispatcher C and E of the JR Central, as heard the talk of the operation dispatcher of the JR West to instruct the measure to open motor circuit, confirmed the context of the instruction. The operation dispatcher A of the JR West transmitted to the operation dispatcher E of the JR Central that the nasty smell was generated but vanished by that moment in the concerned train, the measure to open motor circuit in the concerned vehicle was implemented against the abnormal sound, and received the report from the vehicle maintenance staffs boarding on the concerned train that there was no hindrance in the train running.

**39 "Notch" is the notch engraved on the handle being operated by the train driver.*

**40 "Powering" is the operation to accelerate the train.*

(7) Actions and recognitions at Shin-Kobe station

The concerned train arrived at Shin-Kobe station at about 15:48. The vehicle maintenance staffs B and C got off the train to the platform and checked the underfloor by lighting the gap between the vehicle body and the platform using the flash lights to confirm the nasty smells and smokes, but there was no abnormal situation, then back to inside vehicle as there was little time to the departure time.

(8) Actions and recognitions in the section between Shin-Kobe station and Shin-Osaka station

As the abnormal sound in the concerned vehicle was not vanished after the concerned train departed from Shin-Kobe station, the vehicle maintenance staff A reported to the operation dispatcher B at about 15:55, that "The same sound as before have still been continuing without change, and the sound was considered as generated from around the bogie but it is difficult to decide". As received the report, the operation dispatcher A instructed the train driver A to restore the measure to open motor circuit of the concerned vehicle, and communicated to operation dispatcher E of the JR Central about the situation.

The operation dispatcher B asked the vehicle maintenance staff A as "As we asked many times, your impression is that there was no hindrance in the train running at this moment. Is it sure?", then, the vehicle maintenance staff A replied as "It could not be judged as far as onboarded. Then I am not sure that there is no hindrance in the train running. But I am sure that the status is not as usual, as I could not say anything because I have been in above the floor".

At this moment, the operation dispatcher B recognized that there was no hindrance in the operation of the concerned train, as he had received the answer as "It was not in the situation

such as to disturb train operation", from the vehicle maintenance staff B responding the inquiry as "Is there any hindrance in train running?", while the concerned train was running between Okayama station and Shin-Kobe station. In addition, the operation dispatcher B also thought that the vehicle maintenance staffs will communicate as there is hindrance in train running if it was dangerous actually and will communicate clearly to request implementation of the inspection if it is necessary, because the vehicle maintenance staffs are the professional engineers of the vehicles.

On the other hand, the vehicle maintenance staff A understood that the request to implement inspection of the underfloor was transmitted to the dispatcher and the arrangement of the inspection has been implementing. The vehicle maintenance staff A was not conscious that there was no answer about the implementation of the inspection from the dispatchers, because he had been entrusted the decision to implement underfloor inspection to the dispatches, and he had been preoccupied to get off the concerned train at Shin-Osaka station, where is the boundary station with the JR Central, as the concerned train approached to Shin-Osaka station while communicating with the operation dispatcher many times. In addition, he thought that the staff of the JR West could not implemented the inspection at Shin-Osaka station, because Shin-Osaka station is within the jurisdiction of the JR Central.

The vehicle maintenance staff A told to the operation dispatcher B that they would get off the train, and three vehicle maintenance staffs got off the concerned train at Shin-Osaka station.

(9) Actions and recognitions at Shin-Osaka station

When the concerned train arrived at Shin-Osaka station at about 16:01, the purser E who was in charge from Shin-Osaka station, heard the sound as roared from the platform, but she did not worry about it as considered that the vehicles had been used for many years. The purser F also heard the unusual sound as roared, but she did not worry about it also because the concerned train stopped normally and there was no unusual situation in the cabins.

After the concerned train arrived at Shin-Osaka station, the train driver A of the JR West handed over to the train driver B of the JR Central, and the conductors and the cabin attendants of the JR West handed over to the conductors of the JR Central about the status of the nasty smells in Sanyo Shinkansen section, respectively. The precise handed over information were described in the following paragraph 2.9.2.

(10) Actions and recognitions in the section between Shin-Osaka station and Nagoya station

The train driver B, the conductors D and E and the other conductor, the pursers D, E and F of the JR Central, were boarded on the concerned train from Shin-Osaka station. The concerned train departed from Shin-Osaka station on schedule at about 16:03.

The operation dispatcher C of the JR Central had been reported from the operation dispatcher of the JR West as there was no hindrance in train running in the concerned train, but instructed the operation dispatcher E to let the conductors of the concerned train to check the existence of the nasty smell again. The operation dispatcher E who received the above instruction, instructed the conductor E to check the existence of the nasty smell from the No.8 to the No.14 vehicles, and to check the existence of the abnormal situation in the concerned vehicle in the arrival at

and the departure from Kyoto station. The operation dispatcher E considered to judge earlier whether the concerned train should be forwarded to the train depot or not at Tokyo station according to the level of the abnormal situation, then let the train crews to check the status in the cabins, as usual.

On the other hand, the vehicle maintenance staff B, standing on the platform, noticed the sound as something scraping from the concerned vehicle, when the concerned train departed from Shin-Osaka station. The vehicle maintenance staff A reported to the operation dispatcher A that the abnormal sound was generated from the concerned vehicle when departed from Shin-Osaka station. The operation dispatcher A recognized that the vehicle maintenance staff A had reported that he heard the sound as "tickity-tick" from the concerned vehicle when the concerned train departed from Shin-Osaka station, and felt that the report was not urgent, then, he communicated the contents of the report to the operation dispatcher E of the JR Central.

The operation dispatcher E of the JR Central received the report from the operation dispatcher A of the JR West, that there was the sound as creak when the vehicle maintenance staff got off the vehicle at Shin-Osaka station, but he thought that the sound was the creak within the usual level generated from the halting train because he was told as the sound was confirmed when getting off the vehicle. In addition, he was thinking that the conductor would report if there is abnormal situation, because he had already instructed the conductor to check the status.

The purser D felt a slight nasty smell in the preparation room for the on-train sales in the No. 11 vehicle, after the concerned train departed from Shin-Osaka station, but she did not worry about it particularly.

At about 16:12, the operation dispatcher D sound the possibility to let the vehicle maintenance staffs onboard the concerned train and implement the inspection, to the Nagoya Train Depot. The arrangement to dispatch the vehicle maintenance staffs was implemented usually when the abnormal sound in the cabin was reported, then he implemented the same arrangement as usual at that time.

The conductor E did not feel an abnormal situation while the concerned train was running between Shin-Osaka station and Kyoto station, but while the concerned train was accelerating after departed from Kyoto station at about 16:18, he felt the nasty smell as burnt candle and the abnormal sound "ting" as the wind noise in the concerned deck, then reported to the operation dispatcher D. In addition, the purser E confirmed the abnormal sound, the nasty smell and white hazy feeling in the concerned vehicle after the concerned train departed from Kyoto station, but she did not reported it particularly, because she was watching that the conductors D and E were communicating each other and thought that they were talking about these situations.

The staff in charge of inspection and repair of the day A in the Nagoya Train Depot, judged that it is difficult to let the vehicle maintenance staffs onboard the concerned train and implement inspection from the viewpoint of the required time, and considered to implement the inspection at Nagoya station if there was the nasty smells in the cabins. Then, he instructed three staffs, *i.e.*, the vehicle maintenance staffs D and E, and one more staff, to go to Nagoya station, and reported to the operation dispatcher D, at about 16:20.

At about 16:25, the operation dispatcher D confirmed the train driver B whether the abnormal situation was indicated or not on the monitor in the driver's desk and received the report that there was no abnormal indication. Then, the operation dispatcher D judged that the concerned train could continue the operation until to the next stop, *i.e.*, Nagoya station.

At about 16:34, the conductor E reported to the operation dispatcher E that there was the nasty smell after the train departed from Kyoto station but no smell at present. Then, he received the instruction to check the nasty smell in the concerned deck while arriving at and departing from Nagoya station.

At about 16:40, the conductor E joined with the conductor D in the concerned deck and checked the status of the nasty smell and the sound each other. The conductor E did not feel the nasty smell before joined but thought that the nasty smell was generated after joined with the conductor D. He heard the abnormal sound as "ting" or "zing", and felt the smell as metals are rubbing when the sound became louder. The conductor E reported to the operation dispatcher E about it, and was instructed from the operation dispatcher E to identify the place where the abnormal sound generated, but he could not identify the place where the sound was generated as the sound was echoed in the deck.

The operation dispatcher D arranged with the staff in charge of inspection and repair of the day A in the Nagoya Train Depot that the vehicle maintenance staffs would implement the inspection for around the concerned bogie from the platform of Nagoya station when the concerned train arrived at Nagoya station. At about 16:50, the vehicle maintenance staffs D and E arrived at the platform for the up track of Nagoya station.

(11) Actions and recognitions at Nagoya station

The concerned train arrived at the up track of the main line of Nagoya station on schedule at about 16:53.

The vehicle maintenance staffs D and E, waiting for the concerned train on the platform, noticed the abnormal sound as something rattled from the concerned vehicle, while the concerned train was arriving at Nagoya station. After the concerned train stopped, the vehicle maintenance staffs D and E felt the slight nasty smell as something burnt when they entered the concerned deck from the front door of the concerned vehicle.

The vehicle maintenance staff D reported to the technical staff A in charge of office work in the Nagoya Train Depot about the abnormal sound and the nasty smell. The technical staff A requested to the operation dispatcher D to stop the departure of the concerned train from Nagoya station because the underfloor inspection is required as the lining of the concerned vehicle generated the rattling sound. The operation dispatcher D, received this request, talked, as to be transmitted to the operation dispatchers, that to stop the departure of the concerned train from Nagoya station. The traffic dispatcher A, as heard the voice, instructed the driver of the concerned train not to start the concerned train.

The doors of the concerned train had already closed as it was the scheduled departure time, but the train driver B did not start the concerned train as he was instructed from the traffic dispatcher A that the movement of the train was forbidden in order to implement inspection of

the bogies.

At about 17:03, the vehicle maintenance staffs D and E moved to the underfloor of the concerned vehicle and inspected the concerned bogie. The vehicle maintenance staff E found the leaked oil in around the gear box when checked the concerned bogie, and found that the right wheel of the 1st axle in the concerned bogie was hot compared to the right wheel of the 2nd axle in the concerned bogie when he touched the right wheel of the 1st axle in the concerned bogie. The vehicle maintenance staff D was asked by the operation dispatcher D about the possibility to continue train operation, then he reported to the operation dispatcher D that the train operation was impossible as the oil was leaked in around the axle box, at about 17:10. Then, the operation of the concerned train was cancelled at Nagoya station.

The staffs of the JR Central, while implementing the works to move the concerned vehicle toward the Nagoya Train Depot, found the tilting of the left axle box in the 1st axle of the concerned bogie and the abnormal situation of the wheel base of the left side of the concerned bogie frame, and suspended the works. The staff of the JR Central who participated the on-site work due to receive the communication from the staff of the JR West, who jointly possessed the information on the status of the bogie by the photographs, as "I found the line considered as something defect in the bogie frame in the photograph. Would you check the bogie frame?", found the concerned crack when checked the designated place, at about 23:40.

Here, there was no report as the train crews, etc., noticed the abnormal sound or the nasty smell in the outbound 15A train operated just before the concerned train on the day of the occurrence of the serious incident.

2.9. Information on the Handling Train Operation, etc.

2.9.1. Regulations on Handling in Abnormal Situation for the Train Crews in the JR West

"The Standard of Operation of the Crews of the Power Car, for Shinkansen", "the Standard of Operation of the Train Crews, for Shinkansen" and "the Standard of Operation of the Cabin Attendants, for Shinkansen" of the JR West, *hereinafter referred to as "the Operation Standards of Driver", "the Operation Standards of Conductor", and "the Operation Standards of Cabin Attendant", respectively*, prescribed the fundamental works and fundamental actions, handling in the normal and abnormal situations, etc., for the train crews in order to implement their operations to provide safe, accurate and comfortable transportation to the users of the railways, based on the Working Regulation, the Standards for Safe Operation, the Regulation for the Implementing Standard of Handling Operation of Shinkansen, etc., of the company.

The composition of regulation in the Operation Standards of Driver, the Operation Standards of Conductor and the Operation Standards of Cabin Attendant was as shown in Table 6.

Table 6. Composition of regulations on the operation standards for the train crews

	Operation Standards of Driver	Operation Standards of Conductor	Operation Standards of Cabin Attendant
	Fundamental volume	Fundamental volume	Fundamental volume
Separate volume 1		Details	Details
Separate volume 2	Block diagram for handling in the abnormal situation		Handling in the abnormal situation
Separate volume 3	Block diagram for temporary measures for the troubles in Shinkansen electric railcars for the 500 series vehicles, Block diagram for temporary measures for the troubles in Shinkansen electric railcars for the 700 series vehicles, Block diagram for temporary measures for the troubles in Shinkansen electric railcars for the N700 series vehicles		

The procedure of measures in the abnormal situation was mainly prescribed in "the Separate Volume 2. Block Diagram of Handling in the Abnormal Situation", *hereinafter referred to as "the Block Diagram for Abnormal Situation"*.

The basic measures in abnormal situation were prescribed in the fundamental volume of the Operation Standards of Driver as follows.

"Operation Standards of Driver", Fundamental Volume, extracted.

Chapter 9. Fundamentals in abnormal situation

(Preparation in abnormal situation)

9-1. In case of abnormal situation such as an accident, etc., secure the safety of the passengers and yourself, as considered the respect for the human lives as the top priority. In addition, implement the measures considered as the safest, composedly, calmly and promptly, asking the passengers for cooperation according to the situation. Here, the measures should be implemented paying attention to the following points.

(1) Calm down the mind and judge accurately.

(2) to (5) [Omitted]

In addition, the similar regulations were prescribed in the "Operation Standards of Conductor", Fundamental Volume and the "Operation Standards of Cabin Attendant", Fundamental Volume.

Here, the following regulation was prescribed in the "Chapter 1. General rules" of the "Operation Standards of Driver", Fundamental Volume and the "Operation Standards of Conductor", Fundamental Volume.

(Measures in the suspicious situation)

1-12. In the cases facing the situation that are not prescribed in the operation standard, and there is no time to receive instructions for the handling against the situation, implement actions considered as the safest supposing all situations, considering the respect for the human lives as the top priority.

Here, the same regulation was prescribed in the "Operation Standards of Cabin Attendant", Fundamental Volume.

The block diagram in abnormal situation indicated the procedures to prevent errors in the handling by standardizing the handling, etc., of the train crews of Shinkansen in the JR West. The handling when detected the abnormal sound, etc., was prescribed in the block diagram in abnormal situation as shown in Figure 11. Here, in the block diagram in the abnormal situation, the measures in blue frame indicated the handling of the driver, and the measures in red frame indicated the handling of the conductor.

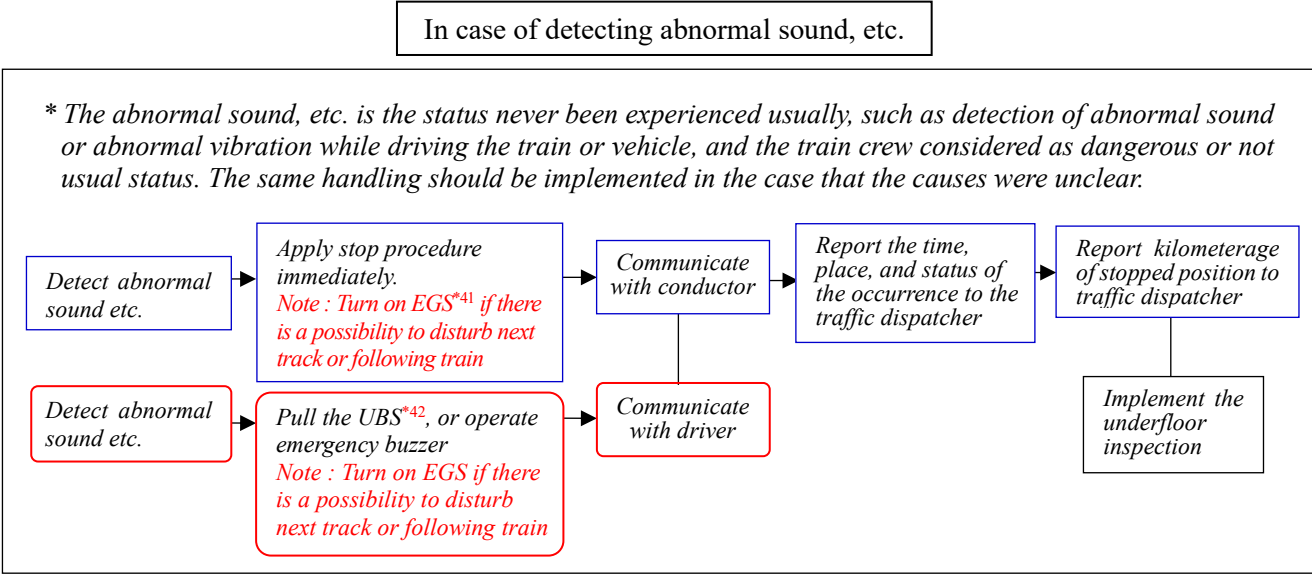


Figure 11. Block diagram when abnormal sound, etc., was detected, extracted blocks up to implementation of the underfloor inspection.

**41 "EGS" is the abbreviation of Emergency Ground Switch, which is the device to stop power feeding from substations by grounding the overhead contact lines forcibly.*

**42 "UBS" is the abbreviation of Urgent Brake Switch, which is the pull switch used by the train crews when stop the train urgently.*

According to the JR West, the measures for the concerned serious incident were out of application of the above procedures because the train crews did not understand the situation as dangerous.

As for the measures against the generation of nasty smell, the block diagram for handling in the abnormal situation was prescribed mainly on the handling of the guidance for evacuation when the poisonous gas had broken out, and there was no prescription of the block diagram against generation of the nasty smell generated in the concerned serious incident. The train crew judged as the nasty smell was not the poisonous gas because no passenger reported the bad physical condition, then, the train crew did not implement measures based on the prescribed procedure.

In addition, the handling in the occurrence of train fire was prescribed as "implement measures considering the train fire when the broken out smoke was found", However, in the concerned serious incident, the train crews considered that the haze is not the smoke because the origin of a fire could not be identified and the haze had vanished soon, then they did not judge that the train

fire had broken out.

Based on the above information, the train crews recognized the abnormal sound, the nasty smell and the haze, but they judged the individual phenomena did not correspond to the items in the Operation Standards of Driver, the Operation Standard of Conductor and the Operation Standards of Cabin Attendant, then, they did not reached to the situation to implement measures based on the manuals particularly.

2.9.2. Regulations on the Transfer Operation between Train Crews in the JR West

The methods and contents of the transfer operation between train crews were prescribed in the Operation Standards of Driver, the Operation Standard of Conductor, and the Operation Standards of Cabin Attendant, as follows.

"Operation Standards of Driver", Fundamental Volume, extracted

(Types of transfer relay)

6-17. *Types of the transfer relay should be the meeting transfer and the telephone transfer.*

(1) *Meeting transfer*

(i), (ii) [Omitted]

(iii) *The drivers should confirm the train number each other, then transfer the required items such as the operating status, status of vehicles, etc.*

(iv) [Omitted]

(2) *Telephone transfer* [Omitted]

(Handling of operation notice card for vehicle transfer)

6-20. *Handling of the operation notice card for vehicle transfer should be implemented as follows.*

(1) [Omitted]

(2) *Write the contents of the vehicle troubles occurred during in operation and the implemented measures in the operation notice card according to its necessity, and transfer the written contents to the succeeding driver certainly, in case of transfer relay.*

(3) [Omitted]

"Operation Standards of Conductor", Fundamental Volume, extracted.

(Method of transfer relay)

6-4. *Method of the transfer relay should be as follows. After saluted each other by the order of the arrived conductor, report to the succeeding conductor using the operation transfer sheet obeyed to the principle, then confirm each other and repeat. Here, the transfer can be implemented orally.* [Omitted]

(Transferred contents)

6-5. *The transfer should be implemented by writing the following items in the operation transfer sheet.*

<i>Transferred Contents</i>
<i>(1) Train number</i>
<i>(2) Name of the trainset</i>
<i>(3) Operating status</i>
<i>(4) Status of vehicles, such as the air conditioning, microphones, etc.</i>
<i>(5) Status of on-train examination of tickets, group passengers, lost articles.</i>
<i>(6) The other required matters</i>

"Operation Standards of Cabin Attendants", Fundamental Volume, extracted.

(Method of transfer relay)

4-3. *Method of the transfer relay should be as follows, after saluted each other by the order of the arrived crew, report to the succeeding attendants using the operation transfer sheet obeyed to the principle, then confirm each other and repeat. Here, the transfer can be implemented orally.*

(Transferred contents)

4-4. *The transfer should be implemented by writing the following items in the operation transfer sheet.*

<i>Transferred Contents</i>
<i>(1) Train number</i>
<i>(2) Name of the trainset</i>
<i>(3) Operating status</i>
<i>(4) Status of vehicles, such as the air conditioning, microphones, etc.</i>
<i>(5) Status of on-train examination of tickets, group passengers, lost articles</i>
<i>(6) The other required matters</i>

According to the JR West, the transferred contents from the driver of the JR West to the driver of the JR Central, and from the conductor and the cabin attendant of the JR West to the conductor of the JR Central, implemented at Shin-Osaka station, were as shown in Table 7.

Table 7. Contents of the transferred matters between train crews at Shin-Osaka station

	Method	Contents
Driver	Orally	- As for the status of vehicles, there was the report on the existence of the smell as something burnt in the 7th, 8th and 13th vehicles. The vehicle maintenance staffs had boarded on the train and checked the situation but could not find the causes.
	Operation notice card for vehicle transfer	- There was the smell as something burnt in the preparation room for the on-train sales in the 7th vehicle and in the middle of cabin to the deck in Tokyo station side in the 8th vehicle. - There was the smell as something burnt. The measure to open motor circuit of the No.13 vehicle was implemented obeying the instruction by dispatcher based on the report from the running management team that the sound became large when the notch was operated. After that, the measure to open motor circuit was restored as the situation was not changed.
Conductor and Cabin attendant	Orally	- There was the nasty smell in the 13th vehicle, and the vehicle maintenance staffs had inspected. - The train operation was continued as the nasty smell was considered as not to disturb the train operation. Please report to the dispatcher if noticed something suspicious. - The inspected results were reported to the dispatcher from the vehicle maintenance staff, but we received no instruction after that.

2.9.3. Regulations on Handling Abnormal Situation for Dispatchers in the JR West

The "Standard of Dispatching Operation", Fundamental Volume, of the JR West prescribed as follows.

The matters to be obeyed as the dispatcher, extracted.

Philosophy of the dispatching activities

The action to be taken by the dispatcher in order to achieve their missions for the railway transportation based on the philosophy to secure the safety, should not be ambiguous. The fundamental of the dispatching action is to practice strictly the prescribed confirming works, handlings, report, communication, and transmission, considering always that "act what should be acted and never act what should not be acted" as the principle to secure the safety.

<Exact comprehension of the situation>

Person in charge of the dispatching operation should endeavor to comprehend the situation exactly in any situations. In other words, the dispatching actions based on the speculation without comprehending the situation are the most dangerous action, then the action that is considered as the safest should be implemented in case of the unclear situation.

<Practice of the fundamental action>

[Omitted]

<Prompt arrangement>

Next, the handling of the dispatching operation should be implemented the required actions promptly and strictly based on the prescribed rules. Particularly, the person in charge of the

dispatching operation should never postpone the action that should be arranged because the dispatching actions were implemented in the situation changing every moment.

<Rigid report and communication>

Finally, the "provision of the safe and accurate transportation" is formed by the cooperation between the company staffs concerned. Therefore, the actions of communication and receipt of reports should be processed accurately by writing the contents and repeating each other, never treated as trivial even if the situation was considered as insignificant.

In addition, the measures against abnormal situation were prescribed as follows.

Chapter 2. Preparation of the dispatchers related with transportation.

1-2-1. Preparation of dispatchers related with transportation

(1), (2) [Omitted]

(3) The dispatchers related with transportation should act calmly and composedly in any situations, and should implement safe and proper measures promptly by judging the situation exactly when an abnormal situation such as the occurrence of the operation accident occurred, and do their best considering the rescue activities as the top priority when the dangerous situation for human lives occurred.

1-2-2. Matters to be obeyed by the dispatchers related with transportation

(1) [Omitted]

(2) The dispatchers related with transportation should implement activities considered as the safest supposing all the situations when there is no time to receive the instruction from their superior on the judgment and handling in the urgent situation that is not prescribed in the standards of Dispatching Operation.

(3) [Omitted]

When an abnormal sound occurred in the cabin while the train is running, handling of the dispatcher should be implemented as Figure 12, based on the "Standards of Dispatching Operation related with Transportation, Sanyo Shinkansen, Abnormal Situation Volume", *hereinafter referred to as the "Dispatching Standards in Abnormal Situation"*.

According to the JR West, the sound generated in the concerned serious incident did not correspond to the sound for which the stop procedure arrangement and the underfloor inspection should be implemented.

The measures against the generation of the nasty smell were prescribed in the Dispatching Standards in Abnormal Situation, as the handling to aim guidance for evacuation against the generation of the poisonous gas, mainly, but the measures against the smell as something burnt as generated in the concerned serious incident were not prescribed.

In addition, the measures against the occurrence of train fire were prescribed, but the measures related with generation of haze were not prescribed.

