RA2019-1-II

RAILWAY ACCIDENT INVESTIGATION REPORT

Train Derailment Accident between Tarui station and Ozaki station of the Nankai Line of Nankai Electric Railway Co., Ltd.

January 31, 2019

Japan Transport Safety Board

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

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 Accident Investigation Report

Railway operator :	Nankai Electric Railway Co., Ltd.
Accident type :	Train derailment
Date and time :	About 16:40, October 22, 2017
Location :	At around 42,439 m from the origin in Namba station, between Tarui station and Ozaki station, double track, Nankai Line, Hannan City, Osaka Prefecture

January 8, 2019

Adopted by the Railway Committee, the Japan Transport Safety Board

Chairman	Kazuhiro Nakahashi
Member, Chair	Fuminao Okumura
Member	Hiroaki Ishida
Member	Toshiyuki Ishikawa
Member	Miyoshi Okamura
Member	Miwako Doi

SYNOPSIS

SUMMARY

On October 22, 2017, the outbound Local 6867 train, composed of 4 vehicles started from Namba station bound for Wakayamashi station, Nankai Line of Nankai Electric Railway Co., Ltd., departed from Tarui station on schedule at 16:38. While the train was operated in coasting at about 70 km/h on Onosatogawa bridge, the driver of the train noticed that the track about 50 m ahead had sagged, and applied the brake immediately but the train passed the sagged track and stopped after running for about 250 m.

It was found in the investigation implemented after the occurrence of the accident, that the 2nd axle in the rear bogie of the 3rd vehicle of the train derailed to right on Onosatogawa bridge, and restored after that.

In addition, the pier No.5 of the down track of Onosatogawa bridge had been subsided and tilted, and the track had been sagged and wound.

There were about 250 passengers and 2 train crews, *i.e.*, the driver and the conductor, onboard the train, among them 5 passengers were injured.

Here, it had been raining in wide area in the southern area of Osaka Prefecture including the

accident site, as the front crossed the southern coast of the main island of Japan was activated by the Heisei 29th year Typhoon No.21 which was moving northward in south of Japan, on the day of the occurrence of the accident.

PROBABLE CAUSES

It is highly probable that the accident occurred as the 2nd axle in the rear bogie of the 3rd vehicle had derailed to right because the train was running on the track on the bridge significantly deformed by the subsided and tilted pier, after that, the derailed axle restored in the level crossing while passed as being derailed.

It is probable that the pier had subsided and tilted because the ground in around the pier was scoured in wide area by the swollen river water at the time of the occurrence of the accident, while the function to protect the piers from scouring had already been deteriorated before the occurrence of the accident, such as the subsided riverbed in around the pier caused by the concentration of the river water due to the change of the water route, damages of the foot protection as the scour protection work, etc.

It is probable that the deterioration of the function to protect scouring was related with that the measures such as the repair, reinforcement, etc., of the foot protection were not implemented, because the evaluation for the unusual status were not implemented sufficiently, even though the unusual status of the foot protection of the pier was recognized in the inspection of the piers.

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Attached Materials

1. PROCESS AND PROGRESS OF THE RAILWAY ACCIDENT INVESTIGATION

1.1. Summary of the Railway Accident

On Sunday, October 22, 2017, the outbound Local 6867 train, composed of 4 vehicles started from Namba station bound for Wakayamashi station, Nankai Line of Nankai Electric Railway Co., Ltd., departed from Tarui station on schedule at 16:38. While the train was operated in coasting at about 70 km/h on Onosatogawa bridge, the driver of the train noticed that the track about 50 m ahead had sagged, and applied the brake immediately but the train passed the sagged track and stopped after running for about 250 m.

It was found in the investigation implemented after the occurrence of the accident, that the 2nd axle in the rear bogie of the 3rd vehicle of the train derailed to right on Onosatogawa bridge, and had restored after that. Hereinafter, the words "front", "rear", "left" and "right" are used based on the running direction of the train.

In addition, the pier No.5 of the down track of Onosatogawa bridge had been subsided and tilted, and the track had been sagged and wound.

There were about 250 passengers and 2 train crews, *i.e.*, the driver and the conductor, onboard the train, among them 5 passengers were injured.

Here, it had been raining in wide area in the southern area of Osaka Prefecture including the accident site, as the front crossed the southern coast of the main island of Japan was activated by the Heisei 29th year Typhoon No.21 which was moving northward in south of Japan, on the day of the occurrence of the accident.

1.2. Outline of the Railway Accident Investigation

1.2.1. Organization of the Investigation

At the beginning of the investigation, the accident was considered as the railway accident with casualty prescribed in Item 6, Paragraph 1, Article 3 of the "Ordinance on Reporting on Railway Accidents, etc., Ministerial Ordinance No.8 prescribed by the Ministry of Transportation, 1987", in addition, the train ran on the inclined bridge. Then, the Japan Transport Safety Board, *hereinafter abbreviated as "the JTSB"*, decided to start investigation as the accident was the "particularly rare and exceptional status" prescribed in Item 3, Article 1 of the "Ordinance for Enforcement of the Act for Establishment of the Japan Transport Safety Board, Ministerial Ordinance No.124 prescribed by the Ministry of Land, Infrastructure, Transport and Tourism, 2001". *Hereinafter the Ministry of Land, Infrastructure, Transport and Tourism was abbreviated as "the MLIT".*

The JTSB designated the chief investigator and the railway accident investigator to engage the investigation of the concerned accident on October 23, 2017. In addition, two railway accident investigators were designated additionally on November 6, 2017.

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

After that, as it was found that the train had been derailed, the category of the concerned accident was changed to the train derailment prescribed in Number 2, Clause 1, Article 3 of the "Ordinance on Reporting on Railway Accidents, etc.", on November 22, 2017.

As it is somewhat likely that the subsidence of the pier due to being scoured*1 was related to the concerned accident, the JTSB appointed the professional member to engage in the investigation of the concerned accident, and designated the professional area to be investigated as the analysis on the mechanism of subsidence of the pier, prevention of weather disaster, prevention of ground disaster, geology, etc., as shown in Table 1.

In addition, the JTSB dispatched the Board members, the professional member, the railway accident investigators to the accident site, etc.

The JTSB entrusted the analysis on the effects by the water flow of river to the piers and the mechanism to cause the subsidence of the pier, etc., in the investigation of the concerned accident, to the Railway Technical Research Institute.

*1 *"Scour" is the phenomena that the riverbed in around the piers were washed away deeply affected by the water flow.*

Table. 1 The professional member and the professional area to be investigated

Affiliation	Title	Name	Professional area to be investigated
Railway Technical Research Institute	General Manager, Disaster prevention Technology Division	N. Ohta	Analysis on the mechanism of subsidence of the pier, prevention on weather disaster, prevention on ground disaster, geology, etc.

1.2.2. Implementation of the Investigation

Oct. 23 to 25, 2017 — On-site investigation, vehicle inspection, and hearing statements
Oct. 27, 2017 — On-site investigation
Nov.15, 2017 to March 16, 2018 — Entrusted investigation
Nov.16 to 17, 2017 — On-site investigation, vehicle inspection, and hearing statements
Dec.13 to 14, 2017 — On-site investigation
Jan.19, 2018 — On-site investigation, and hearing statements
July.11 to 12, 2018 — On-site investigation

1.2.3. Comments from Parties Relevant to the Cause

Comments from parties relevant to the cause were invited.

2. FACTUAL INFORMATION

2.1. Process of the Train Operation

According to the statements of the driver, the conductor, and the boarded passenger of the outbound Local 6867 train, started from Namba station bound for Wakayamashi station, Nankai Line of Nankai Electric Railway Co., Ltd., and the records of the operating status of the train, summary of the process to the accident was as follows. *Hereinafter, the driver, the conductor, the passenger, the 6867 train, and Nankai Electric Railway Co., Ltd., were referred to as "the concerned* *driver", "the concerned conductor", "the passenger A", "the concerned train" and "the company", respectively.*

2.1.1. Statements of the Train Crews, etc. *[Refer to Attached Figures 1, 2 and 3]*

(1) The concerned driver

I started the operation of the concerned train from Namba station. There was no report on abnormal situation when I was transferred from the former driver of the concerned train, and I did not feel any abnormal status in the train operation until to the occurrence of the concerned accident.

I had received the instruction to operate the train paying attention as the typhoon was approaching, in the roll call before started my duties.

The concerned train departed from Namba station on schedule at 15:13. When the concerned train crossed Yamato river and Ohtsu river, I felt that the water flow of the river had been swollen compared to the usual status. I had operated the wiper because it was rain.

After that, the concerned train departed from Tarui station, located at 40,918 m from the origin in Namba station, *hereinafter "from the origin in Namba station" was omitted*, on schedule at 16:38, and passed the upgrade track and right curved track existed before Onosatogawa bridge, located between 42,354 m and 42,447 m, *hereinafter referred to as "the concerned bridge"*. When the concerned train started to cross the concerned bridge at the velocity of about 70 km/h, I found that the track about 50 m ahead had been sagged significantly and wound to leftward. I stood up in an instant and applied the emergency brake, at the same time, I felt as my body had dropped and felt the violent rolling motion and the impact accompanied with the sound as "dong". After that, the concerned train stopped after running for about 200 m.

After the concerned train stopped, I reported to the operation dispatcher using the train radio that the track had been sagged and wound, the concerned train had passed though there and stopped, and I would go to check the situation of the track from now on.

After I had reported to the operation dispatcher, I received the report from the concerned conductor by the on-train intercom that the concerned conductor had operated the train protection radio.

I got off the concerned train and went to the edge of the concerned bridge together with the concerned conductor, and checked the situation of the track and found that the sagged level of the track was considered a little larger than that I had found when the concerned train passed there.

I returned to the train and reported again to the operation dispatcher that the track had been sagged and wound, and communicate that I would inspect the vehicles from now on.

I got off the vehicle and checked underfloor of the vehicles. As the vehicles had not derailed but the skirt[*2] in front of the 1st vehicle had been deformed a little, then I reported it to the operation dispatcher.

After that, I implemented the braking test of the concerned train, but the brake could not be released. Then I reported it to the operation dispatcher, and I was instructed to implement guidance for evacuation of the passengers. Then, I guided passengers to the 1st vehicle and implement guidance for evacuation of the passengers in cooperation with the company staffs who were rushed from Ozaki station, located at 43,392 m. The passengers evacuated to the neighboring level crossing or Ozaki station, being guided by the company staffs.

After evacuation of the passengers had completed, the staffs engaged in the inspection of vehicles arrived and implemented the measures to release the brake. After that, I operated to move the concerned train to Ozaki station, obeyed to the instruction to resume train operation from the operation dispatcher.

*2 *"Skirt" is the cover attached to lower part of the bogie frame along the front head or the side surface, to protect the devices mounted on underfloor of the locomotive or the passenger cars or to fix the shape of the vehicle.*

(2) The concerned conductor

I started the duty of the concerned train from Namba station, I did not feel any abnormal situation until to the accident site. It rained all the time on the day of the occurrence of the accident, but its strength was varying.

After the concerned train departed from Tarui station, while I was working in the conductor's cabin in the rear part of the 4th vehicle, the vehicle suddenly sank and there was the shock as the standing my body shook and blew to leftward. I checked the backward of the train after the shock and found that the track had been dented and wound. As the concerned train seemed to be acted by the brake already, I operated the train protection radio when the concerned train seemed as almost stopped.

After the concerned train stopped, I checked the cabin from the conductor's cabin and found that the passengers in the cabin were not confused as there was a little stirred.

The concerned driver reported to the operation dispatcher using the train radio after the concerned train had stopped. After that, I was asked from the concerned driver by the on-train intercom about the situation of the concerned bridge, I checked the dented status of the concerned bridge from the conductor's cabin and reported it.

After a while, the concerned driver came to the conductor's cabin in the 4th vehicle. As he told me that he would go to check the situation of the concerned bridge, I decided to go together with him. We went to the edge of the concerned bridge and confirmed the situation that the track had been sagged and wound toward upstream direction.

We returned to the concerned train and reported to the operation dispatcher using the train radio that the track had been sagged and wound. I told the passengers using the public announcing device that there was the trouble in the track and announced that "If there was injured person, please declare it", then I patrolled back and forth in the concerned train and checked the status of existence of the injured persons.

After returned to the conductor's room in the 4th vehicle, I received the instruction from the operation dispatcher to guide the passengers for evacuation, because the concerned train could not be moved as the brake could not be released. As I was informed that the staffs of Ozaki station and the company staffs would be dispatched to implement the guidance for evacuation of the passengers, I asked the passengers to move to the 1st vehicle and wait for the arrival of the support team.

After the support team had arrived, I took off the long seat in the 1st vehicle and set it as the slope from the 2nd door from the front in right side of the 1st vehicle to the outside of the vehicle, and let the passengers get off the vehicle as being supported by the station staffs. As for the persons who could get off from the door in the driving cab in the 1st vehicle, I guided them to get off the train from the door for train crews using the ladder.

(3) The passenger A

I had boarded on the concerned train from Namba station and sat in the rear most seat in the 3rd vehicle. It had been heavy rain while I was boarding on the concerned train. Almost all the persons had been seated but several persons were standing in the cabin.

While the concerned train was passing the concerned bridge, I had been sitting edge of the seat and twisted my body to look at the surface of river water in the upstream. The status of the river was that the beaches along the river were submerged under water and the river seemed to overflow its dikes if the water level rises about 1 m higher. As I had been watched Onosato river for a long time, the river water usually flows as trickled.

When the concerned train passed through the concerned bridge, there was the impact as "clunk" and felt to roll laterally, after that, there was the sound as some metals are scrubbing such as "rat-tat-tat". When I felt the impact, I was thrown out from the seat and hit my left buttock against the floor. When I looked around, the person who had been sitting in my opposite seat had also thrown out from the seat to the floor.

After the concerned train had stopped, the conductor patrolled in the cabin and check the existence of the injured persons.

After a while, there was the announcement that the crews would guide the passengers for evacuation to outside of the train because the concerned train could not be moved. I got off the train from the door for the train crew in the 1st vehicle, and walked the track of the up track, and went out of the track from the level crossing.

2.1.2. Records of the Operating Status

The device to record the operating status, *hereinafter referred to as "the operating status recording device"*, was equipped in the concerned train. The device has the functions to record the information such as time, velocity of the running train, running distance, braking operation, etc. According to the records in the device, summary of the operating status of the concerned train at the occurrence of the concerned accident were as shown in Table 2.

The velocity of the running train and the running distance were the values calculated from the rotating speed of the 1st axle in the rear bogie of the 1st vehicle, and the running distance was the distance between the position of the front head of the train and the departed point in Tarui station.

The time information was the value compensated to the actual time, but the information of the running velocity of the train and the running distance had the possibility to include some errors because they were not the compensated values. In addition, the kilometerage of the 2nd axle in the rear bogie of the 3rd vehicle was the value calculated from the information on the running distance recorded in the operating status recording device and the drawings of the vehicle in the concerned train, as the stopped position of the front head of the concerned train described in the following 2.3.1.3, was treated as the standard.

It is highly probable that the time of the occurrence of the derailment in the concerned accident was about 16:40, based on the analysis described in the following "3.2. Analysis on the Time of the Occurrence of the Derailment".

Table 2. Summary of the Operating Status

Time	Velocity of the Running train [km/h]	Running distance [m]	Normal brake #1	Emergency brake #1	Kilometerage, *i.e.*, position of the 2nd axle in the rear bogie of the 3rd vehicle	Remarks
16:40:35	68.95	1,548.2	1	0	Around 42,360 m	Normal brake operated
16:40:38	68.84	1,608.8	1	0	Around 42,421 m	Around the most dented place #2
16:40:39	66.41	1,624.8	1	0	Around 42,437 m	Start point of the derailment #3
16:40:40	64.25	1,641.2	1	0	Around 42,453 m	Restored place #3
16:40:57	0	1,800.8	1	0	Around 42,613 m	Stopped

#1 *"1" in the normal brake and emergency brake columns indicated that the instruction of these brakes was issued.*

#2 *The kilometerage of "the most dented place" was the position described in the following 2.4.1.1 (1).*

#3 *The kilometerage of the "Start point of the derailment" and the "Restored place" were the position described in the following "3.1 Analysis on the derailment".*

Here, according to the company, the company judged that the concerned train had derailed once and restored after running for a while, because there were the flaws in right and left wheels of the 2nd axle in the rear bogie of the 3rd vehicle, the damages on the track, and the linear traces on the top surface of the rails in around the accident site.

The status of damages and the traces of the tracks and the vehicles are described in the following 2.4.1 and 2.4.2, respectively.

2.2. Injuries to Persons

There were about 250 passengers and 2 train crews, *i.e.*, the driver and the conductor, boarded on the concerned train. Among them, 5 passengers were slightly injured.

Two persons in the 1st vehicle, a person in the 2nd vehicle and two persons in the 3rd vehicle, boarded in around the rear part of each vehicle, were injured.

2.3. Information on the Railway Facilities and Vehicles, etc.

2.3.1. Information on the Accident Site

2.3.1.1. Outline of the topography, etc. *[Refer to Attached Figure 2]*

The accident site was located on the western edge of the Osaka Plains, and the Osaka Bay and the Izumi Mountains are expanded in northward and southward, respectively. The concerned accident occurred on the concerned bridge crossing the Onosato river which flows from the Izumi

Mountains into the Osaka Bay. The concerned bridge was located at about 1 km upstream from the estuary of Onosato River.

2.3.1.2. The track shape and the operating velocity *[Refer to Attached Figures 2 and 3]*

The accident site was located between Tarui station and Ozaki station of Nankai Line.

The track shape in around the accident site was straight and horizontal section. There was the compound right curved track[*3] of 610 m and 1,250 m radiuses from 41,740 m to 42,333 m, and the upgrade track of 11.5 ‰ from 41,828 m to 42,306 m, before the concerned bridge. The maximum operating velocity in around the accident site was 105 km/h, and the limited speed in the compound right curved track located before the concerned bridge was 90 km/h.

2.3.1.3. Status of the concerned train *[Refer to Attached Figure 3]*

The concerned train had been halted as its front head was in around 42,672 m, and all wheels had been staying on rails. Here, as described in 2.4.2 (4), the concerned train had been halted in the status that the brake could not be released, because there was the crack in the brake pipe[*4] in around the front coupler of the 4th vehicle and the air was leaked.

*3 *"Compound curve" is the track shape where the different radius curves in the same direction are continued.*

*4 *"Brake pipe" is the air pipe for the automatic air brake equipment.*

2.3.2. Information on the Railway Facilities

2.3.2.1. Outline of the route *[Refer to Attached Figure 1]*

The track in around the accident site was the double track, electrified section, and the gauge was 1,067 mm.

2.3.2.2. Outline of the track

The 50 kgN rails and the over bridge guard rails[*5] were laid on the track in the concerned bridge. The synthetic sleepers were used and laid as 55 sleepers for each 25 m, and there was no ballast floor.

The Implementing Standard of Railway Structures, *hereinafter referred to as "the implementing standard"*, reported from the company to the Chief of the Kinki District Transport Bureau based on the "Ministerial Ordinance to Provide Technical Regulatory Standards on Railways", Ministerial Ordinance No.151 prescribed by the Ministry of Land, Infrastructure, Transport and Tourism, 2001, prescribed to implement the track irregularity inspection, the rail inspection, etc., as the periodic inspections of the track.

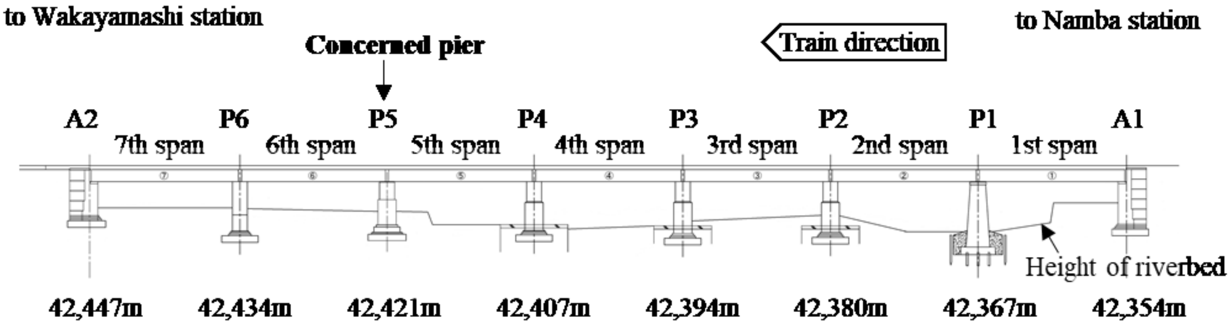
There was no abnormal situation in the records of the latest periodic inspections for the track in around the accident site, implemented before the occurrence of the concerned accident.

*5 *"Over bridge guard rail" is the rail for guidance installed along the rail to guide vehicles not to fall from the bridge as being deviated when the vehicle had derailed on or in around the bridge.*

2.3.2.3. Outline of the concerned bridge

The concerned bridge was composed of the separated bridges for the up and down tracks.

The down track bridge of the concerned bridge was completed in 1918. The upper structure*6 composed of the 7 spans deck plate girder*7, which the bridge length was 93.6 m and the span lengths were from 12.9 m to 13.6 m. The substructure*8 were composed of the pier P1 which was constructed by concrete and the pile foundation*9 type, and the piers P2 to P6 and the abutments*10 A1 and A2 which were constructed by the bricks and the spread foundation*11 type. Here, the pier P1 had originally constructed by bricks and the spread foundation type when the down track bridge of the concerned bridge had completed but it was rebuilt in about 1935. Here, the piers and abutments were named as "P" and "A", respectively, with the numbers counted in turns from the direction of Namba station. *[Refer to Figure 1]*



* *The heights of the riverbed in the figure showed the status at about 1935.*

Figure 1. Side view of the down track bridge of the concerned bridge

As describe in the following 2.4.1.2 (1), the pier P5 of the down track bridge, *hereinafter referred to as "the concerned pier"*, had been subsided and tilted. In addition, the foot protection*12 was constructed for the concerned pier as the scour protection work to reinforce the durability against scouring for the foundation of the piers.

