Examination of Structure Specifications that Affect Seismic Safety of Running Trains



Yuka Ito* Kaoru Kobayashi* Masaya Hirabayashi**

To evaluate seismic safety of running trains, we focused on structure specifications. We investigated structure specifications of the Tohoku-Shinkansen to make structure models. By changing several parameters of those models, we identified structure specifications that influenced train running safety. As a result of those examinations, we found that specifications of the upper structure affected gap deformation and specifications of the lower structure affected rotation.

●Keywords: Train running safety, Vibration displacement, Uneven displacement, Bearing

1 Introduction

In light of the derailment of Shinkansen trains in the 2004 Mid Niigata Prefecture Chuetsu Earthquake and the 2011 Earthquake off the Pacific Coast of Tohoku, the Frontier Service Development Laboratory has been working on seismic safety of running trains.

Seismic motion is amplified by via civil engineering structures such as viaducts and transmitted to trains as shown in Fig. 1. Thus, train running safety could be greatly affected by those structures. We therefore conducted basic research on identifying structures that can easily cause derailment so as to quantify train running safety in earthquakes. This paper reports the results of that research.

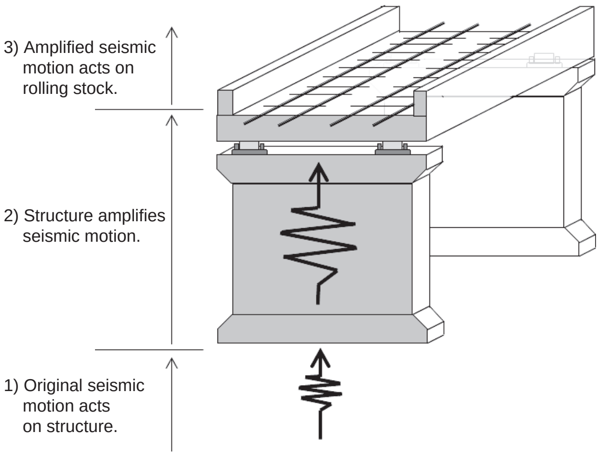

Fig. 1 Image of Amplification of Seismic Motion Affecting Train Running Safety

2 Evaluation of Train Running Safety in Earthquakes

In order to secure train running safety in earthquakes, civil engineering structures are designed in compliance with the railway structure design standards (displacement limitation).[2] Check items in design are lateral vibration displacement ("vibration displacement") and uneven displacement of track surface ("uneven displacement") in seismic motion that may statistically occur several times in the design service life of individual structures. Those items must be kept within the design threshold values. We studied vibration displacement and uneven displacement as indices in this research too, and we will explain those first.

2.1 Vibration Displacement

Vibration displacement can be calculated by obtaining acceleration response of a specific structure as shown in Fig. 2.

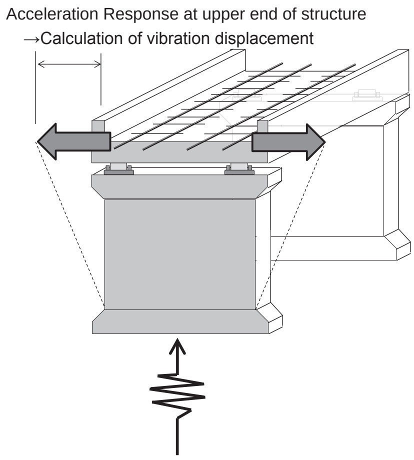

Fig. 2 Overview of Vibration Displacement

Explaining this in more detail, we obtained the velocity response spectrum for acceleration response waves at the upper end of a structure, and then we obtained spectrum intensity by integrating frequency components of that response velocity. The derived spectrum intensity is a check item when designing.

Vibration displacement is used to check how easily individual structures are shaken.

2.2 Uneven Displacement

Uneven displacement is used to check gaps that might occur on the border of structures, while vibration displacement is used to focus on a specific structure. Uneven displacement is further classified into corner folding and linear misalignment.