10-37 Handling when abnormal sound had generated in the cabin

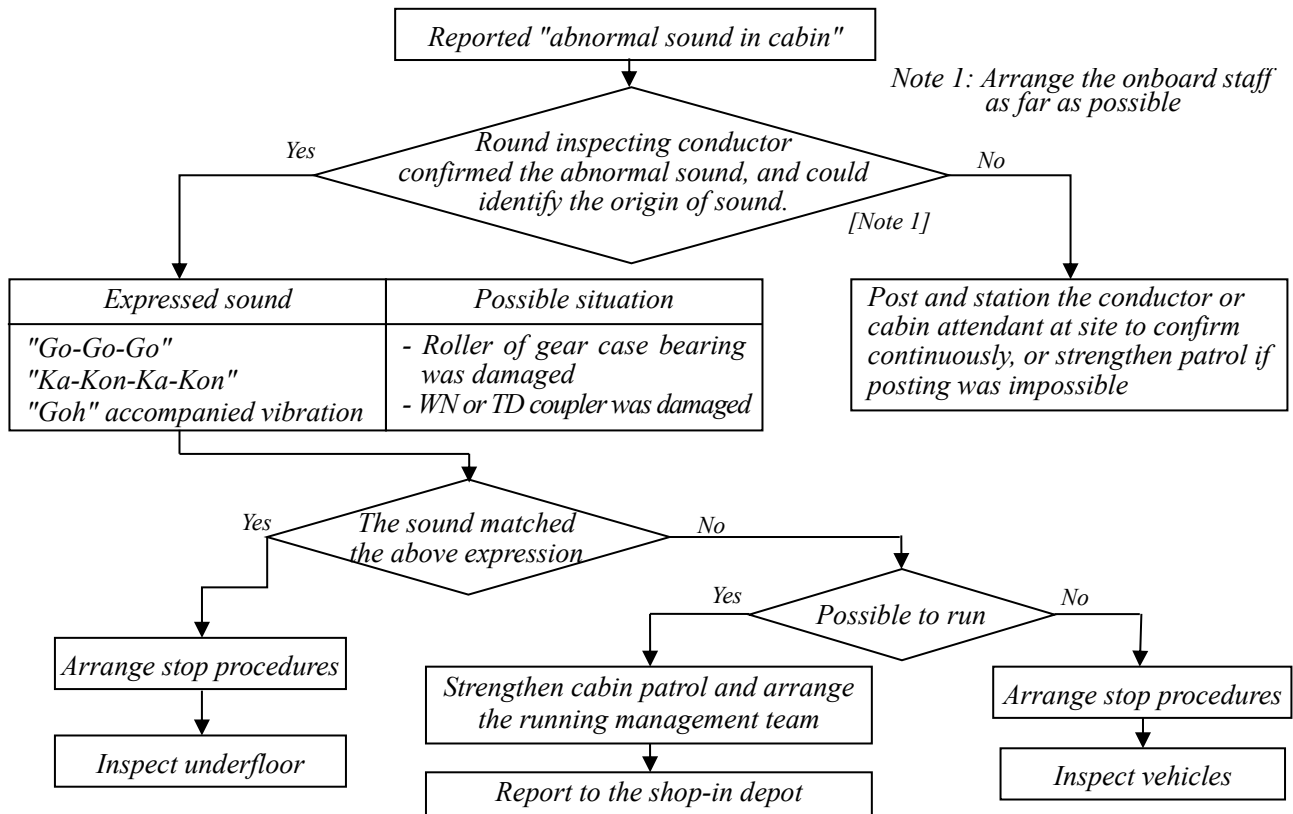


Figure 12. Flow chart of handling for the occurrence of abnormal sound in the cabin

2.9.4. Possessing Information Jointly Between Dispatchers in the Abnormal Situation

Possessing information jointly and transfer relay between dispatchers were prescribed in "the agreement on the central dispatching operation in Tokaido, Sanyo and Kyushu Shinkansen" as follows.

"Agreement on the central dispatching operation in Tokaido, Sanyo and Kyushu Shinkansen", extracted.

(Boundary of the territories for dispatchers, etc.)

Article 37. The information on the vehicles, etc., in the train in through operation should be transferred at the boundary station. [Omitted]

(Measures against the vehicle trouble, etc.)

Article 40. When the vehicle trouble during the operation and the inspection and repair of vehicle in the train depot occurred, the dispatcher of the company controlling the place where the accident occurred should implement measures, regardless of the owner of the vehicle, then should communicate their results to the chief staff of the day, etc., of the other company, and consider so as not to disturb the appropriation for operation, etc. [Omitted]

The information possessed jointly between dispatchers engaged in the operation control of the JR West and the JR Central, on the concerned serious incident were as shown in Table 8.

Table 8. Information possessed jointly between dispatchers of the JR West and the JR Central

Time	Major contents
About 15:38	<ul style="list-style-type: none"> - There were smells as something fumigated in the No.8, No.13, <i>i.e.</i>, the concerned vehicle, and No.14 vehicles of the concerned train, the K5 trainset. - The vehicle maintenance staffs were boarded on the concerned train from Okayama station and confirmed that there was no smell at present. The abnormal sound as "ting" is there. - As there was no abnormal situation, the measure to open motor circuit was implemented in the concerned vehicle.
About 15:58	<ul style="list-style-type: none"> - The abnormal sound did not change as the measure to open motor circuit of the concerned vehicle was implemented. - The measure to open motor circuit of the concerned vehicle was restored.
About 16:11	<ul style="list-style-type: none"> - There was the sound as "tickity-tick" from the concerned vehicle when the concerned train departed from Shin-Osaka station.

Here, the concerned train was the train in through operation in Sanyo Shinkansen of the JR West and Tokaido Shinkansen of the JR Central, and the communicating system between two companies was prescribed in the "Details to implement traffic control of Tokaido, Sanyo and Kyushu Shinkansen" as follows.

(Communicating system between companies)

Article 3. Each company should always comprehend the operating status of the trains in the territory of the company and communicate to the other company promptly in case the situation to affect or to fear to affect to the other company due to the delay in train operation, etc., happened. [Omitted]

(Consultation between dispatchers)

Article 6. In an abnormal situation, the consultation between dispatchers consisted of the concerned dispatchers of each company should be held, according to the necessity, based on the consultation between companies.

In an abnormal situation, the representatives of each dispatching section gather and possess information jointly, confirm the situation, discuss and decide the best measures for the early recoveries and the future operation plans. When the subject of discussion stretches over Tokaido Shinkansen, Sanyo Shinkansen and Kyushu Shinkansen, the JR Central, the JR West and Kyushu Railway Company, *hereinafter referred to as "the JR Kyushu"*, hold the consultation between dispatchers jointly.

The consultation between dispatchers was held when the delay or the train service cancellation was anticipated due to the vehicle trouble, the operation control or the measures against the flying objects due to heavy rain or strong wind, etc., and the troubles in the railway facilities, etc. The consultations between dispatchers including the dispatchers of the JR West were held for the total 361 cases from April 1 to December 11, 2017, except for the consultation between dispatchers related to the concerned serious incident. The 48 consultations in the above 361 consultations were held related with vehicles.

In case of the concerned serious incident, the consultation between dispatches was not implemented until to the arrival of the concerned train at Nagoya station, provided that information on the abnormal situation of the vehicle were possessed jointly between the dispatchers of the JR West and the JR Central, as described in 2.8.3.

After the concerned train arrived at Nagoya station, the vehicle maintenance staffs implemented the underfloor inspection and found the leaked oil in the bogie. Then the first consultation between dispatchers composed of the dispatchers of the JR West, the JR Central and the JR Kyushu, was held at 17:12. The consultations between dispatchers were held total four times after the arrival of the concerned train at Nagoya station in the concerned serious incident.

2.9.5. Inspection by the Vehicle Maintenance Staffs in the Abnormal Situation

The measures, when the abnormal situation occurred in the train and the inspection by the vehicle maintenance staffs was required in the JR West, were prescribed in the "Regulation for Implementing Maintenance" as follows.

(Running inspection)

Article 6. The running inspection should be implemented by the staff boarded on the train for the dynamic characteristics of the running train, such as acceleration, deceleration, vibration, jolts, etc., and the comprehensive actions and the functions of each device, when the situation corresponds to one of the followings.

- (1) The inspection of the operating status of the train was required by the report from train crews, etc.*
- (2) The adjustment of functions of the train in operating status was required.*
- (3) The other status considered that the inspection was needed.*

The inspections of the operating train had been implemented in the normal inspection, in addition to the abnormal situations. The onboard inspections in the operating train were implemented 361 times from April 1 to December 11, 2017, in the JR West, except for the concerned train. Among these inspections, the inspections by the vehicle maintenance staffs, based on the report of the abnormal situation from the train crews or the passengers while the trains were operating, were implemented 21 times.

2.10. Information on Generated Status of Abnormal Sound, Nasty Smell and Smoke, in the Past

2.10.1. The Generated Status in the JR West

The abnormal sounds reported in Sanyo Shinkansen section of the JR West from April 1 to December 11, 2017, in the total reports on the vehicle troubles reported from the train crews or the passengers collected in the dispatcher office, were as shown in Table 9.

Among these 101 cases, the inspection implemented after stopped the train by the decision of the train crew was only once, there was no case that the dispatcher decided to stop the train based on the status of the abnormal sound and implement inspection. The inspection by the vehicle maintenance staffs boarded on the train were implemented in four cases. Here, the inspections of

the train in the terminal stations or in the train depot were implemented in all cases.

There was no case as generated nasty smell due to abnormal status in the vehicle in the above period. As for the generation of smoke, there was one case that was reported from the inhabitant as it seemed that the smoke had broken out from the underfloor of the vehicle, but it was found that there was no abnormal situation as the result of the inspection.

Table 9. Generated status of abnormal sound reported in Sanyo Shinkansen section

Category	Contents	No. of reports
Abnormal sound	- Sound as "creak" from the doors - Sound as rattling from underfloors - Sound as "bzzt" from ceiling, etc.	101 cases

2.10.2. The Generated Status in the JR Central

According to the JR Central, there were 156 reports on the abnormal sound in Tokaido Shinkansen section from April 1 to December 11, 2017. Among these, 127 reports were the case that the vehicle maintenance staffs of the company boarded on the train and implemented inspections. Here, the inspections were implemented after the trains entered the depot, in all cases.

There was no case of generation of the nasty smell and smoke due to the abnormal situation in the vehicle in the above period.

2.11. Information on the Past Serious Troubles Occurred in Sanyo Shinkansen

2.11.1. The Nasty Smell Generated in the Nozomi 56

Time of occurrence : At about 20:40, Wednesday, March 3, 2010.

Place of occurrence : In the premises of Shin-Kobe station, Sanyo Shinkansen

Concerned train : The inbound 56A train, the Nozomi 56, composed of 16 vehicles of the N700 series, started from Hakata station bound for Tokyo station.

Summary : While the train was running between Nishi-Akashi station and Shin-Kobe station, the conductor was reported from the passenger as "The cabin of the No.12 vehicle was filled by smoke and smelled as something burnt, and heard large sound before arrived at Okayama station". As he checked the situation and confirmed that the smoke was generated in the concerned vehicle, then he guided the passengers to the No.13 vehicle and reported to the dispatcher. After the train had arrived at Shin-Kobe station, the conductor, etc., implemented the underfloor inspection and found that a part of the gear box in the No.12 vehicle was damaged and oil was leaked.

2.11.2. The Abnormal Sound Generated in the Nozomi 31

Time of occurrence : At about 17:11, Wednesday, January 25, 2017.

Place of occurrence : Between Kokura station and Hakata station, Sanyo Shinkansen.

Concerned train : The outbound 31A train, the Nozomi 31, composed of 16 vehicle of the N700 series, started from Tokyo station bound for Hakata station.

Summary : The train driver received the report from the conductor that "I noticed the spark outside vehicle and heard the sound as "clang-clang" from the underfloor when the train entered Fukuoka tunnel", then he took the emergency stop procedure to stop the train. In addition, he noticed the display indicating abnormal situation in the monitor display in the driver's cab until the train came to stop. After that, obeying to the instruction by the dispatcher, the conductor implemented the underfloor inspection and confirmed that there was no abnormal situation, then, the train resumed the operation. After the train had arrived at Hakata station, the vehicle maintenance staffs implemented the underfloor inspection and found the damages of the gear device and the WN coupler in the No.11 vehicle.

2.12. The Other Information

2.12.1. Records in the Bogie Temperature Detecting Device

According to the JR Central, the bogie temperature detecting devices were installed in the up and down tracks in Sakawagawa bridge in Odawara City, Kanagawa Prefecture, and Toyokawa bridge, Toyohashi City, Aichi Prefecture, respectively, in Tokaido Shinkansen section.

The device measured the temperatures of the axle box, the wheels, the gear box and the WN coupling in the bogies of the passing train by the heat detectors installed in the track, and issued the alarm when the measured values, estimated in the data processing device on the ground, were judged as abnormal.

The records measured when the outbound 15A train, operated just before turned back as the concerned train, had passed the places where the bogie temperature detecting devices were installed, were investigated after the occurrence of the concerned serious incident, and it was found that the records of the concerned bogie showed the higher temperatures than as usual although they were lower than the standard value as judged as abnormal.

2.12.2. The Risk Assessment tackled by the JR West

The JR West introduced the risk assessment as the concrete measure in the Fundamental Plan for Safety decided in April, 2008, based on the recognition of the necessity of the stance to implement the prior measures for the safety by shaking off the measures for safety mainly oriented to the measures against the past accident, raising sensitivity for the safety or against the risks, and pursuing higher level safety. The company has been implementing the measures for the safety against the risks to be measured as in high priority, based on the prior estimation on the level of the possibility to cause the accident with casualties of the railway users and the severe industrial accidents for the company staffs.

2.13. Information on the Weather Condition

According to the observed records in the Nagoya District Observatory of the Japan Meteorological Agency, in Nagoya City, located in about 8 km east from the site of the concerned serious incident, the nearest observatory to the concerned serious incident site, it was clear at 21:00,

December 11, 2017.

Here, according to the observed records in the observatories located in the track side between Hakata station and Nagoya station, on the day of the occurrence of the concerned serious incident, the weather conditions observed at the nearest time when the concerned train was running were almost fine although it was a light rain in some places.

3. ANALYSIS

After the analysis on the concerned crack, which was the major factor of the concerned serious incident, was implemented, the analysis on each stage such as the strength design and verification, manufacturing, operated process of the bogie frames was implemented, and the process of the train operation was analyzed from the viewpoint of the prevention of enlarging damages.

3.1. Analysis on the Vehicle

3.1.1. Analysis on the Generation of the Concerned Crack

It is highly probable that the concerned crack had expanded from downward to upward, because the height and the interval of the unevenness of the beach mark pattern observed in the broken surface of the concerned crack became larger toward upward in the side plates and the reinforce plates, as described in 2.4.2.1. In addition, it is highly probable that the concerned crack had expanded from both inside and outside bogie and united at around the center part of the side beam because the beach mark patterns were observed in the broken surface of the center part of the bottom plate of the side beam and the backing metal located in the above.

It is highly probable that the crack was not expanded in a short period because the broken surface in around the slot welded part of the bottom plate of the side beam was smooth as the corrosion and the abrasion due to contact between the broken surfaces were deteriorated compared to the broken surfaces in around the center of the side plate, the reinforce plate and the bottom plate.

Based on the above analyses, it is highly probable that the origin of the concerned crack was in around the back boundary in two slot welded parts in the inside and outside of the bogie where the axle spring seat was attached to the bottom plate of the side beam.

It is probable that the slit in the slot welded part in outside bogie in the rear left of the concerned bogie frame was generated when the welding works was implemented because the slit was generated from around the back boundary toward the bottom plate of the side beam and the slit was generated in the place where affected by the heat due to welding work, and the titanium included in the paint existed in the entire broken surface, based on the observed results of the broken surfaces and cross section of the slot welded part in outside of the bogie in the rear left of the concerned bogie frame, as described in 2.4.2.4.

It is somewhat likely that the slit, generated when the welding works was implemented, existed at the originated point of the concerned crack, because there was a slit considered as generated in the welding works in the slot welded part in outside of the bogie of the rear left of the same bogie

frame, and the unevenness due to being acted by the plastic deformation larger than observed in general fatigue crack was observed in the broken surface in around the slot welded part in inside of the bogie of the concerned crack, as described in 2.4.2.3 (1) (vi).

Here, the unevenness being acted by large plastic deformation as described in 2.4.2.3 (1) (vi), was not observed, but the titanium also included in the paint for the bogie frames was detected in a part of the broken surface of the bottom plate of the side beam in around the slot welded part as described in 2.4.2.1 (6), in the observed results for the cross section of the slot welded part in outside of the bogie of the concerned crack as described in 2.4.2.3 (2).

Therefore, it is probable that the paint had entered in the area, where the titanium was detected in the slit in around the slot welded part in outside of the bogie in the rear left of the concerned bogie frame, when the bogie frame was painted in the concerned bogie maker.

3.1.2. Analysis on the Factors to Generate the Concerned Crack

It is probable that the bottom plate of the axle spring seat in the place where the concerned crack had generated was implemented the overlay welding after annealed, as described in the following paragraph 3.3.4. In addition, it is highly probable that the strength of the concerned side beam had been deteriorated because the thickness of the bottom plate of the side beam in around the concerned axle spring seat was less than the standard value as described in 2.4.2.2.

It is highly probable that the thickness of the bottom plate of the concerned side beam was thinner than the standard value was related to the generation of the concerned crack, in addition to the existence of the residual stress in around the slot welded part due to implement the overlay welding on the bottom plate of the concerned axle spring seat after annealed, based on the followings.

- (1) In the results of the FEM analysis recreated the strains caused by the overlay welding, the high stress status was estimated in around the slot welded part compared to the surroundings, as it is considered that the stress in around the place neighboring the weld bead part become large due to being acted by the deformation of its shape, etc., as described in 2.6.1.1.
- (2) There was the trend to generate the fatigue crack by obviously small number of repetition of loading in the test piece recreating the overlay welding after annealed, compared to the test piece in the normal condition, in the results of the fatigue test using the test piece recreating the overlay welding, as described in 2.6.1.2.
- (3) There was the trend to generate the fatigue crack in slightly small number of repetition of loading when the thickness was insufficient, in the results of the fatigue test using the test piece recreating the overlay welding, etc., as described in 2.6.1.2.

3.1.3. Analysis on the Expansion of the Concerned Crack

3.1.3.1. Transition of Expansion of the Concerned Crack

- (1) The slit was observed in the slot welded part in outside of the bogie of rear left of the concerned bogie frame, and the ratchet mark pattern, usually found in the fatigue crack was found in a part of its tip, as described in 2.4.2.4. Based on these observed results, it is

somewhat likely that the concerned crack generated as originated from the fatigue crack caused by the slit generated in the welding works and expanded.

In addition, the striation pattern was not found in the place where the corrosion and the abrasion due to contact between the broken surfaces each other, had deteriorated to around the R-part, in the broken surface of the side plate, but the striation pattern was found in their upper part to around the tip of the crack, as described in 2.4.2.1(5). Therefore, it is highly probable that the crack expanded to the tip due to the fatigue.

Here, the rusts had generated to about 40 mm in height direction from the bottom surface of the side beam, and there was the metallic gloss without rusts in their upper part, in the broken surface of the crack, as described in 2.4.1 (1). Therefore, it is probable that the crack expanded faster after the crack had expanded to around over 40 mm in height direction from the bottom surface of the side beam.

- (2) It is probable that the expanding speed of the generated crack becomes faster substantially when the bottom plate of the side beam was thin due to being grinded extremely exceeding the standard value, because the simulation for the crack expansion implemented in case of the initial width and the initial depth of the fatigue crack were 15 mm and 1 mm, respectively, showed that the tip of the crack already expanded to the supposed dimension reached to the R-part in about 35 years if the thickness of the bottom plate of the side beam was 7.0 mm, but about 5 years if the thickness of the bottom plate of the side beam was 4.3 mm, as described in 2.6.2.

Based on the above discussion, it is highly probable that the thin bottom plate of the side beam extremely grinded promoted the expanding speed of the crack, and the crack had expanded in the period shorter than the vehicle life, *i.e.*, the usable period of the bogie,

Therefore, it is probable that the bogie frame, which was in the state that the bottom plate of the side beam was thin as being grinded extremely exceeding the standard values in the same type bogie frames as the concerned bogie frame, should be replaced promptly.

3.1.3.2. Time When the Concerned Crack Expanded in the Level as to Affect the Bogie Frame

The records of the wheel loads in the concerned vehicle measured in the latest general inspection implemented before the concerned serious incident was checked, and it was found that the unbalance of the wheel loads in left and right wheels of the concerned vehicle were within the standard value decided in the JR West, as described in 2.5.3.3. In addition, there was no remarkable difference in the thicknesses of the adjusting plates used in each axle spring.

If the crack had expanded in the level as the bogie frame deformed by the weight of the vehicle body due to the decreased rigidity of the side beam by the crack at the time of the general inspection, it is probable that the wheel load would decrease in the concerned part. Therefore, it is probable that the difference will exist such as the increase of thicknesses of the adjusting plates used for the axle spring of the axle box suspension device located in beneath the concerned crack, because it is required to compensate the decreased wheel load to adjust the balance of the wheel loads in this situation.

Therefore, at the time of the latest general inspection implemented before the serious incident, it is somewhat likely that the concerned crack was not expanded in the level to affect the rigidity of the side beam.

In addition, it is probable that the concerned crack expanded in the level to affect the rigidity of the side beam on the previous day of the occurrence of the concerned serious incident, and expanded furthermore in the level to affect the other bogie components such as the WN coupling, etc., as the side beam deformed in the operation on the day of the occurrence of the concerned serious incident, because the diagonal inner pressure differences calculated based on the record in the concerned vehicle were in the status as follows.

- (1) The diagonal inner pressure difference was in the trend to deflect in the plus side a little in the inbound 6A train operated in the previous day of the occurrence of the serious incident, and the trend did not change by the turn-back train, the outbound 33A train.
- (2) The diagonal inner pressure difference increased a little from the inbound 60A train operated in the previous day of the serious incident.
- (3) The diagonal inner pressure difference increased remarkably in the 15A train and the concerned train operated in the day of the occurrence of the serious incident.

3.1.4. Analysis on the Damages in the Bogie Components Except for the Concerned Bogie Frame

According to the analysis on the process of the generation of damages in the bogie components except for the concerned bogie frame described in 2.4.3, it is highly probable that all damages were the secondary damages due to the expansion of the crack previously generated in the concerned bogie frame.

3.1.4.1. The WN Coupling

It is highly probable that the concerned WN coupling had worn abnormally and heated, because the WN coupling had been rotating in the status being deflected as exceeded the designed allowable range, based on the followings.

- (1) It is probable that the 1st axle in the concerned bogie deflected in forward about 34 mm in the maximum dynamically at the position of the wheel while running, based on the traces on the front rim surface of the wheel confirmed in the dismantling investigation implemented after the occurrence of the concerned serious incident, as described in 2.4.3 (3) (iii). As the calculated deflection in the forward direction, as the relative displacement, at the position of the WN coupling was about 24 mm, it is highly probable that the concerned WN coupling had been rotating as being deflected about 24 mm dynamically.
- (2) It is highly probable that the concerned WN coupling had been rotating as being deflected about 18 mm statically, because the distance between the center of the concerned bogie and the center of the left axle box of the 1st axle, measured when the concerned train was in the halted status at Nagoya station was 30 mm longer than as usual, then the forward deflection of the WN coupling calculated based on the measured value was about 18 mm, as described in 2.4.1 (3).

(3) The designed allowable relative displacement of the WN coupling was about 10 mm, as described in 2.3.2.

Therefore, it is highly probable that the abnormal sound was generated from the concerned WN coupling. It is probable that the normal contacting status of the teeth surface were transferred to the abnormal status in relatively short time, based on the shape of the worn surface of the inner gear teeth, as shown in Attached Figure 4 and description in 2.4.3 (1) (iv).

In addition, it is highly probable that the smoke had generated from the heated grease for lubricating inside of the WN coupling, based on the followings.

(1) It is probable that the discoloration to blue found in the surface of the outer pipe of the concerned WN coupling, etc., was the temper color caused by the thin oxidized skin formed on the surface of steel material when it was heated in atmosphere, and it is highly probable that the steel material had become as high as about 300 °C, based on the tone of the temper color, as described in 2.4.3 (1) (i).

(2) The smoke was generated when the grease in the WN coupling was heated to 300 °C, as described in 2.4.3 (1).

It is highly probable that the O-ring made of rubber, which was preventing leakage of grease, melted by the heat and the grease leaked to outside of the WN coupling, and scattered to the traction motor, surface of the gear box, the bottom surface of the vehicle body, etc., because the O-ring was lost and there was the linear trace colored black as rubber, in the groove for keeping the O-ring and the opposing flat surface, as described in 2.4.3 (1) (iii). It is probable that the WN coupling had been heated to the level that grease had leaked to outside of the WN coupling just after the concerned train departed from Hakata station, based on the situation of the nasty smell, etc., in the cabins as described in 2.8.3.

It is probable that the nasty smell and the haze in the cabins of the concerned train were caused by the grease leaked from the concerned WN coupling, and diffused in the cabins of the concerned vehicle and its rear vehicles in the running train, because the air conditioning device mounted on the underfloor of each vehicle had been inhaled the open air from around the center of the underfloor for ventilation of the cabin, as described in 2.7.1. *[Refer to Figure 13]*

In addition, there were the traces as the inner gear and the oil thrower had contacted each other, the deformation of the oil thrower, and the weakened fastening torques in some bolts fixing the oil thrower, in the WN coupling, as described in 2.4.3 (1) (ii).

It is probable that the fastening torque of the bolt had weakened because the oil thrower had deformed due to being contacted with the inner gear and the screw of the bolts had deformed, as the axle box deflected to forward direction due to the strong tensile load acted on the WN coupling and caused the following situations.

(1) The shaft of the WN coupling had displaced and been stretched in the direction of the shaft.

(2) The relative displacement between the traction motor and the gear device had increased.