According to the materials of the company, the outline of the concerned pier and the foot protection of the concerned pier were as follows. Here, the definition of the structure body and the footing in this report were shown in Figure 2.

(1) Outline of the concerned pier

Completion	1918
Materials	The bricks and the concrete
Foundation	The spread foundation
Dimensions	As shown in Figure 2

(2) Outline of the foot protection for the concerned pier

Completion	About 1954
Materials	Concrete, cobble stones*13, steel sheet pile*14, wooden pile, wooden sheet pile
Dimensions, etc.	As shown in Figure 3

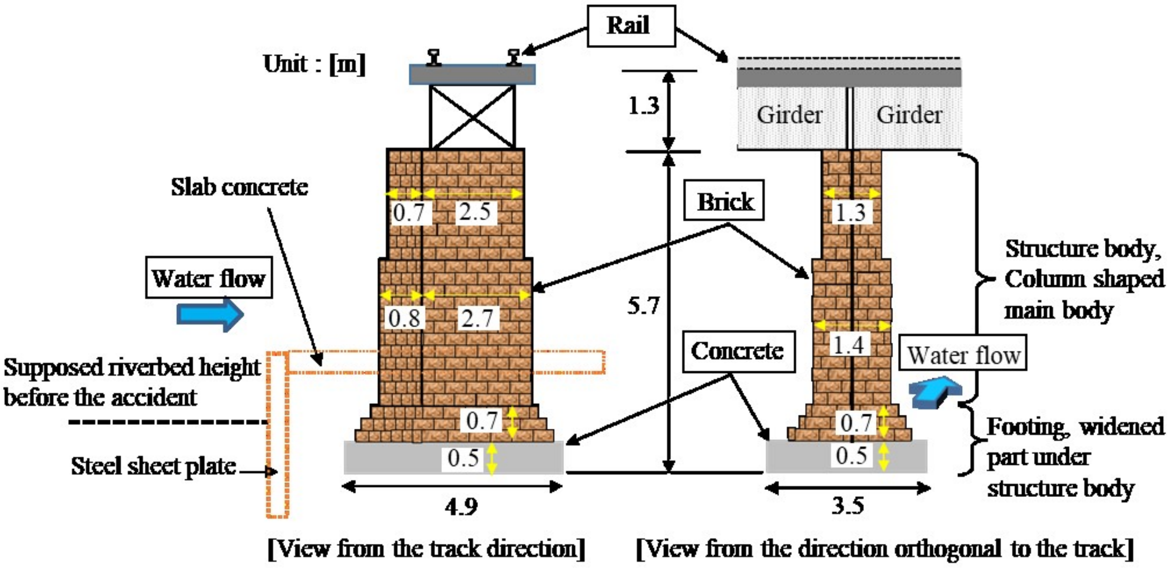


Figure 2. Shape of the concerned pier, restored diagram

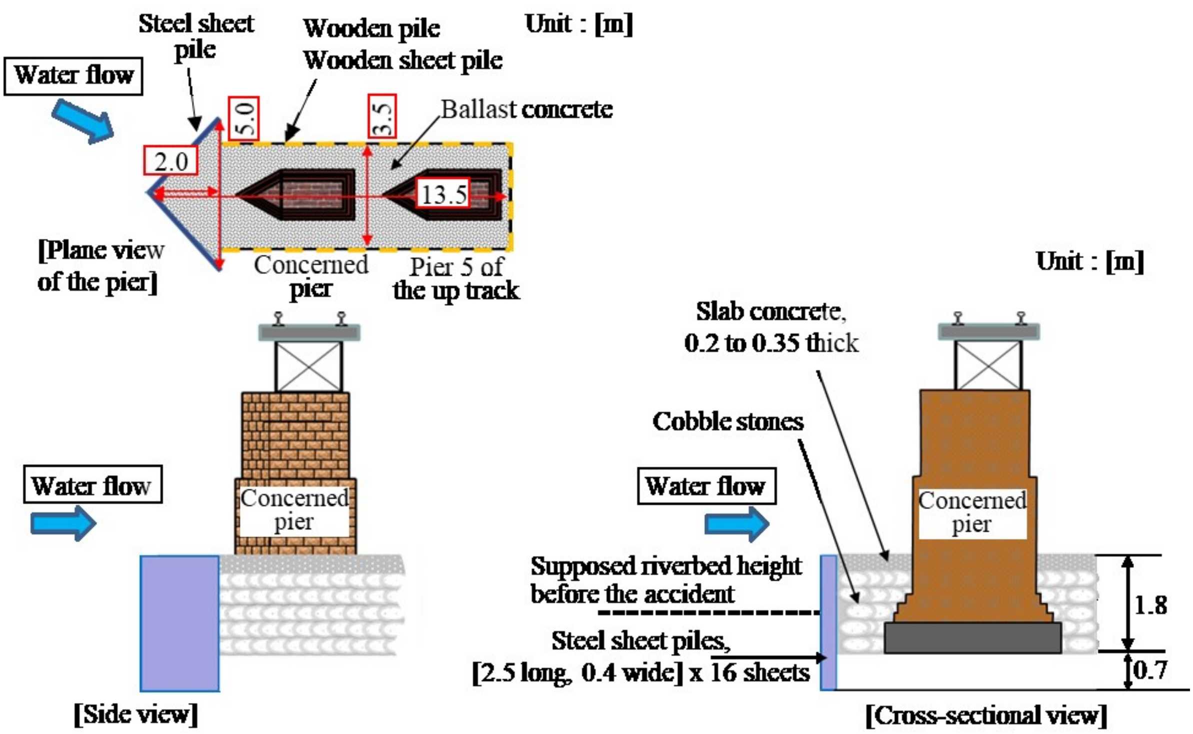


Figure 3. Shape of the foot protection of the concerned pier, restored diagram

*6 *"Upper structure" is the generic name of the structure part suspended by the piers, abutments, etc.*

*7 *"Deck plate girder" is the structure, that the trains run on the girders, composed of a pair of left and right main girders assembled in "I" shape.*

*8 *"Substructure" is a part of the bridge, i.e., the part to transfer the load weight from the upper structures to the ground surrounding foundation safely, and the generic name for the abutments, the piers and their foundations.*

*9 *"Pile foundation" is one of the foundation types suspending the structures by the piles.*

*10 *"Abutment" is the substructure to connect the bridge to the embankment for attachment, generally, located at both ends of the bridge.*

*11 *"Spread foundation" is the foundation type to transfer the load weight from the upper structures to the supporting layer directly in the bottom surface of the foundation, used when the depth of the supporting layer is shallow.*

*12 *"Foot protection" is to protect the riverbed or the foundations of the dikes from being scoured by the water flow, the mud flow or the waves.*

*13 *"Cobble stone" is the round stone of about 10 to 15 cm diameter in the river.*

*14 *"Steel sheet pile" is the steel wall material equipped with the coupler meshed closely with each other to prevent the leakage of dirt and outflow of water. The shapes of the cross-section of steel sheet piles were U-shape, H-shape, etc., to obtain large coefficient of cross-section and the rigidity.*

2.3.2.4. Status of the foot protection of the concerned pier before occurrence of the concerned accident *[Refer to Attached Figure 7]*

The company had been checked the situation that the foot protection of the concerned pier was in the status as a part of the floor deck concrete had lacked and damaged, and the cobble stones, etc., were washed away, in October 2012.

In addition, the steel sheet pile planted in the upstream side and the log piles in the pier side could be confirmed in the photographs took and recorded in the on-foot patrol implemented on June 2, 2014. In addition, the status of the washed away cobble stones and the exposed side surface of the footing were also confirmed in the recorded photographs.

2.3.2.5. Information on the management of the bridges

(1) Rules on the periodic inspection of the bridge

The periodic inspections of the bridges were prescribed in the Implementing Standard as to implement the normal general inspection[*15] every two years, and to implement the individual inspection[*16] if more precise inspection was required.

In addition, the Inspection Manual of the Structures of the company prescribed to implement the judgment based on the judged class of the healthiness shown in Table 3, and to implement the individual inspection for the unusual status[*17] judged as the healthiness was class A, in the normal general inspection.

Table 3. Status of the structures and the standard judged class of the healthiness

[Extracted from the Inspection Manual of the Structures]

Judged Class		*Status of the railway structures*
A		*Unusual status, etc., threaten or have the fear to threaten to secure the safe operation, safety of passengers and publics, etc., and the normal train operation, had existed.*
	AA	*Unusual status, etc., threaten to secure the safe operation, safety of passengers and publics, etc., and the normal train operation had existed and required the urgent measures.*
	A1	*Regressing unusual status, etc., had existed and performance of the structures are deteriorating, or there was the fear to lose the functions of the structures by the heavy rain, the flood, the earthquake, etc.*
	A2	*Unusual status, etc., having the fear to deteriorate the performance of the structures in the future, had existed.*
B		*Unusual status, etc., having the fear to become healthiness class A in the future, had existed.*
C		*Slight unusual status had existed.*
S		*Healthy structures*

*15 *"Normal general inspection" is a kind of the inspection for the structures in the company, to implement periodically for the purpose to comprehend the existence of the unusual status in the structures and their regressing rates, etc.*

*16 *"Individual inspection" is a kind of the inspection for the structures in the company, to implement for the purpose to judge the healthiness in high accuracy for the structures which were judged as required the precise inspection in the results of the normal general inspection.*

*17 *"Unusual status" in this context is the status that the performance of the structure is deteriorated from the healthy status that they should be.*

(2) The results of the normal general inspection for the concerned bridge

The company has been implemented the judgment of the existence of the unusual status and the healthiness using the check list for the whole structure, *hereinafter referred to as "the check list"*, prescribed by the company as the format for the inspected records for the upper structures and the substructures, respectively, in the normal general inspection for the bridges.

The latest normal general inspection for the concerned bridge before the occurrence of the concerned accident, was implemented on June 13, 2017. According to the records of the inspection, the girder in the 5th span of the upper structure of the down track was judged as the healthiness class B for the unusual status such as the deviation of the sole plate[*18] in the support and the crack in the cover plate[*19] for the upper flange of the main girder, etc. As for the substructure of the down track, there was the record that the cracks of less than 5 mm were existed in the girder seats of the piers P1 to P4, but the column for judgment had been blank.

The extraction of the check list for the concerned bridge implemented on June 13, 2017, was shown in Figure 4. The check list was made in the format to write down the existence of the unusual status for each item to be inspected for the substructure, *i.e.*, subsidence, tilting, scoured and subsided riverbed[*20]. There was the description as "protecting concrete removed" in the remark column of the item "scoured", but all columns for the inspected results were checked as "nothing".

In addition, there was the description as "protection concrete removed" but all columns for inspected results were checked as "nothing", same as in Figure 4, in the inspected results for the substructures, in the inspection records for the concerned bridge implemented on May 17, 2013 and May 29, 2015.

According to the company, "nothing" in the column for inspected results indicates that there is no unusual status, and the judgment of the healthiness is class S. In addition, the "protection concrete" means the floor deck concrete for the foot protection, and the description as "protection concrete removed" were written in the remark column because the floor deck concrete was found as coming loose and falling, when checked in the opportunity as received the report from the inhabitants on the unusual status of the foot protection in October 2012. However, the foot protection was not the main body of the pier, then the company did not include the foot protection as the target to be judged the healthiness in the check list. Therefore, there was no record that the investigated results for the unusual status in the foot protection was reflected to the judgment of healthiness.

The company did not implement the individual inspection as there was no unusual status judged as the healthiness class A for the concerned bridge in the results of the latest normal general inspection implemented before the occurrence of the concerned accident.

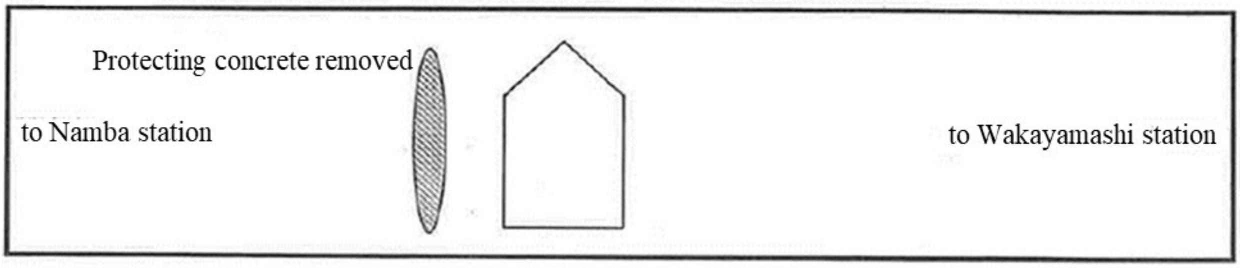
Here, there has been no case to judge as "yes" for the items of "scoured" and "subsided riverbed" in the check list for the bridges, including the concerned bridge and the other bridges.

*18 *"Sole plate" is the steel plate to attach in the bottom surface, as the load weight would act as uniformly in the support.*

*19 *"Cover plate" is one of the steel plates composed of the components, to attach as to put the lid from outside to reinforce the cross-section or to assemble the components.*

*20 *"Riverbed" is the generic name of the part corresponded with the bottom of a river.*

Simple diagram



Inspected items			Inspected results							
Materials	Position	Category of unusual status	No	Yes	X	Y	Z	Position	Judge	Remarks
Structure body	General	Crack of 5mm & above	✓							
		Crack less than 5mm	✓							
		Lack of bricks	✓							
		Broken joint	✓							
		Swelling out	✓							
		Leaked water	✓							
	Lower structure	Subsidence	✓							
		Tilting	✓							
		Scoured	✓							Protecting concrete removed
		Subsided riverbed	✓							
	Gap with wing wall	Disconnected	/							

X : Judgement impossible, Y : Inspection impossible, Z : Out of judged items

[Quoted from the inspection record implemented on June 13, 2017]

Figure 4. Check list of the whole structures for the concerned pier, extracted

(3) The implemented results of the impact vibration test and the reinforcing plan

The company implemented the impact vibration test*21 to measure the natural frequency*22 for the concerned bridge in May 2003 and December 2012, different from the periodic inspections. The measurement implemented in May 2003 was the first measurement for the concerned bridge, and the measurement in December 2012 was implemented as the precise investigation against the unusual status of the foot protection described in the previous paragraph (2). The change of the natural frequency by the impact vibration tests was shown in Table 4.

According to the company, the results of the impact vibration test implemented on December 2012, showed that the natural frequency did not decrease significantly compared to the value in the initial measurement in May 2003, therefore, the company judged that the unusual status was not in the status as to threaten the safety immediately.

Table 4. Change of the natural frequency obtained from the impact vibration test

May 2003	11.597 Hz
December 2012	11.108 Hz
Difference	0.489 Hz
Decreased ratio	4.22 %

After that, the company checked the status that the damages of the foot protection of the concerned pier were deteriorating, in the on-foot patrol implemented on June 2, 2014 described in 2.3.2.4. Then the company judged that the reinforcement was necessary and planned to implement the reinforcing works in 2018 fiscal year in the long-term budget plan from 2015 to 2025 fiscal years, starting from the next fiscal year.

However, in the review of the budget of 2016 fiscal year, the reinforcing works was judged as low priority compared to the other items, then the budget for the reinforcing works was postponed for one year, so that the concrete contents of the reinforcing work were not studied at the time of the occurrence of the concerned accident.

In addition, the measures to monitor the change toward unstable in the pier or to review the operation control, etc., were not implemented until to the completion of the reinforcing work of the foot protection.

*21 *"Impact vibration test" is the test method to identify the natural frequency of the target structures based on the response waveforms obtained by hitting around the top edge of the piers or the upper part of the rigid frame viaduct using the weight of about 30 kg.*

*22 *"Natural frequency" is the vibrating frequency inherent to the vibrating body when it is vibrating freely.*

(4) The implemented results of the major repair work, etc., for the concerned bridge

The major repair works, etc., for the concerned bridge, implemented up to the moment were as shown in Table 5. There was the record that the foot protection work of the concerned pier was constructed in 1954, because the ground around the piers P5 and P6 in the up and the down tracks were damaged as eroded by the Typhoon No.13 in 1953.

Table 5. Implemented status of the repair works, etc., for the concerned bridge

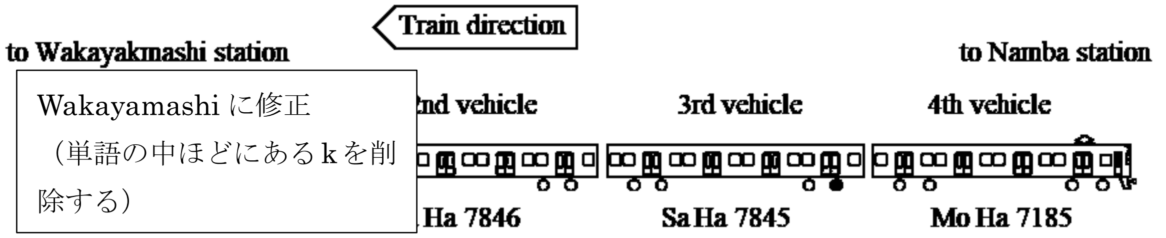
Implemented time	Parts	Contents of the repair works, etc.
1935	Pier P1 in the up & down tracks	Rebuilt to the concrete structure
1936	Piers P2, P3, P4 in the up & down tracks, a part of foundation of the concerned pier	Constructed the foot protection
1949	Foundation & wing wall*23 of abutment A1	Rebuilt
1954	Piers P5, P6 in the up & down tracks	Constructed the foot protection
1966	Girder seat of pier P2 in the up track	Repaired the girder seat concrete
1967	Bridge girders in the down track	Repaired

*23 *"Wing wall" is the earth retaining in left and right sides of the abutment.*

2.3.3. Information on the Vehicles

(1) Outline of the vehicles in the concerned train

The trainset of the concerned train was as shown in Figure 5.



● : The wheel axle supposed as restored after running as being derailed.

Figure 5. The trainset of the concerned train

The major specification of the vehicles are as follows.

Category of the vehicles — DC electric cars, 1,500V

Number of vehicles in the train set — 4 vehicles

Passenger capacity of the train set — 602 passengers

Tares of the vehicles

Symbol# & number	Mo Ha 7186	Sa Ha 7846	Sa Ha 7845	Mo Ha 7185
Tare*24	38.0 t	30.0 t	30.0 t	38.0 t

 # "Mo" : Motor coach, "Sa" : Trailer coach, Ha : Ordinary class

Length of the train set — 82.9 m

*24 *1 [t] = 1,000 [kgw], 1 [kgw] = 9.8 [N]*

(2) History of the inspection, etc.

The latest periodic inspections for the concerned train implemented before the concerned accident were as shown in Table 6.

There was no abnormal situation in the records of each periodic inspection. In the latest general inspection or the latest important parts inspection*25 implemented before the concerned accident, the static wheel load ratio was within the control value, *i.e.*, 10 %, and the dimension of the wheel axles and the assembled dimensions of the vehicles and the bogies were within the maintenance standard values. In addition, in the vehicle inspection implemented after the accident, there was no particularly abnormal situation, except for the damaged place considered as caused by the concerned accident.

Table 6. Implemented time of each periodic inspection

	Mo Ha 7186	Sa Ha 7846	Sa Ha 7845	Mo Ha 7185
General Inspection*26	May 18, 2012		February 16, 2016	
Important parts inspection	February 16, 2016			
Status & function inspection*27	October 16, 2017			

*25 *"Important parts inspection" is one of the inspections implemented in the company, for the important parts such as the power generation devices, the running gear, the brake gear, etc., implemented every shorter periods of 4 years or not exceed 600,000 km running distance.*

*26 *"General inspection" is one of the inspections for the vehicles in the company, implemented for the whole vehicle in every period not exceeded 8 years.*

*27 *"Status & function inspection" is one of the inspections for the vehicles in the company, implemented for the status and the functions of the vehicle in every periods not exceeded 3 months.*

2.3.4. Information on Onosato River

2.3.4.1. Outline of Onosato river *[Refer to Attached Figures 2, 4 to 6]*

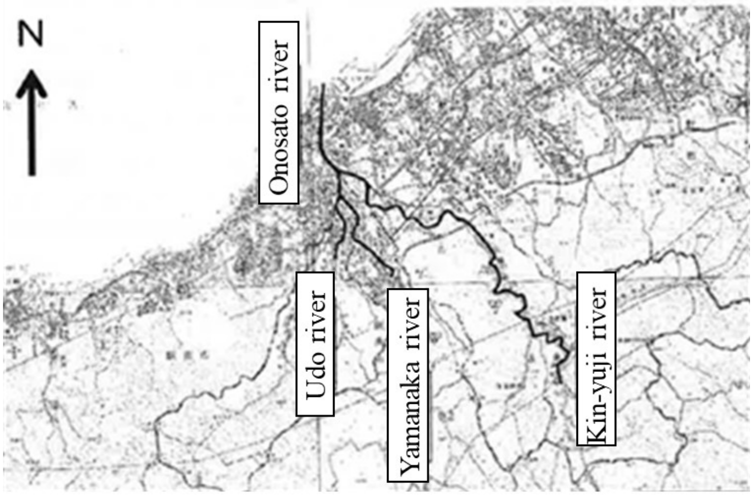
Onosato river flows along the border between Sennan City and Hannan City of Osaka Prefecture, jointed by the 3 rivers, *i.e.*, Kinyuji river, Yamanaka river and Udo river, and flow into Osaka Bay, and is the 2nd class river[*28] administered by the Kishiwada Civil Engineering Office of Osaka Prefecture. The total length is about 2.5 km, the area of the river basin is about 58.66 km^2, the gradient of riverbed is from 1/300 to 1/250, the structure is mainly composed of the embankment structure, the width of the river between the place where jointed with Kinyuji river to the estuary was from 90 m to 110 m, and the structure is the compound cross-section structure[*29] with the over bank.