2.2.1 Corner Folding

Corner folding expresses the level of rotation between structures adjacent to each other as shown in Fig. 3. It is accepted that continuous corner folding causes hunting of trains on structures, seriously affecting train running safety.

*Frontier Service Development Laboratory, Research and Development Center of JR East Group
**Tokyo Construction Office (previously at Frontier Service Development Laboratory)

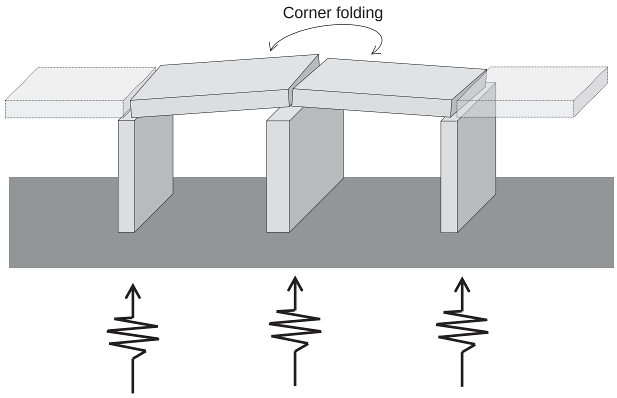

Fig. 3 Overview of Uneven Displacement (Corner Folding)

2.2.2 Linear Misalignment

Linear misalignment is the difference in horizontal displacement of structures adjacent to each other as shown in Fig. 4.

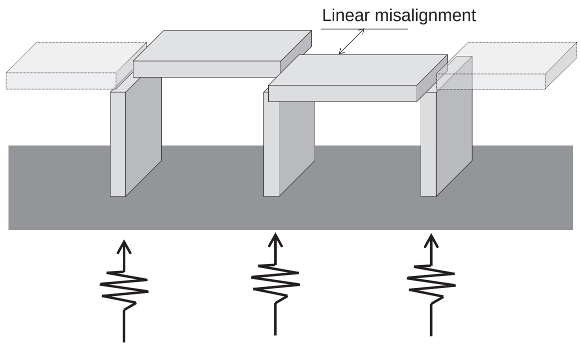

Fig. 4 Overview of Uneven Displacement (Linear Misalignment)

It is accepted that prominent linear misalignment increases horizontal movement of wheels increases, seriously affecting train running safety.

As introduced above, vibration displacement is a check item that focuses on a specific structure's own displacement, and uneven displacement is a check item that focuses on relative displacement of structures adjacent to each other.

Of those two check items, it is known that vibration displacement is dominant with general civil engineering structures. We therefore decided to proceed by studying with a focus on what specifications of a civil engineering structure make uneven displacement dominant, differing from usual cases.

3 Study of Specifications Affecting Train Running Safety in Earthquakes

We studied what specifications of a civil engineering structure make uneven displacement dominant over vibration displacement in earthquakes. The following is the procedure by which we did that.

1) First, we investigated structures of the Tohoku Shinkansen and set basic ordinary structure specifications. In this research, based on the investigation results of structures within approx. 100 km from Sendai Station, we specified structure specifications where the upper structure has girder structure of 20 m length and lower structure of wall structure has 10 m height as those of the ordinary structure.

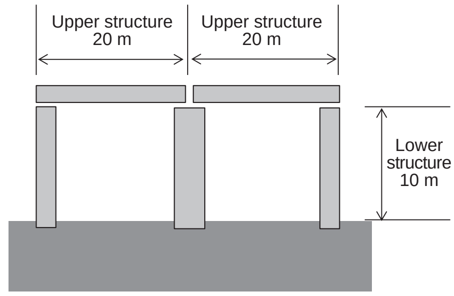

Fig. 5 Ordinary Structure Specifications Based on Survey of Tohoku Shinkansen Structure

2) Next, with the ordinary structure as set as in Fig. 6, we input gradually increasing seismic motion to obtain the seismic motion αg that is intensity of the seismic motion when vibration displacement reaches the design threshold value. The value obtained for αg was 324 gal.