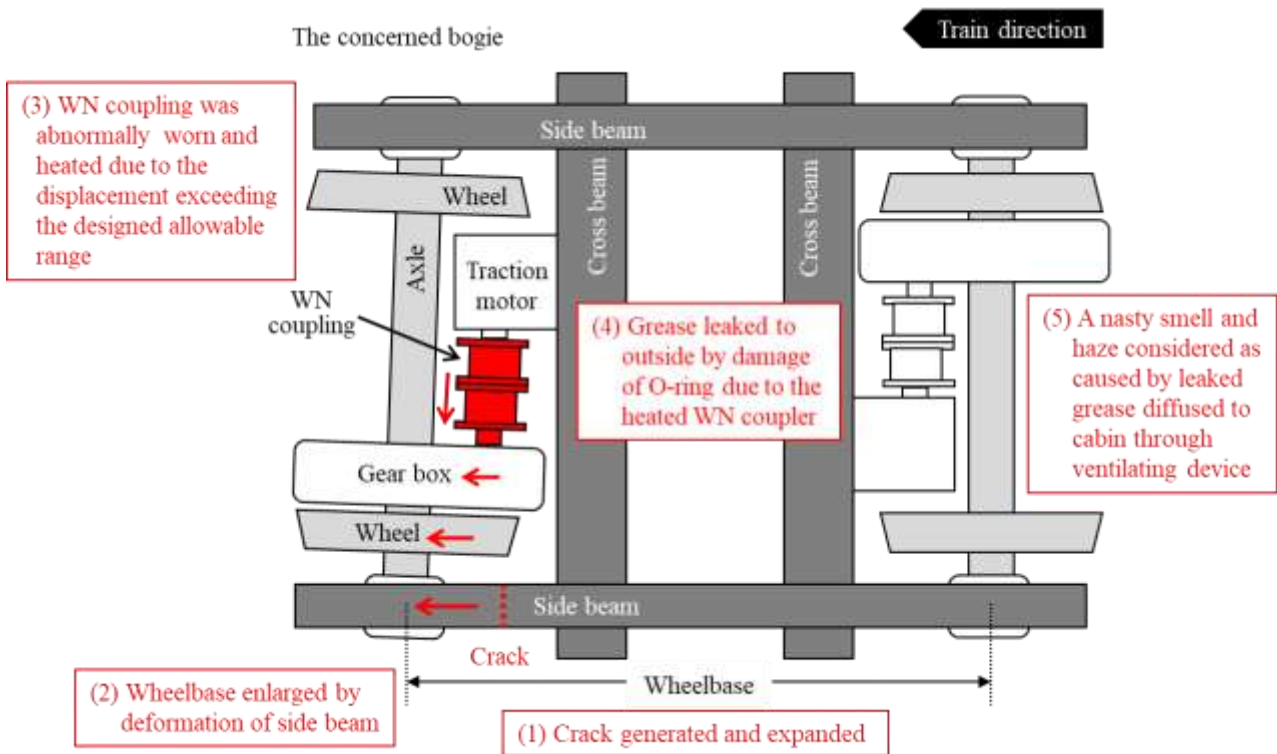


Figure 13. Process to generate the abnormal sound and the nasty smell, etc.

3.1.4.2. The Wheels

It is probable that the remarkable abrasion, observed in the flange of the right wheel in the 1st axle of the concerned bogie, was generated because the flange of right wheel continued running as being shifted to right and contacted with rail due to the attack angle^{*43} of the 1st axle against right rail, based on the followings.

- (1) The displacement of the left edge of the 1st axle was about 41 mm dynamically, based on the calculation in the assumption that the 1st axle moved as to rotate around the right bearing of the 1st axle as rotating center, and based on the displacement of the front rim surface of the left wheel of the 1st axle, *i.e.*, about 34 mm, described in 2.4.3 (3) (iii).
- (2) The position of the left axle box of the 1st axle was displaced about 30 mm statically in forward direction as described in 2.4.1 (3).

It is somewhat likely that the wheel was in the heated status at the time of the inspection of the vehicle implemented at Nagoya station because the vehicle had been running in the status that the 1st axle had the attack angle against the right rail as described in 2.8.3 (11).

Here, the right wheel of the 2nd axle had relatively worn compared to the other wheel, as described in 2.4.3 (3) (i). Therefore, it is probable that the flange of the right wheel of the 2nd axle descended and had been running as being contacted with the left rail of the running direction of the outbound 15A train, that became to the concerned train after turned back, because the 1st axle of the concerned bogie descended and shifted to right of the running direction of the outbound 15A train and let the concerned bogie in the turned status as the rear axle.

^{*43} "Attack angle" is the relative angle between wheel and rail while the wheel is rolling on the rail.

3.1.4.3. The Wheel Tread Cleaning Device for the Left Wheel of the 1st Axle

There was the fretting trace in the rack shaped components equipped to inside of the wheel tread cleaning device as described in 2.4.3 (4). It is highly probable that the fretting trace was caused by the large forces acted repeatedly, to the rack shaped components, etc., as the rack shaped component in the tread cleaning device had sent out widely and put back forcibly by the wheel, because the wheel tread had displaced due to the static and dynamic displacement of the position of the axle box of the concerned bogie, as described in 3.1.4.2.

3.2. Analysis on the Strength Design and Verification of the Bogie Frame

3.2.1. Analysis on the Strength Design

It is probable that the design and verification to prevent the fatigue damages for the strength of the concerned welded part had been implemented in the estimation of the strength in the strength design of the same type bogies as the concerned bogie, based on the followings.

- (1) The calculated stress obtained by the FEM analysis and the measured stress obtained by implementing the static load test prescribed in the JIS E 4208, were estimated by the method prescribed in the JIS E 4207, as described in 2.5.1 (1)
- (2) The actual stress obtained by implementing the running test using the commercial vehicles in Tokaido and Sanyo Sinkasen sections, were estimated by the method prescribed in the JIS E 4207, as described in 2.5.1 (2).
- (3) It was confirmed that the crack was not generated by the magnetic particle test implemented after the fatigue test loading the vertical vibration of the traction motor and the caliper corresponded to the 9,000,000 km running, in addition to the vertical load corresponded to the same running distance, based on the actual stress obtained in the running test using commercial vehicles, as described in 2.5.1 (3).
- (4) The results of confirmation on the fatigue life of the slot welded part based on the stress measured in the running test using the mass produced N700A vehicles, showed that the fatigue life remarkably exceeded the vehicle life, *i.e.*, the usable period of the bogie, even if the vehicles were supposed to be operated in the condition as being always loaded by the passenger capacity, as described in 2.5.1.

3.2.2. Analysis on the FEM Analysis

As described in 3.2.1, it is probable that the design and the verification for the strength of the concerned welded part had been implemented so as not to be broken by fatigue. However, it is probable that the studies on the following matters are required to improve further safety in the designing of the bogie frame using the FEM analysis and the evaluation of the tests referring the results of the FEM analysis, etc.

3.2.2.1. Modeling of the Bogie Frame

In the model when designed, the area, where the axle spring seat was attached to the bottom plate of the side beam, was treated as the 23 mm thick plate that simulated as the summation of

the designed thickness 8 mm of the bottom plate of the side beam and the designed thickness 15 mm of the axle spring seat. The calculated results using this model showed that the large stress was not generated in the position corresponded to the concerned slot welded part, in the loading conditions supposing the vertical, lateral and front/rear directions generated in the running train, as described in 2.5.1.1.

However, in the simulation, implemented after the occurrence of the concerned serious incident to estimate the expanding process of the fatigue crack, the slot welded part composed of the axle spring seat and the neighboring side beam were welded each other, was modeled as the structure that the two plates were fixed in the slot welded part same as the actual bogies using the three dimensional elements, *i.e.*, solid elements. The results obtained from the calculation using this model showed that the stress larger than in the surroundings was generated as concentrated at the back boundary in the slot welded part.

The structure of the concerned welded part of the actual side beam was that the bottom plate and the axle spring seat were piled up and jointed. Usually, the side beam deformed as bent being acted by the vertical load mainly, and its bottom plate stretched microscopically being acted by the tensile force, on the contrary, the tensile force did not act to the axle spring seat. Furthermore, as the designed thickness of the bottom plate was 8 mm and the designed thickness of the axle spring seat was 15 mm, then, the magnitudes of deformation, *i.e.*, the rigidity, when being acted by the load were also different. It is probable that the large stress compared to the surrounding area would generate in the vicinity of the welded part due to the structural characteristics that two plates of the different rigidities and the different loaded weights were locally jointed by the slot welding.

Generally, the errors in the calculated results against the actual values became large, in the strength analysis using the FEM analysis, in the part where the variables changed significantly, such as the modeled shape for the back boundary of the concerned slot welding part. Therefore, the values of the calculated stress in such part was improper to be used for evaluation comparing to the allowable values, but it is useful to comprehend the qualitative trends of the part where large stress had generated based on the exact understanding on the characteristics of the FEM analysis.

3.2.2.2. Modelling of the Axle Box Suspension Device

The model of the axle box suspension device, used in the strength analysis in the designing stage was checked, and found the situation that the position, supporting the horizontal forces supposing the loads in lateral and front/rear directions generated in the running vehicles, was different from the actual device, as described in 2.5.1.2.

It is desirable to adopt the constraint condition recreated the actual situation as far as possible because it is probable that the calculated stresses, etc., may different from the actual ones in some degree, as there are the cases that the repulsive forces and the moment acting on the materials generated in the supported position differ with the actual values, if the constraint condition was different from actual value, in the strength analysis using the FEM analysis, in general.

3.2.2.3. The Importance to Comprehend the Trends of the Generation of Large Stress

Based on the situation described in 3.2.2.1 and 3.2.2.2, when the stress distribution in the bogie frame that adopted the new structures are studied by the FEM analysis, in order to comprehend the stress expressed the actual situation more accurately, it is desirable to pay attention for the importance to recreate the characteristics of the structures such as to joint locally the plates with the different rigidities and the constraint conditions such as the positions suspending the load weights, etc., as far as possible, in the calculation model. In addition, it is desirable to comprehend the trends of the places where the large stress had generated based on the results of the analysis, considering the inherent properties of the calculation errors in the FEM analysis.

It is desirable to reconfirm whether the characteristics of the structures such that the plates of the different rigidities were jointed locally, and the constraint conditions such as the positions suspending the loads, etc., were recreated as far as possible, in the calculation model used in the strength design of the bogie frame, and, it is desirable to comprehend again the trends of the place where large stress is generated by revising the calculation model, even in the existing bogie frame, if it is required.

Here, when measuring the stress using the strain gauges in the static load test using the actual structures such as the bogie frame, etc., in the running test using the commercial vehicles and in the fatigue test, the measurements were implemented in the following method. These are, implement the FEM analysis before the testing to predict the magnitude and direction of the stress and designated the positions where the strain gauges should be pasted, then paste the strain gauges and confirm the values of the measured stress. In addition, if the strain gauge cannot be pasted to the designated position such as around the welded part where considered as the originated place of the concerned crack, there was the method indicated as the sample of the evaluation prescribed in the annex of the JIS E 4207. In any case, the proper selection of the measuring points will result to secure the validity of the evaluation.

Therefore, it is important to comprehend the trends of the position where large stress was generated using the proper calculation models, even in the implementation of the proper evaluation by the test using the actual objects, etc.

3.3. Analysis on the Manufacturing of the Concerned Bogie Frame

3.3.1. Analysis on the Pressed Materials for the Side Beam

It is highly probable that there was no problem in the strength of the pressed material for the side beam and there was no defects such as the press flaw, etc., and no abnormal size in the completed status of the pressed material for the side beam used in the concerned side beam, based on the followings.

- (1) As described in 2.5.2.1 (1), the chemical ingredients and the tensile strength of the material were investigated by cutting off the test piece from a part of the concerned bogie frame after the occurrence of the concerned serious incident, and it was found that they were within the standard values, *i.e.*, the JIS standards, required to the materials prescribed in the drawings.

- (2) As described in 2.5.2.1 (3), according to the new cooperating company who manufactured the pressed material for the side beam, the sampling test had been implemented for the pressed material for the side beam after implemented the bend machining. There was no abnormal situation in the inspection records of the pressed material for the side beam in the same lot as the concerned side beam, as there was no record of the press flaw and sizes including the size of the opening of the upper and bottom plates of the U-shape side beam, were within the tolerance prescribed in the drawings of the vehicle maker.
- (3) As described in 2.5.2.1 (3) (ii), the size correcting work using the small press machine was implemented, as measuring the sizes of the pressed material for the side beam, for all products including the products without the inspected records. Therefore, it is probable that the work in the same level had been also implemented when the pressed material for the concerned side beam was bend machined.

3.3.2. Analysis on the Assembling Work of the Side Beam and the Axle Spring Seat

As described in 2.4.2.2, the thickness of the side beam was prescribed as to use the steel plate of the nominal thickness 8 mm, and the thickness after bent by machining should be 7 mm and above. However, the measured thickness of the bottom plate of the side beam at the broken surface of the concerned crack was 4.7 mm at the thinnest place. Thus, it is highly probable that the thickness of the bottom plate of the side beam was reduced because the bottom plate of the side beam was grinded to fit the axle spring seat to the concerned side beam, considering the following situation in the works to attach the axle spring seat to the side beam.

- (1) As described in 2.5.2.2 (2) (ii), the bottom plate of the side beam was swelled as folded and the upper surface of the axle spring seat was flat, then, there was the gap and in the rattling situation when assembled each other.
- (2) As described in 2.5.2.2 (2) (iii), when the on-site manager had engaged in the assembling works of the side beam of the bogie frame for the former 700 series vehicles, as the assembling worker, there was a little rattled situation and the rattled status had corrected by grinding the bottom plate of the side beam using the grinder. Based on this experience, the on-site manager considered that the rattling level in the bogie frame of the N700 series mass produced vehicle was in the same level, and instructed to fit by grinding the part of the bottom plate of the side beam contacting with the axle spring seat until the rattling situation was corrected, without confirming the actual object by himself.
- (3) As described in 2.5.2.2 (2) (vi) to (ix), there was the instruction prescribed that the gap between the bottom plate of the side beam and the axle spring seat of the side beam should be "less than 0.5 mm as the target value, but permitted as 1 mm in the maximum", in the files at the time of manufacturing bogie frames of the past Shinkansen 300 series vehicles, and it was prescribed in the instruction that "the grinder finishing of the bottom plate of the side beam should not be implemented". When the on-site manager confirmed the instruction sheet for the gap management for N700 series vehicle issued by correcting the above instruction, he focused that the instruction had relaxed from "less than 0.5 mm" to "0.5 mm as the target",

and instructed the concerned worker to implement the fitting by grinding works until the gap width became in the level whether the 0.5 mm thick metal scale could be inserted or not, and this instruction was communicated to the other assembling workers.

- (4) As described in 2.5.2.2 (2) (viii) and (ix), the instruction sheet was distributed up to the on-site managers, and the assembling workers were transmitted only to implement the fitting by grinding works so as to set the gap to the level that the 0.5 mm thick metal scale could be inserted or not, and the prescribed contents as "the grinder finishing should not be implemented in the bottom plate of the side beam" was not transmitted.
- (5) As described in 2.5.2.2 (2) (xi), the allowable amount to be grinded by the grinder in the direction of the thickness of the base material was prescribed in the working standards of the company. The limited grinding depth was prescribed in the company's standard as 0.5 mm for the grinder finishing in the weld bead edge of the butt-welded part, but it had not been made well known particularly in the education, etc., of the company. Then, the on-site manager understood that grinding could be implemented up to 0.5 mm in depth regardless of the finishing work for the weld bead, based on the education, etc., by the more experienced coworkers, and the assembling workers did not care about the limit of the amount to be grinded.

In addition, it is probable that the swell as folded in the bottom plate of the side beam, which caused to implement the fitting by grinding work, was caused by the slanted upper and bottom plates of the side beam as the process to remove strain had not been implemented, in addition, the correction of the joint stagger, etc., had not been implemented in the hold welding work, when the concerned side beam was manufactured, based on the followings.

- (1) As described in 2.5.2.2 (2) (xii), the correction of the joint stagger was not implemented in the hold welding works, and the correction of accuracy of the right angle of the pressed material for the side beam when the reinforce plates were attached, at the time of manufacturing the concerned side beam.
- (2) As described in 2.5.2.5, the works, in the process from the delivery of the pressed materials for the side beam to the concerned bogie maker to the work to attach the axle spring seat by welding, were implemented as measuring sizes including the level of the opening between the upper and the bottom plates of the side beam for the bogie frame manufactured for the use of replacement, after the occurrence of the concerned serious incident, then, the slight strain had generated in the welding works of the reinforce plates, etc. Therefore, it was required to implement correction by removing the strain in each stage after welding work because these strains caused the slant in the upper and the bottom plates of the side beam.

Here, as described in 2.5.2.1 (2), the bend machining of the pressed material for the side beam used in the bogie frame for the N700 series mass produced vehicles, had changed from the hot press method, that had been used in the bogie frames of the 700 series vehicles, to the cold press method. Generally, it is probable that the bend machining by the cold press method was implemented in the status of the high yield point^{*44} of the material, and caused the high tensile strength compared to the hot press method. Then, it is probable that the inner residual stress after the bend machining implemented by the cold press method was larger than that by the hot press

machining. In case of the concerned side beam, it is somewhat likely that the machining works considering the amount of the stress generated by the changed status of the residual stresses was insufficient in the process to remove the part where the residual stress had generated in the machining of the groove for the hold welding after removed surplus part such as the both edges of the material and the tips of the plates to become the upper and the bottom plates, from the pressed material for the side beam, and the process being acted by the heat of welding such as the welding of the inner reinforce plates.

Thus, it is probable that the swell in the bottom plate of the concerned side beam was large when the concerned side beam was bend machined in the cold press method, and it is probable that the thickness of the bottom plate of the side beam was reduced significantly as being grinded too much in the grinding works to make the swelled part flat when attached the axle spring seat.

Generally, the thickness of the plates was determined by implementing the strength design to correspond the sufficient strength required to suspend the large loads being acted while the vehicles are running, in the major parts of the vehicle bogies. Then, the works, that may cause to reduce the designed strength of the parts such as to reduce the thickness of the plate considerably, should not be implemented, in the parts except for the part where the removal machining process in the succeeding machining process was scheduled or the part instructed as to be finished by grinding works in the design.

It is required for the concerned bogie maker to let well known the staffs engaged in the related works about these information, and to implement the manufacturing management thoroughly to ensure the manufacturing process not to reduce the strength of the components to secure the designed strength.

Here, as described in 2.5.2.2 (2) (xii), the welding works for all side beams had finished when started the work to attach the axle spring seat, furthermore, it was in the situation difficult to implement the correcting works of the swells by the method such as the removal of the strain, etc., in this stage, related with the existence of the vertical reinforce plates in inside of the side beam. Therefore, it is probable that these situations were the background to implement measures by grinding the bottom plate of the side beam.

In addition, as described in 2.5.2.2 (2) (xii), in the succeeding lots, the measures such as the method to set the axle spring seat to the side beam by pushing using the press machine when attached the axle spring seat temporary, the method to correct the joint stagger by the press machine in the hold welding process, the method to correct by the press machine when attached the inner reinforce plates for the side beam in the process prior to the hold welding, etc., were implemented and the amount to be grinded was reduced, but the finishing works by grinding were still implemented. Then, it is probable that the investigation of the causes on the situation that the swell had generated in the bottom plate of the side beam and the fundamental measures were not implemented at that time.

When the concerned side beam was manufactured, as the upstream manufacturing process were reviewed, the situation was already in the status as the correcting works could not be implemented because the manufacturing process had already been advanced. Then, in order to prevent these

situations, it is required for the concerned bogie maker, to implement the fundamental measures by investigating the causes, based on the confirmation on the existence of problems in the manufacturing process in the trial product and the first product of the lot, and investigate back to the prior process if there is the problem, in the manufacturing works for the following products.

- The product manufactured in the first time,
- The product having some changes compared to the past products,
- The product manufactured after the long blank time from the previous manufacturing.

In addition, it is desirable to consider the manufacturing schedule having margins for the first product in the lot to enable to implement above measures.

**44 "Yield point" is the amplitude of the force, when the object being acted by the increasing force, rapidly deformed as exceeded the limit of plasticity and never restored to the original shape.*

3.3.3. Analysis on the Slot Welding

As described in 2.5.2.3, the microscopic incomplete penetrations were observed in some test pieces, where the finish welding was implemented after welded temporarily obeying to the guideline for implementing welding work at that time, in the results of the welding test simulated the slot welded part implemented after the occurrence of the concerned serious incident. However, it could not be determined that the temporary welding had affected to the incomplete penetration observed in around the concerned crack, because the shape and the size of the cross section of the incomplete penetration were different from that observed in the neighborhood of the originated point of the crack in the concerned slot welded part described in 2.4.2.3 (1) (iv).

It is probable that the incomplete penetration observed in the cross section of the slot welded part of the concerned crack was large as the incomplete penetration. In order to improve quality of the welding, it is desirable to implement the following matters before start welding works of the products.

- (1) To comprehend the proper guideline for implementing welding works, after implemented the welding test using test pieces.
- (2) To implement the training, etc., continuously in order to enable the workers to implement the welding work obeying the proper guideline for implementing welding works.

3.3.4. Analysis on the Overlay Welding

It is probable that the bottom plate of the concerned axle spring seat, in the place where the concerned crack had generated, was implemented the overlay welding after annealed, based on the following matters, as described in 2.4.2.5.

- (1) The stiffness in the part of the aspect different from the material of the axle spring seat was the same level as in the place of the welded material in the test piece recreated the status that had not been annealed after welded.
- (2) The annealing of the entire bogie frame had been implemented.

It could not be determined why the overlay welding was implemented because the information, that someone remembered to implement the overlay welding in the entire bottom plate of the axle

spring seat, could not be obtained in the hearing investigation implemented for the workers engaged in the welding works and the machining process of the bogie frames when the concerned bogie frame was manufactured in the concerned bogie maker, as described in 2.5.2.4.

However, it is somewhat likely that, as some abnormal situation had occurred in the machining process of the bottom surface of the axle spring seat, that was the first machining work for the bogie frame after annealed, the concerned axle spring seat and the axle spring seat in the bogie edge side were machined by about 5 mm, excessively, then, the machining was suspended, and the overlay welding to correct the exceeded machining was implemented, and the machining works was implemented again to correct the dimensions to the normal values, based on the followings.

- (1) As described in 2.4.2.5, the designed thickness in around the concerned part of the base material for the axle spring seat was 20 mm.
- (2) As described in 2.4.2.5, the thickness of the cross section of the axle spring seat after implemented the machining process for the bottom surface of the axle spring seat was about 20 mm, which was the same level as the thickness of the base material for the axle spring seat even though the bottom surface of the axle spring seat had been machined.
- (3) As described in 2.4.2.5, the aspects different from the material for the axle spring seat were found in only two axle spring seats in beneath the place where the concerned crack was originated and in its bogie edge side, among eight axle spring seats equipped in the concerned bogie frame.
- (4) As described in 2.5.2.4, the machining process were implemented to start from the bottom plate of the axle spring seat in the bogie edge side of the concerned axle spring seat, then implemented the bottom plate of the concerned axle spring seat, in turns, in the concerned bogie maker.
- (5) It is difficult to consider as possible that the welded material could penetrate 5 mm in depth form the surface of the base material in the usual welding work.

Based on these situations, the concerned bogie maker is required to implement measures not to implement the works to generate the residual stress by the large heat input in the bogie frame after annealed, such as the overlay welding in wide area, in order not to shorten the life of the bogie frame until to generate fatigue crack in the bogie frame by the residual stress due to the welding works.

It is required to let the workers, engaged in the manufacturing works of the bogie frame including the welding works, well known by the education in the company, etc., about that the bogie frame after annealed should not be implemented the works accompanying large heat input again, except for the works that could be implement by the small heat input such as the welding of small parts inevitable in the manufacturing process.

3.3.5. The Desirable System to Manufacture the Sound Bogie Frames

As described in 2.5.2.1 (2), the concerned bogie maker had been held the meeting to possess information jointly on the outline of the specifications, the changed points, etc., and the quality of the products, before starting the manufacturing works, however, the information on the change of

the outsourced company and the machining method of the pressed material of the side beam, were not well known in the related sections in the company, and the effects by these changes, etc., were not studied.

In addition, it is probable that the speed of the crack expansion when the fatigue crack had generated was increased, because the life until to the generation of the fatigue crack was shortened by the reduced strength of the material due to the thin thickness of the bottom plate of the side beam, and by the residual stress due to being overlay welded, as the results of the measures against the problems in the manufacturing site as follows.

- (1) As described in 3.3.2, the fitting work by grinding swelled part of the bottom plate of the side beam was implemented to measure against the situation that the bottom surface of the side beam had been swelled as folded and in the situation as rattling when the axle spring seat was assembled.
- (2) As described in 3.3.4, the overlay welding to the bottom surface of the axle spring seat was implemented, to measure some abnormal situation in the process after the bogie frame was annealed.

Based on these situations, the concerned bogie maker should study the risks considered as to be generated accompanied with the changes from the existing products, etc., in cooperation with the sections concerned before to start manufacturing, and should evaluate the effects by the problem and the counter measures to the safety of the bogie frame as the action of the organization, when the problems as the hindrance or the difficulties, etc., in the manufacturing process, which required the measures accompanied by the machining, etc., of the material, had occurred in the manufacturing site of the bogie frame, after started manufacturing process.

In addition, at the same time, when the problems occurred in the manufacturing site and the counter measures were considered as to affect the safety of the bogie frame, it is required to suspend the works and implement steadily the methods to measure the problems as to investigate the causes considering the processes back to the manufacturing process or the design stage, and to study the countermeasures, then resume the works after confirmed the effectiveness of the implemented results of the measures.

It is necessary to establish the system to implement steadily the measures as the system which only the sound products have been supplied to the actual use.

3.4. Analysis on the Inspection of the Concerned Bogie Frame

There was no record indicating the existence of the abnormal situation in the concerned bogie frame in the latest periodic inspections implemented before the concerned serious incident.

As described in 2.5.3.1, the inspection method and the place to be inspected by the flaw detection for the bogie frame were designated based on the past data of the crack generation, etc., and the place where the concerned crack had generated was not designated as the place to be detected by the flaw detection because there was no precedent of crack generation.

It is somewhat likely that the concerned crack was not opened at the time of the general inspection, because the bogie frame was in the no load status as separated from the vehicle body in the general

inspection, even if the concerned crack had reached to the side plate of the side beam at that time, and there was no abnormal situation in the size inspection for the bogie frame separated from vehicle body, as described in 2.5.3.2.

It is desirable to study to add the designating places to be inspected by the flaw detection based on the safety ratio for the welded joint, etc., comprehending the trends of generation of large stress even in the place where crack was not generated in the past as same as the concerned serious incident.

In addition, as described in 2.6.2, in the same type bogies as the concerned bogie, it is probable that the time required for the fatigue crack to expand and bore through the bottom plate of the side beam was considered as longer than the life time of the vehicle, *i.e.*, the usable period of the bogie, even if the fatigue crack had generated in the area of the bottom plate of the side beam invisible from outside due to the welded axle spring seat, when the thickness of the bottom plate of the side beam was just the designed value. However, it is required to comprehend the expanding status of the inner defects by the ultrasonic flaw detection, etc., in proper frequency in order to find the crack in the area invisible from the outside, because it is probable that the expanding speed of the crack will become faster after the fatigue crack had expanded to the area where the inspection by the magnetic particle test or the penetrate test can be applied, *i.e.*, the area visible from the outside.