The map of the basin of Onosato river system was shown in Figure 6.

As for the concerned bridge, all the piers from P1 to P6 were located in the low water course and from Wakayamashi station side of the pier P6 to the abutment A2 are in the over bank.

*28 *"The 2nd class river" is one of classes of the river, and the river designated by the governor of the administrative divisions of Japan, in the river system related seriously with the public interests except for the 1st class rivers, prescribed in Number 1, Article 5 of the Act of the River, the law No.167, 1964.*

*29 *"The compound cross-section structure" is the river channel having the cross-sections separated by the low water channel where water always flow and the over bank where water passed only in the flood.*



* This figure was provided from Kishiwada Civil Engineering Office

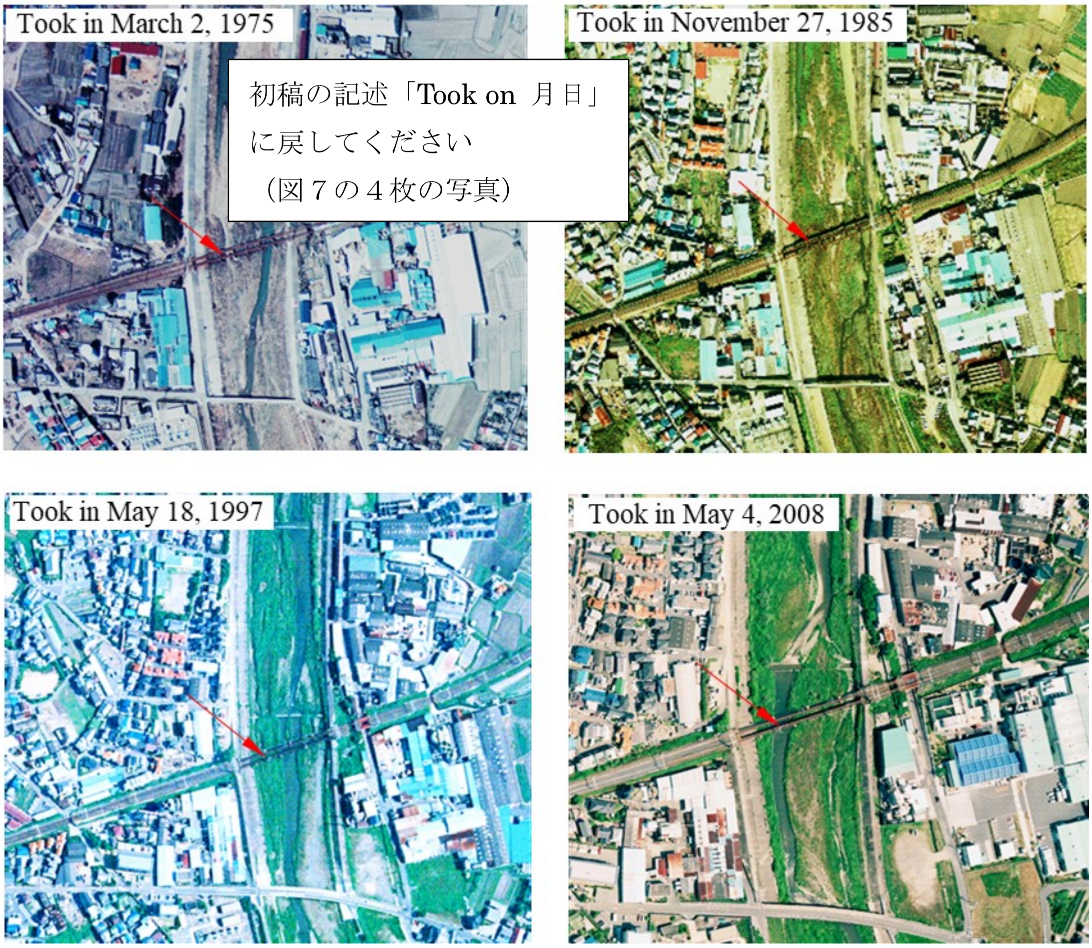
Figure 6. The map of the basin of Onosato river system

2.3.4.2. Changes of the water route *[Refer to Attached Figures 7 and 8]*

The status of the changes of the water route[*30] in around the concerned bridge that could be checked by the aerial photograph taken in the past, the photographs and the drawings, etc., provided from the company, were shown in Table 7, and a part of the aerial photographs corresponding with these change were shown in Figure 7. In addition, the changes of the rough positions of the sand bar[*31] in the direction to Wakayamashi station after 2009 were drawn on the aerial photograph taken in 2008 as shown in Figure 8.

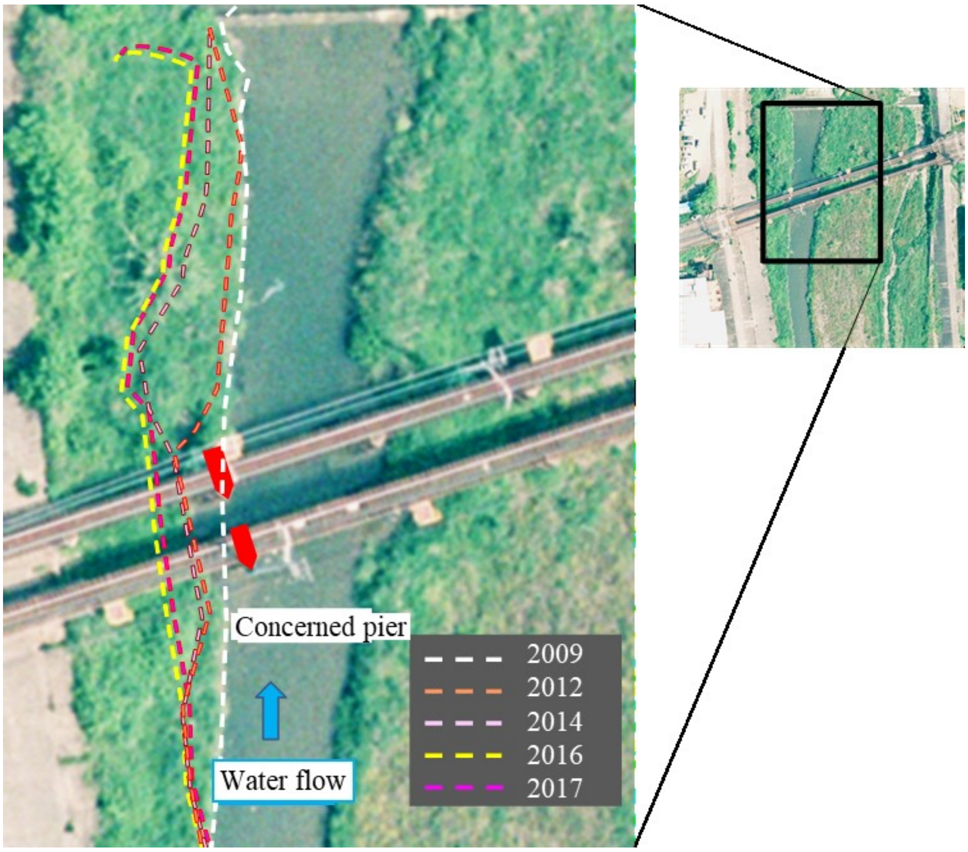
Table 7. Changed status of the water route

Time	Changed status of the water route
About 1935	Water route existed in around the pier P1
About 1954	Water route existed in around the pier P1
March 1975	Water route moved to around the piers P1 to P2
November 1985	Water route moved to around the pier P1 to abutment A1, and the fixing of vegetation on sand bar was advanced.
May 1997	Water route moved to around the piers P3 to P4
April 2006	Water routes existed in around P1 and in around the piers P4 to P5
May 2008	Water route existed only in around the piers P4 to P5, and the fixing of vegetation in around the piers P2 to P4 were advanced.
2012 to 2016	Water routes enlarged toward Wakayakashi station of the piers P4 to P5, and the fixing of vegetation on sand bar was advanced.



** River water flows from downward to upward in the above photographs.*
** Arrows in the above photographs indicate the position of the concerned pier.*
** The above pictures were made by arranging tone of colors, etc. in the aerial photographs taken by the Geospatial Information Authority of Japan.*

Figure 7. Change of the water routes from 1975 to 2008



** The above pictures were made by arranging tone of colors, etc., in the aerial photographs taken in 2008 by the Geospatial Information Authority of Japan.*

Figure 8. Change of rough positions of the sand bar from 2009 to 2017

The position of the water routes at 1935 and the position at about 1954 when the foot protection described in 2.3.2.3 (2) had been constructed, were in around the pier P1, but the water route became to exist also in the position between the pier P4 and around the concerned pier at 2006, and the water route became to exist only in the position between around the pier P4 and around the concerned pier in about 2008.

The sand bar in around the concerned pier was eroded gradually after 2008, and the concerned pier had already been existed in the flow channel in 2012.

As for the status of the riverbed in around the concerned pier after 2008, it could be confirmed that the top edge of the foot protection of the concerned pier, composed of the concrete floor deck and the steel sheet pile, was in almost the same height of the riverbed, in the photograph took in 2008, but it could be confirmed that the riverbed in around the concerned pier has been subsided and the sand bars had been lost by erosion in the photographs took in 2012 and 2014, based on the recorded photographs took by the company as shown in Figure 9.

*30 *"Water route" is the route where water flows in the normal condition.*

*31 *"Sand bar" is the gravels heaped up in narrow and long in the river, the estuary, the sand beach in seaside, etc.*

Figure 9. Status of the water flow in around the concerned pier

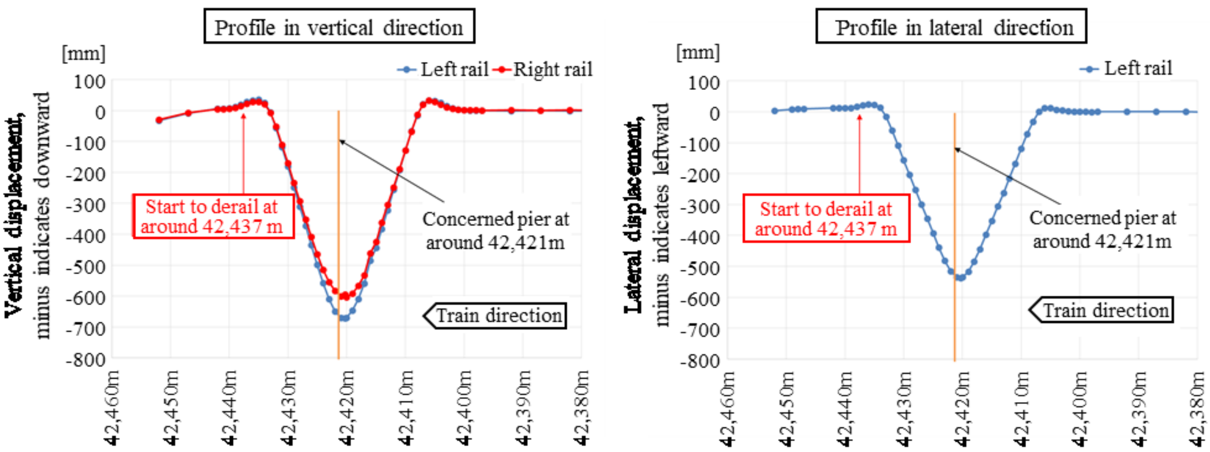
2.4. Information on the Damages and Traces in the Railway Facilities and the Vehicles, etc.

2.4.1. Status of Damages and Traces in the Railway Facilities

2.4.1.1. Status of the track

(1) Status of deformation of the track

It was confirmed in the on-site investigation that the track was sagged and wound to left from around 42,407 m to around 42,434 m of the down track, and the amount of deformation of the track was the largest at just above the concerned pier.



** The start point of the derailment in the above figure, i.e. around 42,437 m, was the position based on the analysis described in the following paragraph 3.1.*

Figure 10. Status of deformation of the track

In the measurement implemented after that, on November 1 to 2, 2017, the sagged and wound track had been deformed 672 mm in downward and 537 mm in leftward as the maximum, as shown in Figure 10.

(2) Damaged status of the track and traces of the derailment

Status of the major damages of the track and the traces of the derailment were as shown in Figure 11 and Table 8.

There was the linear trace from inside to outside gauge on the top surface of right rail from around 42,437 m to around 42,439 m. Beyond there to Tarui No.10 level crossing located at 42,454 m, a part of the rail fastening devices*32, etc., in each right side of left and right rails were damaged, and the contacted traces considered as caused by the running wheels were found continuously.

In addition, it was found that the left guardrail*33 was folded and damaged and the pavement blocks were damaged in Tarui No.10 level crossing in around 42,453 m, and a part of the folded and broken guard rail was found in between up and down tracks about 8 m distant from the folded and damaged position toward Wakayamashi station.

Here, there was no damage on the track beyond Tarui No.10 level crossing to the place where the concerned train stopped as described in 2.3.1.3.

*32 *"Rail fastening device" is the device to maintain the gauge against the load weight and vibration caused by the running vehicle, by fastening left and right rails to the sleepers.*

*33 *"Guardrail" is the guard rail installed in inside gauge parallel to the rails of the main track, to prevent serious accident due to derailment of the vehicles, as to keep the flangeways needed to the train running through the level crossing.*

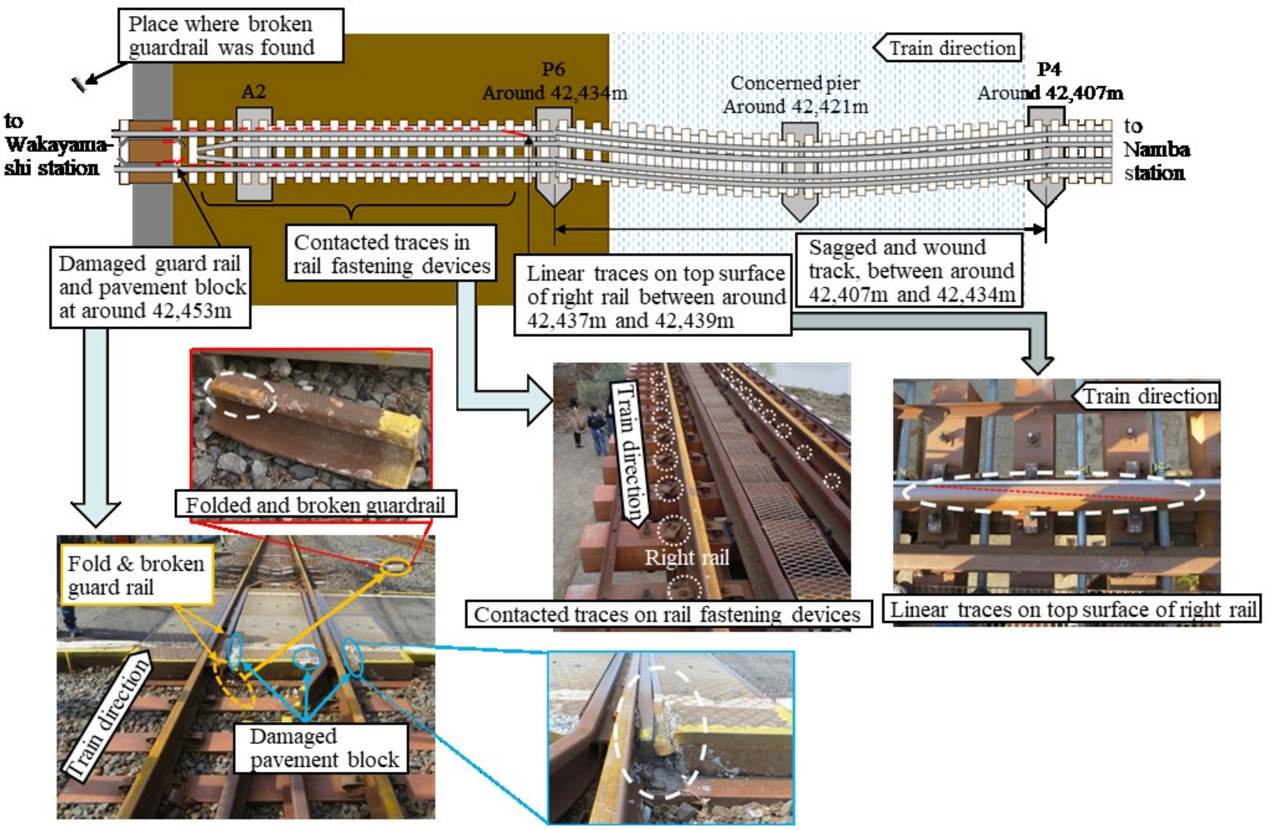


Figure 11. Damaged status of the track and traces of the derailment

Table 8. Status of the major damages of the track

Damaged parts	Damaged amount
Bridge sleepers, synthetic sleepers	2 sleepers
Rail fastening devices	81 sets
Fish bolt	24 bolts
Guardrail	1 rail
Pavement block	3 blocks

2.4.1.2. Damaged status of the concerned bridge

(1) Damaged status of the concerned bridge

The concerned pier had been subsided and tilted to left, *i.e.* toward upstream, and two girders suspended by the concerned pier were in the status as being displaced caused by the subsided and tilted concerned pier.

According to the survey implemented after that, on October 25, 2017, the concerned pier had been in the status as moved 674 mm downward and 494 mm leftward, *i.e.*, toward upstream, as shown in Figure 12.

Furthermore, according to the investigation implemented after that, the main body and the footing part of the concerned pier were in the status as being separated each other and tilted.

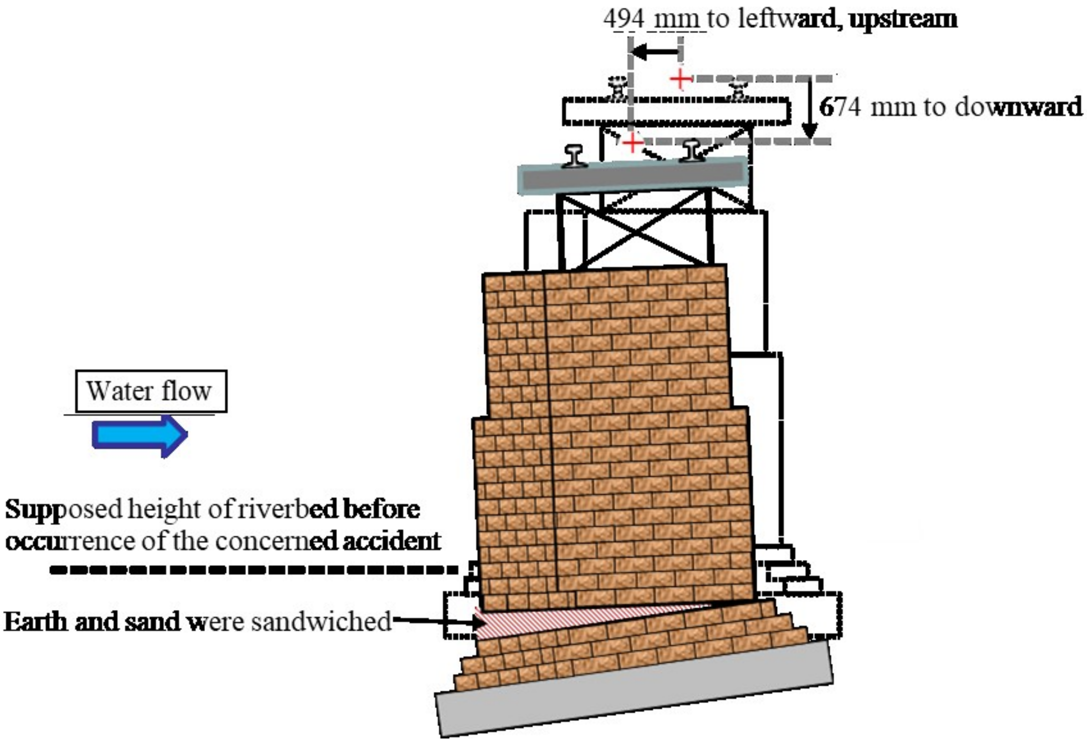


Figure 12. Status of the subsidence and tilting of the concerned pier

The status of major damages of the concerned bridge were as follows.

(i) The upper structures

As for the 5th girder, *i.e.*, the girder between pier P4 and the concerned pier, the anchor bolt[*34] of the support in P4 side was broken and lost, and there was the crack in the cover plate of the upper flange of the main girder.

As for the 6th girder, *i.e.*, the girder between the concerned pier and the pier P6, the sole plate in the support in the direction of the concerned pier, was floated.

(ii) The substructures

As for the concerned pier, the main body and the footing part were separated each other and tilted, and the foot protection was broken.

*34 *"Anchor bolt" is the generic name of the bolts used to be buried into foundation such as the bolt to be used to fix the support or the steel pier to the concrete foundation.*

(2) Status of the foot protection of the concerned bridge *[Refer to Attached Figure 6]*

The foot protection had been constructed to the concerned pier, but the most of the foot protection had broken and retained nothing of its original form, and it was found that the concrete brocks considered as the floor deck concrete of the broken foot protection stuck to the pier P5 of the up track located on right side, *i.e.*, downstream, of the concerned pier.

The concrete block, which was about 3.8 m long, about 1.1 m wide, and about 0.25 m thick in maximum, and the steel sheet pile, which was 2.5 m long, 0.4 m wide, etc., were found in around the concerned bridge, in the investigation implemented after that.

