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Development of a Construction Method for Reducing Deflection of PC Girders Utilizing Binding of Existing Sound Insulating Walls



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JR East has successfully developed a construction method using existing sound insulating walls to reduce deflection of existing prestressed concrete (PC) girders in line with Shinkansen speed increase. Existing sound insulating walls have joints at fixed intervals to form a structure that prevents transmission of stress to the walls by the load of a running train. The construction method developed has achieved an increase in the bending stiffness of girders by binding deformation of joints of sound insulating walls so they behave as if integrated into girders. In the development, we carried out load tests using model specimens and resin filling tests at installation of steel covers using a full-scale model and development of a construction method using hollow bolts that ensures filling of resin around through bolts. The construction method was applied to three PC girders, bringing about a reduction of deflection at the center of each girder by passing trains in service to approx. 1/2 of that before the application of this method.

●Keywords: Shinkansen speed increase, Deflection, PC girder, Sound insulating wall, Increase of stiffness

1 Introduction

Civil engineering structures for the Shinkansen are designed with a maximum design speed of 260 km/h. For Shinkansen speed increase, we carried out analysis simulation that reproduces dynamic behavior of structures at trains running on approx. 17,500 concrete girders in sections for which speed increase was planned. That was done to identify the impact of increases in operation speed. The results of study proved that the three PC girders do not meet the standard value of deflection for ride quality defined by current design standards (for concrete structures)[1] at a maximum speed in excess of 300 km/h.

To solve this problem, we developed a construction method utilizing binding of existing sound insulating walls to reduce deflection of PC girders. Existing sound insulating walls are of cast-in-place reinforced concrete (RC) structure and have structural joints at a fixed interval to prevent cracks by shrinking of concrete after casting, and those are constructed without taking into account contribution to reduction of girders deflection. Some existing sound insulating walls pose concerns in terms of quality or are starting to degrade with age, so we will need to be careful when using existing sound insulation walls attached to PC girders to reduce deflection.

In light of that situation, we studied the effects of reinforcing existing sound insulation walls through load tests and FEM analysis using model specimens in the development of this construction method. We applied trial construction to one PC girder to check the effect and also continued to check the existing sound insulating wall for approx. a year after the trial construction, finding no problems with the wall. The countermeasures for the remaining two PC girders were completed in fiscal 2010.

This report will cover an outline of the development of a construction method for reducing deflection of PC girders utilizing binding of existing sound insulating walls.

2 Outline of Construction Method for Reducing Deflection Utilizing Binding of Existing Sound Insulating Walls

The methods to reduce deflection of the girders by passing trains include the following as noted in 1) to 3).

1) Adding members afterward to increase bending stiffness of girders
2) Using damper effect by adding mass that synchronizes with natural frequency of girder
3) Combining a steel panel pressure bonding construction method and a reinforcement method that introduces prestress by external cables if stress as well as deflection of girders is an issue

As the deflection reduction method for those PC girders, we chose a method of increasing bending stiffness of the girders. The reasons for that selection is that practical measures are possible due to 1) stress or bearing force of girders issues not being found in advance examination, 2) unavailability of space for additional damper and 3) deflection in line with train speed increase can be made into bending stiffness that meets the standard value of ride comfort.

One method to improve bending stiffness of the girders is to add members according to the main girders. However, work to add members was expected to be difficult because the interval of the main girders of those PC girders was small.

So, we focused on the fact that there are cast-in-place reinforced concrete sound insulating walls at the PC girders and examined ways to make use of those.

Existing RC sound insulating walls have joints at fixed intervals so as not to transmit stress to sound insulating walls by the load of a running train. So, to bind deformation of the joints of existing walls under the load of a running train, we fill joints with high-strength mortar. That mortar binds the deformation of the joint of the walls, so the walls become resistance members that contribute to increasing stiffness of the girders. Fig. 1 shows a general diagram of a viaduct with those PC girders. The

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girders have a single track structure separated into inbound and outbound tracks (with four main girders) as the viaduct crosses a local road at an acute angle. The girder height is limited to 1 m despite having a span of 21.2 m. Compared to usual PC girders, the ratio of the girder height to the span length is small.

3 Outline of Study on Binding Effect of Existing Sound Insulation Walls

3.1 Load Test Using a Model Specimen

In this construction method, joints of existing sound insulating walls are filled with high-strength mortar, binding the deformation of the joints. That binding of the joints of the walls contributes to increasing stiffness of the girders by the walls.

In order to check the effects on the improvement of bending stiffness of girders and the destruction behavior at the ultimate state of the existing sound insulating walls with bound joints, we carried out load tests using a model specimen. An outline of the tests is as follows.

(1) Outline of the specimen

Fig. 2 shows a diagram of the specimen. Due to the limits of the testing machine etc., the span of the specimen was 3,000 mm. The girder was of RC, and on the top of that was installed an RC member modeling the existing sound insulating wall. The thickness of the member modeling the existing sound insulating wall was the same as that of the PC girders this construction method is applied to, and the height was approx. 1/3 of an actual sound insulating wall of a viaduct at 600 mm. The number of reinforcements was approx. 1/2 fewer than with an actual wall. At the center of the member modeling the wall, we made a slit that models the joint.

After production of the RC girder, we cast concrete for the sound insulating wall. And after the specified curing period, we set the form in the slit and filled the slit with high-strength mortar. In order to prevent “dry out”, where the moisture of the mortar is absorbed into the concrete of the sound insulating wall while filling, we supplied sufficient water to the mortar.

(2) Outline of the load test

Fig. 3 shows the application of a load. To apply a load to the specimen, we produced a load application jig that crosses over the sound insulating wall so that the load could be placed on the RC girder. The load points were set to hold the joint of the wall between the points, making the bending stress be predominant at the joint.