Based on the above discussions, it is desirable to implement the ultrasonic testing, etc., in proper frequency for the bogie frame which have the place where there is the trend to generate large stress in the place invisible from outside by the other components, *i.e.*, the place where the magnetic particle test or the penetrate test could not be implemented, even if the crack had expanded and bored through the material as same as the concerned bogie frame.

3.5. Analysis on the Process of the Train Operation

3.5.1. Analysis on the Comprehension and Judgment of the Abnormal Situation by the Dispatchers

The cabin attendant A noticed the abnormal sound in around the concerned deck from just after the concerned train departed from Hakata station as described in 2.8.3 (1), and the purser also felt the abnormal sound in the concerned vehicle and the nasty smell in the 8th vehicle after the concerned train departed from Kokura station. Then, it is probable that the abnormal situation accompanied with the abnormal sound and the nasty smell had been generated in the bogie, just after the concerned train departed from Hakata station.

It is highly probable that the concerned crack had expanded and the damages of the WN coupling had deteriorated in the bogie of the concerned vehicle, based on the followings.

- (1) The cabin attendant A thought that the status of the sound heard in around the concerned deck while the train was running between Hiroshima station and Fukuyama station was the same level as the sound heard while the train was running between Hakata station and Kokura station, as described in 2.8.3 (3), but he felt that the sound heard while the train was running between Fukuyama station and Okayama station became larger than the sound heard while the train was running between Hakata station and Kokura station, as described in 2.8.3 (4).
- (2) The diagonal inner pressure difference of the air springs in the concerned vehicle were in the trend to increase in the operation of the concerned train between the departure from Hakata

station and the arrival at Nagoya station, as described in 2.7.2.

In these situations, the dispatchers had been collected information on the abnormal status of the concerned vehicle, but they could not conclude to judge the necessity to stop the train in early stage and to inspect the vehicle. The analyses on these situations were as follows.

3.5.1.1. Discontinuous Generation of Abnormal Sound, Nasty Smell, etc.

As described in 2.8.3, the status of the abnormal sound and the nasty smell in the concerned train were reported from the conductor and the vehicle maintenance staff to the dispatcher, then, it is highly probable that the information on the status of the site were jointly possessed in the concerned staffs.

However, when the conductor A arrived at the concerned deck to confirm the abnormal sound, he could not noticed the abnormal sound because the concerned train was decelerating to approach Kokura station, as described in 2.8.3 (1), and he did not worry about the abnormal sound when checked the situation due to being reported after the concerned train departed from Hiroshima station, also did not felt the nasty smell, then he reported the dispatcher that the nasty smell in the cabin were vanished, as described in 2.8.3 (3). Thus, the abnormal sound and the nasty smell were generated discontinuously as sometimes generated and sometime vanished. It is probable that these situations were related with that the dispatcher could not judge as there was the hindrance for the operation of the concerned train in early stage.

3.5.1.2. Lack of the Definite Information on the Importance of the Abnormal Situation

The vehicle maintenance staff who got on the concerned train at Okayama station, reported to the dispatcher about the status of the abnormal sound in around the concerned deck. However, the dispatcher was not in the status as to obtain the definite information to understand the importance of the abnormal situation generating in the bogie of the concerned vehicle, because of the followings.

- (1) As described in 2.8.3 (6), when the dispatcher asked about the existence of the hindrance in the train operation, the vehicle maintenance staff replied as "I think it is not in such situation". Then the dispatcher thought that there was no hindrance in the train operation, although there was the sound from the underfloors.
- (2) As described in 2.8.3 (6), there was no indication to show the existence of the abnormal situation in the monitor device in the driver's desk of the concerned train.
- (3) As described in 2.10.1, there was only one case to stop the running train due to generation of the abnormal sound, and there was no incident due to the nasty smell or the smoke caused by the abnormal situation in the vehicle, from April, 2017 to the occurrence of the concerned serious incident.

It is probable that the dispatcher did not conclude to judge that there was the hindrance in the operation of the concerned train in early stage, related with the above situation.

3.5.1.3. Difference in Recognition on the Implementation of the Underfloor Inspection Between

Dispatcher and Vehicle Maintenance Staff

The vehicle maintenance staff understood that the dispatcher had been arranging the implementation of the underfloor inspection of the concerned train based on the followings.

- (1) The vehicle maintenance staff stated that he would like to inspect the underfloor of the vehicle as his own opinion, as described in 2.8.3 (6).
- (2) The vehicle maintenance staff recognized that the judgement to implement the underfloor inspection for the vehicle was entrusted to the dispatcher, as described in 2.8.3 (8).

On the other hand, the dispatcher once received the report from the vehicle maintenance staff offering to implement underfloor inspection, but the dispatcher understood as follows.

- (1) When the dispatcher asked about the existence of the hindrance in the train operation, the vehicle maintenance staff replied that "I think it is not in such situation", as described in 2.8.3 (6).
- (2) Although there was the talk on the underfloor inspection, the dispatcher thought that the vehicle maintenance staff would implement the measure to open motor circuit in the concerned vehicle instead of the underfloor inspection, as described in 2.8.3 (6).
- (3) The dispatcher considered that the vehicle maintenance staff would clearly request to implement underfloor inspection, if it is necessary, as described in 2.8.3 (6) and 2.8.3 (8).

Thus, there was the difference in the recognition for the necessity of the underfloor inspection of the vehicle between the dispatcher and the vehicle maintenance staff. It is probable that the dispatcher did not conclude to instruct the underfloor inspection related with these situations.

In addition, as described in 2.8.3 (6), the operation dispatcher B could not catch the report from the vehicle maintenance staff as "Shall we inspect the underfloor of the vehicle at Shin-Osaka station to secure safety?", because he had been responding to the inquiry from the other dispatcher on the situation at that moment, being took off the receiver of the telephone from his ears. It is probable that the difference in the recognitions for the necessity of the underfloor inspection existed between the dispatcher and the vehicle maintenance staff did not clear and continued afterwards, related with the above situations.

3.5.1.4. Interdependence Between Dispatcher and Vehicle Maintenance Staff

It is probable that the dispatcher and the vehicle maintenance staff had the side of the characters to depend on their opponents each other for the judgement of the continuation of the train operation, as both of the dispatcher and the vehicle maintenance staff thought that their opponent would communicate to stop the train clearly if it is required actually, based on the followings as described in 2.8.3 (8).

- (1) The dispatcher considered that the vehicle maintenance staffs would communicate that there was the hindrance in train running if it was dangerous actually, because they were the professional engineers about vehicles.
- (2) The vehicle maintenance staff understood that the judgement to implement the underfloor inspection for the vehicle had been entrusted to the dispatcher.

3.5.1.5. The Expression Leading as if the Continuous Operation was the Premise in the Conversation Between Dispatcher and Vehicle Maintenance Staff

When the dispatcher asked the vehicle maintenance staff, he talked in the leading expression as if the continuation of the train operation was the premise as "Is it all right to consider that there is no problem in train running?" and "Didn't you feel that there is a hindrance in the train running?", as described in 2.8.3 (6) and 2.8.3 (8). It is probable that the above situation had a side to affect the vehicle maintenance staff mentally to hesitate the severe report.

It is somewhat likely that the discussion was not oriented toward to stop the train and implement inspection, affected by the leading expression in the communication between the dispatcher and the vehicle maintenance staff in the situation, that the vehicle maintenance staffs at the site were also in the status that the definite information on the existence of the hindrance for train running were not obtained, in addition to the difference in the recognitions between the dispatcher and the vehicle maintenance staff described in 3.5.1.3, and the interdependence described in 3.5.1.4. Thus, it is somewhat likely that the judgment of the necessity to stop the train in early stage and implement the underfloor inspection for the concerned vehicle, was not concluded related with the above situations.

3.5.1.6. The Psychological Trends of the Human Beings

The human beings have the psychological trends named as "the normal bias" to act to maintain calmness by judging as within the normal situation even when faced to the abnormal situation^{*45}. Also, human beings have the psychological trends named as "the positive proof bias" to choose and consider as the most important information that support their wishes or beliefs, but slight and exclude the information against them^{*46}. It is somewhat likely that the judgement of the existence of the hindrance to the train running was not concluded because these psychological trends had acted under consciousness of the staffs concerned as the background, in the concerned serious incident.

For example, it is somewhat likely that the train crews and the vehicle maintenance staffs were acted by the mentality that it would not become severe under consciousness, because the direct and easy understanding information that the serious crisis had been approaching did not exist visibly. In addition, it is somewhat likely that the operation dispatcher asked the vehicle maintenance staff in the leading expression being acted by the mentality that it would not disturb the train operation, under consciousness. It is somewhat likely that the abnormal sound and the nasty smell were not considered to relate the serious crisis due to these psychological activities, and it is somewhat likely that these situations were caused by the normal bias. Furthermore, it is somewhat likely that a few precedents of the abnormal sound and the nasty smell caused by the abnormal situation in the vehicles, enhanced the psychological activities as the above situation.

In addition, it is somewhat likely that the mentality toward the information that supported the wish as "there was no hindrance in the train operation, no hindrance was welcome", had acted under the consciousness in the above situation. It is somewhat likely that these situations were the result of the positive proof bias.

*45 *S. Tsuchida, "Psychology of the safety and the risk", pp.156-158, 2018, Baifukan Ltd., in Japanese.*

*46 *M. H. Bazerman, D.A. Moor, "Judgement in Managerial Decision Making", translated by K. Nagase, pp.45-50, 2011, Hakuto Shobo Publishing Co., translated in Japanese.*

3.5.1.7. Means to Implement Accurate Judgment

- (1) It is required for the staffs in the railway company to act as being conscious to communicate information or to make judgement from the neutral viewpoint not to fall into the interdependence, based on the understanding of the psychological trends of the whole human beings described in 3.5.1.6, as the knowledge, in order to implement the accurate judgement in the situation such as the concerned serious incident. It is important to promote the improvement of the ability of communication in order to secure the transmission of the exact information, excluding the predictions. Particularly, it is required for the dispatchers not to use the leading expressions as if the continuation of train operation was the premise when they asked the staffs.

In addition, it is required for the related staffs to act based on the understanding for the individual missions each other by making clear the roles assigned to each related staff, including that the dispatcher possesses the authority to judge the propriety to continue train operation, in order not to fall into interdependence.

Based on the above situation, it is required to promote the improvement of the consciousness to enable steady implementation of the "matters to be obeyed as the dispatcher" prescribed in the "Standards of Dispatching Operation", Fundamental Volume, described in 2.9.3. It is important to judge the situation and act having the consciousness as "there is a possibility to cause the severe accident in the situation that it could not be understood what happened", when the situation could not be understood what happened or when being in irresolute situation, considering the case that the unusual incident may threaten the transport safety.

- (2) The serious troubles accompanied with the abnormal sound, the nasty smell and the smoke in the running train had occurred in the past, as described in 2.11. As it is probable that there was the serious abnormal situation in the vehicles in the high possibility when the nasty smell or haze as smoke something burnt was generated, it is probable that there was the room to use the past troubles for the judgement of the abnormal situation in the concerned serious incident.

Therefore, it is effective to collect the past troubles and the various information suggesting the abnormal situation such as the abnormal sound and the nasty smell generated in the troubles, to possess jointly between the staffs concerned, and to accumulate these information as the systematic knowledges, then apply them in the judgement of the abnormal situation. It is desirable to promote improvement of the knowledge and the judging ability of the staffs concerned by implementing the training to experience abnormal sound, nasty smell, etc., in the abnormal status of the vehicles in the bodies of the trainee, using the above information. In addition, it is desirable to possess the accumulated information jointly between the other railway operators who have the same kinds of the vehicles or the facilities and the makers, and to apply each other.

Furthermore, if it became possible to transmit information such as the actual sound and pictures to the dispatcher, in addition to the oral report to the dispatcher about the situation of the site, it is probable that the dispatcher can comprehend the accurate situation in the site accurately and promptly, assisted by these information. Therefore, it is effective to use the information terminal devices such as the portable tablet, etc., for the accurate judgment for the continuation of the train operation by the dispatcher.

3.5.2. Analysis on the Actions in the Abnormal Situation

3.5.2.1. Actions of the Train Crews and the Dispatchers in the Abnormal Situation

As described in 2.9.1, the actions in the abnormal situation of the train crews were prescribed in the Operation Standards of Driver, the Operation Standards of Conductor and the Operation Standards of Cabin Attendants, as follows.

- (1) Implement the measures considered as the safest, in the abnormal situation such as an accident, etc.
- (2) Implement the actions considered as the safest supposing all possible situations, if there is no time to be instructed the measures from their superior, when faced the incidents that were not prescribed in the standards.

In addition, as described in 2.9.3, the actions in the abnormal situation for the dispatcher were prescribed in the Standards of Dispatching Operation, Fundamental Volume, as follows.

- (1) When the abnormal situation such as the accident in operation happened, judge the situation accurately, and implement safe and proper measures promptly.
- (2) If there is no time to get instructions for the judgement and measures from the superiors, when faced the urgent incidents that were not prescribed in the operation standards, implement the action considered as the safest supposing all possible situations.

However, it is somewhat likely that the judgment as there was the hindrance in the train operation could not be concluded in the concerned serious incident, because of the followings.

- (1) As described in 2.9.1, the conductor and the cabin attendant recognized the abnormal sound, the nasty smell and the haze, but they judged that the abnormal sound, the nasty smell and the haze, which occurred in the concerned serious incident, the status of these phenomena did not correspond to the situation in the procedures of measures for the abnormal situation prescribed in the Operation Standard of Conductor and the Operation Standard of Cabin Attendant.
- (2) As described in 3.5.1.4, it is probable that there was a side of the characters to depend on each other in the responses of the vehicle maintenance staff and the dispatcher, on the judgement to continue train operation.

It is probable that the judgement of the measures against the abnormal situation, particularly the judgement to act as considered as the safest, greatly depend on the personal experiences in the past, when it was judged that the situation did not correspond to the prescribed situation in the procedures of measures in the abnormal situation.

In addition, it is important to endeavor to dip up the latent risks and reflect them, in the studies

on the regulations or the manuals such as the procedures of measures in the abnormal situation. Therefore, it is required to reflect the knowledges and the experiences obtained in the concerned serious incident, to the regulations, the manuals, etc., from the viewpoint to prevent train operation being missed to find the abnormal situation.

On the other hand, as the regulations, manuals, etc., were not always covered the whole concrete cases, it is important to check and review the regulations and the manuals to prescribe the measures as to stop the train and confirm safety, when the situation could not be understood as what had happened or hesitated to judge, and let the company staffs known well by the education, training, etc.

3.5.2.2. Utilization of the Consultation Between Dispatchers

As described in 2.9.4, the consultation between dispatchers between the dispatchers of the JR West and the JR Central was not held until the concerned train arrived at Nagoya station, although the information on the abnormal situation of the vehicle had been possessed jointly.

The consultation between dispatchers that the dispatchers of the JR West had participated were held for the 361 cases from April 1 to December 11, 2017. These consultations were held in the cases "delay of train operation or train service cancellation occurred or was anticipated", caused by the vehicle troubles, the operation control due to heavy rain or windstorm and measures against flying objects, the facility malfunction, etc., based on the analysis on the previous results.

It is probable that the consultation between dispatchers was not held in the concerned serious incident related with that the concerned train had been operated on schedule until to Nagoya station although being reported on the abnormal sound and the nasty smell, as the background.

It is desirable to use the consultation between dispatchers effectively when the dispatcher implement the judgement of the train operation or the countermeasures, in order to realize the following items effectively.

- (1) The dispatchers who have a variety of experiences and knowledges, implement the proper judgement by integrating the knowhows.
- (2) Study on the measuring method and the operation management which are optimum in wide area exceeded the control regions of the relevant companies.
- (3) Possessing jointly the analyses on the situations and judgement of the policies.

3.5.3. Analysis on the Safety Management in the JR West

It is probable that there was a side of the characters that the dispatchers and the vehicle maintenance staff depended on each other, in the process of the train operation in the concerned serious incident, as described in 3.5.1.4. The inquiry by the dispatcher was to confirm as if the continuation of train operation was the premise as "Is it all right to consider that there is no problem in the train running?" and "Didn't you feel that there was a hindrance in the train running?". Thus, the dispatcher could not understand, as the result, the will of the vehicle maintenance staff as "We want to implement underfloor inspection", included in the report from the site as "I would like to inspect the underfloor as my opinion, but isn't there any time to do it?".

In addition, there were 101 reports on the abnormal sound in the Sanyo Shinkansen section, from April 1 to December 11, 2017, in the JR West. Among these, the vehicle maintenance staff had got on the train and implemented the inspection in the 4 cases, *i.e.*, 4.0 %, as described in 2.10.1. On the contrary, there were 156 reports on the abnormal sound in the Tokaido Shinkansen section in the same period, in the JR Central. Among these, the vehicle maintenance staffs had boarded on the train and implemented the inspection in the 127 cases, *i.e.*, 81.4 %. It was confirmed that there was the situation that the JR West had used to implementing the inspection in the terminal station of the train, as the simple comparison might be improper because the situation was different in each incident.

There were various regulations to consider the safety as top priority in the JR West, for instance, the Standards of Dispatching Operation, Fundamental Volume described as "Implement the action judged as the safest when the situation was not clear", as described in 2.9.3. In order to make the prescripts to the concrete actions, it is important that the JR West should promote to establish firmly the actions based on the consciousness that the safety is the top priority, by confirming the concrete method of the safety management based on the action model corresponding the concept that safety is the top priority as "the action judged as the safest should be implemented", and by reflecting in the review of the regulations, the educations and trainings of the staffs, according to the necessity.

In addition, as described in 2.12.2, the JR West has been tackling to improve the system toward the extraction of the latent risks and further effective risk management, by introducing the risk assessment in the "Fundamental Plan for Safety" collected the problems and the measures on the safety, established in 2008. It is desirable that the method to reduce the risks in the actual train operation will be established by promoting introduction of the risk assessment, including the analysis on the latent risks in the incidents related to the generation of the abnormal sound, the nasty smell and the haze, as in the concerned serious incident.

3.6. Analysis on the Detection of Abnormal Situation

It is probable that the concerned crack had expanded to the level as affected the rigidity of the concerned side beam in the previous day of the occurrence of the concerned serious incident, based on the changes of the diagonal inner pressure difference of the air springs obtained from processing the data recorded in the data recording device of the vehicle, as described in 3.1.3.2, and it is probable that the concerned crack had expanded still worse, in the level to affect to the other bogie components such as the WN coupler, etc., as the side beam had deformed in the train operation in the day of the occurrence of the concerned serious incident.

The original purpose of the detection of the inner pressure of the air springs was to adjust the acceleration and deceleration of the vehicle according to increase or decrease of the boarded passengers. However, it is probable that the inner pressure of the air spring changes corresponding to the decrease of the suspending force of the air spring in the vicinity of the damaged part of the bogie. Then, it is somewhat likely that the abnormal situation when the components suspending the vehicle body, including the side beam of the bogie frame, vertically was damaged, can be detected

in early stage by monitoring always the diagonal inner pressure difference calculated from the inner pressure of the air springs, and can detect the change of the balance in the load weights acting on the air springs.

In addition, the change of the loaded weight suspending the vehicle body vertically can be also detected by measuring the wheel loads. The measurement of wheel loads is implemented in the chances in the general inspection and the bogie inspection at present, but it is somewhat likely that the abnormal situation can be detected in early stage by monitoring the changes of the balance of wheel loads of the bogies or vehicles more frequent than in at present, to equip the wheel load detecting devices which can measure the wheel loads while the train was running in low velocity when entering to or departing from the train depot.

It is desirable to study the system notifying the abnormal situation in the bogie to the train crews, etc., by the effective use of the data on the inner pressures of the air springs, wheel loads, etc., as described in the above.

In addition, as described in 2.12.1, according to the JR Central, the data recorded when the concerned train, while operated in the previous operation as the outbound 15A train, had passed the places where the bogie temperature detecting devices were installed, were checked after the occurrence of the concerned serious incident, and it was found that the temperature higher than as usual were recorded for the concerned bogie, as it was within the standard value to be judged as dangerous.

It is probable that the levels of the effects to the WN coupling, etc., and the generated heat in the bogie components will differ by the difference of the vehicles that the crack had generated and the parts where the crack had generated. However, it is somewhat likely that the abnormal situation could be detected as the unusual heat generation in the same situation as the concerned serious incident, by the effective use of the bogie temperature detecting devices, based on the followings.

- (1) As described in 3.1.3.2, it is probable that the crack had expanded to the level as to affect the other bogie components such as the WN coupling, etc., due to the deformation of the side beam in the train operation on the day of the occurrence of the concerned serious incident.
- (2) As described in 3.1.4.1, it is probable that the WN coupling was heated in the level as the grease had leaked to outside of the WN coupling, at the time just after the concerned train departed from Hakata station.
- (3) As described in 3.1.4.1, it is highly probable that the temperature of the WN coupling became in high temperature considered as about 300 °C, based on the results of the dismantle inspection, etc., for the WN coupling implemented after the concerned serious incident.

4. CONCLUSIONS

4.1. Findings

- (1) It is highly probable that the originated point of the concerned crack was in the neighborhood of the back boundary of the two slot welded parts in the inside and outside of the bogie where the axle spring seat was attached to the bottom plate of the side beam. *[Refer to 3.1.1]*

- (2) It is highly probable that the strength of the concerned side beam had been deteriorated because the thickness of the bottom plate of the side beam in around the concerned axle spring seat was less than the standard value. *[Refer to 3.1.2]*
- (3) It is highly probable that the crack had expanded to the tip due to fatigue. It is probable that the expanding speed of the generated crack becomes faster substantially when the thickness of the bottom plate of the side beam was thin due to being grinded extremely exceeding the standard value, based on the simulation for the crack expansion. It is highly probable that the crack had expanded in the period shorter than the vehicle life, *i.e.*, the usable period of the bogie, because the speed of the crack expansion had become faster as the thickness of the bottom plate of the side beam had been thin due to being grinded extremely, based on the above analysis. *[Refer to 3.1.3.1]*
- (4) It is probable that the concerned crack expanded in the level to affect the rigidity of the side beam on the previous day of the occurrence of the concerned serious incident. It is probable that the concerned crack expanded furthermore in the level to affect the other bogie components such as the WN coupling, etc., due to the deformation of the side beam on the day of the occurrence of the concerned serious incident. *[Refer to 3.1.3.2]*
- (5) It is highly probable that the damages in the bogie components except for the concerned bogie frame was the secondary damages caused by the expansion of the crack generated in the concerned bogie frame. It is probable that the nasty smell and the haze in the cabins were caused by the grease leaked from the concerned WN coupling, and diffused in the cabins of the concerned vehicle and the rear vehicles, because the air conditioning devices equipped in the underfloor of each vehicle had been inhaled the open air from around the center of the underfloor of the vehicle body for the ventilation of the cabins. *[Refer to 3.1.4.1]*
- (6) It is probable that the strength of the slot welded part was designed and verified as not to generate fatigue crack. *[Refer to 3.2.1]*
- (7) It is highly probable that there was no abnormal situation in the strength of the pressed material for the side beam and in the sizes of the part to become the bottom plate of the side beam. *[Refer to 3.3.1]*
- (8) It is probable that the swell was generated in the bottom surface of the side beam because the plates to become the upper and the lower plates of the side beam were widened as the strain was not removed, in addition, the correction of the joint stagger, etc., was not implemented in the hold welding, when the concerned side beam was manufactured. It is somewhat likely that the machining work considering the amount of the stress due to changed status of the residual stress, in the process of the material machining and the welding accompanied heat, was insufficient, as the concerned side beam was manufactured by the cold press machining. Therefore, it is probable that the swell of the bottom plate of the side beam became large, when the concerned side beam was manufactured by the cold press bend machining. *[Refer to 3.3.2]*
- (9) It is probable that the thickness of the bottom plate of the side beam had remarkably decreased as the result of the large amount of the grinded volume in the grinding work for the swell to make flat when attached the axle spring seat, as the information prescribed in the work instruction, "the

finishing by grinding should not be implemented for the bottom surface of the side beam", was not transmitted to the assembling workers, in the situation described in 4.1 (8). *[Refer to 3.3.2]*

(10) It is probable that the overlay welding work was implemented after annealed in the bottom surface of the concerned axle spring seat. It is somewhat likely that, as some abnormal situation had occurred when the machining work for the bottom surface of the axle spring seat was implemented as the first process of the machining works for the bogie frame after annealed, the machining works was suspended after the concerned axle spring seat and the axle spring seat in the edge side of the bogie was grinded excessively, then, the overlay welding to correct the excessively grinded part was implemented, and the machining works to correct to be the normal sizes was implemented again. However, it could not be determined why the overlay welding was implemented. *[Refer to 3.3.4]*

(11) The inspection method and the place to be implemented by the flaw inspection were designated based on the data on the cracks occurred in the past, etc., and the place where the concerned crack had generated was not designated as the place to be implemented the flaw detection as there was no precedent of the crack generation. It is somewhat likely that the concerned crack did not open at the time of the latest general inspection implemented before the concerned serious incident because no abnormal situation was found in the size inspection for the bogie frame separated from the vehicle body. *[Refer to 3.4]*

(12) The abnormal sound and the nasty smell were generated in the cabins of the concerned train, but they were generated discontinuously. When the dispatcher asked as "Is there any hindrance in the train operation?", the vehicle maintenance staff replied as "I think it is not in such situation". Then, it is probable that the dispatcher did not conclude to judge as there was a hindrance in the train operation in early stage, related with the situation that the dispatcher could not obtained the definite information to understand the seriousness of the abnormal situation.

[Refer to 3.5.1.1, 3.5.1.2]

(13) The vehicle maintenance staff understood that the dispatcher had been arranging the implementation of the underfloor inspection of the vehicle, but the dispatcher thought that the vehicle maintenance staff would implement the measure to open motor circuit instead of the underfloor inspection based on the reports from the vehicle maintenance staff. Then, it is probable that the implementation of the underfloor inspection was not instructed related with the existence of the difference in the recognition on the necessity of the underfloor inspection of the vehicle between the dispatcher and the vehicle maintenance staff.