2.4.2. Status of Damages and Traces of the Vehicles *[Refer to Attached Figures 9 and 10]*

The fretting traces were found in the back side of right wheel flange[*35] and the surface side of left wheel flange of the 2nd axle in the rear bogie of the 3rd vehicle, and the hit traces and the fretting traces were found in the tip of the flange of the both wheels in the same axle. In addition, it was found that the small broken pieces considered as crushed concrete had been adhered to the rear part of the 3rd vehicle and the front part of the 4th vehicle.

The status of the other major damages in each vehicle were as follows.

(1) Mo Ha 7186, the 1st vehicle

The skirt had been deformed and the 2 fretting traces, about 5 cm wide and about 1 m distant with each other, were found in the lower part of the skirt.

(2) Sa Ha 7846, the 2nd vehicle

The shank guide[*36] of the rear coupler was damaged, and the traces caused by the contact of the rear coupler and the bottom edge of the outside plate[*37], were found.

(3) Sa Ha 7845, the 3rd vehicle

The shank guides of the front and the rear couplers were damaged, and the traces caused by the contact of these couplers and the bottom edge of the outside plates were found.

(4) Mo Ha 7185, the 4th vehicle

The skirt had been deformed and the 2 fretting traces, about 5 cm wide and about 1 m distant with each other, were found in the lower part of the skirt. In addition, the shank guide of the front coupler had been bent and damaged, and the crack and the leakage of air in the brake pipe and the contacted traces in the bogie frame[*38] of the front bogie and the cross beam[*39] of the vehicle body, were found.

*35 *"Flange" is the projected part, i.e., the ring edge, mounted on the circumference of the wheel continuously, in order to guide the wheel not to derail while the rotating wheels run on the rail.*

*36 *"Shank guide" is the device to maintain height of the parts used to couple with the other vehicle, by supporting the coupler body of the railway vehicles from downward.*

*37 *"Outside plate" is the outer plate consisted of the structure frame.*

*38 *"Bogie frame" is the important structure component to compose the bogies.*

*39 *"Cross beam" is the beam shaped reinforcing component in the sleeper direction composed the bogie frame, except for the end beam, the bogie bolster and the center beam.*

2.4.3. Status of Onosato River

The status of Onosato river in around the concerned bridge confirmed in the on-site investigation implemented on October 23 to 25, 2017, were as follows.

(1) Status of the place of the flowing water

The place of the flowing water was in between pier P4 and pier P6, and the concerned pier was existed in almost the center of these piers. The wreckage drifting down the river such as the miscellaneous small trees were heaped in all piers, especially heaped for the pier P4 and for the left side, *i.e.*, upstream side, of the concerned pier remarkably.

(2) Status of the place except for the flowing water

There was the sand bar from the pier P4 toward Namba station. There was the vegetation fixed on the heaped earth and sand in around the pier P3, and the status as to being eroded and scoured was not found in the pier and the riverbed around the pier.

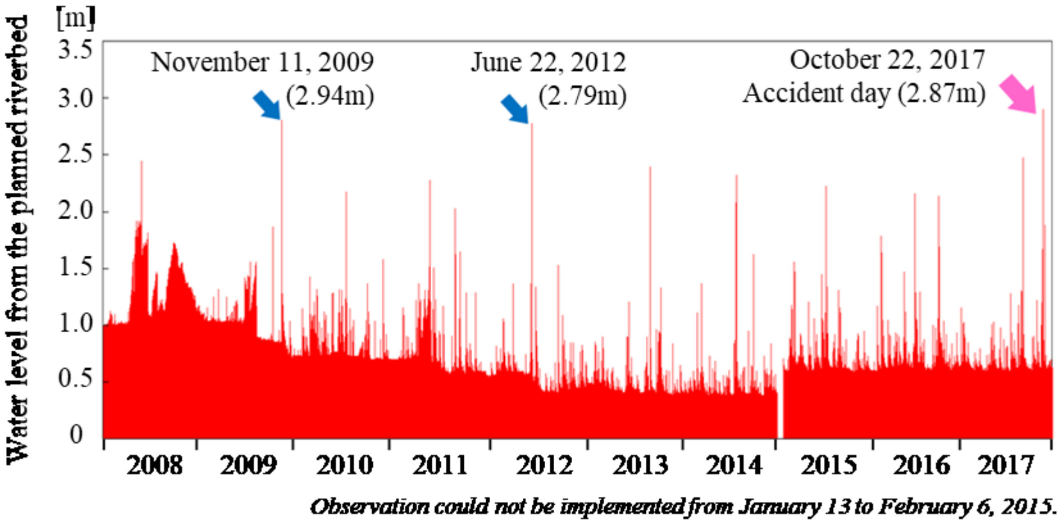
The local slight scouring was found in the upstream side of the piers P1 and P2.

(3) Water level of the river

The water gauge of the company, *hereinafter referred to as "the company's water gauge"*, was installed in the side wall of the downstream side of the abutment A1. The company's water gauge had observed that the water level had increased to 2.31 m beneath girder until to the occurrence of the concerned accident, as described in the following paragraph 2.6.2 (2).

According to the company, the highest water level observed in the company's water gauge after it was installed in 1990, was 1.79 m beneath girder, measured on July 4, 1995, and it was the 12th time that the water level exceeded 2.50 m beneath girder, which was the value to issue the caution alarm as described in the following paragraph 2.6.2, was observed. Here, after 2008 when the water route became to exist in around the concerned pier, the rise of water level observed in this case was the 3rd highest, *i.e.*, the highest rise was 2.00 m beneath girder observed on November 11, 2009, and the second highest rise was 2.02 m beneath girder observed on June 22, 2012.

In addition, the water level observatory "Onosatogawa bridge" administrated by Kishiwada Civil Engineering Office of Osaka Prefecture, located at about 700 m upstream from the concerned bridge, has been observing the water level from the planned height of riverbed. According to the observed records, *hereinafter referred to as "the observed record by Osaka Prefecture"*, the changed status of the water level from 2008 to 2017 were as shown in Figure 13. The frequent rises of water level were observed in the observed period including the remarkable rises of water level in November 11, 2009, and June 22, 2012, in addition to the water level in the concerned accident, provided that the observation could not be implemented from January 13 to February 6, 2015.



** This figure was made by using the observed records provided from Kishiwada Civil Engineering Office.*

Figure 13. The change of water level at Onosatogawa bridge from 2008 to 2017.

(4) Status of the riverbed in around the concerned pier

The boring survey were implemented for five points between just beneath the concerned pier and about 5 m left, upstream, of the concerned pier, from December 4 to 22, 2017, in the investigation implemented after the occurrence of the concerned accident.

The summary of the boring survey was as shown in Figure 14. The strata in around the concerned pier were, from ground surface, sand and gravel layer*40 of about 10 to 40 N-value*41, arenaceous clay layer, sand layer mixed with the silt layer*42, and these layers are heaped almost horizontally. The bottom of the footing was positioned in the sand and gravel layer.

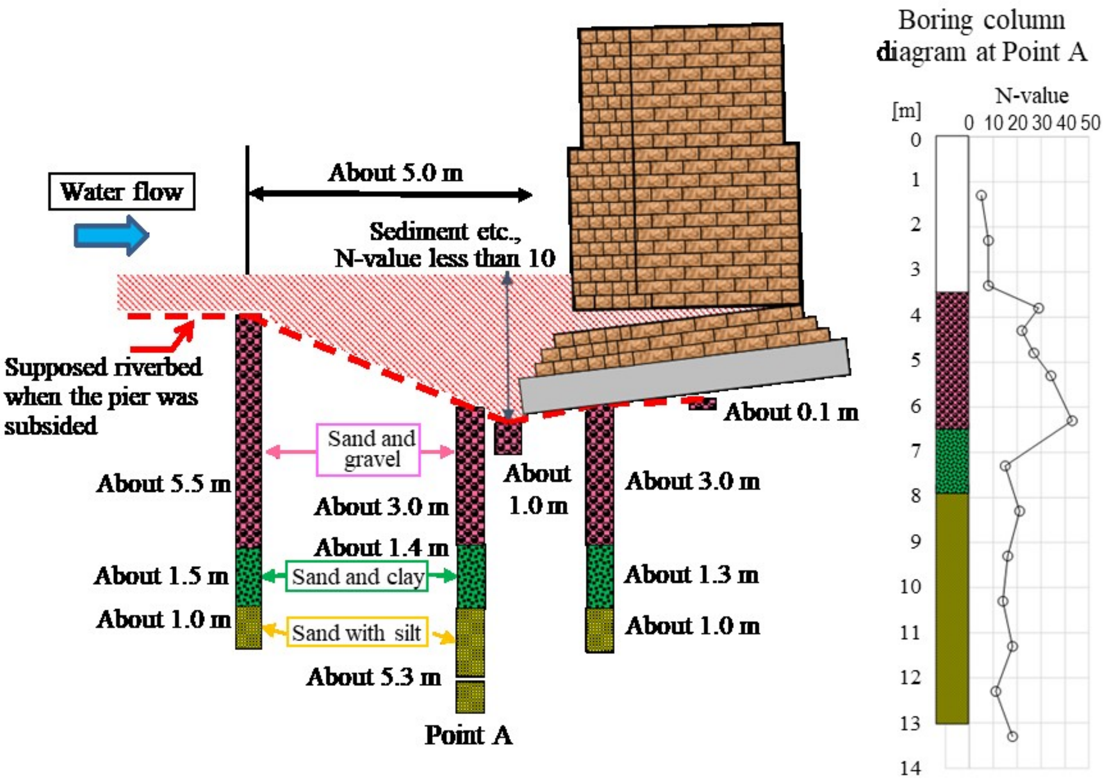


Figure 14. Summary of the results of the boring survey

In addition, the company implemented the construction works to change the flow channel and to fill the soils in around the concerned pier to keep the working yard for the urgent recovery construction works after the concerned accident, from October 27 to November 3, 2017. It was found in the boring survey that the sediments of the low density as the N-value was less than 10, considered as being heaped when the velocity of water flow became slower, and the soils used for filling soils, *hereinafter referred to as "the sediments, etc."*, were distributed in the surface layer in around the concerned pier in the area from the concerned pier to about 5 m toward upstream.

*40 *"N-value" is the index to indicate the hardness or the tightness of the soils, which is the hitting number required to drive the indicator bar for measurement 30 cm into the soil, by dropping the 63.5 kg weight hammer from the height of 75 cm.*

*41 *"Sand and gravel layer" is the sediments of the coarse crushed rubbish such as sand or gravels.*

*42 *"Silt particle" is defined as the particle of earth in the diameter from 5 to 75 μm in the Japanese unified classification method of soils.*

2.5. Information on the Train Crews

The concerned driver was 50 years old male, having the class A driver's license for the electric motor car issued on March 25, 1992.

The concerned conductor was 48 years old Male.

2.6. Information on the Handling Train Operation, etc.

2.6.1. Operation Control under Rainfall

(1) Regulations on the operation control under rainfall, etc.

According to the Guideline of Handling Operation Preventing Disasters of the company, the operation control under rainfall, etc., in around the accident site should be implemented based on the observed results in the rain gauge installed in the premises of Yoshiminosato station about 4 km distant in NE from the accident site, *hereinafter referred to as "the Yoshiminosato rain gauge"*. The values to issue the alarm for each alarm category, in the section between Izumisano station and Ozaki station including the accident site, prescribed in Article 11 of the above Guideline were as shown in Table 9

Table 9. The values to issue the alarm for each alarm category

Control section			Between Izumisano and Ozaki
Alarm category	Caution alarm	Drizzle	30 mm
Alarm category	Caution alarm	Continuous	200 mm
Alarm category	Caution alarm	Drizzle + Continuous	25 mm + 180 mm
Alarm category	Advisory alarm	Drizzle	40 mm
Alarm category	Advisory alarm	Continuous	250 mm
Alarm category	Advisory alarm	Drizzle + Continuous	35 mm + 230 mm
Alarm category	Warning alarm	Drizzle	50 mm
Alarm category	Warning alarm	Continuous	300 mm
Alarm category	Warning alarm	Drizzle + Continuous	45 mm + 280 mm
Alarm category	Stop alarm	Drizzle	60 mm

** "Drizzle" indicates the one hour precipitation, "Continuous" indicates the continuous precipitation, in the above table.*

In addition, the handling when the value exceeded the value to issue the alarms was prescribed as follows.

Guideline for Handling Operation Preventing Disasters, extracted

[Issue and cancellation of the formation in abnormal situation]

Article 4. When the caution alarm continued, for 10 minutes as the standard, or the alarm became to more severe category, the dispatcher should report it to the relevant sections and should ask to issue the Number 4 formation prescribed in Article 9 of the Guidelines of Caution and Handling for Abnormal Situation, issued by the Railway Headquarter A-29, 1989, to the general manager of the division of transportation, according to its necessity.

[Omitted]

[Instruction of the operation control]

Article 5. The dispatcher should instruct the operation control listed in the following items, when the values became to exceed their control values by the reports from the disaster protecting information device, the station master or the section chief, or the dispatcher received the request for the operation control from the maintenance section chief, hereinafter including the staff who was ordered from the section chief. Here, the advisory operation control and the warning operation control are excluded for the cable railways.

(1) Instruction of operation suspension control

When the stop alarm was issued, the dispatcher should instruct to suspend operation of the trains or the vehicles.

(2) Instruction of warning operation control

When the warning alarm was issued, the dispatcher should instruct to control the velocity of the trains or the vehicles less than 25 km/h.

(3) Instruction of advisory operation control

When the advisory alarm was issued, the dispatcher should instruct to control the velocity of the train less than 50 km/h.

2 to *4* [Omitted]

[Operation control under rainfall]

Article 12. The dispatcher should instruct the operation control prescribed in Article 5, when the precipitation, in the section where the operation control prescribed in Article 10 should be applied, exceeded the alarm value prescribed in the previous Article, or, the dispatcher received the request for the operation control from the station master, the section chief, or the maintenance section chief, including the inspection section chief for the cable railways.

[Omitted]

Guidelines for Caution and Handling for Abnormal Situation, extracted.

[Category of formation]

Article 9. The categories of the formation should be as follows.

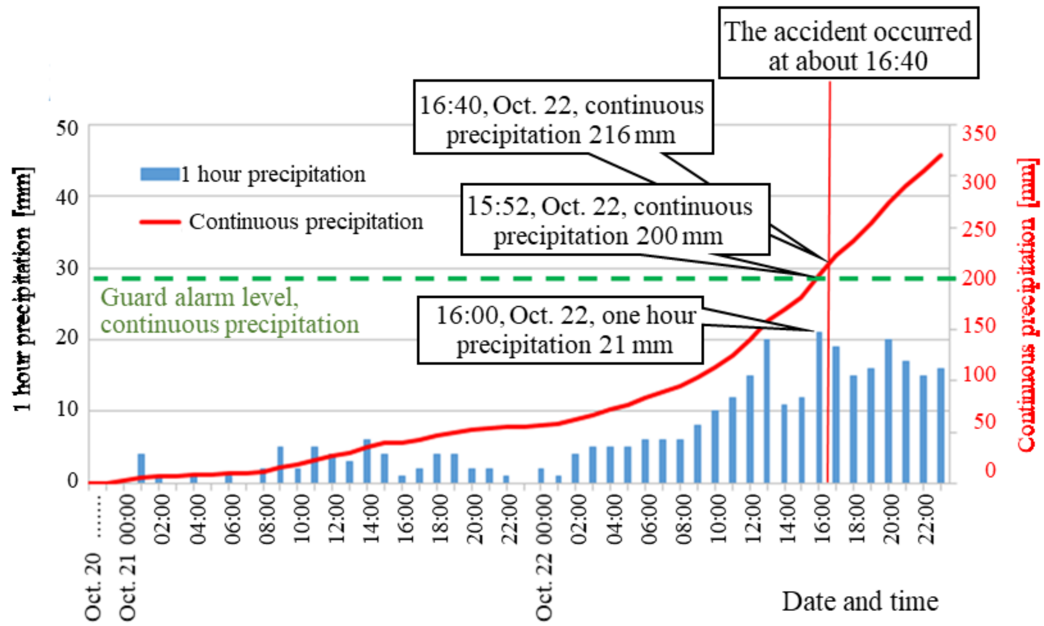
Category of formation	*Degree of disasters*	*Director and vice director of headquarter for measures*	*On-site supervisor*
[Omitted]	[Omitted]	[Omitted]	[Omitted]
Number 4 formation	** When meteorological observatory issued the weather alarm and the special caution was needed. * The other cases when the special caution and measure were needed.*	*General manager of Division of the Transportation or the person designated by the general manager*	*General manager of the Division of Transportation should designate whenever needed.*
[Omitted]	[Omitted]	[Omitted]	[Omitted]

2 [Omitted]

(2) Status of the operation control under rainfall on the day of the occurrence of the accident, etc.

According to the observed record of the Yoshiminosato rain gauge, observation of the precipitation started from 21:10 on October 20. The maximum value of "the 1 hour precipitation for each hour"*43, *hereinafter referred to as "the 1 hour precipitation"*, until to the occurrence of the accident was 21 mm observed at 16 o'clock on October 22, and the maximum continuous precipitation*44 was 216 mm. [Refer to Figure 15]

As the continuous precipitation reached to the value to issue the caution alarm, *i.e.*, 200 mm, at 15:52 on October 22, the dispatcher reported this information to the relevant sections. Here, the operation control was not implemented until to the occurrence of the concerned accident.



** The time of the occurrence of the accident in the above figure indicates the time when the derailment occurred analyzed in the following paragraph 3.2.*

Figure 15. Observed data in the Yoshiminosato rain gauge

*43 *"One hour precipitation" is the precipitation measured for one hour before every hour on the hour.*

*44 *"Continuous precipitation" in this context is the cumulative precipitation from the start of the rain fall, which was reset by the suspension of rain fall over 12 hours.*

2.6.2. Operation Control under Water Level of the River

(1) Regulations on the operation control under water level of the river, etc.

According to the Guideline of Handling Operation Preventing Disasters of the company, the operation control under water level of the river, etc., for the concerned bridge was prescribed as to implement based on the water level beneath girder in the concerned bridge. The water level beneath girder in the concerned bridge for each category of the alarm, prescribed in the Article 25 of the above Guideline, was as shown in Table 10.

Table 10. The water level beneath girder for each alarm category

Location of water gauge of the river			Alarm category	
Line name	Bridge name	Section between stations	Caution alarm	Warning alarm
Nankai Line	Onosatogawa	Between Tarui and Ozaki	2.5 m beneath girder	1.5 m beneath girder

The handling when the water level reached to the level of the warning alarm was prescribed as follows. According to the company, "when the water level beneath girder of the river reached to the level prescribed in the previous article" in the Article 26 indicates the water level beneath girder for the warning alarm.

Here, the regulation of the Article 4 and the Article 5 of the Guideline of Handling Operation Preventing Disasters described in 2.6.1, are applied, respectively to the handling and the instruction of operation control when the water level reached to the level for the caution alarm.

Guideline of Handling Operation Preventing Disasters, extracted.

[Operation control under swollen river water]

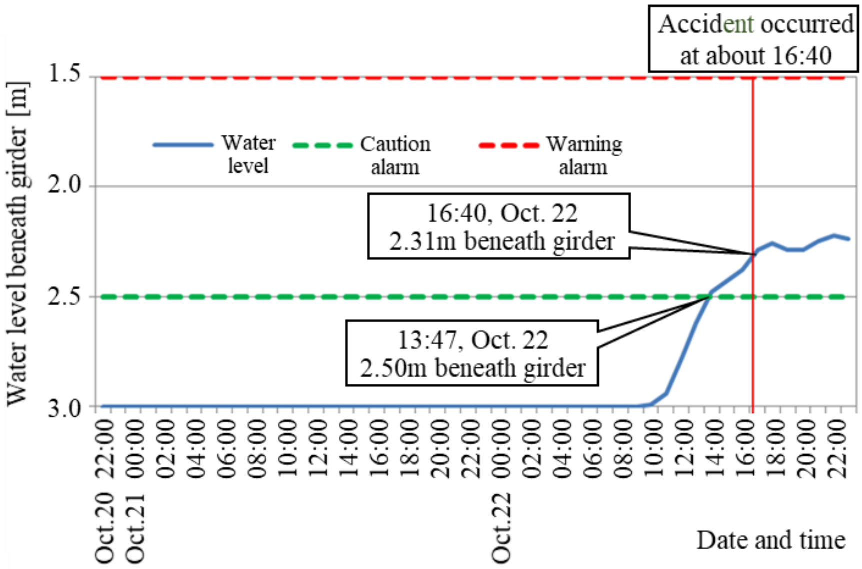
Article 26. The dispatcher should implement the instruction of the warning operation control when the water level beneath girder of the bridge crossing the river reached to the level prescribed in the previous article, or when received the request for the operation control from the station master, the section chief or the maintenance section chief.

[Omitted]

(2) Status of the operation control under water level of the river, etc., on the accident day.

The company's water gauge observes the water level when it exceeded 3.00 m beneath girder, as the specification. On October 22, 2017, the water level became to exceed 3.00 m beneath girder from about 10 o'clock and increased to 2.31 m beneath girder by about 16:40. [Refer to Figure 16]

As the water level beneath girder had reached to the level to issue the caution alarm, *i.e.*, 2.50 m beneath girder, at 13:47, the operation dispatcher reported this information to the relevant sections. Here, the operation control had not been implemented until to the occurrence of the concerned accident.