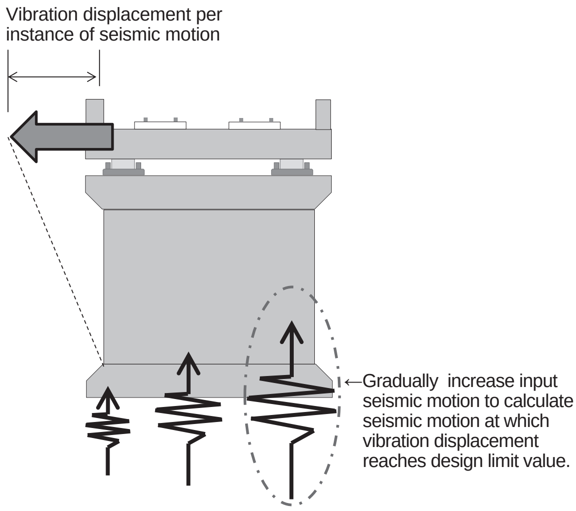

Fig. 6 Calculation of Intensity Seismic Motion (αg) Determined by Vibration Displacement

3) Then, we temporarily set a structure to study uneven displacement by changing structure specifications within the area between the minimum and maximum values of upper structure length and lower structure height based on the structure investigation results. From the results, we set upper structure length between a minimum length of 10 m and maximum length of 65 m and lower structure height between a minimum height of 5 m and maximum height of 20 m. Corner folding and linear misalignment are the values that are generated between upper structures adjacent to individual civil engineering structures.

Fig. 7 and 8 are models to study the upper structures.

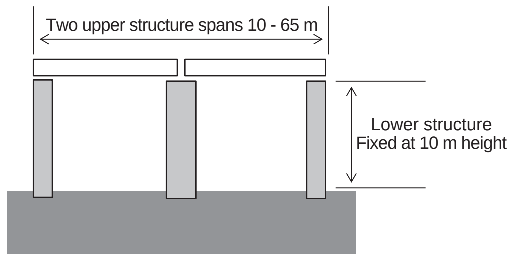

Fig. 7 Structure (1) with Upper Structure Length Changed

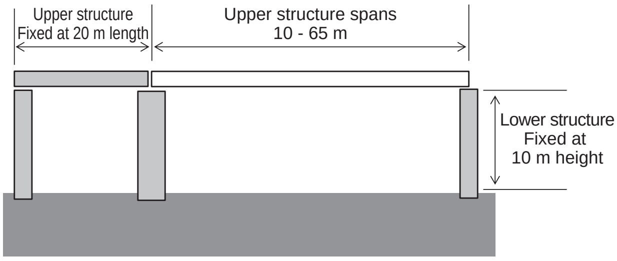

Fig. 8 Structure (2) with Upper Structure Length Changed

Fig. 7 shows model (1) where the lengths of two continuous upper structures are changed equally within the minimum and the maximum values. Fig. 8 shows model (2) where the length of an upper structure is fixed at 20 m and the length of the other upper structure is changed.

We used model (1) to check the effect of increasing total length of upper structures and model (2) to check the effect on relative displacement of increasing length difference of upper structures adjacent to each other.

Next, Fig. 9 and 10 are models to the study the lower structures.

Fig. 9 is model (3) where the heights of three continuous lower structures are equally changed within the minimum and the maximum values. Fig. 10 shows model (4) where the height of the center lower structure in between is fixed to 5 m and the heights at those at both ends are changed.

We used model (3) to check whether or not displacement increases as height of the lower structures increases and model (4) to check whether or not height difference of lower structures adjacent to each other affects relative displacement.

4) By inputting αg to model structures (1) to (4) with structure specifications changed, we checked or not whether uneven displacement exceeds the design limit value. Fig. 11 and 12 are the results of upper structure length changes. In both figures, the horizontal axis is the length of the changed upper structure, and (1) and (2) are the model numbers of the structures described above.

The railway structure design standard specifies the design limit values of uneven displacement in an earthquake as 3.0 mrad for corner folding and 7.0 mm for linear misalignment.