In addition, it is probable that the difference in the recognitions did not clear and continued related with that the dispatcher could not listen the report from the vehicle maintenance staff, because he took off the receiver of the telephone from his ears as being responding to the inquiry from the other dispatcher about the status at that time, when he received the report from the vehicle maintenance staff. *[Refer to 3.5.1.3]*

(14) The dispatcher considered that the vehicle maintenance staff would report that there was the hindrance in train operation if it was dangerous actually, because the vehicle maintenance staff was the professional engineer about the vehicles. On the contrary, the vehicle maintenance staff

understood that the judgment to implement the underfloor inspection was entrusted to the dispatcher. Therefore, it is probable that there was a side of the characters to depend on each other between the dispatcher and the vehicle maintenance staff, about the decision on the continuation of the train operation as considered that the opponent would communicate the necessity to stop the train if needed actually. [\[Refer to 3.5.1.4\]](#)

(15) It is somewhat likely that the inquiry from the dispatcher to the vehicle maintenance staff in the expression leading that the continuation of the train operation is the premise as "Is it all right that there is no problem in the train running?", etc., affected the communication between the dispatcher and the vehicle maintenance staff, that did not proceed to "stop the train immediately and implement inspection", because of the difference in the recognitions between the dispatcher and the vehicle maintenance staff described in 4.1 (13), and the interdependence described in 4.1 (14). Thus, it is somewhat likely that the judgment of the necessity to stop the train in early stage and implement the underfloor inspection on the concerned vehicle was not concluded related with the above situations. [\[Refer to 3.5.1.5\]](#)

(16) It is somewhat likely that the psychological trends, which are possessed in all human beings, as "act to maintain calmness by judging as within the normal situation when faced to the abnormal situation" and "consider as the most important and choose the information that support their wishes or beliefs, but slight and exclude their negative information", had acted under consciousness of the dispatcher as the background that the dispatcher did not conclude the judgement that there was the hindrance in the train running. [\[Refer to 3.5.1.6\]](#)

4.2. Probable Causes

It is highly probable that the concerned serious incident occurred because the gear type flexible shaft coupling displaced exceeding the allowable range and damaged due to deformation of the bogie frame caused by the crack which had generated in the side beam of the bogie frame of the vehicle and had expanded by fatigue.

The crack had generated in the side beam of the bogie frame of the vehicle because it is somewhat likely that the split had generated in around the back boundary of the slot welded part where the crack had originated when the welding work had implemented. In addition, it is highly probable that the crack had generated related with the followings.

- (1) The residual stress was generated in around the slot welded part due to the implementation of the overlay welding on the bottom surface of the axle spring seat after annealed.
- (2) The thickness of the bottom plate of the side beam had become thinner than the designed standard value, because the bottom surface of the side beam had been grinded excessively when attached the axle spring seat to the bottom plate of the side beam.

In addition, it is highly probable that the crack had expanded in the period shorter than the vehicle life, *i.e.*, the usable period of the bogie, because the expanding speed of the crack became faster as the thickness of the bottom plate of the side beam became thinner due to the excessive grinding works implemented in the bottom plate of the side beam.

Here, it is highly probable that the bottom plate of the side beam was grinded excessively related

with that the problem, that the machining work was required to attach the axle spring seat due to the swell in the bottom surface of the side beam generated in the manufacturing process of the bogie frame, was dealt without studying the essential causes and counter measures, and the manufacturing works had implemented without well understandings on the instructions for the work related to the strength of the bogie frame.

4.3. Factors to Continue Train Operation as Being Noticed Abnormal Sound and Nasty Smell, etc.

It is probable that the staffs concerned in the JR West could not concluded to judge that there was the hindrance in the train operation although they had noticed the abnormal sound, the nasty smell, etc., related with the followings.

- (1) The dispatcher was in the situation that the definite information to understand the seriousness of the abnormal situation were not obtained, as the generation of the abnormal sound, the nasty smell, etc., were discontinuously, and when the dispatcher asked as "Is there any hindrance in the train operation?", the vehicle maintenance staff had replied as "I think it was not in such situation".
- (2) The vehicle maintenance staff understood that the dispatcher had been arranging the implementation of the underfloor inspection of the vehicle, but the dispatcher received some reports from the vehicle maintenance staff and thought that the vehicle maintenance staff would implement the measure to open motor circuit instead of the underfloor inspection against the abnormal situation in the vehicles. Thus, the difference in the recognition on the necessity of the underfloor inspection of the vehicle between the dispatcher and the vehicle maintenance staff was brought out, and the differences did not clear and continued after that.
- (3) The dispatcher considered that the vehicle maintenance staff would report that there was the hindrance in the train operation if it was dangerous actually, because the vehicle maintenance staff was the professional engineer on the vehicles. On the contrary, the vehicle maintenance staff understood that the decision to implement underfloor inspection had been entrusted to the dispatcher. Therefore, there was a side of the characters to depend on each other between the dispatcher and the vehicle maintenance staff, to judge the continuation of the train operation.

5. SAFETY ACTIONS

5.1. Measures to Prevent the Recurrence Considered as Required

It is highly probable that the concerned serious incident occurred because the gear type flexible shaft coupling displaced exceeding the allowable range and damaged due to the deformation of the bogie frame caused by the crack which had generated in the side beam of the bogie frame of the vehicle and had expanded by fatigue.

In addition, it is probable that the staffs concerned did not conclude to judge the situation as there was the hindrance in the train operation, in spite of being noticed the abnormal sound and the nasty smell, etc., because there was the difference in recognition on the necessity of the underfloor inspection of the vehicle and the interdependence for the judgment to continue the train operation between the staffs concerned in the JR West.

To prevent the recurrence of such situations, it is required to implement the following measures.

5.1.1. On the Crack in the Bogie

(1) On the manufacturing process of the bogie frame

- (i) The sufficient strength is needed to the major materials of the bogies as large weight is loaded in the running vehicles, and the strength design, etc., were implemented for the thickness of the material corresponding to such condition. Then, the works causing the reduction of the strength of the designed material such as to reduce the thickness of the plate significantly, should not be implemented except for the place where the removal machining was scheduled in the later manufacturing process and the place where the finishing by grinding was instructed in the original design.

In addition, the works to cause the residual stress by the large heat input to the bogie frame after annealed such as the overlay welding in wide area should not be implemented, so as not to shorten the life till the generation of the fatigue crack in the bogie frame by the residual stress due to the welding.

It is required to let the staffs engaged in the manufacturing works well known the above information, and to implement the manufacturing management thoroughly in order to ensure the manufacturing process not to reduce strength of the materials to secure the designed strength.

- (ii) As the system that only the sound products are supplied to the actual use, it is required to organize the system that can implement the following matters certainly.

- a. It is required to evaluate the probable effects for the safety of the bogie frame by the problems and the counter measures, as the action of the organization, when the problems such as the hindrances and the difficulties in the manufacturing and the necessity of the counter measures accompanied the machining of the materials in the manufacturing site of the bogie frame after started the manufacturing. Particularly, it is required to ensure the existence of the problems in the manufacturing, by the trial product and the first product in the lot, when manufacturing the products for the first time, after changed something, and after suspended manufacturing for a long time.

- b. If the problems occurred in the manufacturing process and the counter measures affected the safety of the bogie frame, it is required to suspend the works once, and to implement certainly the method to measure the problem such as to restart works after confirmed the validity of the implemented measures by investigating the causes back to the manufacturing process or the design stage.

(2) On the design and the verification of the bogie frame

- (i) When the stress distribution in the bogie frame, such as being applied the new structure, was estimated by the strength analysis by the FEM analysis using the computer, in the strength design, it is desirable to pay attention to the importance to recreate as far as possible the structural characteristics such as the plates of the different rigidities were jointed locally, and the constraint conditions such as the positions suspending load weights, in the calculation

model, in addition, to comprehend the trends of the place where large stress had generated, considering the inherent property of the calculation errors in the FEM analysis, from the results of the analysis, in order to obtain the stress which was the closest to the actual values.

(ii) It is desirable to reconfirm whether the structural characteristics or the constraint conditions described in 5.1.1 (2) (i), were recreated as far as possible, in the calculation model in the strength design, then, comprehend again the trends of the place where large stress had generated after revised the calculation model, even in the conventional bogie frame if required.

(3) On the inspection of the bogie frame

(i) The inspection method and the place to be inspected by the flaw detection were designated based on the data of the crack generation in the past, etc., and the place where the concerned crack had generated was not designated as the place to be implemented by the flaw detection, as there had been no precedent of the crack generation.

Therefore, it is desirable to study to add the place to be inspected by the flaw detection considering the safety ratio against the welded joint, etc., being comprehended the trends of the generation of large stress, as described in 5.1.1 (2), even in the place where crack was not generated in the past.

(ii) It is probable that the time required for the fatigue crack to expand and bore through the bottom plate of the side beam is longer than the vehicle life, *i.e.*, the usable period of the bogie, when the thickness of the bottom plate of the side beam was the designed thickness, in the same type bogies as the concerned bogie, even if the fatigue crack had generated in the area in the bottom plate of the side beam invisible from outside due to the welded axle spring seat. However, it is probable that the speed of the crack expansion becomes faster after the fatigue crack had expanded in the area where the inspection by the magnetic particle test or the penetrate test can be applied, *i.e.*, visible from outside. Therefore, it is required to comprehend the expansion of the inner fault by the ultrasonic test, etc., in proper frequency, to enable to find the crack in the area invisible from outside.

It is desirable to implement the ultrasonic test, etc., in the proper frequency, for the place where the trend to generate large stress was estimated in the area where the status could not be confirmed visually from outside due to the other components, *i.e.*, the area where the magnetic particle test or the penetrate test could not be applied, even when the crack had expanded and bored through the material same as in the concerned bogie frame.

5.1.2. On the Judgment to Continue Train Operation

(1) On the management as the organization to make the exact judgment

It is required to promote the management as the organization to bring up the consciousness to judge the situation and act having the consciousness as "the situation that could not be identified what happened has the possibility to cause the serious accident", when it could not be identified what happened as being noticed the existence of the abnormal sound, the nasty smell, etc., as in the concerned serious incident.

As for the judgment to continue the train operation in the situation that there are various information to suggest the abnormal status of the train but could not be identified what had

happened, the dispatcher should collect the information and the opinions on the status of the site from the train crews or the vehicle maintenance staffs, etc., and judge by evaluating these information comprehensively. In this case, it is required to act consciously to transmit information and to judge from the neutral viewpoint, as not to fall into the interdependence between train crews and dispatchers. In order to realize this situation, it is important to promote improvement of the communication ability to secure transmission of the accurate information excluding the prediction. Particularly, the dispatcher should endeavor not to use the expression leading that the continuation of the train operation is the premise when he asks.

In addition, in order to make the communication accurate and exact, it is considered as effective to act being understood as the knowledge that the human beings had the psychological trend to maintain calmness as considered as in the normal range even in the abnormal situation, etc., as the human characteristics and to promote the judgment based on the objective information by increasing information to transmit the pictures of the site, etc., to the dispatcher using the information transmitting tools, to implement communication properly and exactly.

Furthermore, in order not to fall into the interdependence, it is important to act being understanding the roles of the opponents each other, to make definite the assigned roles for the staffs concerned, including that the dispatcher has the authority to judge the continuation or the suspension of the train operation.

In addition, in the situation that could not identify what had happened or strayed to make judgment, it is required to check and review the regulations, the manuals, etc., to become the measures to confirm safety after stopped the train, and to let the company staffs known well by the educational training, etc.

(2) On the jointly possession of information and measures using hardware effectively

It is very important to reduce the situation that it could not be understood what had happened, as far as possible, to implement the judgment to continue the train operation properly and exactly. In order to realize these situations, it is considered as effective to promote the following measures.

- (i) It is desirable to collect the past troubles and the various information suggesting the abnormal situation such as the abnormal sound and the nasty smell generated in these troubles, and to possess jointly between the staffs concerned, then, to accumulate these information as the knowledge of the organization to use effectively in the judgment of the abnormal situation. In addition, it is desirable to try to improve the knowledge and the ability of judgment of the staffs concerned by implemented the training to experience the abnormal sound and the nasty smell generated in the abnormal situation of the vehicle utilizing the above information. Here, it is desirable to utilize the accumulated data mutually by possessing jointly with the other railway operators having the same type of vehicles or facilities and the makers.
- (ii) It is desirable to build up the system to detect the abnormal situation by the hardware, such as to utilize the sensors, etc., equipped in the vehicle or to install the status monitoring devices in the vehicles or on the ground, and to study the system to inform the generation of the abnormal situation and its level to the train crews and the dispatcher. It is desirable to study the system to detect the abnormal situation of the bogie such as the crack earlier and

exactly, by utilizing the data of the inner pressure of the air springs, etc., effectively.

5.2. Measures Implemented after the Concerned Serious Incident

5.2.1. Opinions to the Minister of Land, Infrastructure, Transport and Tourism Pursuant to Article 28 of the Act for Establishment of the Japan Transport Safety Board

On June 28, 2018, the Japan Transport Safety Board expressed its opinions as follows to the Minister of Land, Infrastructure, Transport and Tourism, pursuant to Article 28 of the Act for Establishment of the Japan Transport Safety Board in order to promote the prevention of the recurrence of the similar situation on the cracks generated in the bogie.

As it is somewhat likely that the contents of the works in the manufacturing stage of the bogie frame significantly related to the generation of the crack in the bogie in the concerned serious incident, the items to be measured toward prevention of recurrence in every stage including the design, verification and the operating process, in addition to the manufacturing process of the bogie frame, based on the results obtained in the investigation and the analysis on the bogie frame up to the moment, were listed as follows.

The Minister of Land, Infrastructure, Transport and Tourism should implement the required measures for these items.

(1) Items related to the manufacturing

- (i) Implement the manufacturing management thoroughly, in order to ensure the manufacturing process not to reduce the strength of materials to secure the designed strength, in the stage of manufacturing bogie frames.
- (ii) Establish the system that can implement the following items certainly, as the system in which only the sound products are supplied to the actual use.
 - a. When the problems, such as the hindrance or the difficulties in the manufacturing process and the necessity to take measures accompanied with the machining of materials, occurred in the manufacturing site of the bogie frames, evaluate the probable effects to the safety of the bogie frame by the problems and the counter measures, as the measures of the organization.
 - b. When the problems occurred in the manufacturing process or its counter measures are to affect the safety of the bogie frame, suspend the works, investigate the causes back to the manufacturing process or the design stage and study the counter measures, then, resume the works after confirmed the validity of the results of the measures implemented.

(2) Items related to the design and verification

- (i) When implementing the strength analysis using computer by the FEM analysis in the strength design stage of the bogie frame as being applied the new structure, mind the importance to recreate the structural characteristics such as the plates with different rigidities were jointed locally, and the constraint condition for the place suspending the load weight as far as possible, and study to comprehend the trends of the place where large stress had

generated considering the inherent property of the calculation errors in the FEM analysis from the results of the analysis, in order to comprehend the stress closer to the actual value,

- (ii) Even in the conventional bogie frame, if it is required, reconfirm whether the calculation model in the strength design recreated the structural characteristic that the plates with different rigidities were jointed locally and the constraint conditions as the place where suspending the load weight, etc., as far as possible, then, study again to comprehend the trends of the place where large stress had generated, after revised the calculation model.

(3) Items related to the inspections

- (i) Study to add the place to be inspected by the flaw detection, considering the safety ratio against the welded coupling, etc., based on the comprehension on the trends of the place where large stress had generated, for the flaw detection by the magnetic particle test or the penetrate test in the periodic inspection of the bogies.
- (ii) Study to implement the ultrasonic test, etc., in the proper frequency, for the place in the bogie frame where there was the trend to generate large stress in the area invisible from outside due to the other components, *i.e.*, area where the magnetic particle test and the penetrate test could not be applied, even when the expanded crack had bored through the material.

(4) Items related to the detection of the abnormal situation

Study the system to inform the abnormal situation to the train crews, etc., using effectively the data of the inner pressures of the air springs, etc., in order to detect the abnormal situation such as the crack, etc., in the bogies in early stage properly and exactly.

5.2.2. Measures Taken by the Ministry of Land, Infrastructure, Transport and Tourism

- (1) On December 12, 2017, the MLIT instructed the JR West, to investigate the causes and to implement the measures for prevention of the recurrence, thoroughly.
- (2) On December 13, 2017, the MLIT instructed the JR group five companies who are operating the Shinkansen, to implement the urgent inspection of the bogies in the Shinkansen vehicles. On December 18, 2017, the MLIT published that the MLIT received the reports on the result of the inspection that there was no abnormal situation such as the crack, etc., in all 10,375 bogies for the Shinkansen vehicles including the spare bogies. Furthermore, the MLIT provided the information on the summary of the concerned serious incident to the railway and tramway operators in the whole country on December 13, 2017, and instructed to implement the flaw detection, etc., for the bogie frame certainly in the periodic inspections even in the railways except for the Shinkansen.
- (3) On December 20, 2017, the MLIT held the urgent meeting of managers supervising transport safety, and endeavor to possess jointly the information on the recent incidents, and to prevent the recurrence of the similar incidents, considering that the concerned serious incident and the situations such as the transport disorder significantly affected to social order had occurred consecutively. At the same time, the MLIT instructed the railway and tramway operators in the whole country, to endeavor to secure the safe and steady transportations thoroughly.

- (4) On December 27, 2017, the JR West published the results of the company's investigation about that the train operation had continued after noticed the abnormal situation. The MLIT informed and made well known about it, to the railway and tramway operators in the whole country, and instructed to implement the following items in the same day.
- (i) Let all staffs concerned include the staffs in the site known well about the contents of the report published by the JR West, and implement verification, etc., from the viewpoint of each company.
 - (ii) If the situation that was felt as abnormal by the smell, sound, etc., had occurred, take the proper actions considered safety as the first, such as the prompt implementation of the inspection, etc., considering the judgment at the site as the top priority.
 - (iii) Endeavor further reinforcement of the cooperation between the companies, such as to possess jointly the information on the safe train operation certainly between the dispatcher's offices, etc., in the operators who operate the through service of the vehicles.
 - (iv) As for the contents described in the above 5.2.2 (4) (ii) and (iii), implement the measures such as to prescribe clearly in the manuals, etc., of each company according to the necessity.
- (5) On February 2, 2018, the MLIT established the "Study Meeting on the Probable Measures for the Troubles in the Railway Transportation", responding the concerned serious incident and the troubles in the railway transportation occurred consecutively, and held the first meeting. The measures against crack in the bogie, the measures to prevent recurrence of the transport disorder, and the structural factors considered as existed in the background were analyzed and studied in the Study Meetings, that were held for 5 times.
- The "Working Group to Measure the Crack in the Bogie" established under the Study Meeting had held total 7 times, and implemented the study on the measures of preventing the recurrence, including the review of the inspection manual for the bogie frame, etc., as the measures against the crack in the bogie.
- (6) On February 28, 2018, the MLIT let known well the investigated results on the estimated causes of the crack in the bogie, etc., published by the JR West and the concerned bogie maker to the railway and tramway operators in the whole country and the makers through their related organizations, and implemented hearing investigation for the concerned bogie maker on the background such as the manufacturing process, the system of the organization, etc., to cause the concerned serious incident.
- (7) On March 30, 2018, the MLIT let known well the "On the Measure to Improve Safety of Shinkansen" published by the JR West, to the railway and tramway operators in the whole country, and instructed the JR West to endeavor the steady promotion of the measures for preventing the recurrence, etc., and to report on the implemented measures and their progressing status periodically.
- (8) On June 28, 2018, the MLIT let the railway and tramway operators in the whole country and the makers through their related organizations, known well about the publication of the interim report and the opinion of the Japan Transport Safety Board expressed to the Minister of the Land, Infrastructure, Transport and Tourism.

(9) On July 27, 2018, the MLIT published the summation of the Study Meeting on the Probable Measures for the Troubles in the Railway Transportation.

As for the measures against the crack in the bogie, the optimum measures against crack in the bogie frame considering the measures for each stage such as design, manufacturing, inspection, operation, *i.e.*, running in service, comprehensively, were collected. As for the inspection, the necessity to review the inspection manual for the bogie frame, etc., were pointed out in the summation. The measures corresponding to all opinions that the JTSCB had expressed to the Minister of the Land, Infrastructure, Transport and Tourism, on June 28, 2018, were collected in the summation.

In addition, the studies on the fundamental problems related to the safety were also implemented, and the policy for the measures were put together that the executive officer should take the lead to tackle the thoroughgoing of the policy as the safety first such as "do not hesitate to stop the train when the safety could not be ensured", on the thoroughgoing and the implementation of the consciousness for the safety, and that the staffs engaged in the railway operation including the on-site workers should "act with thinking", and their results should be evaluated properly and reviewed again as the organization, etc.

The MLIT informed and made well known the above summation and instructed the examination and the implementation of the measures considering the purposes of the summation to the railway and tramway operators in the whole country, and instructed the implementation of the measures to the makers through their related associations.

(10) On September 28, 2018, the MLIT informed and made known well the "On the Inadequate Manufacturing of the Bogie Frame of the N700 Series Shinkansen Vehicle" published based on the investigated results by the "Committee on the Quality Control in the Whole Company" established in the concerned bogie maker, to every makers through their related association. In addition, the MLIT directed the concerned bogie maker to implement the concerned corrected measures steadily, to report on the progressing status, and to improve the quality control in the whole railway vehicle manufacturing processes to be absolutely sure, based on the results of the hearing investigations described in 5.2.2 (6).

(11) On February 19, 2019, the MLIT revised a part of the "Inspection Manual of the Bogie Frame" based on the "Interpreting Standards on Ministerial Ordinance to Provide Technical Regulatory Standards on Railways, etc.", responded to the summation of the "Study Meeting on the Probable Measures for the Troubles in the Railway Transportation" described in 5.2.2 (9).

[Refer to Attached material 2]

5.2.3. Measures Taken by the JR West Who Owned the Concerned Vehicle

(1) Inspection of the bogies of the Shinkansen vehicle

(i) The urgent inspection

All the 2,487 bogies in the Shinkansen vehicles owned by the JR West had been inspected urgently by December 15, 2017, and it was confirmed that there was no abnormal situation as the existence of the crack, etc.

(ii) The visual inspection

The JR West decided to implement the visual inspection carefully for the crack, the flaw, etc., in the concerned part of the bogies in the daily inspection and the regular inspection, for the moment.

(iii) The ultrasonic fault detection, etc.

The JR West decided to implement the precise confirmation of the status for the welded part by the ultrasonic fault detection and the fiber scope inspection in the general inspection and the bogie inspection for all bogies, for the moment. Here, the company decided to implement the ultrasonic fault detection periodically until to be replaced, for the bogies which the thickness of the bottom plate of the side beam was less than the standard value.

(iv) Replacement of the bogies

The 101 bogies, which the thickness of the bottom plate of the side beam were less than the standard value and manufactured in the concerned bogie maker, were replaced in turns, and completed the replacement of all bogies by December 5, 2018. Here, the 22 bogies, which was suspicious on the existence of microscopic flaws in the results of the ultrasonic flaw detection including the 11 bogies that the thickness of the plate was thick than the standard value, had completed the replacement by March 20, 2018.

(2) The proper measures when the abnormal situation occurred

On January 8, 2018, the company established the "Meeting of Knowledgeable Persons on the Shinkansen Serious Incident" to obtain the evaluation and the proposals for the verified results from the viewpoint of the human factor from the knowledgeable persons outside of the company, on the situation that the train operation had been continued as being noticed the various signs related with the crack. The meeting of the knowledgeable persons edited "The Examined Results on the Measures to Prevent Recurrence of the Continuation of the Train Operation When Abnormal Status was Detected in the Shinkansen", and published on March 27, 2018. The company published "On the Measures to Improve Safety of the Shinkansen", on March 30, 2018, including the proposals of the meeting of knowledgeable persons, and decided to promote the following measures.

(i) The company decided to implement the following items, as there was the difference in recognitions on the status of the vehicle between vehicle maintenance staff and dispatcher, and the standard of judgment to stop the train operation had been unclear.

a. Decided to devise the words used to transmit information by implemented the education, etc., on the linguistic technologies, for example, "Is there any hindrance in the train operation?" was devised as "Will you inspect the vehicle?"

b. The staff experienced vehicle maintenance works was posted to the dispatcher from January 2018, and to strengthen the dispatching system by strengthen the directing system in the dispatcher's office.

c. The communication tools were fulfilled by the use of the application software for the meeting between the train crews and the dispatchers, equipped the additional voice monitors in the dispatcher's office and added the painting and calligraphic functions in

the system to possess information commonly between dispatchers. All measures had been introduced by February 2018.

- d. Strengthen the cooperation between the dispatchers and the vehicle maintenance staffs, etc., by implementing the crossover meetings between dispatchers and vehicle maintenance staffs, etc., the joint simulation training, and the training of the stopping operation and vehicle inspection using the train for the training on the main track.
 - e. Make the standard for the judgment definite, by deciding the rule to cope the situation caused by the combined abnormal sound, nasty smell, haze, vibration, etc., and guide to all train crews and all dispatchers, and implement the training for all train crews to feel, in their bodies the sound generated in the cabins, the smells generated from the oils and fats, etc., of the vehicle, were implemented.
 - f. Implement the educational trainings for the train drivers, the conductors and the cabin attendants, based on the knowledge on the human factors, as to implement the training, in the supposition as the situation was changing as the time had passed, in the Think-And-Act Training^{*47}.
 - g. Decided to install the bogie abnormal detecting devices in five points between Hakata station and Shin-Osaka station, as the ground devices to detect the abnormal situation in the bogies of the running vehicles, to comprehend the abnormal signs from the change of temperatures by monitoring temperatures in each part of the bogies. In addition, decided to introduce the onboard devices to detect the abnormal situation in the bogie of the running vehicles, such as the abnormal status detection by the pressure of the air springs which are equipped to the N700A type vehicles in turns by March, 2019, and the abnormal status detection by the vibration of the bogie components which were equipped in turns to the eight N700 series vehicles trainsets.
 - h. Strengthen the on-board checking system by preparing the prompt responding system of the vehicle maintenance staffs, *i.e.*, the running management groups were newly posted in Okayama station on February 2018, and Hiroshima station on December 2018.
- (ii) It was made thoroughly again to hand over in the consultation between dispatchers when the vehicle trouble had occurred in the train operation, and implemented the education on the rules of the vehicle inspection and the running inspection in the area crossed the boundary of jurisdiction of the companies, as it was judged that there was no hindrance in train operation even though the abnormal sound, etc., had been generated, and handed over the train operation to the JR Central without offering the consultation between dispatchers.
- (iii) Let the company staffs to possess commonly again the sense of values as "to consider the judgment at site as the top priority in the occurrence of the abnormal situation" and transmit the measure "do not hesitate to stop the train when the safety could not be confirmed" repeatedly, as the vehicle maintenance staff and the dispatcher were in the situation as depended on each other about the judgment to stop the train operation.
- (3) Strengthen the system for the safety management
- The company established the "Business Headquarter of Shinkansen Railway" as the

subordinate section in the Headquarter of Railways as the organization exclusive to Shinkansen on June 1, 2018, and the Director of the Business Headquarter of Shinkansen Railway, the Senior Managers of each divisions were posted as the managers of safety management exclusive to Shinkansen. In addition, the Business Headquarter of Shinkansen Railway was combined with the organization in the branch "Headquarter of Shinkansen Management" being engaged in the operation of Sanyo Shinkansen, to realize the system to make smooth mutual understandings between headquarter and the site, the cooperation between power feeding systems, and decision making.