** The time of the occurrence of the accident in the above figure indicates the time when the derailment occurred based on the analysis in the following paragraph 3.2.*

Figure 16. Observed data of the company's water gauge and the values to issue the operation control

2.6.3. Information on the Status of Train Operation before the Occurrence of the Accident

On the day of the occurrence of the concerned accident, the operation control had not been issued in around the accident site before the occurrence of the concerned accident. The inbound train ran in around the accident site at about 16:36, and the outbound train ran in around the accident site at about 16:25, about 4 minutes and about 15 minutes before the concerned train ran in around the accident site, respectively, without any abnormal situation.

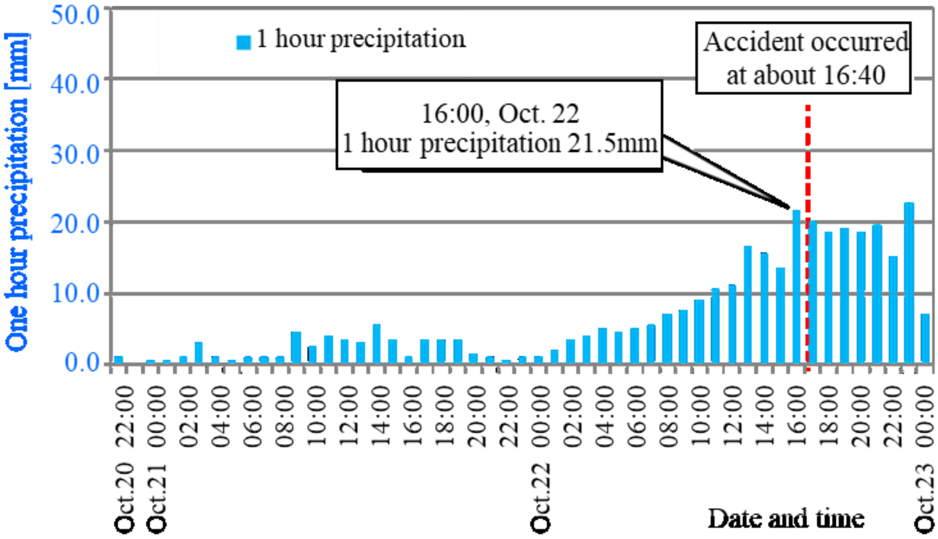
2.7. Information on Weather, etc.

2.7.1. General Weather Condition on the Day of the Occurrence of the Accident

On the day of the occurrence of the concerned accident, as the Heisei 29th year No.21 typhoon moving northward in the south of Japan excited the activity of the front crossing the southern coast of the main island of Japan, the rainfall in the level of the one hour precipitation 10 to 20 mm, had been continued in wide area in southern Osaka Prefecture.

2.7.2. The One Hour Precipitation and the One Day Precipitation

According to the records in the Kumatori District Meteorological Observatory of the Japan Meteorological Agency, *hereinafter referred to as "the AMeDAS Kumatori" and "the JMA"*, respectively, located in about 10 km ENE from the accident site, the one hour precipitation from 22:00 on October 20, 2017, to 0:00 on October 23, 2017, were as shown in Figure 17, and the one day precipitation[*45] in October, 2017 were as shown in Figure 18.



** The time of the occurrence of the accident in the above figure indicates the time when the derailment occurred based on the analysis in the following paragraph 3.2.*

Figure 17. One hour precipitation from 22:00, Oct. 20 to 0:00, Oct.23, 2017 in AMeDAS# Kumatori

 # "AMeDAS" is the abbreviation of the Automated Meteorological Data Acquisition System of the JMA, composed of about 1,300 meteorological observatories in the whole Country.

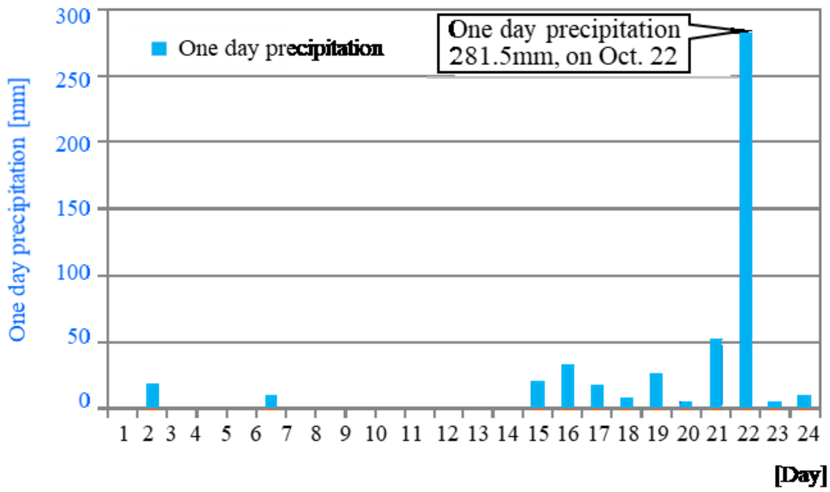


Figure 18. One day precipitation in October 2017 in AMeDAS Kumatori

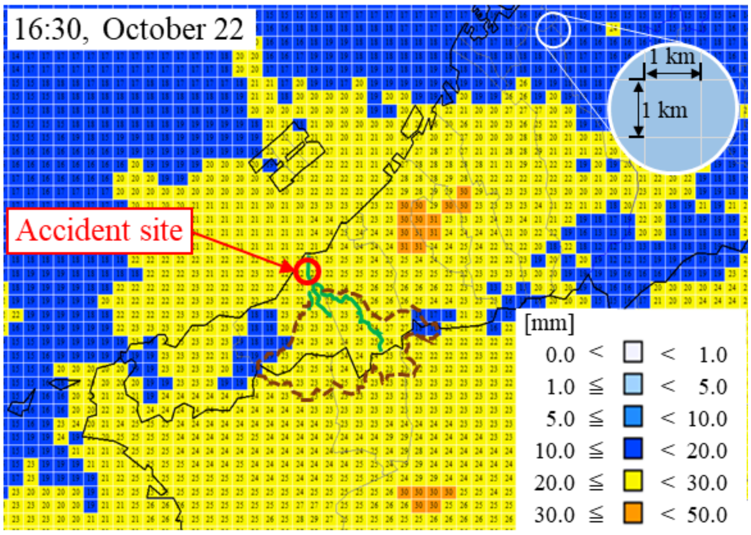
Based on these data, the precipitation had been observed from 22:00 on October 20, 2017, the maximum one hour precipitation was 21.5 mm at 16:00 on October 22, 2017 near the occurrence of the concerned accident, and the one day precipitation of the same day was 281.5 mm.

**45 "One day precipitation" is the precipitation observed between 0 o'clock to 24 o'clock of the day.*

2.7.3. Analyzed Precipitation

According to the analyzed precipitation[*46] by the JMA, the analyzed precipitation at 16:30 on October 22, 2017, when the maximum precipitation was observed before the occurrence of the concerned accident in around the accident site, was as shown in Figure 19. Based on these data, the precipitation in around the accident site was 20.0 to 30.0 mm per an hour.

*46 *"Analyzed precipitation" is the precipitation analyzed by the JMA as the precipitation distribution by combining the rain gauges located on the ground such as the radar, AMeDAS, etc., installed in the whole country by the Water and Disaster Management Bureau and the Road Transport Bureau of the MLIT, and the JMA. The precipitations in the previous one hour were stored as the data for each 1 km square unit and revised every 30 minutes. For example, the analyzed precipitation at 9:30 is the precipitation between 8:30 to 9:30.*



* *The green solid line in around the accident site indicates the water system, the area in the brown broken line indicates the basin, of the Onosato river.*

* *The black solid line indicates the coastline and the border between the neighboring prefectures.*

* *This figure was made by using the distribution map of the analyzed precipitation at 16:30 on October 22, 2017, provided from the JMA, and the material provided from Kishiwada Civil Engineering Office of Osaka Prefecture.*

Figure 19. Analyzed precipitation in around the accident site

2.7.4. Wind Direction, Wind Speed and Temperature

According to the records in the AMeDAS Kumatori, the wind direction was NNE, the wind speed was 1.7 m/s and the temperature was 16.4 ℃ at 16:40 on October 22, 2017, near the occurrence of the concerned accident.

2.8. Information on the Evacuation and the Rescue Activities

According to the company, summary of the guidance for evacuation of passengers implemented after the occurrence of the concerned accident was as shown in Table 11.

Table 11. Information on the guidance for evacuation

Time	Information on the guidance for evacuation
About 16:40	- The concerned accident occurred. - The concerned driver reported to the operation dispatcher that the bridge had been subsided and the concerned train has been stopped at that time, etc.
About 16:53	- The concerned conductor reported to the operation dispatcher that there were the injured passengers. - The concerned driver reported to the operation dispatcher that the skirt of the front vehicle had been distorted.
About 17:26	- Started the guidance for evacuation of the passengers. - Passengers got off the train from the driving cab and the second right door from the front of the 1st vehicle using the ladder and the slope using the long seat.
About 17:50	- Evacuation of the passengers from the vehicles completed. - The refugees walked on the track and evacuated from Ozaki station or the nearest level crossing.
About 18:24	- The measures for the vehicles had finished.
About 18:49	- The vehicles were accommodated in Ozaki station.

2.9. Major Process to Resume Train Operation

To resume the train operation, the company implemented the impact vibration test for all piers of the concerned bridge, and after confirmed their safeness, the company resumed the train operation using the up track of the concerned bridge as the single track operation between Tarui station and Ozaki station, on November 1, 2017.

After that, the company drove the steel piles in the front and rear, and left and right of the concerned pier, built up the temporary pier, and completed the restoring works for the track in the down track. After confirmed the safeness, the company resumed the train operation using the double track on November 23, 2017.

3. ANALYSYS

3.1. Analysis on the Derailment

3.1.1. Analysis on the Derailed Place

As described in 2.3.1.3, the concerned train stopped at its front head was in around 42,672 m, and all wheels had been on the rails. However, it is highly probable that the right wheel of the 2nd axle in the rear bogie of the 3rd vehicle had ran onto the top surface of right rail in around 42,437 m, *hereinafter referred to as "the start point of derailment"*, and had derailed at about 42,439 m in around the end edge of the place where the track had been sagged and wound, based on the followings.

(1) There were linear traces continued from the inside gauge to the outside gauge on the top surface of right rail from around 42,437 m to around 42,439 m, and the rail fastening devices, etc., in right sides of left and right rails were damaged continuously between the end edge of the linear trace and Tarui No.10 level crossing, as described in 2.4.1.1 (2).

(2) The hit traces and the fretting traces were found in the right and the left wheels of the 2nd axle in the rear bogie of the 3rd vehicle, as described in 2.4.2.

3.1.2. Analysis on the Restored Place

As described in 2.4.1.1 (2), the left guardrail in Tarui No.10 level crossing had been folded and damaged and the pavement block in right side of the right rail had been damaged in around 42,453 m, and the damage was not found on the track beyond Tarui No.10 level crossing to the position where the concerned train had stopped. As described in 2.4.2, the hit traces were found in the tip of flanges of left and right wheels of the 2nd axle in the rear bogie of the 3rd vehicle. Therefore, it is highly probable that the derailed left and right wheels of the 2nd axle in the rear bogie of the 3rd vehicle had restored by hitting the guard rail and the pavement block in Tarui No.10 level crossing.

3.1.3. Analysis on the Status of the Derailment

It is somewhat likely that the 2nd axle in the rear bogie of the 3rd vehicle derailed at around the end edge of the sagged and wound track, as described in 3.1.1, because the wheel load of the 2nd axle in the rear bogie of the 3rd vehicle decreased due to large rolling motion of the vehicle while the concerned train was running on the sagged and wound track as described in 2.4.1.1 (1), in addition to the existence of the vertical convex curved track in around the end edge of the sagged and wound track.

3.2. Analysis on the Time of the Occurrence of the Derailment

It is highly probable that the concerned train derailed at about 16:40 based on the followings.

(1) It is highly probable that the right wheel of the 2nd axle in the rear bogie of the 3rd vehicle of the concerned train derailed to right, at around 42,439 m as described in 3.1.

(2) The 2nd axle in the rear bogie of the 3rd vehicle passed around 42,437 m to around 42,439 m at about 16:40:39 to 16:40:40, based on the calculated kilometerage using the information on the running distance in the operating status recording device, as described in 2.1.2.

3.3. Analysis on the Damages of the Railway Facilities and the Vehicles

3.3.1. Analysis on the Deformations of the Railway Track

It is highly probable that that the track in around the accident site was sagged and wound significantly because two girders suspended by the concerned pier had been displaced as the concerned pier had been subsided and tilted, based on the followings.

(1) The track had been sagged and wound to left from around 42,407 m to around 42,434 m, and the amount of deformation of the track was the maximum at just above the concerned pier, as described in 2.4.1.1 (1).

(2) As the concerned pier had been subsided and tiled to left, the both two girders suspended by the concerned pier were in the status as being displaced due to the concerned pier which was subsided and tilted, as described in 2.4.1.2 (1).

3.3.2. Analysis on the Damages of the Vehicles

The fretting traces in two positions in the skirts of the 1st and the 4th vehicles were about 5 cm wide and about 1 m distant with each other, which were almost corresponded with the width of the top surface of rail, *i.e.*, 65 mm, and the gauge, *i.e.*, 1,067 mm, as described in 2.4.2. Therefore, it is probable that these fretting traces were caused by the front part of the vehicle body of the 1st vehicle and the rear part of the vehicle body of the 4th vehicle had contacted with rails when running through the concave track caused by the subsidence.

Here, it is highly probable that the brake could not be released in the braking test as described in 2.1.1 (1), because the brake pipe pressure decreased as there was the crack and the leakage of air in the brake pipe in around the front coupler of the 4th vehicle as described in 2.4.2 (4).

3.4. Analysis on the Rainfall and the Water Level of the River

3.4.1. Analysis on the Rainfall

It is highly probable that the weather condition in around the accident site at the occurrence of the concerned accident was rain, based on the followings.

(1) The crews and the passenger A boarded on the concerned train stated that it was rain, as described in 2.1.1 (1), (2) and (3).

(2) According to the records in AMeDAS Kumatori, the precipitation was observed from 22:00 on October 20, 2017, and the one hour precipitation of 21.5 mm was observed at 16:00 on October 22, near the time when the concerned accident occurred, as described in 2.7.2.

(3) The analyzed precipitation in around the accident site at 16:30 of the same day was 20.0 to 30.0 mm as described in 2.7.3.

Here, it is probable that the rails in around the accident site were in the wet condition based on the weather condition.

3.4.2. Analysis on the Water Level of the River

It is probable that the water level of the river was high when the concerned accident had occurred, as described in 2.4.3 (3), based on the followings.

(1) It was the 12th time that the water level exceeded 2.50 m beneath girder was observed after 1990, based on the observation records of the company's water gauge.

(2) The increased amount of water level was the third largest in the records after 2008, when the water route became to exist in around the concerned pier, based on the observation records of the company's water gauge.

(3) The increased amount of water level as large as in the concerned accident had been recorded twice in the past, after 2008, based on the observed records of Osaka Prefecture.

However, it is probable that the water level at the occurrence of the concerned accident was not particularly high, because the water levels in the same level were observed every few years based on the records of the water level in the past.

Here, the observation records of Osaka Prefecture were the records in the observatory located in about 700 m upstream from the concerned bridge. Then, it is probable that the trend of changes in the water level was almost corresponded with that in around the concerned pier, although there is a possibility to differ from the situation in around the concerned pier in the strict sense.

3.5. Analysis on the Handling Train Operation, etc.

3.5.1. Analysis on the Operating Status When the Sagged Place was Found

It is highly probable that the concerned driver applied the brake immediately after he found the dent and the bend of the track, but it was too late, the concerned train ran through there, based on the followings.

(1) The concerned driver stated that he found the situation that the track about 50 m ahead had been significantly dented and bent when the concerned train entered the concerned bridge at the velocity about 70 km/h, then he applied the brake immediately but, after he felt the violent yawing and the impact, the concerned train stopped after running about 200 m, as described in 2.1.1 (1).

(2) According to the records in the operating status recording device, the brake acted at 16:40:35, while the concerned train was running at the velocity of 68.95 km/h, and the 2nd axle in the rear bogie of the 3rd vehicle passed around the most subsided place at the velocity of 68.84 km/h at 16:40:38, as described in 2.1.2.

Here, the concerned driver stated that he applied the emergency brake as described in 2.1.1 (1), however the normal brake was operated but the emergency brake was not operated, according to the recorded data in the operating status recording device. It is somewhat likely that the brake handle did not reached to the position of the emergency brake because the concerned driver implemented the braking operation in violently swaying status, but it could not be determined the precise situation.

3.5.2. Analysis on the Operation Control under Rainfall, etc.

It is prescribed that the operation control under rainfall in around the accident site should be implemented based on the observed results in the Yoshiminosato rain gauge, as described in 2.6.1 (1).

It is probable that the handling of the operation control, etc., were implemented in accordance with the Guideline of Handling Operation Preventing Disasters of the company describe in 2.6.1 (1), because the continuous precipitation observed in the Yoshiminosato rain gauge on the accident day, reached to the level to issue the caution alarm prescribed by the company, *i.e.*, 200 mm, at 15:52, and the operation dispatcher had reported it to the relevant sections, as described in 2.6.1 (2).

3.5.3. Analysis on the Operation Control under Water Level of the River, etc.

It is prescribed that the operation control under water level of the river should be implemented based on the water level beneath girder in the concerned bridge, as described in 2.6.2 (1).

It is probable that the handling of the operation control, etc., were implemented in accordance with the Guideline of Handling Operation Preventing Disasters of the company describe in 2.6.2

(1), because the water level beneath girder of Onosato river on the accident day reached to the level to issue the caution alarm prescribed by the company, *i.e.*, 2.50 m beneath girder, at 13:47, and the operation dispatcher reported it to the relevant sections, as described in 2.6.2 (2).

3.6. Analysis on the Subsidence and the Tilting of the Concerned Pier

3.6.1. Analysis on the Status in around the Concerned Pier before the Occurrence of the Concerned Accident

3.6.1.1. The height of riverbed before the occurrence of the concerned accident

It is probable that the riverbed in around the concerned pier became lower gradually because the water flow became to concentrate to around the concerned pier after 2012, due to the long term change of the flowing status of Onosato river in around the concerned pier, based on the followings as described in 2.3.4.2.

(1) The water route was in around the pier P1 at about 1935, but it was existed in the area between the pier P4 and around the concerned pier in about 2008

(2) The sand bar in around the concerned pier had been eroded gradually after 2008, and the concerned pier became to stand in the flow channel in 2012.

(3) The situation, that the riverbed in around the concerned pier was subsided and the sand bar had been washed away due to erosion, were confirmed in the photographs which were taken in 2012 and 2014.

As the results, it is somewhat likely that the periphery of the concerned pier was in the situation as being scoured easily, because the situation became easy to block the water flow by the decreased penetration depth[*47] of the concerned pier or the increase of the cross-section of the appearance against the direction of down flow.

*47 *"Penetration depth" is the distance from the level of the ground to the bottom edge of the foundation.*

3.6.1.2. Damaged status of the foot protection before the occurrence of the concerned accident

As described in 2.3.2.4, the structure of the foot protection of the concerned pier was that the steel sheet piles were driven into the ground only in the upstream side, and there were the soldier piles using the log piles in the side of the concerned pier where the steel sheet piles were not driven into the ground, as confirmed in the photograph, *i.e.,* Attached Figure 7. Then, it is highly probable that the foot protection of the concerned pier was composed of the soldier beams and lagging structure using the log piles and the wooden plates[*48]. As the damages such as washed away of the cobble stones, etc., were found in these part in 2012, it is probable that the damages had started from the part of the soldier beams and lagging structure using the log piles and the wooden plates, where it was fragile compared to the steel sheet piles, as the riverbed had been subsided and the foot protection had been exposed due to the erosion by the flowing water after 2008, when the water route became to concentrate to around the concerned pier.

After that, it was found that the side surface of the footing had been exposed by the deterioration of the washed away cobble stones, etc., between 2012 and 2014. Therefore, it is somewhat likely that the foot protection of the concerned pier had not already been provided the functions to protect scouring before the occurrence of the concerned accident.

*48 *"soldier beams and lagging structure using the log piles and the wooden plates" in this text indicates the earth retaining structure to fit the wooden sheet piles between the soldier beams, where the wooden piles were used as the soldier beams.*

3.6.2. Analysis on the Status in around the Concerned Pier after the Occurrence of the Concerned Accident

The low density sediments, etc. considered as accumulated while the velocity of water flow was slow, had been distributed on the surface layer in around the concerned pier, as described in 2.4.3 (4). Therefore, it is probable that the scouring had occurred in this area and had reached to the supporting ground in the bottom of the concerned pier, at the time of the occurrence of the concerned accident.