The study results for model (1) showed both corner folding and linear misalignment to be below design limit values. Therefore, we can say that the effect of uneven displacement is small for continuous upper structures of similar length, regardless of upper structure length.

On the other hand, with model (2), corner folding was less than the design limit value too; however, linear misalignment exceeded the design limit value in the case where length difference of upper structures was 10 m or more. This could be because larger difference of upper structure length meant larger difference of upper structure weight, causing larger difference of relative behavior.

Next, Fig. 13 and 14 are the results of lower structure height changes.

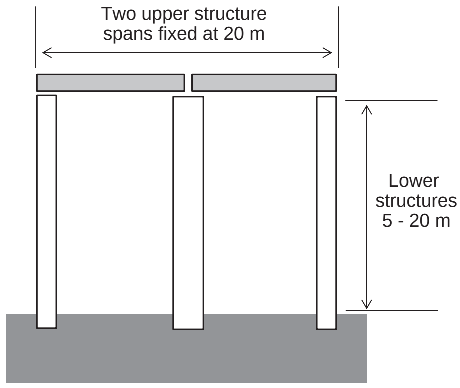

Fig. 9 Structure (3) with Lower Structure Height Changed

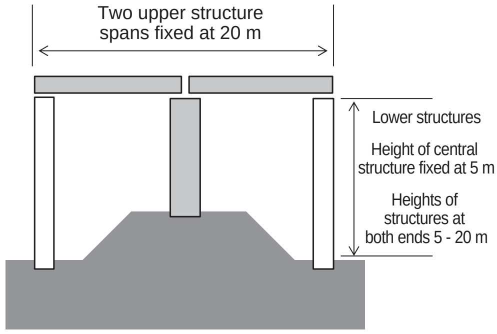

Fig. 10 Structure (4) with Lower Structure Height Changed

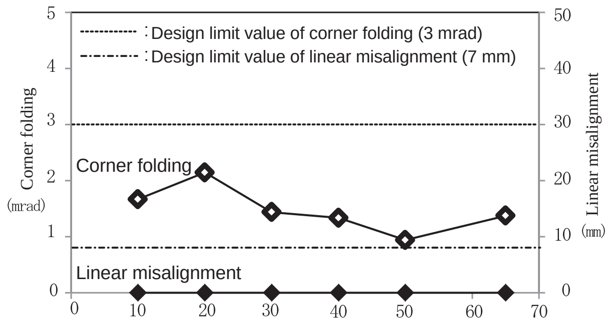

Fig. 11 Results of Studying by Upper Structure Length (1)

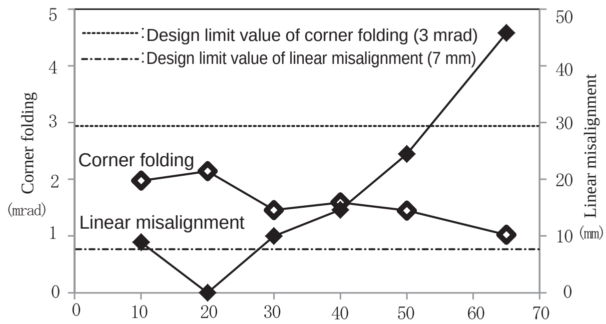

Fig. 12 Results of Studying by Upper Structure Length (2)

The study results for model (3) show that corner folding increased as lower structure height increased, while linear misalignment was less than the design limit value.

The study results for model (4) demonstrate that linear misalignment was less than the design limit value, the same as those for model (3), and corner folding did not increase even when the heights of the lower structures at the both ends

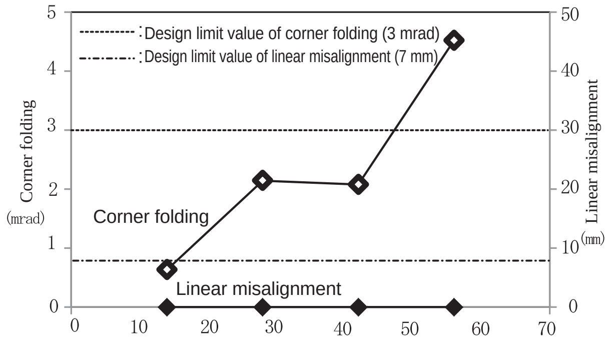

Fig. 13 Results of Studying by Lower Structure Height (3)