**47 "Think-And-Act Training" is the training to strength cooperation between train crews, implemented in the JR West referred to the Crew Resource Management training implemented in the air lines business field.*

5.2.4. Measures Taken by the JR Central Who Owned the Same Type Vehicles as the Concerned Vehicle

(1) Inspection of the bogies of Shinkansen vehicles

(i) The urgent inspection

The JR Central implemented the urgent inspection for all owned bogies, *i.e.*, 4,440 bogies, for Shinkansen vehicles by December 15, 2017, and confirmed that there was no abnormal situation as the crack, etc.

(ii) The visual inspection

The JR Central decided to implement the visual inspection carefully for the crack or the flaw, etc., in the concerned part of the bogie in the daily inspection and the regular inspection, for the moment.

(iii) The ultrasonic flaw inspection, etc.

The JR Central decided to implement the precise confirmation of the status of the welded part by the ultrasonic fault detection and the fiber scope inspection in the general inspection and the bogie inspection for all bogies, for the moment. Here, the company decided to implement the ultrasonic fault detection periodically until to be replaced, for the bogies which the thickness of the bottom plate of the side beam was less than the standard value.

(iv) Replacement of the bogies

As for the bogies manufactured in the concerned bogie maker, the 46 bogies which the thickness of the bottom plate of the side beam were less than the standard value, and the 3 bogies which was suspicious on the existence of microscopic flaws found in the ultrasonic flaw detection although the thickness of the bottom plate were above the standard value, were replaced by November 14, 2018.

(2) The proper measures when the abnormal situation occurred

(i) The temperature detecting device for the bogies of Shinkansen vehicles

The JR Central strengthen the monitoring of the bogies in running vehicles using the temperature detecting devices for the Shinkansen vehicle bogies, by installing the additional 3 temperature detecting devices for the Shinkansen vehicle bogies in addition to the existing 2 temperature detecting devices, to establish the five detecting points system between Tokyo

station and Shin-Osaka station. The company decided to introduce the new detection method to judge the existence of the abnormal status automatically by monitoring the changes of temperatures in each bogie from the data of measured temperatures.

(ii) Addition of the monitoring function of the status of the vehicle

The JR Central decided to add the function to analyze the vehicle data, *i.e.*, the air spring pressure of the bogie, automatically, and indicate alarms in the driving desk when the abnormal situation in the bogie was detected. The new function was planned to equip in turns to the N700A type vehicles.

(iii) Reinforcement of monitoring vehicle status in the dispatcher's office

The JR Central decided to strengthen the monitoring function for the vehicle status by posting the full-time vehicle engineers newly in the Shinkansen Dispatcher's Office on June 2018, and newly equipped the terminal device which can monitor the status of the devices in the vehicle and the bogie temperatures in the running vehicles.

(iv) Fulfillment of the training contents for the train crews

The training, to feel in the body the smells when the abnormal situation had occurred in the vehicle devices such as the bogies and the sounds in the normal running, had implemented for all crews and pursers engaged in Tokaido Shinkansen.

5.2.5. Measures Taken by the Concerned Bogie Maker

(1) The results of the urgent inspection and the replacement of the bogies

The concerned bogie maker collected and edited the information on the situations found out after the concerned serious incident, and published that there was inadequate manufacturing in the bogie frame, etc., in "On the Bogie Frame of the N700 Series Shinkansen Vehicles", on February 28, 2018.

(i) The thickness of the plate in around the place where the axle spring seat was welded were measured for all bogie frames for the N700 series vehicles manufactured in the same specification as the bogie frame that the crack had generated, and the maker decided to replace the bogie frames which were found as the thickness of the bottom plate of the side beam was thinner than the normal thickness 7 mm. In addition, the maker decided to replace the bogie frames which were suspected that there was the flaw in the ultrasonic flaw detection, even in the case that the thickness of the bottom plate of the side beam was not less than the normal thickness 7 mm.

(ii) The urgent investigation was implemented on whether the instruction for the works based on the drawings were obeyed surely or not, and whether the manufacturing inconsistent to the instruction was implemented based on the judgment at site alone or not, and confirmed that there was no similar problem as in the concerned serious incident.

(2) Corrected measures of the quality control to prevent recurrence

The concerned bogie maker established the "Meeting of Quality Control in the Whole Company" inviting the knowledgeable persons from outside of the company, on April, 2018, and implemented investigations on the causes and studies on the measures to prevent recurrence

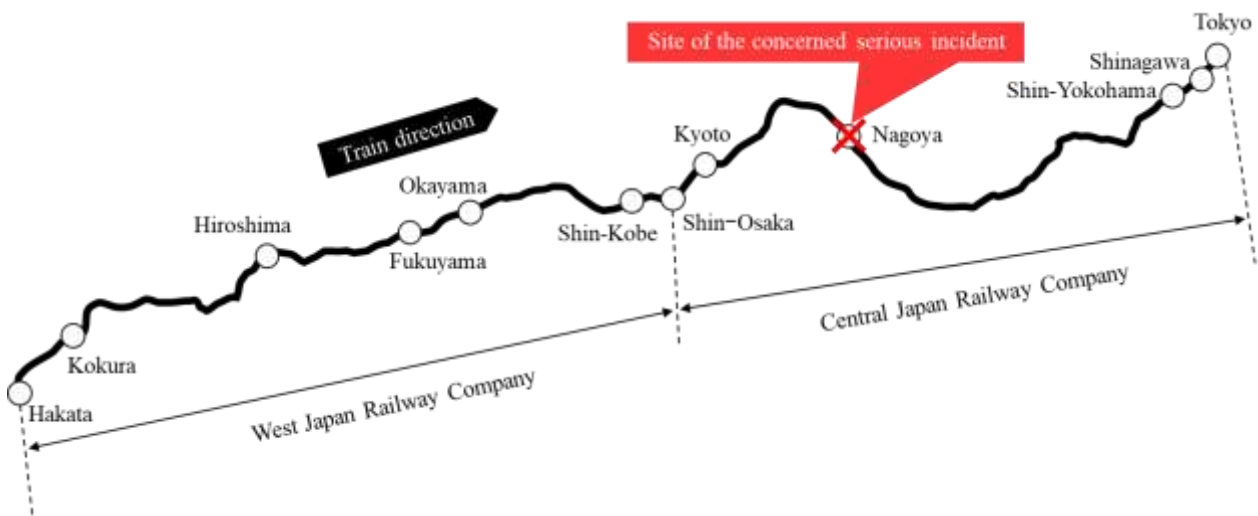
based on the analysis using the quality control method, and the results were edited and published as "On the Inadequate Manufacturing of the Bogie Frame of the N700 Series Shinkansen Vehicles" on September 28, 2018.

After the occurrence of the concerned serious incident, the reviews were implemented for the process to confirm the inspected results in the inspection processes for the first product or the first trainset, and designated the place to be inspected where confirmation is difficult in the completed products. In addition, the concerned bogie maker decided to tackle the following four items mainly as the measures to prevent recurrence in the quality control.

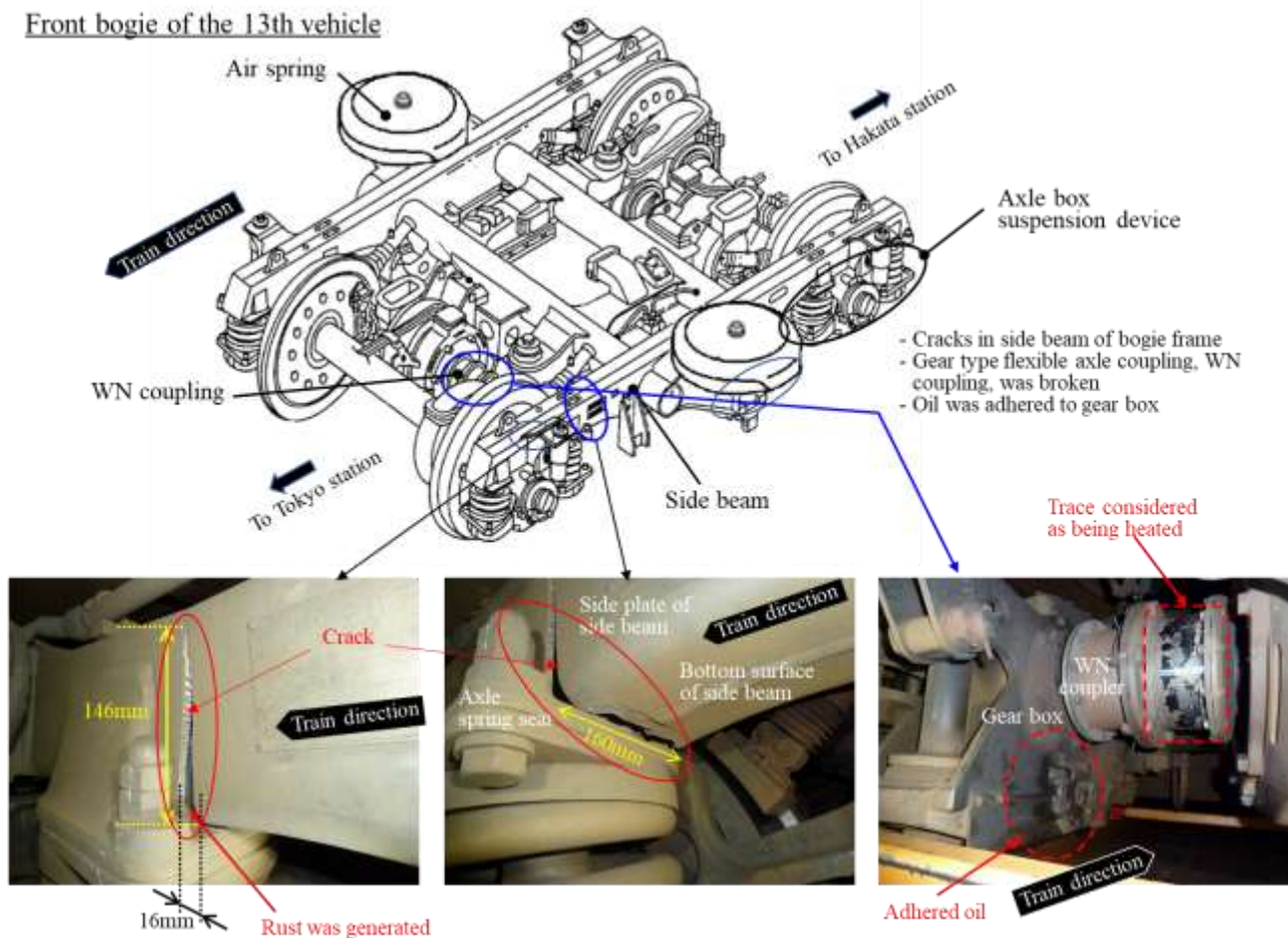
- (i) In order to break away from the exceeding dependence on the manufacturing site, implement the review for the business process such as build up the system that the related section can obtain jointly the points of the design important to secure the quality, and introduce the methods that can make easy to find the problems by standardizing and visualizing the manufacturing works, etc.
- (ii) To prevent troubles from happening, endeavor the reinforcement of the risk management by the management of the changed points in the design and manufacturing stages and pick up the probable problems and implement the beforehand measures thoroughly, in addition to the review of the business process.
- (iii) In order to break away from the exceeding dependence on the manufacturing site, and to strengthen the risk management, promote the reinforcement of cooperation between the related sections.
- (iv) Rearrange the education system in the concerned bogie maker including quality control and safety, and enrich the contents of the education.

Attached Figure 1. Route Map of Sanyo Shinkansen and Tokaido Shinkansen

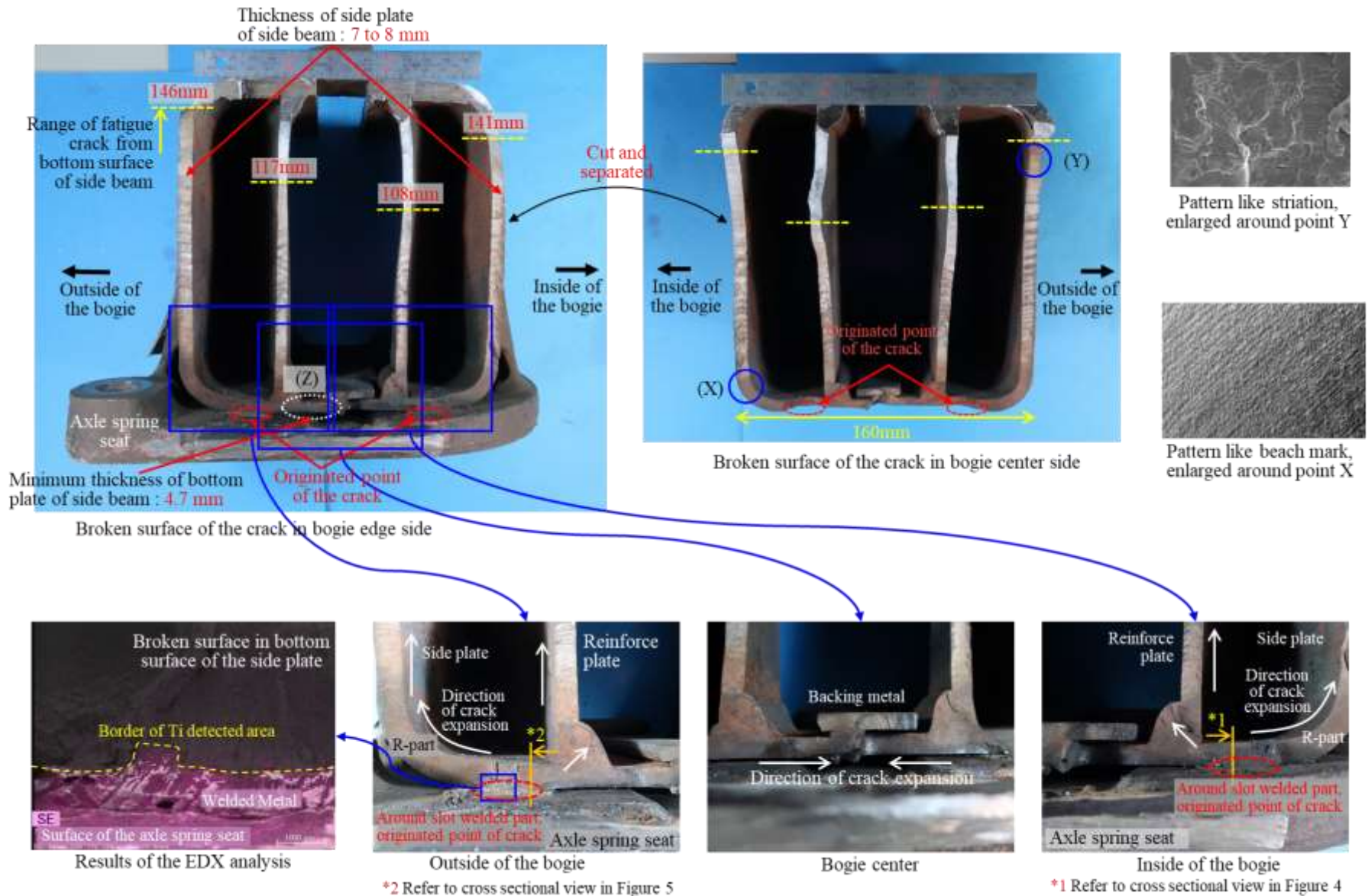
Sanyo Shinkansen : Between Hakata station and Shin-Osaka station, 644.0 km, electrified double track
 Tokaido Shinkansen : Between Shin-Osaka station and Tokyo station, 552.6 km, electrified double track
 Total 1,196.6 km



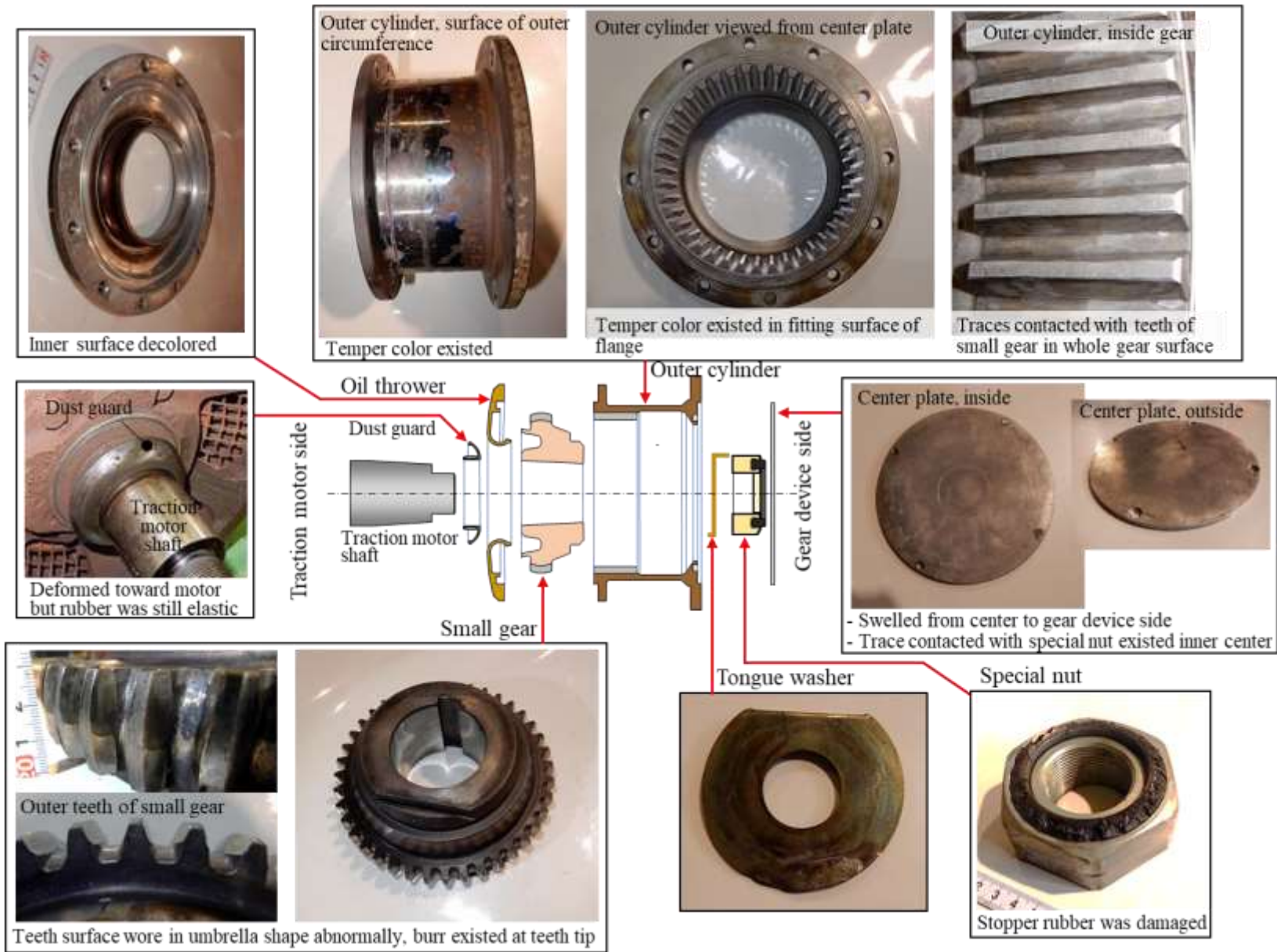
Attached Figure 2. Structures of the Bogie and the Damaged Status



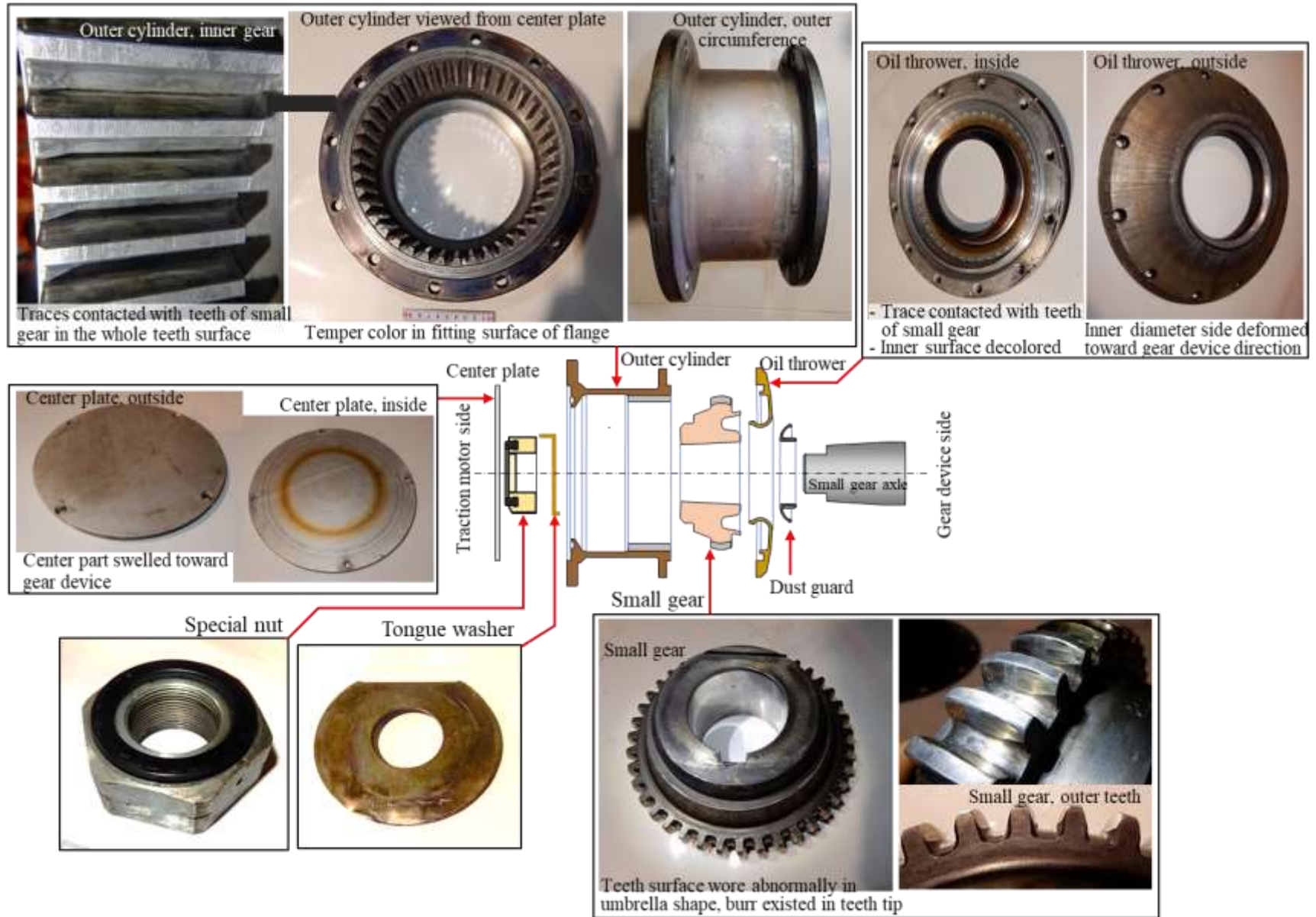
Attached Figure 3. Status of the Broken Surfaces of the Crack



Attached Figure 4. Damaged Status of the Concerned WN Coupling [I]



Attached Figure 4. Damaged Status of the Concerned WN Coupling [II]