3.6.3. Analysis on the Mechanism of Subsiding and Tilting of the Concerned Pier

It is probable that the concerned pier had subsided and tilted in the following process due to the swollen river water at the time of the occurrence of the concerned accident while the function to protect scouring in the concerned pier had already been deteriorated before the occurrence of the concerned accident, such as the subsided riverbed in around the concerned pier and damages of the foot protection, etc., based on the analysis in 3.6.1 and 3.6.2. *[Refer to Figure 20]*

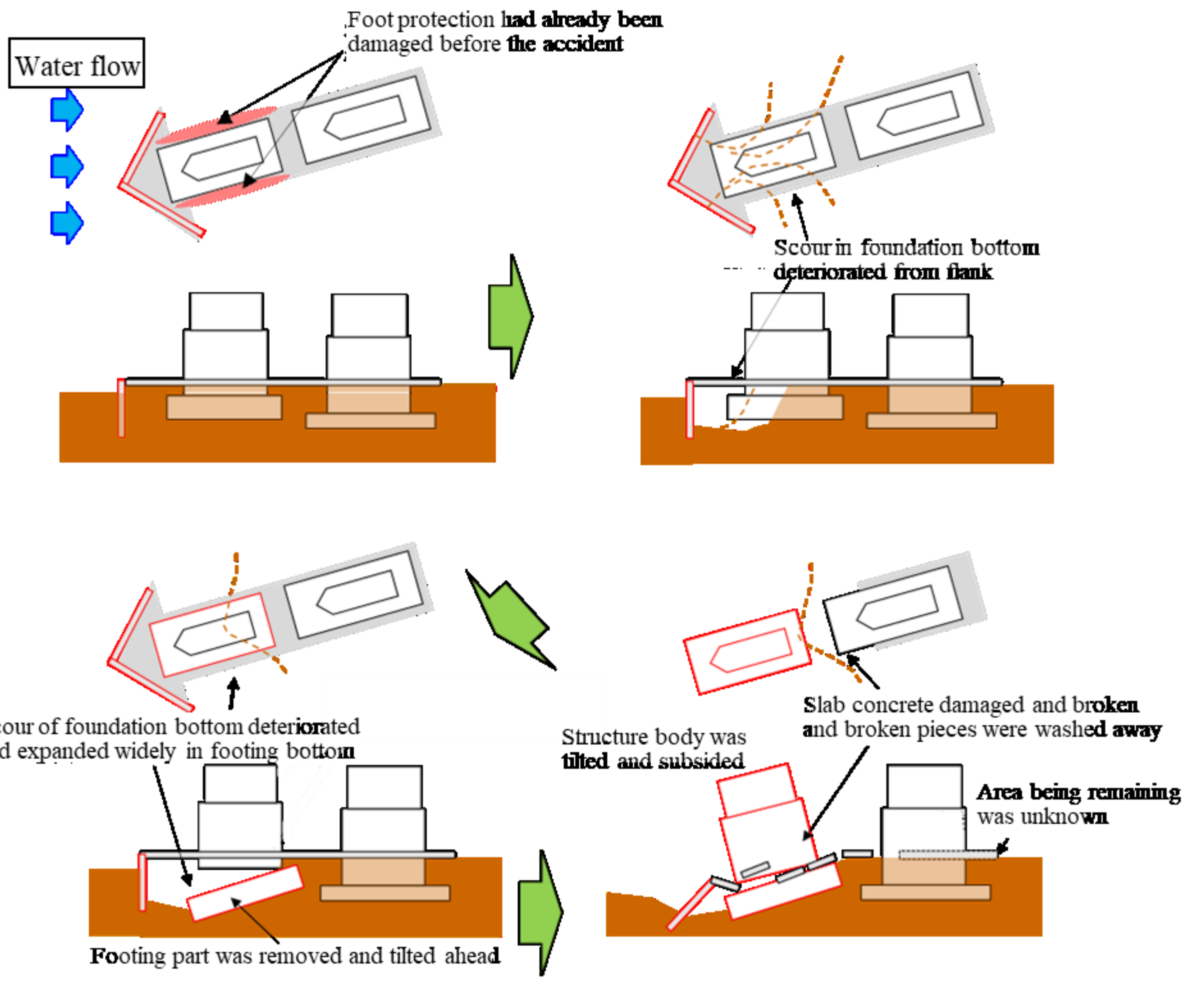


Figure 20. Imaginary figures on the mechanism of subsiding and tilting of the concerned pier

(1) The scouring occurred from the riverbed in the flank of the pier where the foot protection works had been damaged.
(2) The scouring expanded to wide area in the bottom surface of the footing, and the supporting ground reduced significantly.
(3) The footing, that lost the suspending force for the bottom surface, separated at the boundary with the structure body, tilted, and subsided.
(4) The slab concrete had broken and fragmented, and separated with the slab in the up track, then the concerned pier had tilted toward the upstream and subsided.

Here, it is somewhat likely that the bottom plate of the foundation had scoured prior to the front surface of the steel sheet piles, because it is somewhat likely that the water flow acted in diagonal direction to the pier, whose side surface of the footing had been exposed as the cobble stones had been washed away, and the water flow pattern in the rear direction of the steel sheet piles became complex as to generate exfoliating flow and the eddy current, then the scouring had occurred as the ground in around the pier suffered the action mainly composed of the drawing out effects.

3.6.4. Analysis on the Time of the Occurrence of Subsidence and Tilting of the Concerned Pier

It is probable that the subsidence and the tilting of the concerned pier were deteriorating rapidly after about 16:25, when the outbound train had been running at around the accident site without any abnormal situation, to about 16:40, when the concerned train approached to around the accident site. However, it could not be determined the time when the subsidence and the tilting had started.

3.7. Analysis on the Management of Bridges

3.7.1. Analysis on the Normal General Inspection

(1) Evaluation for the subsided riverbed

As it is probable that the water route became to concentrate to around the concerned pier after 2008, and the subsidence of the riverbed was deteriorating gradually, based on the change of the water route described in 2.3.4.2, the subsidence of the riverbed was not recognized because the column "nothing" was checked in the result of the investigation on the "subsided riverbed" in the check list for the concerned pier, as described in 2.3.2.5 (2). Therefore, it is probable that the management considering decrease of the penetration depth of the pier due to the subsided riverbed and the effect of the water flow to the foot protection, etc., could not be implemented.

(2) Evaluation on the unusual status of the foot protection

The company had been checked the unusual status of the foot protection in the normal general inspection implemented in 2013 to 2017, but the foot protection was not included in the target of the judgment of the healthiness in the check list, as described in 2.3.2.5 (2), then, there was no record to reflect the inspected results for the unusual status to the judgment of the healthiness. Based on these facts, it is probable that the required measures were not implemented, as the necessity and the urgency for the repair and reinforcement, etc., for the foot protection were not recognized correctly, because the individual inspection was not implemented as the necessity of the individual inspection was nod judged because the unusual status of the foot protection was not reflected to the result of the judgment of the healthiness.

3.7.2. Analysis on the Impact Vibration Test

The impact vibration test was implemented in December 2012, as the precise investigation for the unusual status of the foot protection in the concerned pier, as described in 2.3.2.5 (3). However, the significant reduction of the natural frequency was not found in the comparison with the measured value in the first measurement implemented in 2003, and the unusual status was judged as in the status that did not threaten the safety. It is probable that these situations were caused by being judged as the stability can be maintained against scouring by the swollen water, based on the confirmation of the healthiness of the pier based on the results of the impact vibration test.

The impact vibration test is implemented to diagnose the healthiness of the pier at that time and does not estimate the ability to maintain functions of the scour protection against the swollen water in the future. Therefore, it is required to judge the healthiness by comprehending the unusual status of the scour protection works such as the status of the riverbed and the foot protection, etc., from the viewpoints to maintain the function of the scour protection works against the swollen water, for the piers which the significant reduction of the natural frequency was not found at that time.

3.7.3. Analysis on the Reinforcing Plan for the Foot Protection

The company had been planned to secure the budget to implement the reinforcing works in 2018 fiscal year, in the long term budget plan, as the unusual status of the foot protection of the concerned pier was confirmed in the on-foot patrol implemented in 2014, as described in 2.3.2.5 (3).

However, the measures, such as to monitor the deteriorating stability of the pier and to review the operation control, etc., were not implemented until to the reinforcing works, furthermore, the reinforcing plan had been postponed without implementing the precise inspection. Therefore, it is probable that the necessity and the urgency of the reinforcing works was not recognized well.

3.7.4. Analysis on the Inspection and the Measures Related to the Scouring

It is probable that the company suffered the disaster by the occurrence of the scouring due to the swollen water in the concerned accident, as the time passed as being the required measures were not implement, even though the company had been recognized the unusual status of the foot protection, as described in 3.7.1 to 3.7.3.

It is probable that the disaster due to the scouring could be prevented if the measures such as the repair and the reinforcement, etc., of the foot protection were implemented, based on the results of the comprehension of the status of deteriorated function to protect scouring by the individual inspection, by implementing the judgement of the healthiness considering the inspected results for the unusual status of the foot protection in the normal general inspection, comprehended the long term changing status such as the status of the recession of sand bars, subsided riverbed, washed away foot protection, etc., changing by years.

It is important to implement these processes referring the Standards for Management of Maintenance for Railway Structures, etc., Structure Edition[*49] as the guideline, and the inspection methods, the judging method of the healthiness and the measures should be determined referring the comments of the above Standards. It is somewhat likely that the implementation of the individual inspection, the measures such as repair and reinforcement, etc., would be determined, because the concerned pier would be picked up as the pier required further precise inspection by the results on the protecting condition, etc., of the scour protection works, if the concerned pier was evaluated using the "Marking Table to Pick Up Bridges Scoured Easily, Attached Material 1" proposed in the comments for the Standards. The evaluating items and the aimed points to pick up the piers having the risks to generate the scour disasters were indicated in the proposals, therefore, it is probable that to pick up the piers which need special attention by referring such proposal is effective to prevent the scour disasters.

In addition, it is important to implement the measures systematically, after decided the repairing plans based on the results of the correct comprehension on the necessity and the urgency of the measures, by implementing the precise inspection by the professional organization, etc., according to its necessity, in addition to study the effective inspecting method to comprehend the situations by implementing the inspection in the dry season when the river water flows a little or to endeavor to comprehend the riverbed position quantitatively by the measurement, etc., as there is the difficult case to comprehend the status of riverbed, the damaged status of the foot protection, the change of water route, etc.

Here, when the measures are planned and decided or implemented, it is desirable to endeavor the common understandings on the actual status of rivers and the individual repair plans, etc., through the discussions, etc. between railway operators and the administrators of the rivers, and implement the measures in cooperation with each other.

*49 *"Standards for Management of Maintenance for Railway Structures, etc., Structure Edition" is the guideline officially notified to each railway operator from the chief of the Railway Bureau on January 16, 2007, described the basic concepts for the maintenance management of the railway structures.*

4. CONCLUSIONS

4.1. Findings

Summary of the results of the analysis on the concerned accident were as follows.

(1) Derailment *[Ref. 3.1.1, 3.1.2]*

It is highly probable that the 2nd axle in the rear bogie of the 3rd vehicle derailed to right at around 42,439 m, near to the end edge of the sagged and wound track, because the concerned train ran on the track where sagged and wound significantly, and restored at around 42,453 m, by hitting the guard rail and the pavement block in Tarui No.10 level crossing.

(2) Deformation of the track *[Ref. 3.3.1]*

It is highly probable that the track had sagged and wound significantly because two girders supported by the concerned pier had been displaced as the concerned pier had subsided and tilted.

(3) Water level of the river *[Ref. 3.4.2]*

It is probable that the water level of the river at the time of the occurrence of the concerned accident was in high level but not so high particularly, because the water levels of the same level were observed every few years.

(4) Subsidence and tilting of the concerned pier *[Ref. 3.6.3]*

It is probable that the concerned pier subsided and tilted because the scouring had occurred in wide areas in around the concerned pier and the supporting ground reduced significantly, due to the swollen water at the time of the occurrence of the concerned accident, while the function to protect scouring in the concerned pier had already been deteriorated, such as the subsided riverbed in around the concerned pier and the damaged foot protection, etc., before the occurrence of the concerned accident.

In addition, it is somewhat likely that the bottom surface of the foundation had been scoured prior to the front surface of the steel sheet piles, because it is somewhat likely that the water flow in backward of the steel sheet piles became to complex and generated exfoliation flow and eddy current, and the ground in around the pier had been suffered the actions mainly composed of the drawing out effects.

(5) Management of the bridges *[Ref. 3.7.2, 3.7.4]*

The company had been implemented the impact vibration test in 2012 as recognized the unusual status of the foot protection works, but the unusual status had been judged as not to threaten the safety in the comparison with the result of the impact vibration test implemented in 2003. However, the purpose of the impact vibration test is to diagnose the healthiness of the pier at that time and does not estimate the ability to maintain function of the scour protection works against the swollen water in the future. Therefore, it is required to judge the healthiness by comprehending the status of the riverbed and the unusual status of the sour protection works such as foot protection, etc., even for the piers that the natural frequency did not decreased significantly in the impact vibration test.

Therefore, it is probable that the disaster due to the scouring could be prevented if the measures such as the repair and the reinforcement, etc., of the foot protection were implemented based on the results of the comprehension of the status of the deteriorated function to protect the scouring by the individual inspection, by implementing the judgement of the healthiness considering the inspected results for the unusual status of the foot protection in the normal general inspection, based on the comprehension of the long term changing status, such as the status of the recession of sand bars, subsided riverbed, washed away foot protection, etc., changing by years.

It is important to implement the measures systematically, after decided the repairing plans based on the results of the correct comprehension on the necessity and the urgency of the measures, by implementing the precise inspection by the professional organization, etc., according to its necessity, in addition to study the effective inspecting method to comprehend the situations by implementing the inspection in the dry season when the river water flows a little or to endeavor to comprehend the riverbed position quantitatively by the measurement, etc., as there is the difficult case to comprehend the status of riverbed, the damaged status of the foot protection, the change of water route, etc.

4.2. Probable Causes

It is highly probable that the concerned accident occurred as the 2nd axle in the rear bogie of the 3rd vehicle had derailed to right because the train was running on the track on the bridge significantly deformed by the subsided and tilted pier, after that, the derailed axle restored in the level crossing while passed as being derailed.

It is probable that the pier was subsided and tilted because the ground in around the pier was scoured in wide area by the swollen river water at the time of the occurrence of the accident, while the function to protect piers from scouring had already been deteriorated before the occurrence of the concerned accident such as the subsided riverbed in around the pier caused by the concentration of the river water due to the change of the water route, damages of the foot protection as the scour protection work, etc.

It is probable that the deterioration of the function to protect scouring was related with that the measures such as the repair, reinforcement, etc., of the foot protection were not implemented, because the evaluation for the unusual status were not implemented sufficiently even though the unusual status of the foot protection of the pier was recognized in the inspection of the piers.

5. SAFETY ACTIONS

5.1. Measures for Prevention of the Recurrence Considered as Necessary

5.1.1. Required Items to Prevent the Recurrence

It is highly probable that the concerned accident occurred because the pier had subsided and tilted by being scoured, then, it is probable that the company suffered the disaster by the occurrence of the scouring due to the swollen water in the concerned accident, as the time passed while the required measures were not implemented although the company had been recognized the unusual status of the foot protection.

It is probable that the company should implement the following measures as follows, to prevent the recurrence of the similar accidents.

(1) Comprehend the long term changes in the status of the recession of sand bars, subsiding riverbed, washing away of the foot protection, etc., and implement the judgement of the healthiness considering the inspected results for the unusual status of the scour protection works such as the foot protection, etc., in the normal general inspection, and judge the necessity of the individual inspection properly and accurately.

(2) To implement the required measures systematically, by studying the necessity and the urgency of the measures such as the repair and reinforcement, etc., of the scour protection works based on the results of the comprehended deteriorating status of protecting functions of the scour protection works by the individual inspection. The impact vibration test is the effective method to diagnose the healthiness of the piers at that moment. However, when the impact vibration test is implemented, the attention should be paid that there is the case as the deterioration of the function to protect scouring by the swollen water in the future, could not be judged based on only the results of the diagnosis in the impact vibration test.

(3) When judged as repair, reinforcement, etc., were required for the scour protection works, the attention should be paid for the deteriorating stability of the piers against occurrence of the scouring by the measures to monitor using the tiltmeter, etc., the review of the operation control under water level, etc., until to the completion of the measures.

5.1.2. Items Required Attention to Prevent the Scour Disasters in the River Bridge

It is important to understand the status of the bridge, in order to prevent the scour disasters in the river bridge. It is necessary to implement the judgement of the healthiness considering the results of the inspection for the scour protection works, based on the understandings that the scour protection works such as foot protection composed a part of the bridge, in the inspection.

In addition, the inspection to confirm the status of the bridge was prescribed to implement the normal general inspection and implement the precise inspection by the individual inspection for the place judged as necessary. It is necessary to pick up the bridge that was judged as having high risks being scoured in the normal general inspection accurately in this process, as the measures for the bridge which was judged as having risks to cause the scour disaster, were also studied in the individual inspection.

It is desirable to pick up the bridges that need special attention against scouring from the viewpoints listed in the followings, based on the scour disaster in the concerned accident.

(1) Measures and pick up of the bridge having foot protection in poor protecting function

Examples of the foot protection in poor protecting function were as follows.

- The crack or the subsidence in the slab concrete was existed.
- The gap caused by the tilted steel sheet piles or the improper mesh was existed.
- The peripheral riverbed subsided to lower than the bottom surface of the footing.

Examples of the foot protection blocks that the measures had been implemented in many cases were as follows.

- The foot protection that the subsidence or the unevenness[*50] was remarkable.
- A part of the foot protection block was washed away.
- River water always flow the bottom surface of the foot protection block, etc.

It is desirable to confirm the deteriorating rate of the subsided riverbed and the unusual status of the foot protection, by comprehending continuously the height of the riverbed by making the cross-sectional diagram of the riverbed and recording them with their deteriorating rate of the unusual status, for the picked up piers. As the change of the riverbed deteriorates in the order of few years to the several ten years, it is important to comprehend the changes in the long term.

(2) Method to comprehend changes of water route and measures when acknowledged changes

It is desirable to endeavor comprehension of the changes and measure after acknowledged the changes of the water route using practically the following methods continuously to take a chance such as the periodic inspections, etc.

(i) As for the change of the water route, there are methods to confirm the position of the water route by taking the pictures for the designated points in upstream and downstream directions from the bridge, and drawing the positions of the water route on the plane sketch, etc. In addition, it is also effective to use the aerial photographs.

(ii) The cross-sectional diagram of the riverbed is drawn up by connecting the measured values obtained by measuring the height of the riverbed in the circumference of the pier and at the center of the girder using the weight and the let-rope[*51] in the upstream side of the bridge, in general. It is necessary to add the measuring points when the span between piers is large or the foundation protections are constructed discretely. The changes of the riverbed can be confirmed by indicating as laying these cross-sectional diagrams for each inspected year on the top of another.

(iii) As for the bridges crossing the river where the changes of the water routes could be confirmed, the careful inspection should be implemented to confirm the existence of the local scours in around the piers, the subsidence of the whole riverbed and the unusual status in the foot protection. In addition, draw up the cross-sectional diagram of the riverbed and accumulate the inspected results continuously together with the recorded photographs, etc., as the measures in long term.

The method using the "marking table to pick up bridges scoured easily" in the comments of the Standards for Management of Maintenance for Railway Structures, etc., the Structure Edition, was proposed as the method to pick up the bridges having high risks against scouring. It is effective to pick up the bridge that should need special attention against scouring, referring to these methods.

When the unusual status such as washed away of the components of the foot protection, etc., was found, it is necessary to implement the measures as the reinforcement of the foot protection, etc., as estimated that there is the possibility as the bridge will suffer the disaster caused by the scouring due to the swollen water in the future.

In addition, it is required to secure the safety transportation of the trains, paying attention to the deteriorating stability of the piers when the scouring had occurred, by the measures to monitor the status using the tiltmeter, etc., and the review of the operation control under the water level, etc., until to the completion of the measures.

*51 *"Unevenness" indicates the status as not flat, i.e., the status that there are concave and convex surfaces.*

*52 *"Let-rope" is the rope equipped with the scale function used for the measurement of the depth of river, etc.*

5.1.3. Measures against Natural Disasters in the River Bridge

On the measures against disasters in the river bridge for railway in the whole country, it was determined to promote urgently to construct the scour protection works and to introduce the abnormal detecting system, for about 50 bridges which are in high urgency against the fear of washing away and tilting due to heavy rain, and located in the large passenger traffic section, etc., based on the "Urgent measures on washing away and tilting of the river bridge for railway by the heavy rain" described in the following paragraph 5.4. If the above urgent measures are implemented steadily, it is probable that the safety of the railway river bridge would be improved, as the protecting function of the bridges against scouring would be improved and the abnormal detecting system using sensors would be used widely.

On the other hand, the urgent measures are planned to regard the maintenance and the security of the function of the important infrastructures as important, then it is necessary to implement the measures on the safety in the section of the small traffic where had not designated as the target, in the viewpoint to secure the safety corresponded with the disasters becoming terrible in recent years. For this purpose, it is important that each railway operator should endeavor actively to implement the software measures such as the implementation of the preventive operation control based on the weather forecast and the data of weather observation, etc., in addition to the proper implementation of the process of the inspection of the bridges based on the understandings of the purposes of the measures described in 5.1.1 and 5.1.2.

5.2. Measures Taken by the Company after the Accident

The company implemented the following measures to prevent the recurrence after the occurrence of the concerned accident.

(1) The company newly constructed the concerned pier as the pile foundation type using the steel pipe piles and the reinforced concrete structure.

(2) The company implemented the construction work to measure scouring by the coffering with steel sheet of 4.5 m long for all piers except for the concerned pier in the concerned bridge. In addition, the company decided to implement the construction work to measure the subsided riverbed by the precast concrete blocks in the entire riverbed under the bridge, in the schedule to complete by the end of May 2019.

(3) The company implemented the urgent inspection for the 38 piers in the 9 bridges which are the same type structure and confirmed that there was no problem in the safety.

(4) The company decided to introduce the urgent train stop system based on the detection of the tilting of the bridge for the concerned bridge and to implement the verifying test.

(5) The company reviewed the control value for the operation control under river water level, and added new alarm "the stop alarm", *i.e.*, the cancellation of operation.

(6) The company reviewed the inspection methods for the scouring of the bridge as follows.

