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Derailment Accident of an Automated Guideway Transit due to Great Earthquake

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Abstract

The Japan Transport Safety Board contributes to preventing the occurrence of accidents and mitigating the damage, thus improving transport safety. As the recent representative example of our activities, we pick up the case of a derailment accident of an automated guideway transit, in which the automatically operated train with rubber tires was derailed due to the 2021 Chiba earthquake. After the derailment accident, about 10 minutes later, the dispatcher in the traffic control office energized the power collection rails again in order to move this train to the near station by remote control, therefore sparks flew because of a ground fault and smoke came from around the current collecting shoes under the floor of the vehicle.

The purpose of this abstract is to set out the contents of the investigation reports and the recommendations on that accident made publicly available by the Japan Transport Safety Board in 2023. We show how the derailment accident occurred on the automated guideway transit line with the running track paved with concrete and side walls, and we address the important point to note in order to secure safety of passengers when the driverless automatic trains get involved in trouble.

Keywords: safety, accident investigation, derailment, earthquake, automated guideway transit, multi-body dynamics.

1 Introduction

The Japan Transport Safety Board (JTSB) is a multi-modal investigation organization responsible for carrying out investigations into aircraft, railway and marine accidents, established on October 1, 2008 [1]. As the representative example of our activities, we pick up the case of a derailment accident of an automated guideway transit (AGT), in which the automatically operated train with pneumatic rubber tires was derailed in the turnout section on the elevated viaducts due to the 2021 Chiba earthquake. Here, the derailment in this case means that the tires of the vehicle, hereinafter referred to as “the running wheels”, had deviated from the running track paved with concrete.

The purpose of this abstract is to set out the contents of the investigation reports and the recommendations on this accident made publicly available by the JTSB in 2023 [2, 3]. We show the procedure of the accident investigation and how the derailment accident occurred on the AGT line with a paved road and side walls. And also, we emphasize the importance of arranging the methods or the procedures of the evacuation and the guidance for passengers against abnormality in case of the automatically operated train without a driver and a crew.

The summary of the accident is as follows: The accident occurred on the Nippori-Toneri Liner of the Bureau of Transportation, Tokyo Metropolitan Government. This line is an automated guideway transit (AGT), where the unmanned automatic train operation started in 2008 [4]. On October 7, 2021, the outbound 2265A train composed of 5 vehicles bound for Minumadai-shinsuikoen station departed from Toneri-koen station on schedule at 22:41. After a while, the dispatcher in the traffic control office felt the shock of earthquake, and operated the button to suppress departure of trains stopping at each station simultaneously. Furthermore, just after that, the dispatcher confirmed the sounding of the earthquake early warning system for railway which noticed the occurrence of the earthquake originated in northwest of Chiba Prefecture as hypocenter, and operated the button to implement simultaneous emergency stop of trains, to stop all running trains. The 2265A train running at 49 km/h approximately along elevated viaducts stopped in the turnout section in the premises of Toneri-koen station by this operation. After that, the staff arrived at the site checked the train and found that left and right running wheels in the front bogie of the first vehicle had been fallen to right from the running track. There were 29 passengers boarded on the train, and 8 passengers among them were injured by the derailment accident [2].

The outline of the facilities in around the accident site is shown in Figure 1, and the guiding system of the train in the concerned turnout section is shown in Figure 2. The guide wheels contacting with the outer surface of the guide rail and the branch wheels contacting with the inner surface of the fixed guide plate installed only in the turnout are installed in each bogie of the vehicles. When the train entered the turnout from the straight direction, left side branch wheels of the vehicle were guided by inner side of the fixed guide plate on the side wall in the straight track side, as shown in Figure 2.