Attached Figure 5. Status of Grease inside the Concerned WN Coupling

The concerned WN coupling



A part of accumulated grease



Small gear, motor side



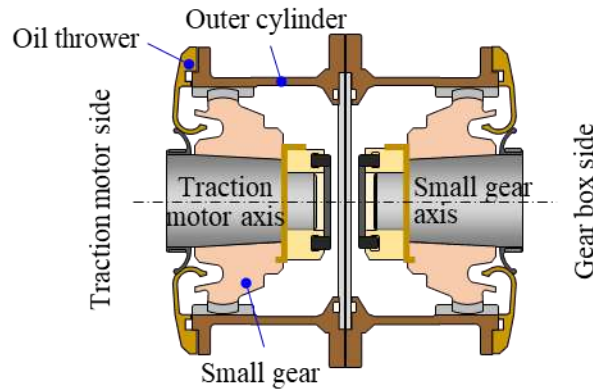
Small gear, gear box side



A part of accumulated grease



Outer cylinder, motor side



Outer cylinder. gear box side

Partly bubbled and hardened as sponge

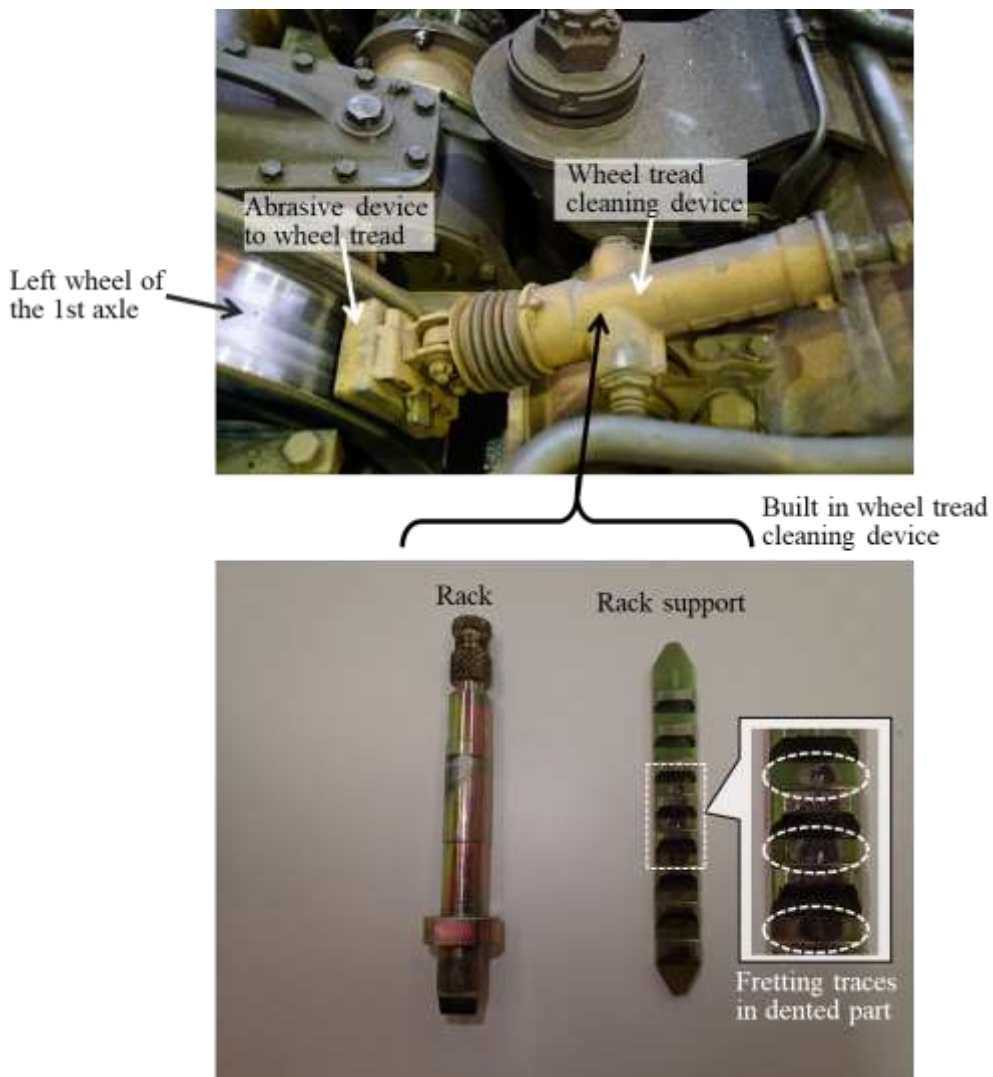
Attached Figure 6. The Traces in the Rim Surface of the Wheels



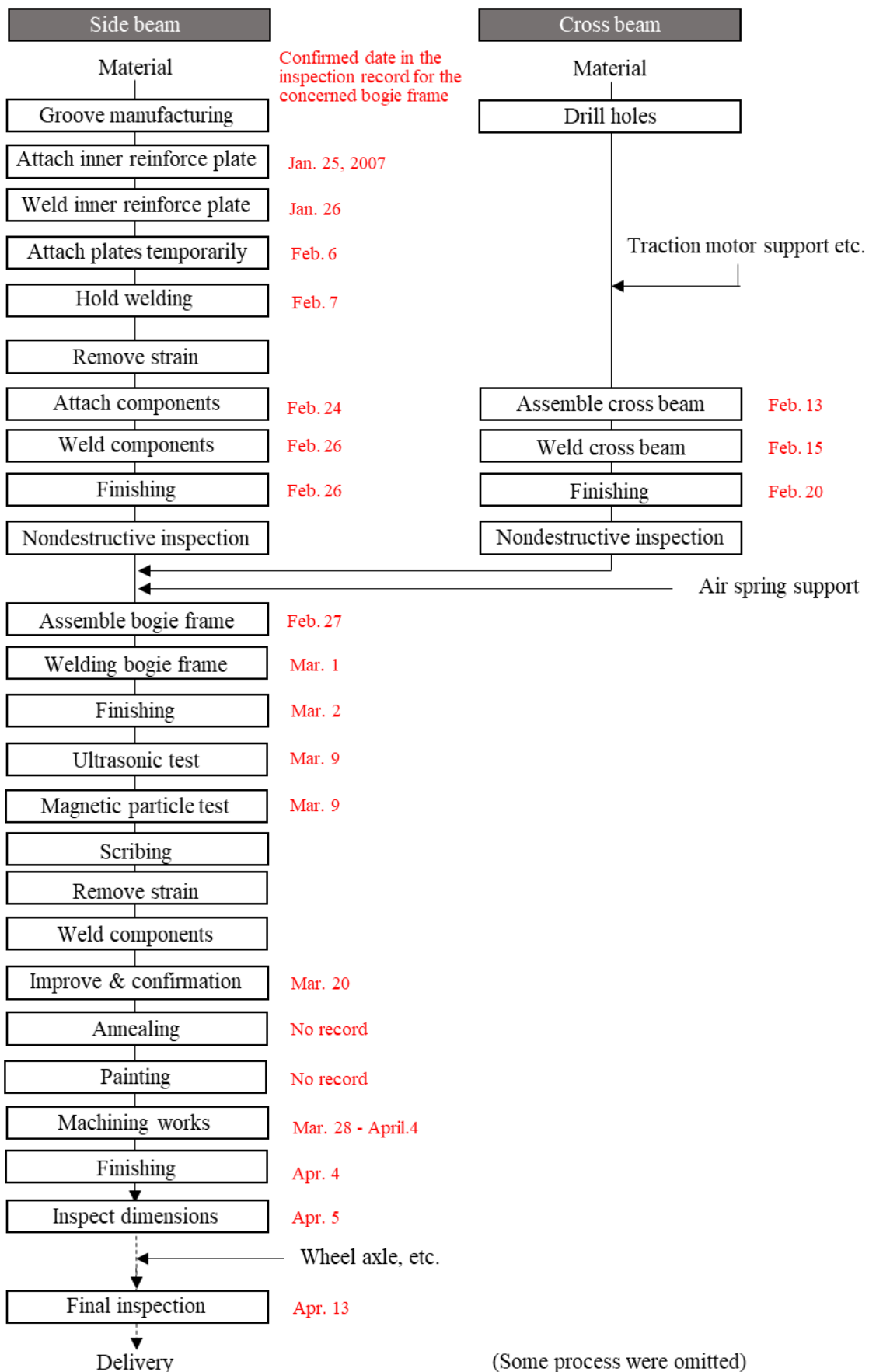
(a) The backside surface of the rim

(b) The right side surface of the rim

Attached Figure 7. The Wheel Tread Cleaning Device and Status of the Inner Rack and Rack Support

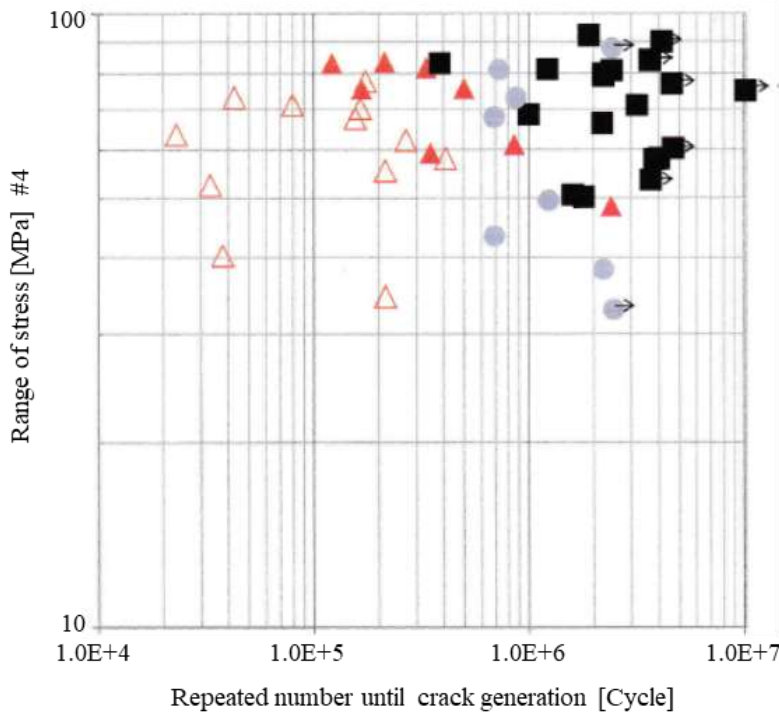


Attached Figure 8. Manufacturing Process of the Bogie Frame



Attached Figure 10. Trends of the Results of the Fatigue Test by the Test Pieces

(a) Relationship between stress range in around slot welded part and life to generate fatigue crack



#1

- ▲ Overlay welded, not used yet, test pieces 1^{#2}, 3^{#2}
- △ Overlay welded, used for about 10 years, test pieces 10, 11, 12^{#2}
- Lack of thickness, test pieces 5, 7
- Normal sample, test pieces 2, 4, 6^{#3}, 8, 9

→ showed the case that test terminated before the fatigue crack had generated from the concerned part

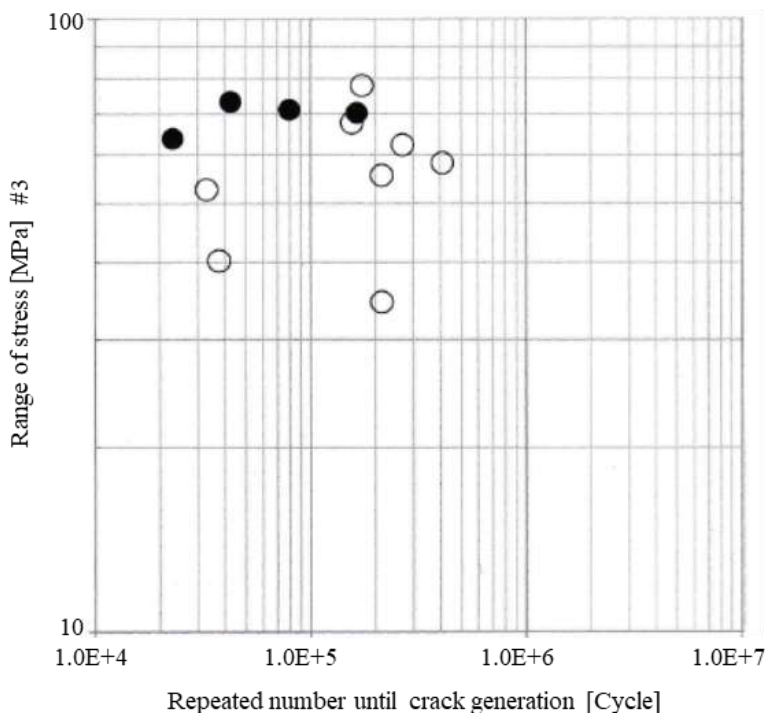
#1 The results for the test pieces not used yet and used for about 10 years were shown in the figure

#2 Test piece 1, 3, 12 were lack of thickness

#3 The data of test piece 6 in the figure was the result for the part without inner defect

#4 The stress was calculated as the strain multiplied by the Young's modulus, *i.e.*, 205,940 MPa

(b) Relationship between stress range in around slot welded part and life to generate fatigue crack, in case of being overlay welded



#1

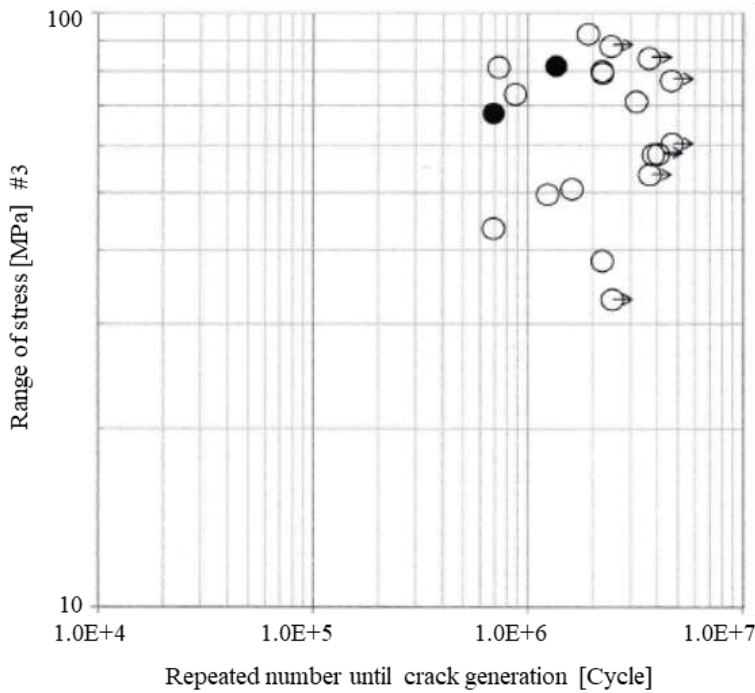
- Inner defects existed^{#2}
- No inner defect

#1 All data in the figure were for the test pieces which were overlay welded and used for about 10 years, test pieces 10 to 12.

#2 Only the slot welded part with the inner defect was defined as inner defect existed, the other part was defined as no inner defect.

#3 The stress was calculated as the strain multiplied by the Young's modulus, *i.e.*, 205,940 MPa

(c) Relationship between stress range in around slot welded part and life to generate fatigue crack, in case of no overlay welded part



#1

● Inner defects existed^{#2}

○ No inner defect

→ showed the case that test terminated before the fatigue crack had generated from the concerned part

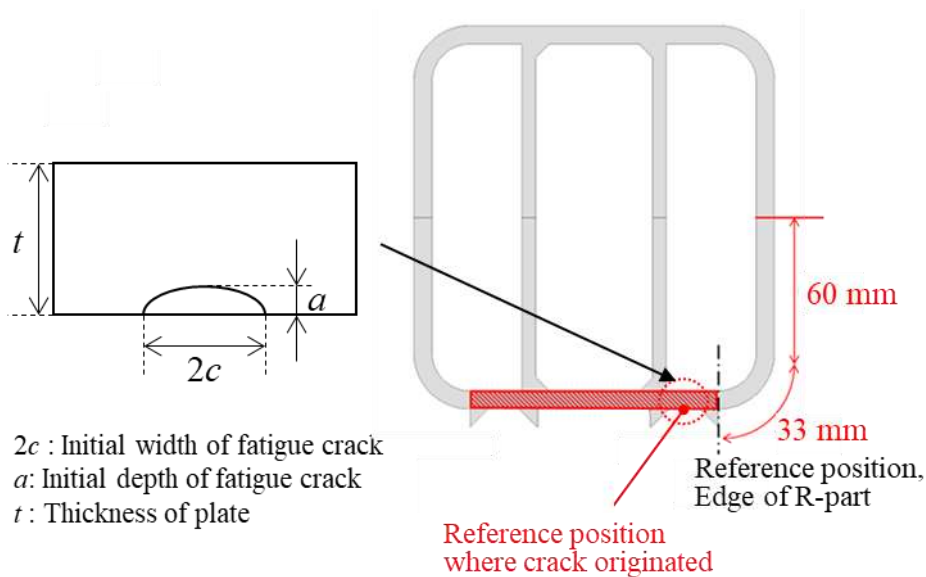
#1 All data in the figure were for the test pieces not overlay welded and used for about 10 years, test pieces 5 to 9.

#2 Only the slot welded part with the inner defect was defined as inner defect existed, the other part was defined as no inner defect.

#3 The stress was calculated as the strain multiplied by the Young's modulus, *i.e.*, 205,940 MPa

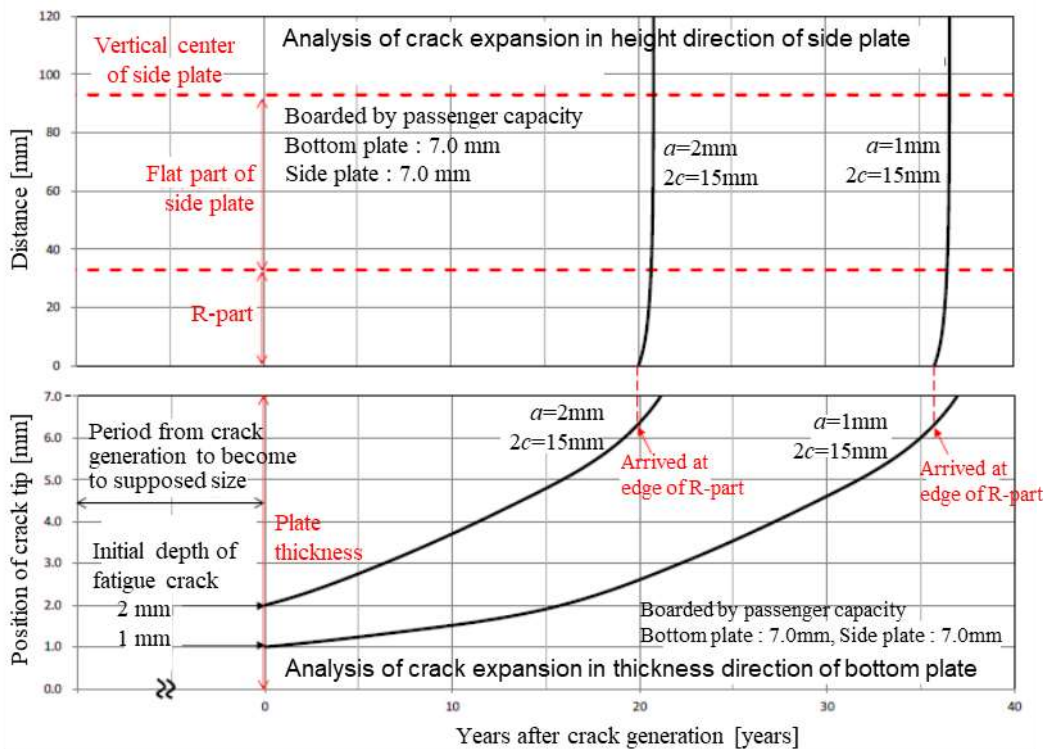
”

Attached Figure 11. Image of Early Stage Fatigue Crack and Reference Point where the Crack had Originated

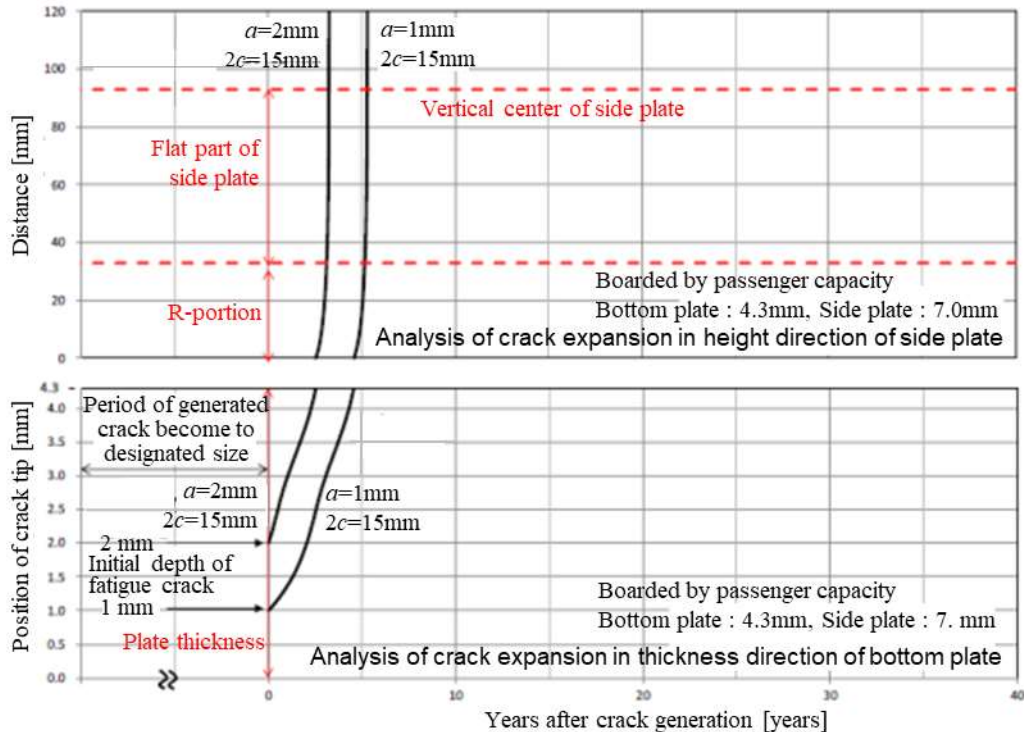


Attached Figure 12. Results of the Simulation Analysis for Expanding Fatigue Crack

(a) Result for the case of 7.0 mm thick lower plate



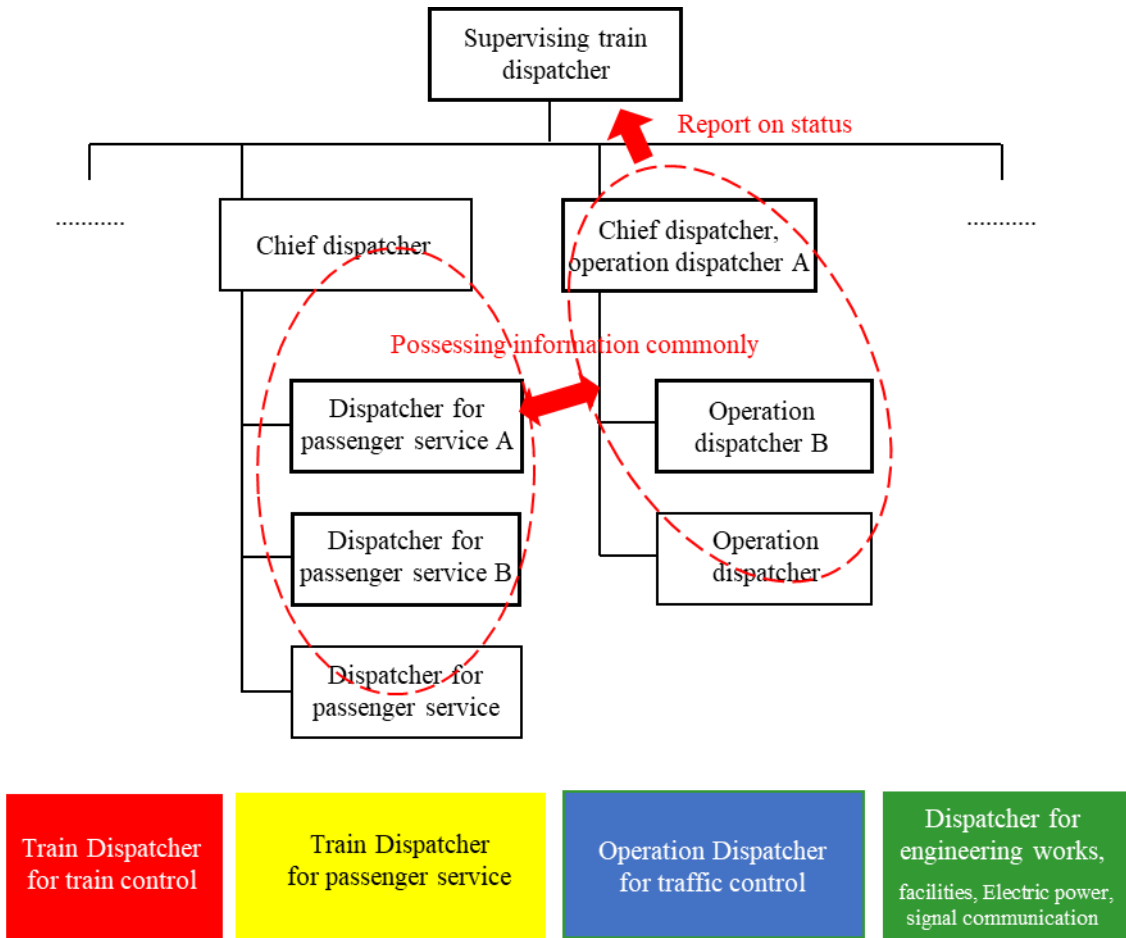
(b) Result for the case of 4.3 mm thick lower plate



* "2c" is the initial width of the fatigue crack, "a" is the initial depth of fatigue crack, in above (a) and (b)

* Years from crack generation was obtained using the stress frequency data measured in the running test using commercial vehicles and converted to the repeated number of loading per year by the average running distance, corresponded to 600,000 km per year.

Attached Figure 13. The Train Dispatching System in The JR West



Attached Material 1. "Inspection Manual for Bogie Frame", extracted, at the time of the occurrence of the serious incident

* The followings are extracted from the Separate Sheet 3 "Inspection manual for bogie frame" in the Separate Volume 3 "Interpretation standard of the notice on the periodic inspection for facilities and vehicles" of the "Interpreting Standards of the Ministerial Ordinance to Prove Technical Regulatory Standards on Railways, etc.", Official Notice from the Director-General of the Railway Bureau, Ministry of Land, Infrastructure, Transport and Tourism, issued on March 8, 2002.

1. On the review of the inspecting method for bogie frame

(1) Process

As the cracks in the bogie frame were found in plural railway operators after October 1998, the investigation on the status of crack generation in bogie frames for the past 10 years for railway operators in the whole country was implemented, then, many cases were reported. Therefore, it was required to measure drastically for the inspecting methods for bogie frames from now on.

To measure this situation, the precise inspection by the magnetic particle test, etc., was implemented for the designated bogies based on the urgent measure "On the Implementation of the Urgent Inspection of the Bogies", Railway Safety No.55, issued on April 8, 2000. In addition, the inspection manual for bogie frame was formulated in order to enable to find cracks in the bogie frame certainly in the important parts inspection and general inspection.

(2) Importance to implement periodic inspection for bogie frames

It had already been made clear that the crack did not expand rapidly because it needs about 1,200,000 km to 1,500,000 km running distance for the crack of about 40 mm, which could be easily detected in the magnetic particle test or the penetrate test, etc., expands to the elastic deformation. [Omitted]

Therefore, it is considered that the serious accident such as the train derailment can be prevented if the small size cracks can be detected and treated, even if the cracks had generated in bogie frame. It is important to inspect the existence of cracks by the method to detect cracks certainly such as the magnetic particle test, etc., in the periodic inspection such as the important parts inspection and the general inspection.