- When inspect the river bridge, the changes of the status of the river around the pier and the surroundings, the change of the scour protection works, etc., should be managed together with each other using the structure management support system. The input data to the structure management support system are determined as follows.
    - a) Status in around the piers, *i.e.*, the scouring, change of the centroid, generation of the eddies, etc.
    - b) Change of the surroundings, *i.e.*, width, embankment, subsided riverbed, dam embankment, etc.
    - c) The repaired history of the foot protection, etc.
- Implement to judge the bridge which needs special attention against scouring using the "marking table to pick up bridges scoured easily" proposed in the comments of the Standards for Management of Maintenance for Railway Structures, etc. Structure Edition.

- Implement the depth surveying and the impact vibration test in every 4 years. Here, frequency of the tests should be reviewed considering the status of the degree of easiness of occurrence of scouring, etc.

5.3. Measures Taken by the MLIT after the Accident

The company published that the company introduced the system to inform the abnormal status to the train crews when there was abnormal situation in the bridge, by linking the measuring devices detecting abnormal status of the bridge and the obstruction warning signal, in the timing of the completion of the restoring works against the concerned accident, and planned to implement the verifying test by installing a various types of the measuring devices from now on. The Railway Bureau, MLIT, instructed the railway and tramway operators in the whole country to study on the introduction of such system, responding to the publication of the company and based on that the prompt measures are required as the similar cases that the piers of the bridge had tilted by scoured had occurred

5.4. Measures against Natural Disasters for the Important Infrastructures

There were the cases of the damaged railway river bridge after the occurrence of the concerned accident, such as the damages in No.1 Misasagawa bridge, Geibi Line of West Japan Railway Company, and Saitagawa bridge, Yosan Line of Shikoku Railway Company, caused by the Heisei 30th year, 2018, July Heavy Rain. In addition, there were frequent disasters that the tracks were severely damaged by the flown earth and sand from the collapsed slope by the heavy rain or the typhoons. As these cases had not caused the operation accident, they caused the severe social effects until to be restored.

On December 14, 2018, the government collected the "Urgent Measures for 3 Years to Prevent Disasters, Reduce Damages, and Make Tough National Land" as the measures to be implemented particularly urgent, based on the results of the overall inspection on the security of the functions of the important infrastructures considering the situation that the disasters became terrible in recent years such as the Heisei 30th year, 2018, July Heavy Rain, the Heisei 30th year, 2018, Typhoon No.21, the Heisei 30th year, 2018, Hokkaido Eastern Iburi earthquake, etc.

The summary of the measures on the railway river bridges in the urgent measures were as shown in Table 12. Here, the MLIT, in order to promote these measures, added the measures against the washed away and tilting of the railway river bridge to the object of the support of the business expenses to measure the railway overall safety, and decided to support the operators to be assisted.

Table 12. Summary of the urgent measures on railway river bridge

Items of the urgent measures	Urgent measures on the washed away and tilting of railway river bridge by the heavy rain
Scale of the inspection and results	About 50 bridges were found as in high urgency feared to be washed away or tilting by heavy rain in the results of the inspections for about 300 routes where the prior trains or the freight trains are operated or the traffic density is above a certain level.
Summary of the urgent measures	Maintain the scour protection works and introduce the abnormal detecting system, which is the signal equipment to prevent the train to enter the bridge by detecting the abnormal situation using sensors when the abnormal such as the tilting, etc., of the bridge had occurred, for about 50 bridges picked up in the inspection, and almost complete introduction by 2020 fiscal year.

6. OPINIONS

In view of the result of the accident investigation, the Japan Transport Safety Board expresses 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 contribute the prevention of recurrence of the accidents of the same kind.

Contents

It is highly probable that the vehicle derailed because the train ran on the track significantly deformed due to the subsided and tilted pier by the occurrence of the scouring in around the pier by the swollen river water, in the concerned accident.

The foot protection had been constructed as the scour protection work to the piers, and Nankai Electric Railway Co., Ltd. had been implemented the diagnosis of the piers by the impact vibration test, as already recognized the unusual status of the pier before the occurrence of the concerned accident. To review the occurrence of the concerned accident, the impact vibration test is the effective method to diagnose the healthiness of the pier at that time, but it suggested that there is the possibility to cause the result to overlook the deterioration of the protecting function of the scour protection works by the swollen water in the future, based on only the diagnosis by the impact vibration test.

In order to prevent the same kind of the scour disasters, it is important to study on the measures by implementing the inspection process properly referring the Standards for Management of Maintenance for Railway Structures, etc., Structure Edition, as the guide line, and to implement the precise investigation steadily for the scour protection works in the individual inspection if necessary.

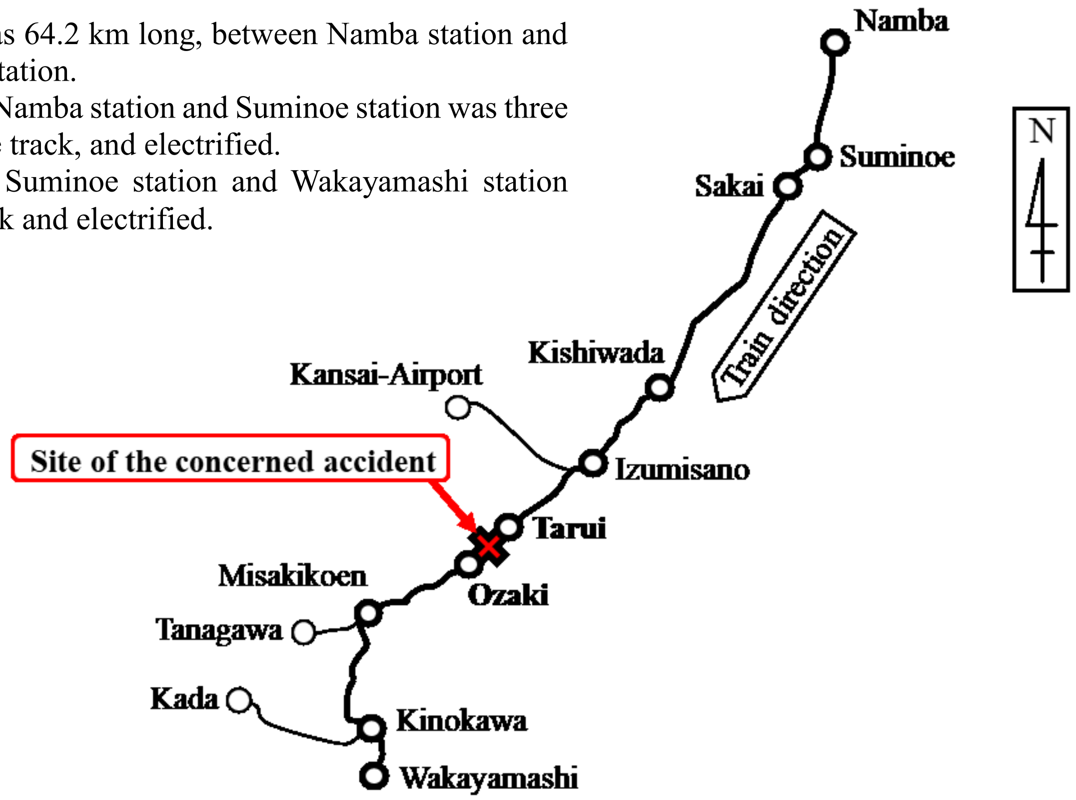
As the Standards for Management of Maintenance for Railway Structures, etc., Structure Edition, have been made well known from the Railway Bureau of the MLIT to the railway and tramway operators by the "On the Establishment of the Standards for Management of Maintenance for Railway Structures", notification from the chief of the Railway Bureau issued on January 16, 2007, the following points should be made well known in the railway and tramway operators having the river bridges, considering that the scour disaster may cause the serious accident, based on the occurrence of the concerned accident.

1. When implement the inspection of the bridges, the Standards for Management of Maintenance for Railway Structures, etc., Structure Edition, should be used as the guideline, and refer to the comments of the Standards on the inspection method, the judging method of the healthiness and the measures, etc. When the unusual status of the scour protection works, etc., were found in the general inspection, implement the judgement of the healthiness considering the inspected results for the scour protection works and judge the necessity of the individual inspection. When the individual inspection was judged as needed, implement the precise inspection for the status around the pier and the maintained status of the protecting function for the scour protection works and study the necessity and the urgency of the measures, then implement the measures systematically.

2. In the comments of the Standards for Management of Maintenance for Railway Structures, etc., Structure Edition, the "marking table to pick up bridges scoured easily" was proposed. The marking table is the optional material in order to pick up the bridges having risks to cause the scour disaster, however, implement the judgement of the necessity of the individual inspection properly and steadily referring to the similar marking table.

Attached Figure 1. Rout Map of Nankai Line

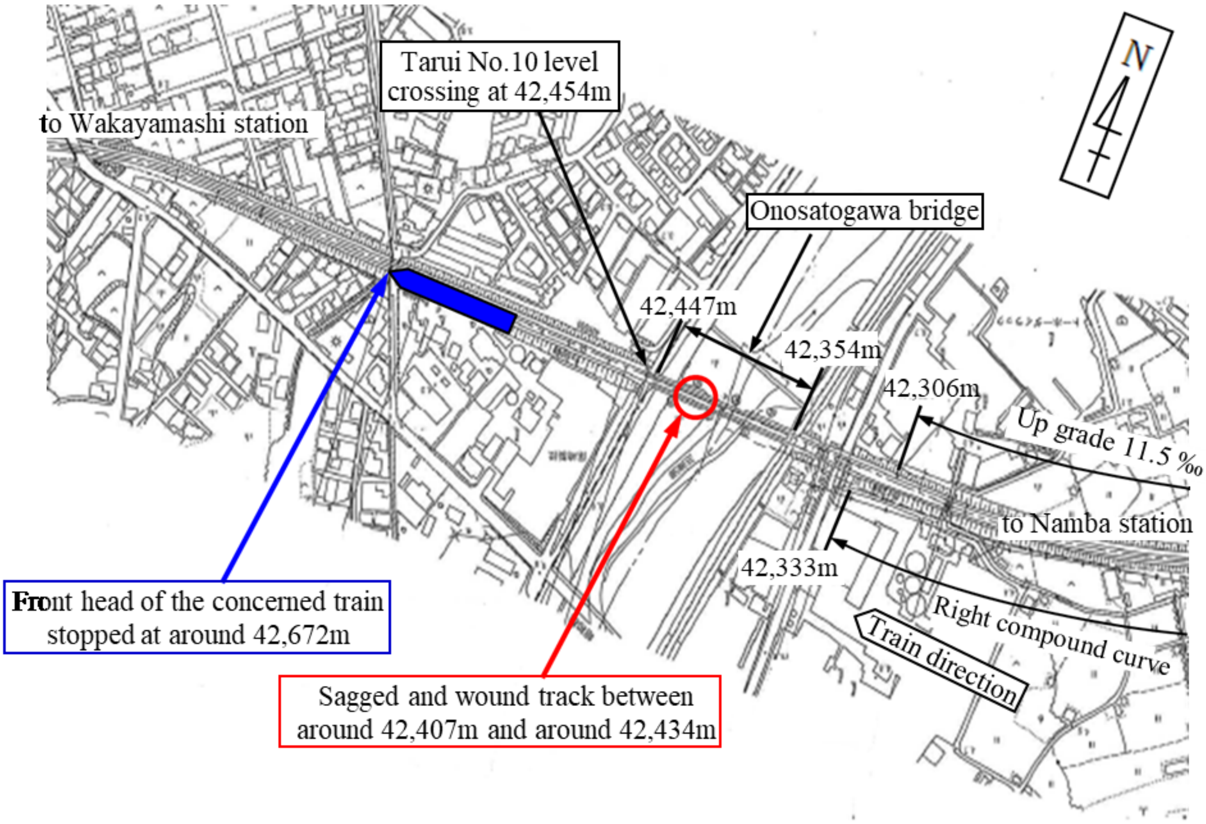
Nankai Line was 64.2 km long, between Namba station and Wakayamashi station.
Track between Namba station and Suminoe station was three lines, quadruple track, and electrified.
Track between Suminoe station and Wakayamashi station was double track and electrified.



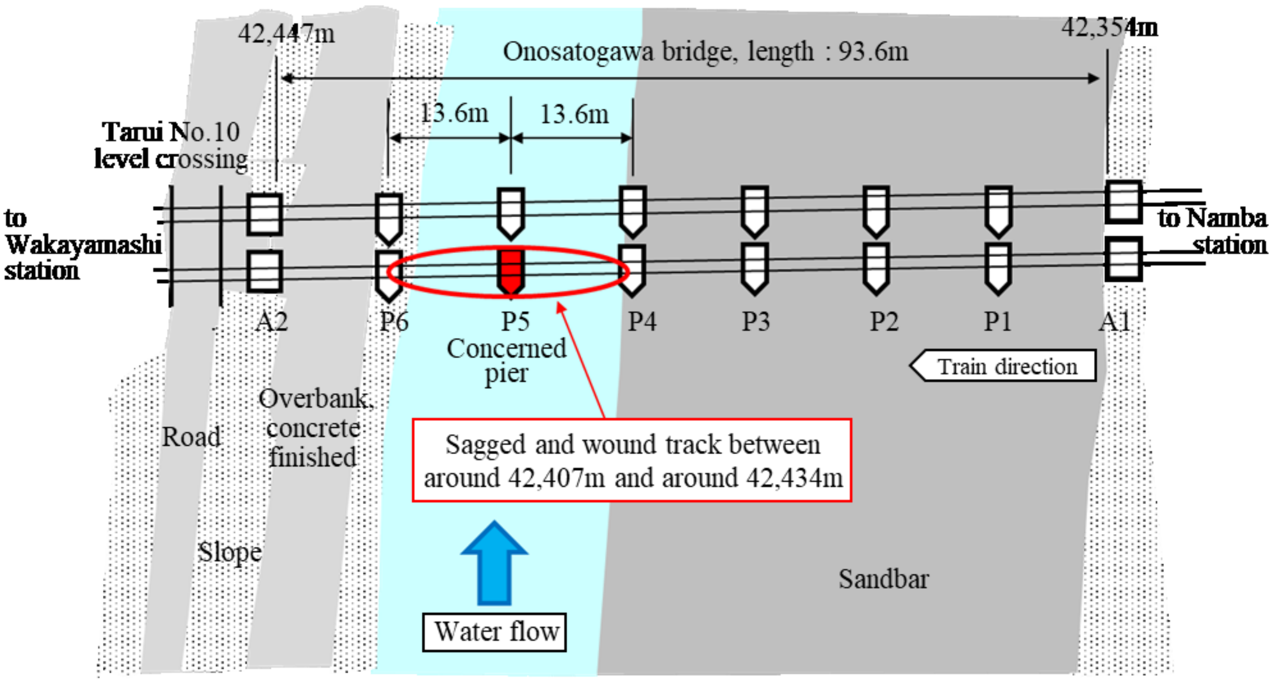
Attached Figure 2. Topographical Map around the Accident Site

* This figure was made by using the Digital Topographical Map published by Geospatial Information Authority of Japan

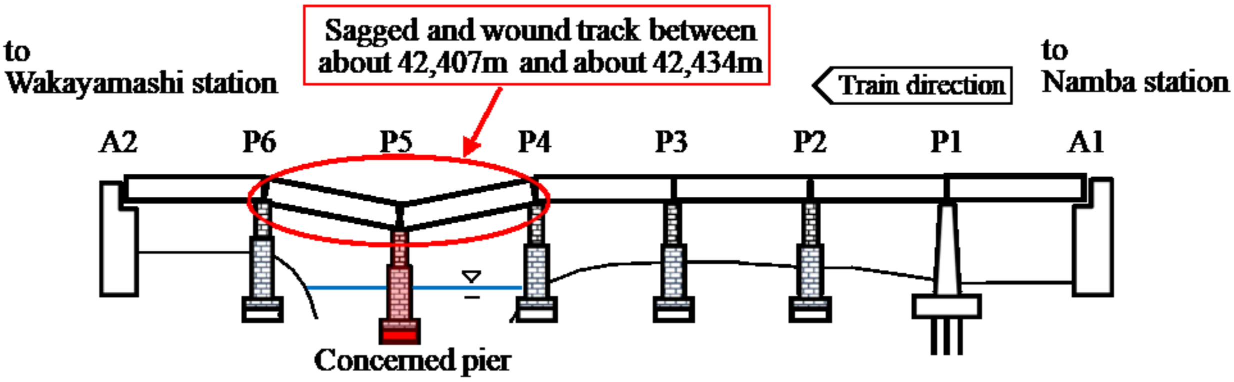
Attached Figure 3. Plane View of the Railway Track in around the Accident Site



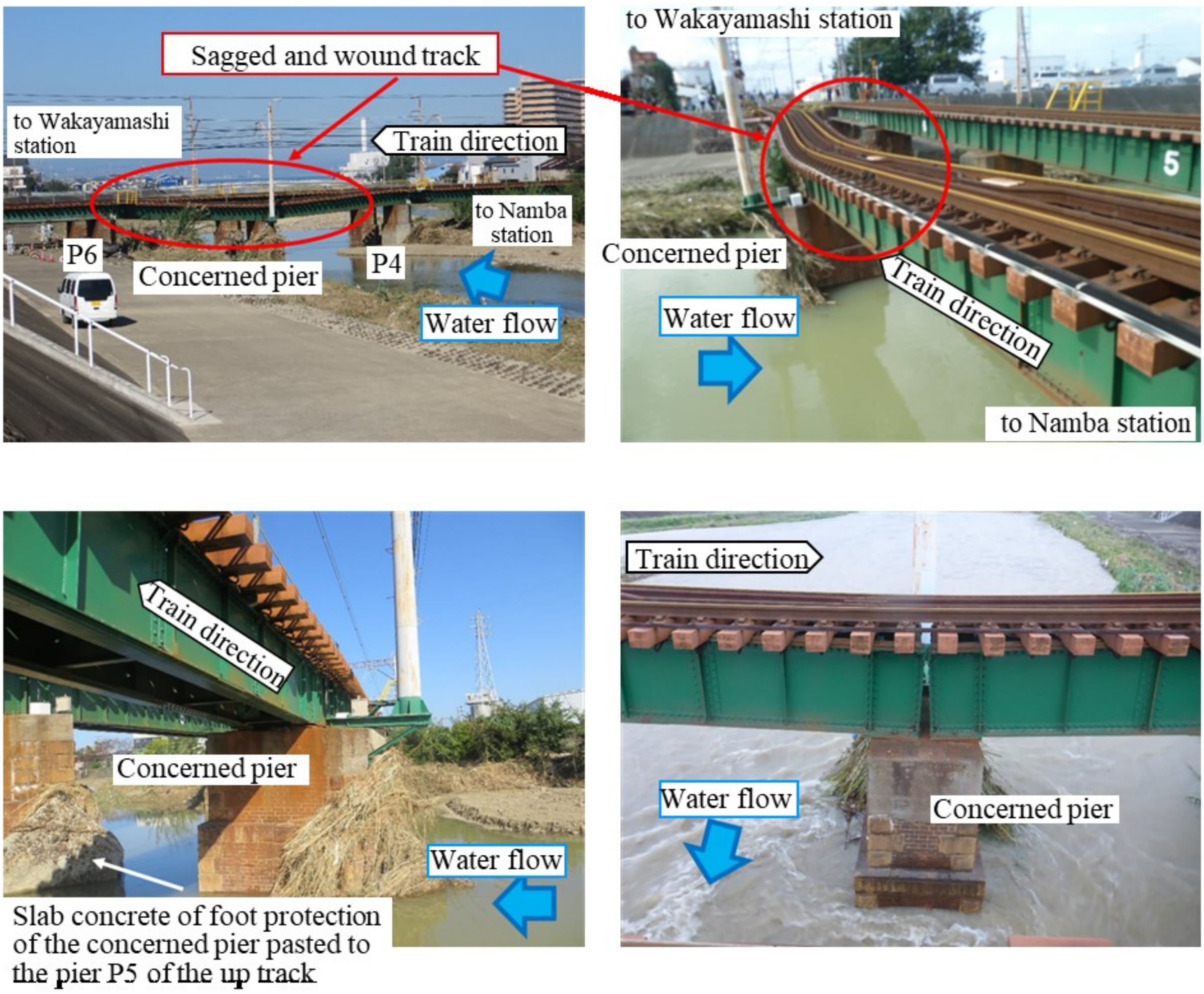
Attached Figure 4. Enlarged Rough Map of the Accident Site, Plane View