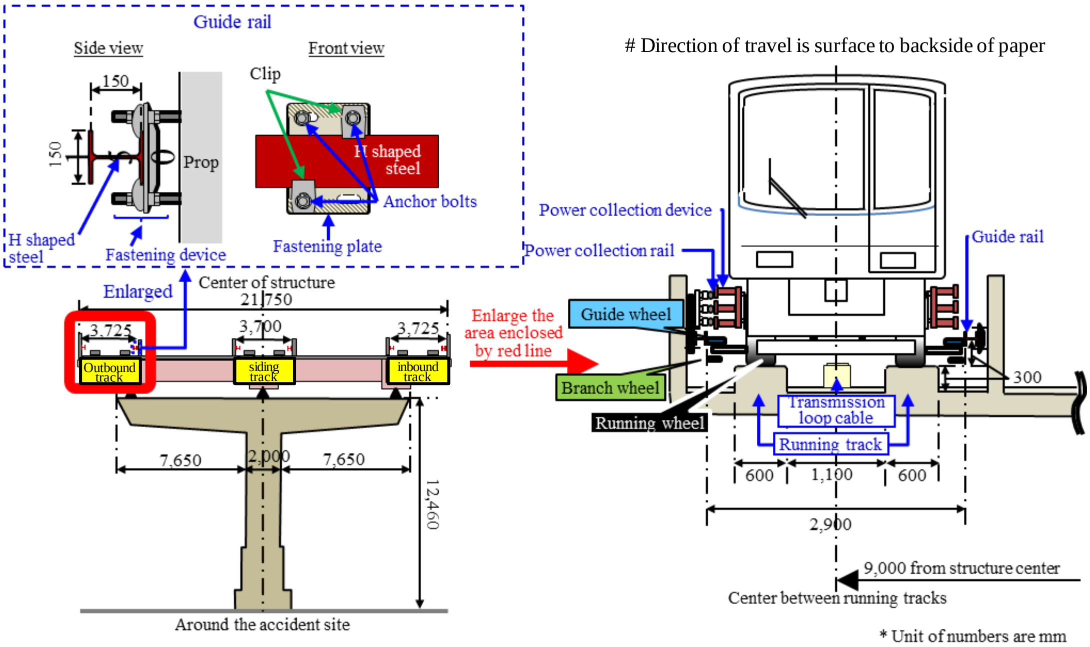
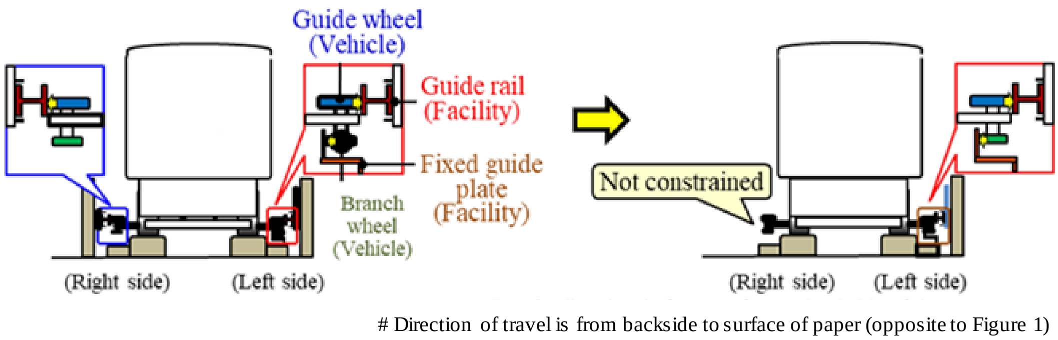


Figure 1: Outline of facilities around the accident site



(a) From straight section to turnout section (b) Mid turnout section

Figure 2: Guiding system of train in turnout around the accident site

2 Methods

2.1 Estimation of the vehicle behavior in the earthquake

When the 2021 Chiba Earthquake (magnitude: 5.9; maximum intensity: 5 upper) occurred, the 2265A train was running on the viaduct in the premises of Toneri-koen station. The point where the train started to be derailed was about 38 km away in west-northwest from the epicenter of the earthquake.