2. Inspection of bogie frames

(1) Designation of the place for prior inspection in bogie frame

Based on the analysis of the data on crack generation in the past, as precise analysis was omitted here, many cracks in bogie frame had generated in the welded part such as the places where spring cap seat and axle spring seat were welded, where side beam was welded, where side beam and cross beam were welded, where traction motor and driving gear were attached, where components were attached, etc. Furthermore, there were the cases that cracks had generated in the place peculiar to each bogie type. Therefore, each railway operator should implement bogie frame inspection by designating the place for prior inspection, considering the characteristics of the bogie

frame structure of each vehicle. Here, the place for prior inspection should be designated referring the "Precedents of Crack Generation in Bogie Frames" described the precedents of the place where crack had generated in the past.

(2) Inspecting method for bogie frame

The inspecting method for cracks in bogie frame in the prior inspecting place should be implemented by the flaw inspection, fundamentally. Here, the visual inspection is allowed as the bogie frame inspection in the case that cracks could be found certainly by removing paint or dirt or the case that the bogie had been implemented special measures indicated in the next paragraph.

Here, it is required to pay sufficient attention on the necessity that the crack inspection method should be determined for each bogie type, because the reliability and durability were different according to the differences in the period when the bogie had designed and manufactured, and the effects by the change of loading conditions accompanied with the increased operating velocity, etc. The precise analysis was omitted here.

(3) The bogie being implemented by the special measures

There are bogies that the following measures had been implemented, in the bogies which were designed and manufactured in the recent years.

- (i) Confirmation of the melted status in the welded joint part, for example, implementation of the ultrasonic test or the X-ray inspection.
- (ii) Removal of the stress concentration due to the improper surface shape in the welded part, for example, implementation of grinder finishing, etc.
- (iii) Confirmation of surface of the welded part, for example, implementation of the magnetic particle test or the penetrate test.
- (iv) The evaluation of the strength in high accuracy. for example, the static loading test with a large number of measuring points.

There was no precedent of crack generation in the bogies which were implemented the measures of above all four items and in the case that the safety, such as strength of bogie, etc., was sufficiently considered from the design and manufacturing stage to the start of commercial operation such as the bogies of the Shinkansen. Therefore, the inspecting method in the important parts inspection and the general inspection can be determined by considering these precedents when it is confirmed that the bogie will not be used in the condition exceeding the designed condition. The precise analysis was omitted here.

[Omitted]

3. Records of the inspection

[Omitted]

4. Others

[Omitted]

Inspection manual for bogie frame

Established on September 7, 2001

Incorporated to the interpreting standards on March 8, 2002

Revised on June 16, 2003

Revised on February 19, 2019

1. Purpose

The purpose of this manual is to prevent the accident, etc., due to the cracks in the bogie frame by prescribing the designation of the prior inspecting place and the inspecting methods, etc., to enable the certain detection of the cracks in the bogie frame by the inspection implemented by the railway operators.

2. On the review of the inspecting method for the bogie frames

(1) Process

As the cracks in the bogie frame were found one after another in plural railway operators after October, 1998, the investigation of the status of crack generation in bogie frames for the past 10 years for railway operators in the whole country was implemented, then, many cases were reported. Therefore, the precise inspection by the magnetic particle test, etc., was implemented for the designated bogies based on the urgent measure "On the Implementation of the Urgent Inspection of the Bogies", Railway Safety No.55, issued on April 8, 2000. Based on the studies implemented after that, the inspection manual for bogie frame was formulated in order to enable the certain detection of cracks in the bogie frame in the important parts inspection and general inspection, on September 2001.

After that, the "Working group to measure the cracks in bogies" was established in the "Study meeting for the measures for the troubles in the railway transport system" in February 2018, responding to the crack generation in the bogie frame which became the serious incident of Shinkansen vehicle which occurred in December 2017, and implemented studying. The study meeting collected measures against cracks in the bogie in July 2018. Based on the collected measures this manual was revised on February 19, 2019.

(2) Importance of the implementation of the periodic inspection for bogie frames

As for the size of the crack generated in the bogie frame, it had already been made clear that the crack did not expand rapidly because it needs about 1,200,000 km to 1,500,000 km running distance for the crack of about 40 mm, to expand in the status of the elastic deformation. Refer to Appended 1, 2.

Therefore, it is considered that the serious accident as the train derailment can be prevented if the small size cracks can be detected and treated, even if the cracks had generated in the bogie frame. It is important to inspect the existence of cracks by the method to detect cracks certainly

such as the magnetic particle test, etc., in the periodic inspection such as the important parts inspection and the general inspection.

3. Inspection of bogie frame

(1) Designation of the prior inspecting place in the bogie frame

Based on the past analysis of the data on crack generation, refer to Appended 3, many cracks in bogie frame had generated in the welded part such as the place where spring cap seat and axle spring seat were welded, where side beam was welded, where side beam and cross beam were welded, where traction motor and driving device were attached, where parts were attached, etc. Furthermore, there were the cases that cracks had generated in the peculiar place for each bogie type. Therefore, each railway operator should implement bogie frame inspection by designating the prior inspecting place, considering the characteristics of the bogie frame structure of each vehicle.

In addition, the prior inspecting place should be designated by considering the following items sufficiently.

- (i) The place where crack was detected, including the incidents in the "precedents of crack generation in bogie frames".
- (ii) The place estimated as necessary in the discussion in the railway operator and the bogie manufacturer based on the information at the time of design stage.
 - The place where the margin for the generated stress against the permitted fatigue stress was smaller.
 - The place considered as fear to become severe situation when a crack expands from the welded part such as included in the "precedents of crack generation in bogie frames", etc.
- (iii) The prior inspecting place designated in the other railway operators.

(2) The inspecting method of the bogie frame

- (i) The inspection for the prior inspecting place should be implemented fundamentally by the flaw inspection, which is the inspection to inspect defects of materials using the physical procedures such as magnetic particle test, penetrate test, ultrasonic test, etc., and by the flaw detecting method prescribed in the Japan Industrial Standard, JIS, or the same level methods.
- (ii) Here, inspection of the prior inspecting place can be implemented by the visual inspection for the place where the certain confirmation can be implemented by removing paints or dirt, except for the place where the margin for the generated stress against the permitted fatigue stress was smaller in the place where considered as fear to become severe situation when a crack expands from the welded part as described in the "precedents of crack generation in bogie frames", etc.

In this case, implement the inspection paying attention to the eye position and good light considering the working conditions referring to the "JIS Z 3090 Method of Visual Inspection for the Fusion Welded Coupling", refer to the Appended 4.

- (iii) The inspecting method for the crack should be determined properly according to the bogie type, etc., because it is considered that reliability and durability of the bogie are different

according to the difference in their designed and manufactured times and there might be affected by the changes of the dynamic load weight due to increased operating velocity, etc., as listed in the followings.

- Change of the static load weight, such as the effects of the considerably increased vehicle body weight due to the remodeling, etc.
- Change of the dynamic load weight, such as increased maximum operating velocity or increased passing velocity in the curved track, etc.
- Effects by the condition of track section used for train operation, such as ballast or slab track, turnouts, status of track maintenance, etc.

(3) Time of the inspection

The bogie frame inspection should be implemented in the periodic inspection, such as the important parts inspection and the general inspection, fundamentally.

(4) The inspecting method for the bogie which the special measures were implemented

When the bogie manufacturer confirmed that the bogie had been implemented the following special measures and the railway operator could certainly confirmed the results, and when it is confirmed that operating condition of the bogies do not exceed the designed condition, the inspecting methods in the important parts inspection and the general inspection can be determined regardless of the regulations indicated in the above paragraph (2).

All of the following special measures should be implemented for "the bogie being implemented the special measures".

- (i) Confirmed the melted status in the welded joint part, for example. implementation of the ultrasonic inspection or the X-ray inspection.
- (ii) Removal of the concentrated stress due to the improper surface shape in the welded part, for example, implementation of finishing by grinding.
- (iii) Confirmation of surface of welded part, for example, implementation of the magnetic particle test or the penetrate test.
- (iv) The evaluation of the strength in high accuracy, for example, the static loading test with a large number of measuring points.

Here, when the bogie structure had been considerably changed from the original structures the inspection should be implemented for the changed part of the bogie structure as the prior inspecting place, even when the above items had been confirmed at the time of designed and manufactured.

(5) The engineers engaged in the inspection

The staffs to implement inspection of bogie frame should possess the sufficient knowledges and skills on the inspections to be implemented.

4. Records and procedures of the inspection

The results of the inspection for the bogie frame should be recorded for the inspected items listed

in the Appended 5. The sample of the procedures of the inspections prescribed for each bogie are shown in Appended 6.

5. Handling for the case of the crack generation, etc.

Study to implement urgent inspection and study to replace or repair the defective products promptly according to the results of the inspection according to the necessity. In addition, study the causes of crack generation and measures preventing recurrence in cooperation with the concerned manufacturer, according to the necessity.

Here, the investigation to review the method and timing of the inspection should be implemented, according to the place and the status of the crack generation. In this case, when there is the fear to generate cracks in the hidden place, the implementation of the ultrasonic inspection should be studied.

6. Others

The maintenance should be implemented considering the proper management of the wheel tread to prevent the thermal effects due to remove paints using gas burner and the exceeding stress to the bogie frame.

Appended 1. Sample of the change of fatigue crack length in the side beam accompanied with running distance.

Appended 2. Sample of the simulation of crack expansion in the side beam of the bogie frame.

Appended 3. Parts where the crack had broken out in 10 years.

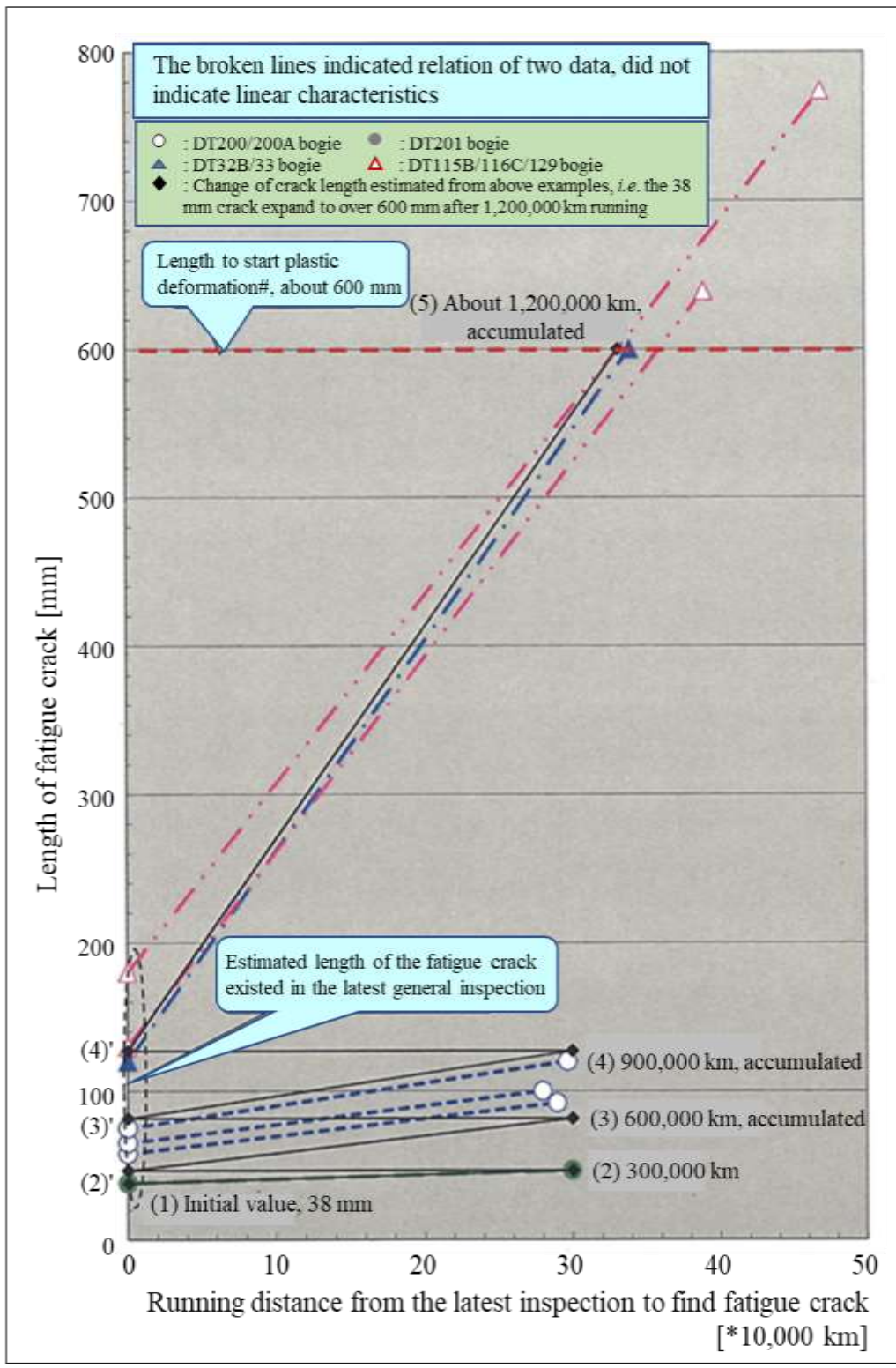
Appended 4. Methods of the Visual Inspection.

Appended. Items for inspection records for bogie frames.

Appended. Sample of inspecting procedures for bogie frame.

Appended 6. Separate Sheet. Sample of the check sheet for inspection of bogie frame.

Change of fatigue crack length in side beam accompanied with running distance, sample



"Length to start plastic deformation" is the length that the fatigue crack expanded to the plastic deformation and corresponded with about 70 % of the circumference of the side beam.

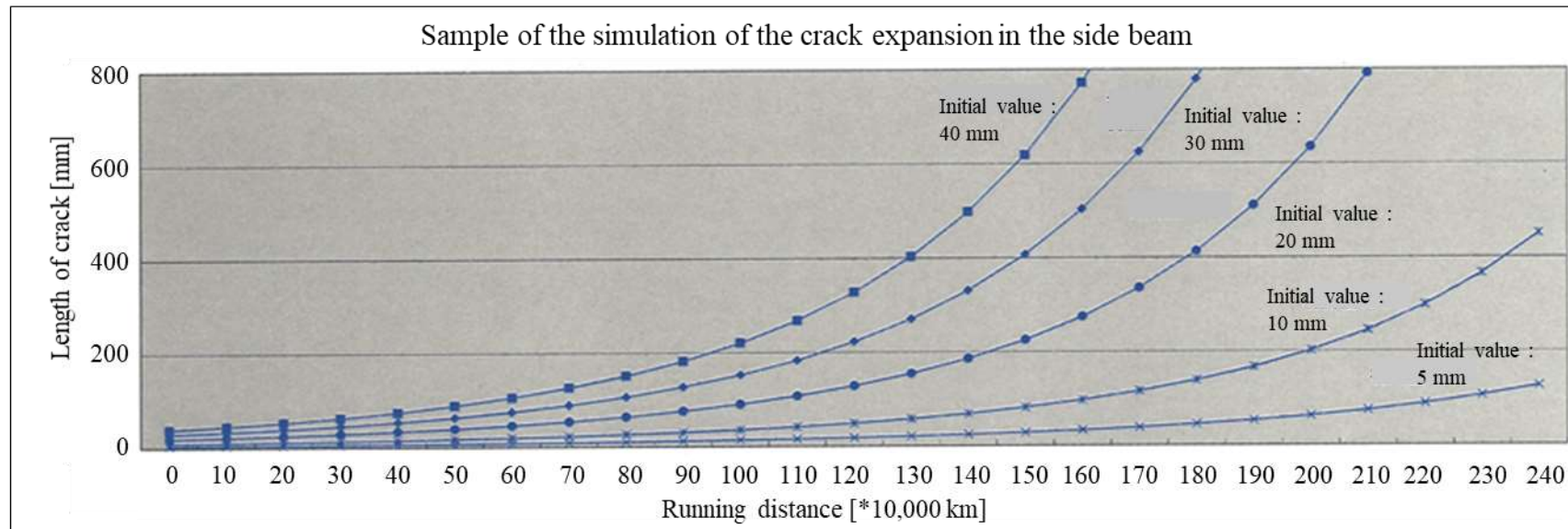
Reference : T. Nagase, "Strength and maintenance of the welded bogie frame", p.18, Kenyusha, 1999, in Japanese.

○ Sample of the simulation of the crack expansion in the side beam of the bogie frame

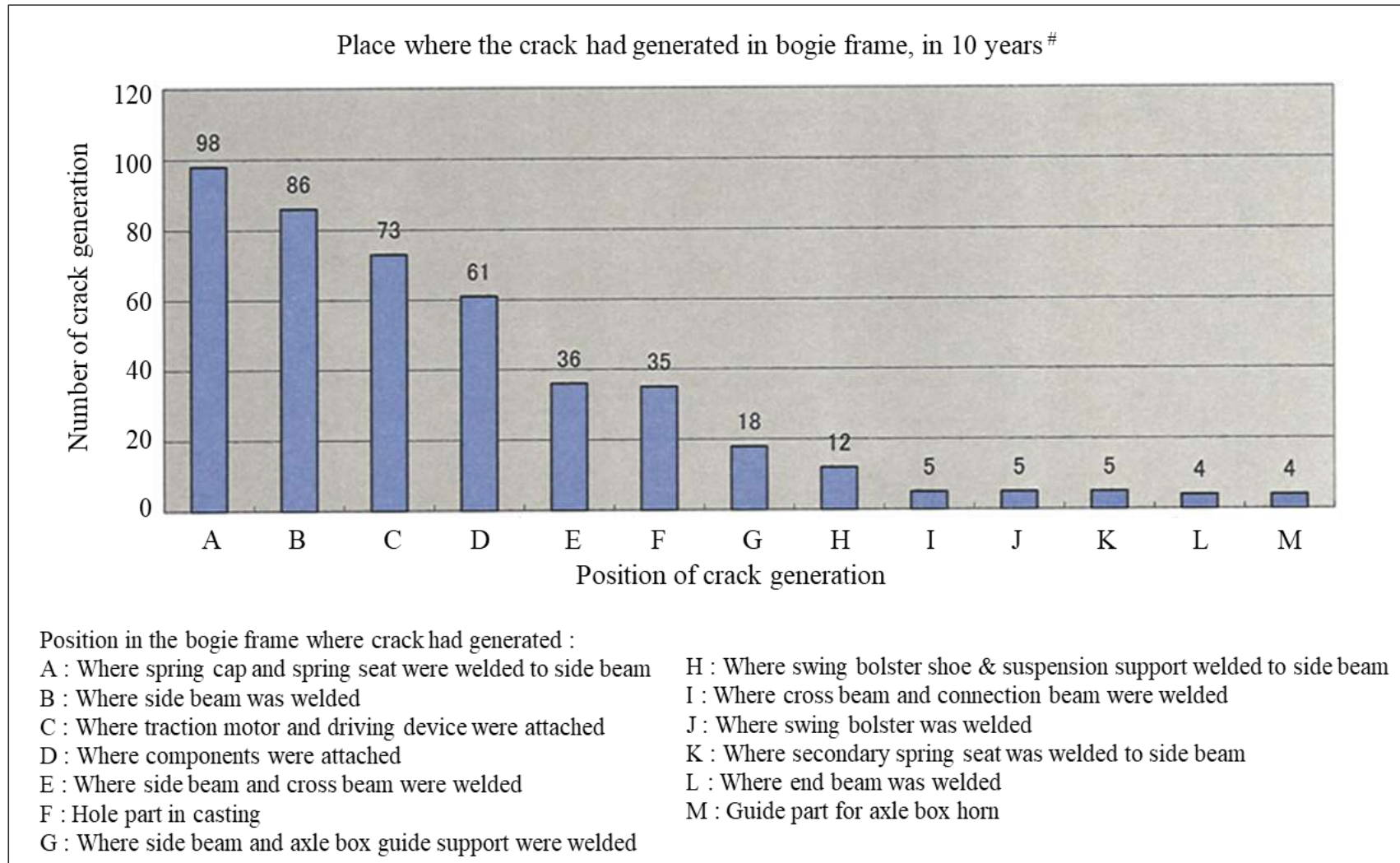
Initial value
↓

Running distance	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
5.0	5.5	6.1	6.8	7.5	8.4	9.4	10.5	11.8	13.4	15.1	17.2	19.6	22.4	25.7	29.6	34.3	39.8	46.3	54.2	63.6	75.0	88.8	105.5	126.0	
10.0	11.2	12.7	14.3	16.2	18.5	21.1	24.2	27.8	32.1	37.2	43.3	50.5	59.2	69.7	82.3	97.7	116.4	139.3	167.5	202.3	245.5	299.2	366.6	451.3	
20.0	22.9	26.3	30.3	35.0	40.7	47.4	55.5	65.2	76.9	91.1	108.3	129.4	155.3	187.2	226.7	275.9	337.3	414.4	511.7	635.0	792.1	-	-	-	
30.0	34.7	40.3	46.9	54.9	64.5	76.0	90.0	107.1	127.9	153.4	184.9	223.8	272.2	332.7	408.6	504.3	625.7	780.2	-	-	-	-	-	-	
40.0	46.6	54.5	64.0	75.5	89.3	106.2	126.8	152.1	183.3	221.9	269.8	329.7	404.8	499.5	619.6	772.4	-	-	-	-	-	-	-	-	

Exceeded the length to start elastic deformation, 600 mm



According to the result of the simulation, over 1,500,000 km train running is required for the 40 mm long crack expand to the plastic deformation, about 600 mm. Here, the simulation was based on the results in the time when the inspection manual for the bogie frame was decided.



Calculated based on the data investigated to decide the inspection manual for bogie frame, in April, 2000.

Methods of the Visual Inspection

The visual inspection of the bogie frame should be implemented referring the following method of the appearance test of the fusion welded coupling, JIS Z 3090.

JIS Z 3090 Methods of the appearance test of the fusion welded coupling, extracted.

4. Conditions and tools for the testing

- (a) The brightness of the tested surface should be 350 lx in minimum. Here, 500 lx is preferable.
- (b) When the test is implemented visually, bring the face close to the tested surface as the position of eyes are within 600 mm distant and over 30 degrees from the tested surface, then implement the observation, as shown in Figure 1.

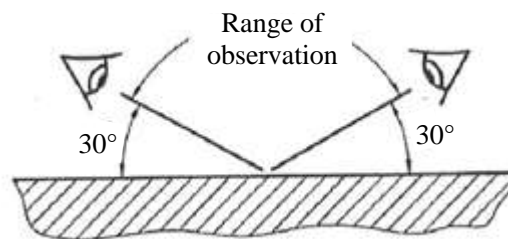


Figure 1. Observation of the tested surface

- (c) When the observation could not be implemented in close position as shown in Figure 1 or the observation was prescribed in the product standard or the applied standard as to use some tools, the observation should be implemented from the distant position using mirrors, bore scope, fiberscope, cameras, etc.
- (d) It is allowed to add light sources to increase contrast between the imperfect part and the others.
- (e) When it could not be judged by the result of the appearance test, it is desirable to add another non-destructive inspection.
- (f) The sample of the tools using in the appearance test are shown in Annex 1.

5. Engineers for the inspection : The engineers for the inspection should have basic knowledge on the required test items, and the knowledges and experiences required to the properties of the mother material and the welded coupling, the method of welding works, the applied standards and specifications, the performance and using method of the measuring devices, etc.

6. Category of the tests : The appearance test is composed of the visual inspection and the measuring inspection. The shapes, defects, etc., should be confirmed visually for the welded coupling and its surroundings by the visual inspection. If it is needed, the auxiliary tools prescribed in Number 1 in the Annex 1 should be used. The measuring inspection is the test to measure the shapes, defects, etc., of the coupling using the measuring instruments prescribed in Number 2 in the Annex 1.

The above material is the extracted JIS protected by the Copyright Act.

Items for inspection records for bogie frames

The inspected records for bogie frames should be recorded for the following items.

- (1) Number of the vehicle
- (2) Category of the inspection, *i.e.*, general inspection, important parts inspection, status and function inspection, etc.
- (3) Implemented date of the inspection
- (4) Running distance of the concerned bogie till the crack was found, *i.e.*, running distance from newly produced and running distance from the latest inspection.
- (5) Bogie types
- (6) Manufacturer of the bogie
- (7) Product number or the management number of the bogie
- (8) Date of manufactured bogie
- (9) Inspection method, such as magnetic material inspection, penetrate test, visual inspection, etc.
 - * When different inspections are applied to the tested positions, write it on the sheet.
- (10) Results of inspections
- (11) Place of the crack generation
- (12) Length and depth of the crack
- (13) Photographs, sketch, etc., which could identify shapes, dimensions and place of the crack generation.
- (14) Contents of the measures for the crack.
- (15) The other remarks.

Sample of inspecting procedures for bogie frame

1. Fixing bogie frame

- Fix the bogie frame to the designated position.

2. Removal of paints and dirt in around the inspected part

- Remove the painted film in around the inspected point in the bogie frame using jet graver



Exfoliating works in around inspected place in the bogie frame

3. Inspection

- Implement inspection whether the crack had generated by the magnetic particle test or the visual inspection prescribed in this manual, for the prior inspecting place prescribed for each bogie type.
- Implement inspections using the appended check sheet.

4. Records of the inspected results

- Write down the inspected results in the predetermined sheet for inspection records.

Separate sheet

Sample of the check sheet for inspection of bogie frame

<p>Outside of No.1 position in side beam</p>	<p>View from No.1 position in side beam</p>		Vehicle No.	○○○-○○○○		
	<p>View from No.2 position in side beam</p>		Category of inspection	General inspection		
	<p>[Remarks]</p>		Date of inspection	Date	Month	Year
			Bogie	Type	DT○○	
Maker				○○ Company		
Product No. Manage No.	○○○○○					
Date of production	Month, Year					
Inspecting method for prior inspecting place	<p> <input type="checkbox"/> : Magnetic particle test <input type="checkbox"/> : Visual inspection </p>		Name of the inspector			
		○○ ○○				
Check 1	Check 2	Check 3				
Date Month:	Date Month:	Date	Month:	Date	Month:	