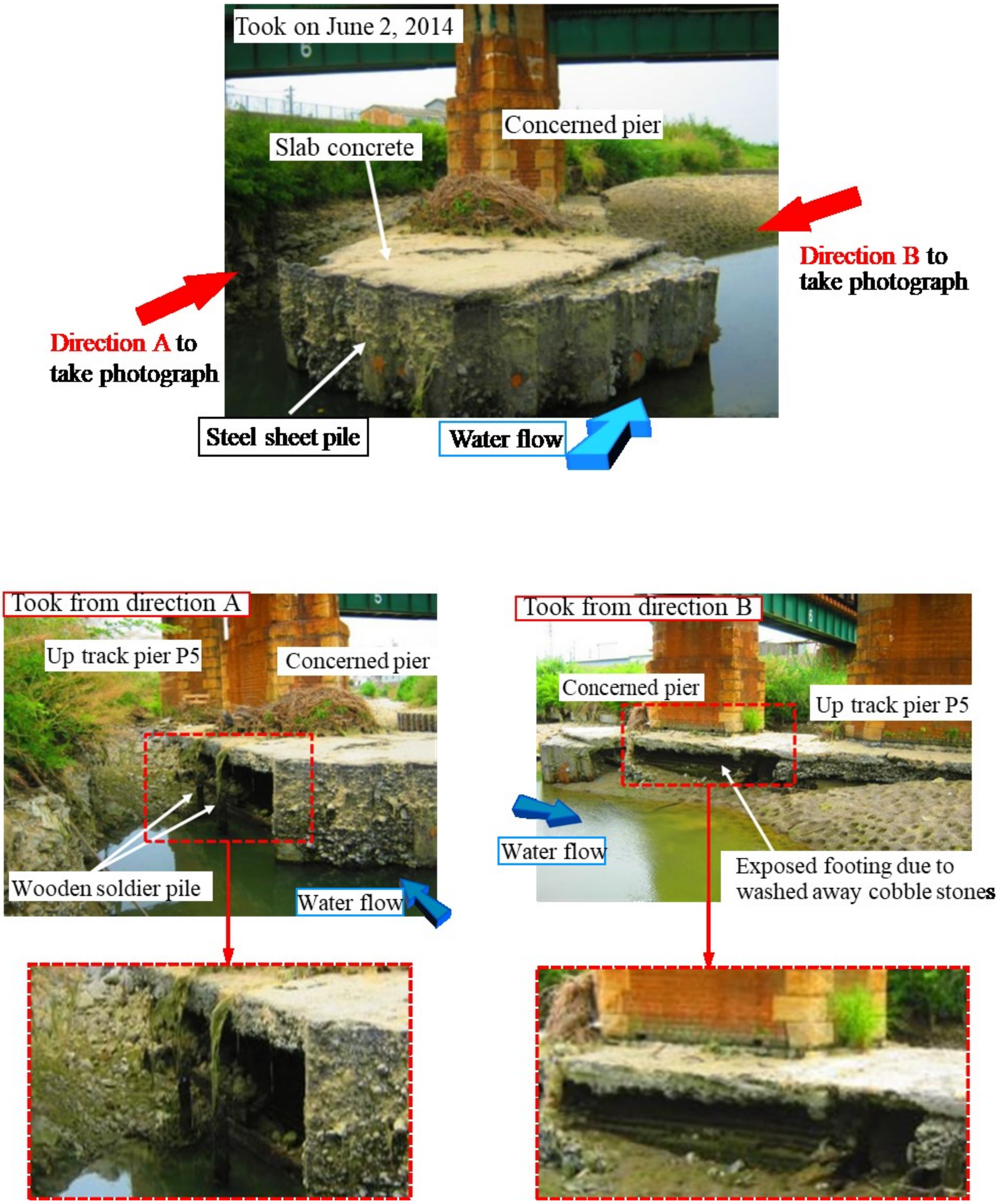
Attached Figure 5. Enlarged Rough Map of the Accident Site, Cross section



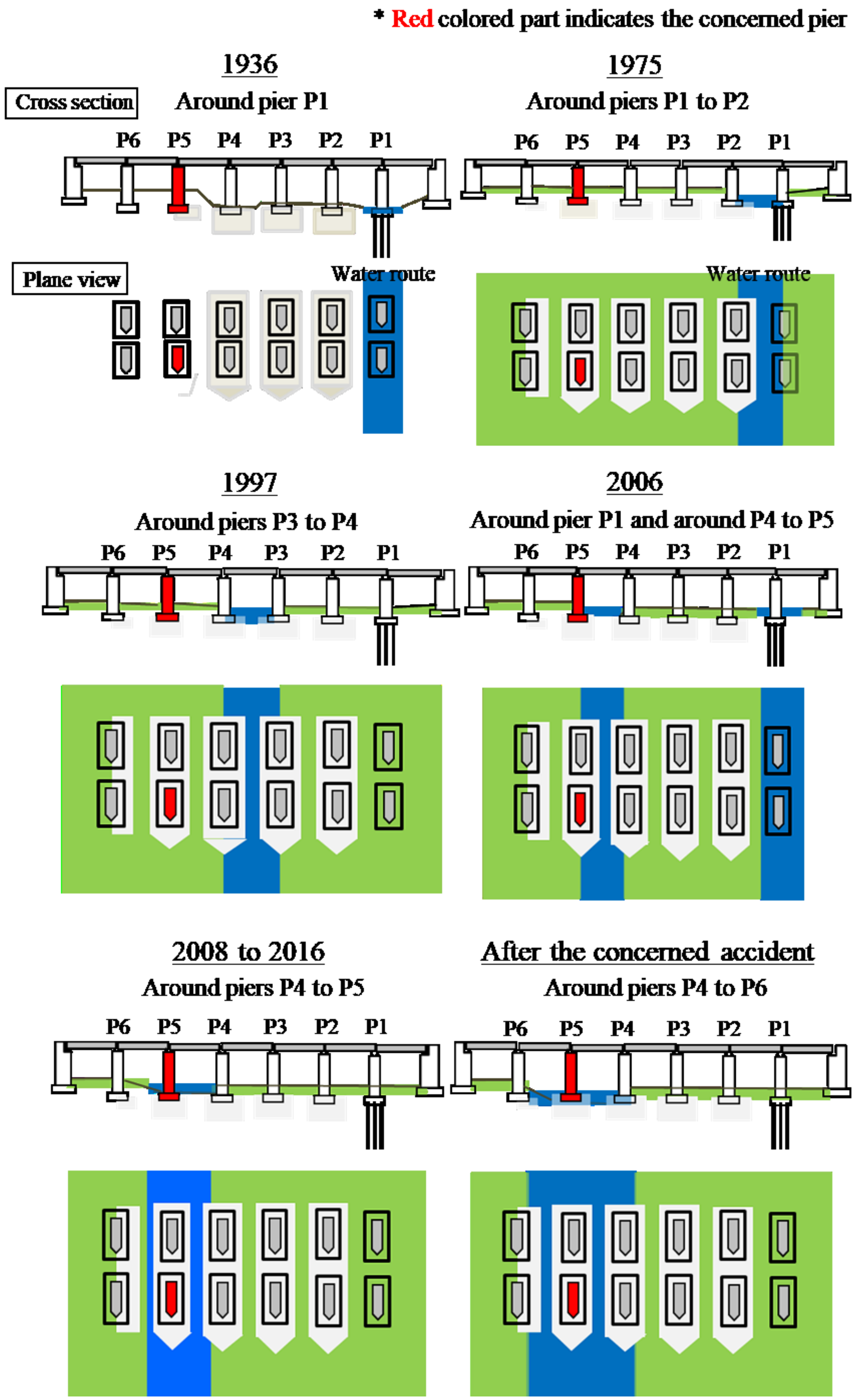
Attached Figure 6. Status of the Accident Site



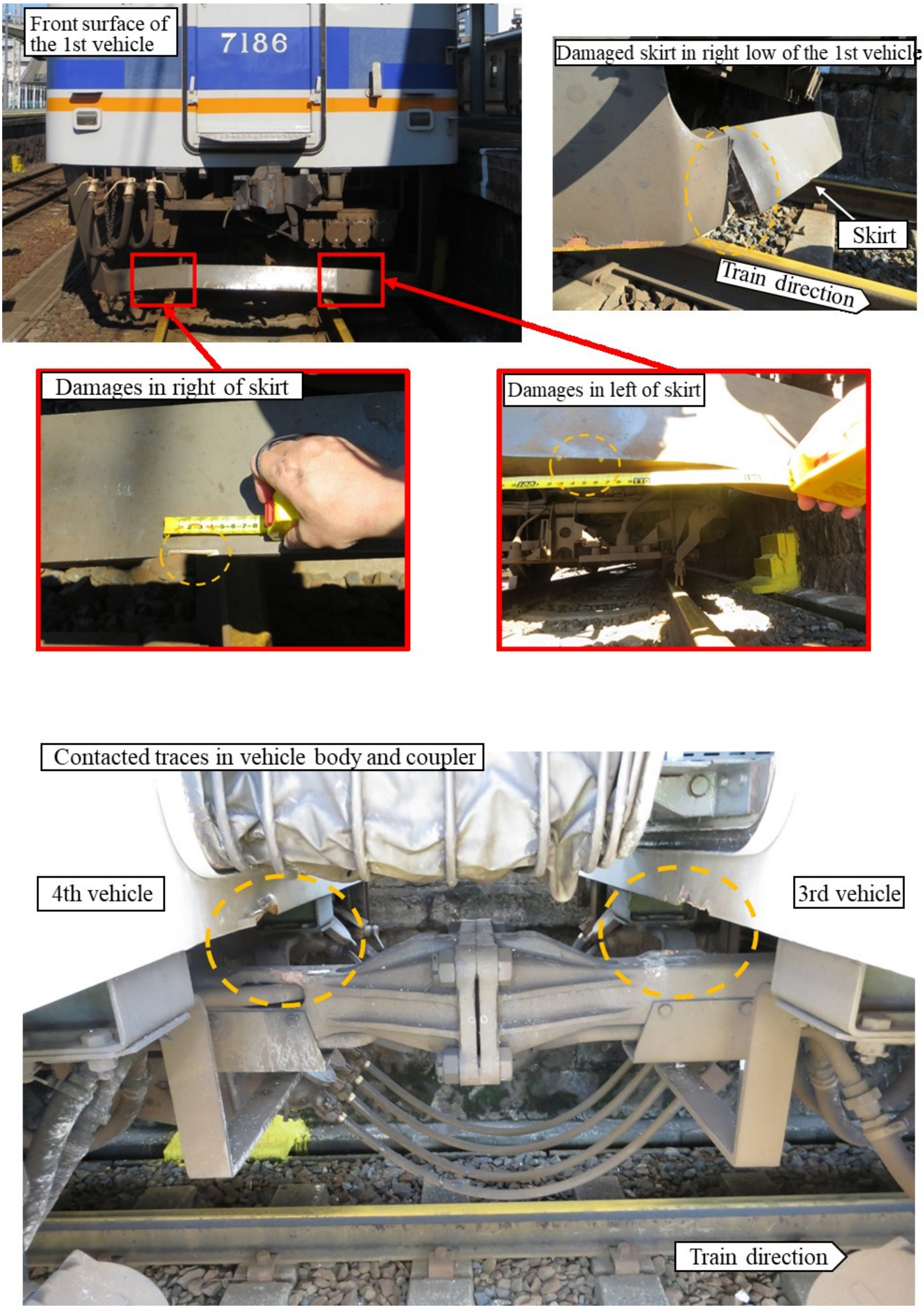
Attached Figure 7. Status of Foot Protection of the Concerned Pier before the Occurrence of the Concerned Accident



Attached Figure 8. Image of Changes of the Water Route in around the Concerned Bridge

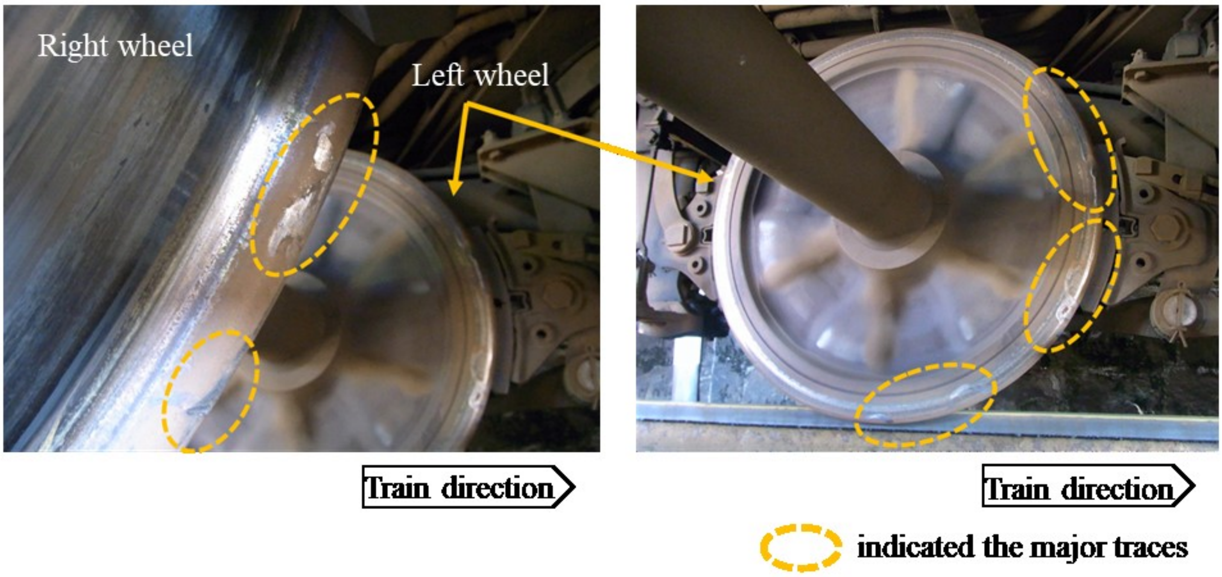


Attached Figure 9. Status of the Major Damages of the Vehicles



Attached Figure 10. Traces in the Wheels

Hit traces and fretting traces in the wheels of the 2nd axle in the rear bogie of the 3rd vehicle



Attached Material 1. Marking Table to Pick Up Bridges Scoured Easily

* Extracted from the attached material 4 of the "Standard of Maintenance and Management of Railway Structures, etc., Structure Edition, Foundation Structures and Retaining Structures"

1. Preface

It is required to have been checked the status of the bridges in order to prevent the scour disaster in the river bridge. As for the inspection to check the status of the bridge, the visual inspection in the general inspection is implemented at first and the precise inspection, *i.e.*, the individual inspection, is implemented for the required place. In the individual inspection, the required measures, such as the needs of the measures for the bridge having the risk of scouring is studied. The important point in this process is to pick up the "bridges scoured easily" accurately in the step of the general inspection.

Some methods have been proposed up to the moment as the method to pick up bridges that need special attention against scouring. However, the precise inspection and the professional knowledges on the river engineering are needed to apply these methods, thus these methods are not always applicable in the stage of the general inspection. Then, the marking table was made by studying the method to pick up the bridge having the risk to cause the scour disaster effectively. Here, this marking table is only to pick up the bridge having the risk to cause the scour disasters, and is not to judge the healthiness of the bridge at that time. In addition, even if the pier was picked up by the marking table, there is no problem to exclude the pier from the target when the pier was judged as having no risk in the inspection implemented after that.

2. The target bridges of the marking table

The type of the scour disasters differs depending on the existence of the piers. Therefore, the marking table was made as available only for the bridges having the piers. In addition, the disasters such as the collapsed pier caused by the submerged girders were excluded from the targets of the marking table, as their causes are clearly different from the scour disasters.

3. Items to evaluate the scouring

Generally, the parameters in the equation of prediction of the scoured depth are well known as the factors to affect the depth and magnitude of scouring in the river bridge. For example, (1) diameter of particles of the riverbed materials, (2) gradient of the riverbed, (3) water level, (4) velocity of water flow, *i.e.*, flow rate, (5) width of the pier, etc. However, these factors are ever-changing or required very complex works to be identified. In this method, the conditions generally considered as related to the scouring phenomena, are classified into three categories, and the factors considered as greatly affected to the scouring were selected as the evaluating items based on the features obtained from the cases in the past disasters, refer to Attached Table 4.1.

Here, the gradient of the riverbed and the diameter of the riverbed materials are represented by the topography and the riverbed material considered as correlated with them, and the basically invariable factor, such as the width of the pier, are not selected as the evaluating items.

Attached Table 4.1. Evaluating Items in the Marking Table

Conditions	Evaluating Items
Surrounding condition of river	(1) Topography, (2) Contraction of river width, (3) Riverbed material, (4) Subsidence of the whole riverbed
Conditions on the structure of the bridge or the pier	(5) Pier position in the curved river, (6) Pier position in flood plain, (7) Drop head in downstream direction, (8) Ratio of underground depth to width, (9) Change of penetration depth, (10) Rock contact of bottom surface of foundation
Condition of the protection	(11) Existence of the protection work, (12) Level of unusual status, (13) Hight difference between riverbed and bottom of foundation, (14) Constructed area

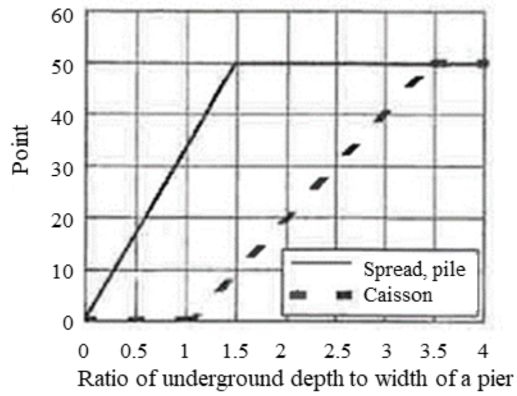
4. Marking Table

The marking table is shown in Attached Table 4.2. The marking should be implemented for each evaluating item, and select the item closest to the status of the actual site. The evaluating items are allotted the points considering the effects to the scour disasters and the total points of each item is the evaluated point of the target pier.

Attached Table 4.2 Marking Table

	Evaluating item		Category	Point
Conditions surrounding river	Topography		Plain	10
			Gorge bottom plane	10
			Alluvial fan	0
			Valley	5
	Contraction of river width		Nothing	15
			Existed	0
	Riverbed material		Sand	10
			Gravel	0
			Bare rock, huge gravel	10
	Subsidence of the whole riverbed		Subsided	0
			Not subsided	10
Condition of structure of bridge or pier	Pier position in the curved river		Straight & inside of curve	15
			Outside of curve	0
	Pier position in flood plain		In the water flow	5
			Land without revetment	10
			Land without revetment next to flow route	0
			Land with revetment	25
			Land with revetment next to flow route	15
	Drop head in downstream		Nothing	20
		Height	～1m	5
			1m～2m	0
			2m～	◆
		Unusual status	Unusual status existed	◆
		Constructed area	Only a part of river width	◆
	Ratio of underground depth to width		Spread foundation, pile foundation	Obeyed to Attached Figure 4.1
			Caisson foundation	
	Change of penetration depth		Increased or decreased over 1.5 m from the previous investigation	◆
	Rock contact of bottom surface of footing		Not contacted to rock	0
			Considered as contacted with rock	15
			Contacted with rock	30

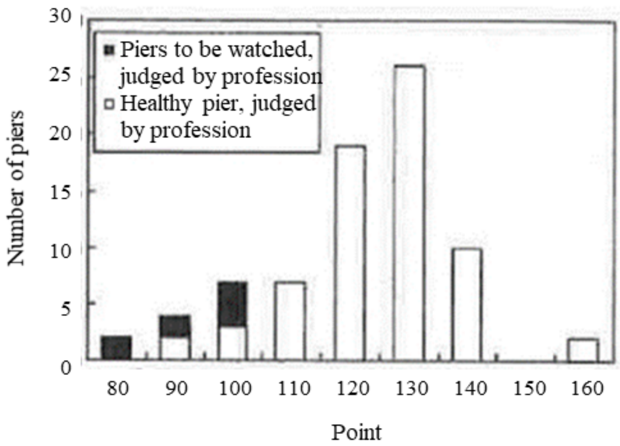
	Evaluating item		Category	Point
Condition of protecting	Nothing			0
	Unknown			0
	Basket		Unusual status existed	0
			No unusual status	5
			Unusual status unknown	0
	Block	Unusual status	No unusual status	20
			Middle level unusual status, partly washed away, random stack	5
			Large level unusual status, washed away	◆
			Unusual status unknown	0
		Connection	Connected	5
	Cradle	Penetration	Riverbed > cradle upper surface	20
			Bottom of cradle < riverbed ≦ cradle upper surface	10
			Riverbed ≦ bottom of cradle	◆
		unusual status	Unusual status existed	◆
			Unusual status unknown	0
	Concrete protection	Constructed area	Whole area in around	40
			Over $2D$ (D : *pier body width*)	20
			Under $2D$ (D : *pier body width*)	0
	Sheet pile	Penetration	Riverbed > foundation bottom	20
			Riverbed ≦ foundation bottom	◆
		Unusual status	Unusual status existed	◆
			Unusual status unknown	0
Remarks	Item investigated certainly		Structure type of drop head in downstream	—
			Structure type of pier foundation	—
	Item desirable to be investigated		River was improved in around	—
			Surroundings of river around pier changed from previous investigation?	—
			Water flow direction and orientation of pier	—
			Existence of obstruction of estuary	—
			Existence of history suffered disaster	—
			Existence of the neighboring piers	—
			The other peculiar conditions	—



Ratio of underground depth to width of a pier = L / B
L : Penetrating depth, B : Width of a pier.

In case of spread, pile foundation,
Point = $50 / 1.5 \times L / B$
* Penetration depth L of the pile foundation is from the footing bottom to the height of the riverbed.
In case of the caisson foundation,
Point = $20 \times L / B - 20$

Attached figure 4.1 Relation between the penetration depth and the point



Attached figure 4.2 Frequency distribution for the points based on the site investigation for 77 piers

When the evaluating point was less than 110 points, the pier is considered as "the pier considered as the more precise inspection is required", *hereinafter referred to as "the pier needed special attention"*. Here, the item marked by "◆" in its point column is the important item with the risk of the scour disasters, therefore, the pier is judged as the pier needed special attention if one of the items was marked by "◆" regardless of the total point of the marked table. In addition, the remarks are not added to the direct evaluation then marked by "-" in their point columns and were not allotted the point. However, the structure types of the drop head in the downstream and the pier foundation are required to be inspected as the fundamental items. It is desirable to inspect on the other items also.

The evaluation, using the marking table in Attached Table 4.2, was implemented for the 27 piers and the 77 bridges in some track section. The histogram of the evaluated points in the evaluation was shown in Attached Figure 4.2. Here, the "pier needed special attention" in the figure is the pier judged as the "pier needed special attention against scouring" by the professional engineer on the scour disaster of piers without using the marking table. Attached Figure 4.2 showed that the piers needed special attention were included in the piers which are evaluated as less than 110 points. Therefore, the boundary point of the piers needed special attention was set as 110 points, based on in the above results of the evaluation.