Firstly, the temporary aftershock observation was carried out on the ground surface around the derailing point and the seismic observation spot at the Toneri Rolling Stock Depot and on the top of the viaduct at the derailing point. Then, the waveforms of the seismic motion in the direction orthogonal to the track, hereinafter refer to as “the lateral direction”, were recreated, and the Fourier amplitude spectrum and the transfer function of the seismic ground motion, in other words, the earthquake amplifying characteristics between the derailment site and the observation spot were calculated. Since the observation spot was near to the accident site, and had almost the same ground conditions, by multiplying the earthquake waveform recorded at the observation spot by this transfer function, the seismic ground motion at the derailment site when the derailment accident occurred was estimated.

Secondly, the seismic waveforms in the lateral direction and in the rolling direction on the top of the viaduct at the derailment site were also estimated considering the vibrating characteristics of the structure. The estimation procedure is the same way as that used in the above mentioned first stage. The vibrating characteristics of the structure around the accident site were calculated using the measured data of the temporary aftershock on the ground and on the viaduct. And then, the seismic waveforms on the top of the viaduct were estimated by multiplying the earthquake waveform estimated on the ground at the derailment site by these vibrating characteristics of the structure.

Finally, the behavior of the vehicles and the maximum rising heights of the guide wheel and the branch wheel were analyzed by modelling the vehicle using the Multi-Body Dynamics (MBD) analysis software and input the estimated vibrating waveform at the top of the structure due to the earthquake. The vehicle was supposed to move in the 2 dimensional plane, and each part was modelled by the rigid body, the spring and damper element. The vertical rigidity of the running wheel was modelled by the spring having the characteristics that the load weight increases proportional to the deflected amount only when contacted with the running track. The rigidity of the guide wheel in the direction orthogonal to the route was also modelled by the spring. The construction and the analysis of the vehicle model were implemented using the MBD software called “Adams” manufactured by MSC Software Limited.

2.2 Problem on rescuing the derailed train without driver and crew

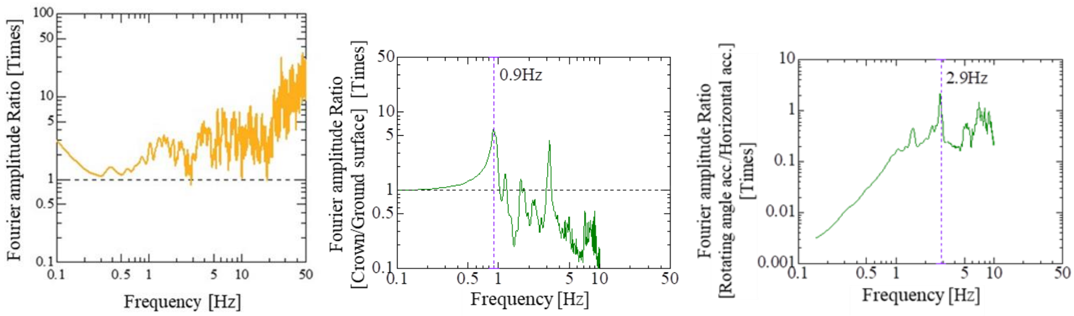
The following factual information was obtained from the statements of the dispatcher and passengers, and was verified using the operating data recorded in the event recorder and the investigation results on the damage status of the facilities and vehicles.

Just after the derailment accident, the electric current of the power collection rails was cut off automatically, because the seismometers along the line detected an earthquake with a seismic intensity of a 5 lower on the seven-point Japan Meteorological Agency’s scale and the urgent safety system worked. Then, about 10 minutes later, the dispatcher in the traffic control office instructed the staff of the substation control center to feed electric power again to the feeding section around the accident site in order to move the derailed 2265A train and to evacuate and guide the passengers, but these treatments was implemented without confirmed that the train had been derailed. Therefore, the spark was scattered from around the power collection rails and shoes, where the train was collecting electric power, and became to the situation that its smoke entered the cabins.