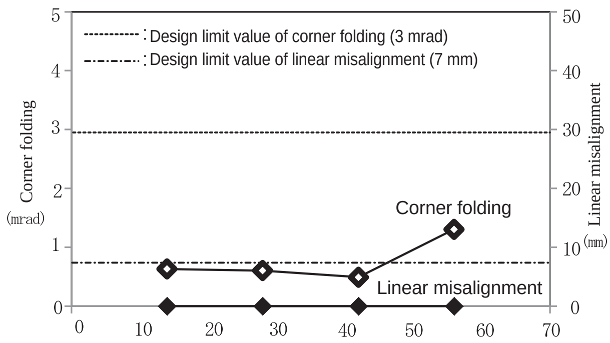

Fig. 14 Results of Studying by Lower Structure Height (4)

increased. This could mean that response value of corner folding was determined by the height of the center lower structure with which we calculated corner folding amount, instead of by height difference between lower structures adjacent to each other.

5) We confirmed that difference in upper structure length caused linear misalignment. As shown in Fig. 15, we can expect linear misalignment control effect from side blocks, a type of structural member. A side block is a member placed next to the bearing that connects upper and lower structures. It bears the upper structure load and controls horizontal deformation when the upper structure deforms horizontally. We did not take into account the effect of side blocks on the safe side in the past studies; so, this time, we incorporated the results of destructive tests of that member to verify its effect.
Fig. 16 is the results of recalculation using model (2) taking into side blocks.
As seen in the results, amount of linear misalignment increased as difference of upper structure length increased; however, the rate of increase was mitigated. That confirmed the effect of side blocks on linear misalignment reduction.

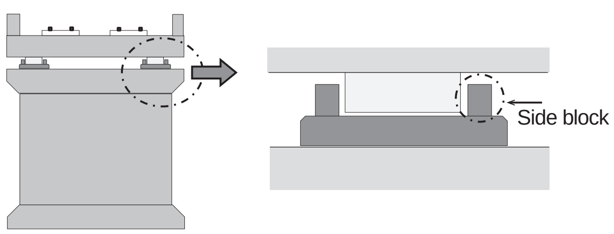

Fig. 15 Details of a Side Block

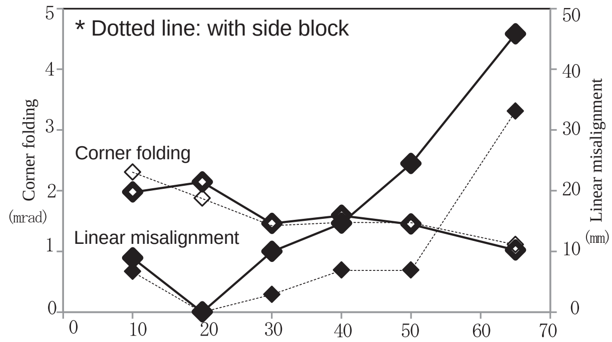

Fig. 16 Results of Studying by Upper Structure Length (with Side Block) (2)

4 Conclusion

In order to secure Shinkansen train running safety in earthquakes, the railway structure design standard (displacement limitation) specifies vibration displacement and uneven displacement as check items. We obtained the seismic motion at which vibration displacement reaches its design limit value, and then obtained the structure specifications where uneven displacement reaches its design limit value when inputting that seismic motion.

This study result confirmed that lower structure height greatly affects corner folding, a type of uneven displacement, and that length difference between upper structures adjacent to each other greatly affects linear misalignment, another type of uneven displacement. For linear misalignment, we confirmed that placing side blocks next to the bearing that connects upper and lower structures has a major effect in controlling horizontal deformation.

This research is basic research that uses design limit values of the railway structure design standard as the indices. We are planning to build a model with which we can evaluate actual derailment and further study in more detail.

Reference:

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