The dispatcher received the notification from a passenger of the train through the emergency phone equipped in the cabin that "please move the train to the next Toneri station, there was the person who blooded from head", "sparks had emitted" and "smokes had filled in the cabin".

3 Results

Figure 3 shows the calculation results of the earthquake amplifying characteristics between the ground surface at the derailment site and the observation spot (Figure 3 (a)) and the vibrating characteristics of the structure at the accident site (Figure 3 (b)). From the amplifying ratio, it was found that the seismic motion in the lateral direction around the accident site was larger than that at the observation spot in the Toneri Rolling Stock Depot. and that the lateral vibration on the top of the viaduct was larger than that on the ground at 0.9 Hz. Based on the Figure 3 (b-2), it was also found that there is the possibility that the viaduct around the accident site showed the rotating behavior in the rolling direction when earthquake occurred. It is likely that the ratio of the rotating behavior accompanied to the displacement in the lateral direction became to relatively large, because the viaduct around the accident site was the 3 tracks structure, which is the unique structure in the whole route, composed of the wide girder and supported by a long pier. The maximum values of acceleration were estimated to be about 354 gal in the lateral direction and about 440 gal in the vertical direction at the position where the train was running, *i.e.*, the position 9,000 mm apart from the center of the structure in the horizontal direction. On the other hand, the maximum vertical acceleration was 48.4 gal at the center position of the structure. Therefore, it is probable that the rolling motion of the viaduct amplified not only the lateral vibration but also the vertical vibration at the running track on the left side of the viaduct (Figure 1).



lateral direction (b-1) lateral direction (b-2) rolling direction / lateral direction
(a) ground at accident site / observation spot (b) top of viaduct / ground at accident site

Figure 3: Earthquake amplifying characteristics of ground and structure

In order to confirm the validity of the vehicle model, the frequency analysis was implemented by measuring the acceleration by vibrating the vehicle of the same type as the vehicle composed of the train with the sinusoidal waves in the simple method. As the results, it was found that the frequency when the rotating angle in the rolling direction around the gravity center of the vehicle body becomes maximum existed in about 1.0 Hz.

Based on the results of the vehicle behavior analysis, the both guide wheel and the branch wheel rose to the height exceeded the top of the guide rail when the rotating behavior of the structure in the earthquake was considered as well as the lateral seismic motion. In addition, considering the information on the damages and traces of the vehicles and the facilities around the accident site, the process to the derailment of the train was estimated as shown in Figure 4.

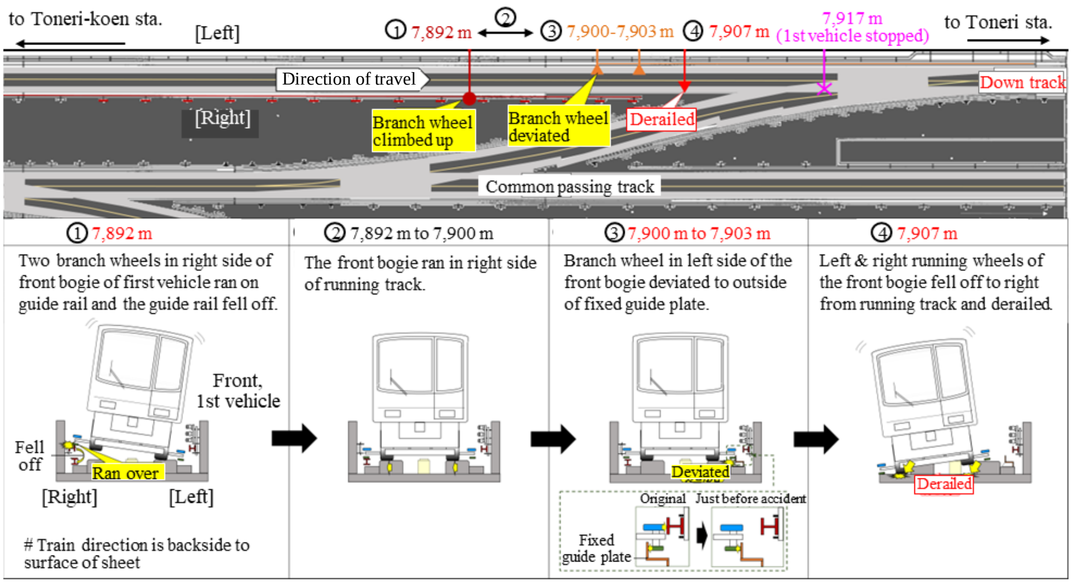


Figure 4. Process to derailment of the train

As for the analysis on the evacuation of passengers, it is necessary to arrange the methods and the procedures of the evacuation and guidance that considered to secure safety of passengers as the highest priority, such as to confirm the vehicles and the facilities in the whole section and not to feed electric power again until the confirmation is completed, when the earthquake of the seismic intensity of lower 5 or greater had occurred, and enter them in the manual to respond abnormality, and let the relevant staffs known well. Here, in case of abnormality, it is desirable to establish the system that the traffic control office can implement the remote monitoring by installing the cabin monitoring cameras, in order to enable the treatment of the injured person, the evacuation and the guidance of the passengers by comprehending the status in the cabins more quickly.

4 Conclusions and Contributions

The fact-finding investigation carried out by the JTSB clarified the cause of the derailment accident occurred on an automatic guideway transit. It is probable that the train was derailed in this accident because suffered from the seismic vibration of the Chiba earthquake occurred at about 22:41, October 7, 2021. This accident made us realize that the AGT with tires, the paved running track and side walls has possibility of the derailment just like the steel wheel-rail system if a great earthquake occurs.

It is probable that the process to the derailment was as follows: The train shook hard in rolling direction by the seismic vibration, and right branch wheels in the front bogie of the first vehicle ran on the guide rail, and the guide rail fell off. It is probable that the bogie ran as being deflected to right side of the running track by the influence of the lost guide rail, and left branch wheel of the bogie deviated to outer side of the fixed guide plate installed in left side of the running track in ahead, and derailed.

It is necessary to take the following measures in order to prevent the recurrence of this accident.

(1) Automatization of simultaneous emergency train stop operation when the early earthquake warning system had operated

It is necessary to automatize the simultaneous emergency train stop procedures when the early earthquake warning system had operated, in order to suppress the damages due to an earthquake in the minimum by stopping trains as quickly as possible.

(2) Measures to prevent train derailment during earthquake around the accident site

It is necessary to take measures that the guide wheel or the branch wheel of the vehicles do not run on the guide rail by the effects of the seismic vibration, in around the accident site where the natural frequency in the lateral direction of the viaduct and the natural frequency in the Rolling of the vehicle almost corresponded each other, and there is the possibility to be significantly affected by the rotating behavior of the structures due to the earthquake. In addition, it is expected to confirm the existence of the place having the possibility to cause the similar situation as the above, in the places other than the accident site, and take similar measures for the place required these measures.

(3) Preparation of the treatment in abnormality considered to secure safety of passengers as the highest priority

When the earthquake of the seismic intensity lower 5 or greater had occurred, it is necessary to prepare the methods and the procedures of the evacuation and guidance that considered to secure safety of passengers as the highest priority such as to confirm the status of the vehicles and the facilities in the whole sections and do not feed electric power again until to complete the confirmation, and enter them in the manual to respond abnormality, and let the relevant staffs known well thoroughly.

In view of the investigated results of this accident, in order to secure the safety of transportation, the JTSB recommended the measures described above (2) and (3) to the Bureau of Transportation, Tokyo Metropolitan Government [3].

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