(3) Test results

Fig. 4 shows as the test results the relationship between the load and displacement at the load points. Fig. 5 shows the destruction that was bending failure with crush of the top of the concrete sound insulating wall.

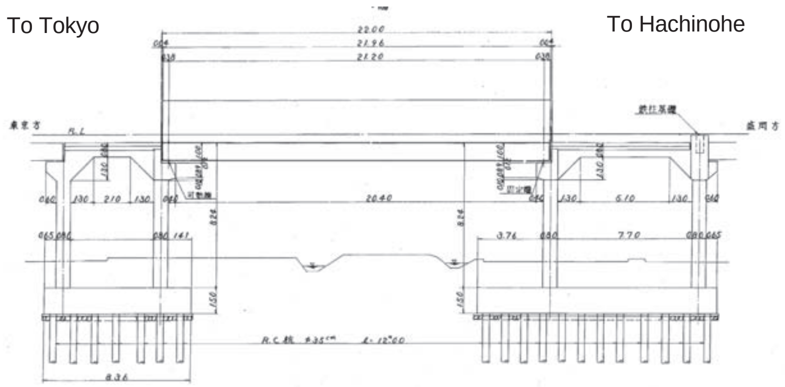


Fig. 1 General Diagram of PC Girders to which Construction Method is Applied

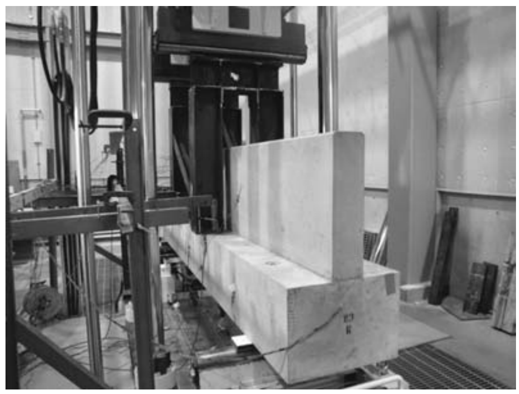


Fig. 3 Applying Load to Model Specimen

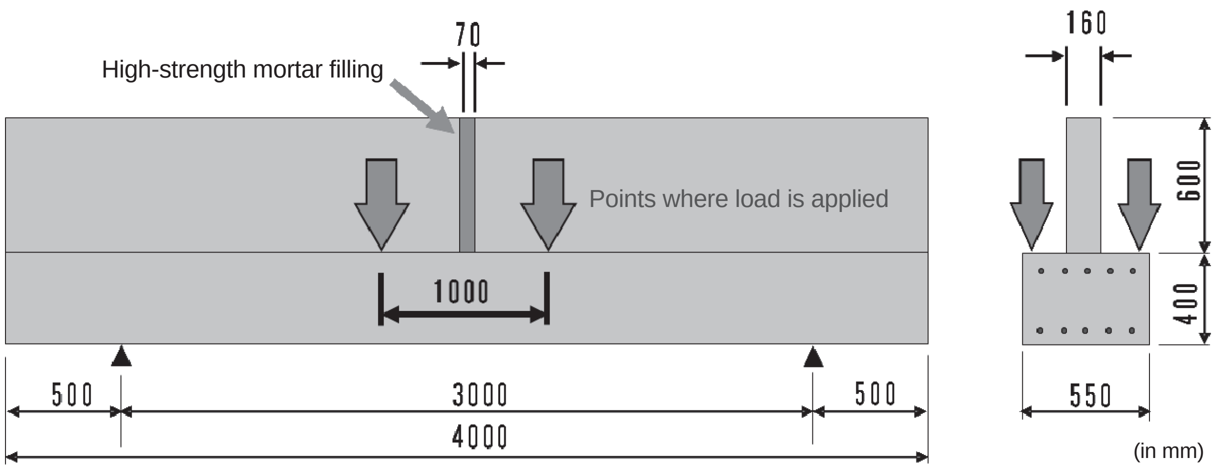


Fig. 2 Diagram of Model Specimen

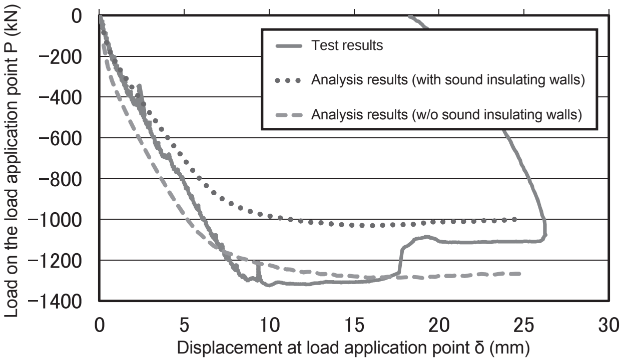


Fig. 4 Test Result

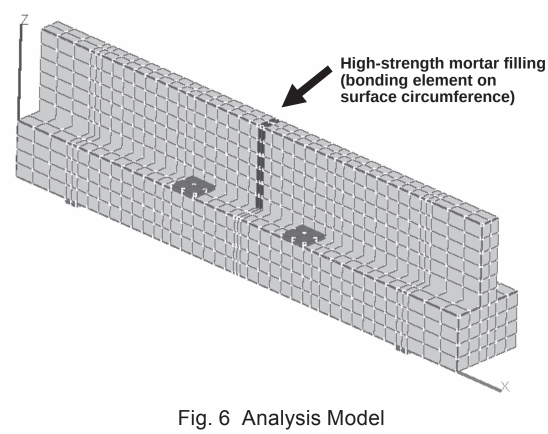


Fig. 6 Analysis Model

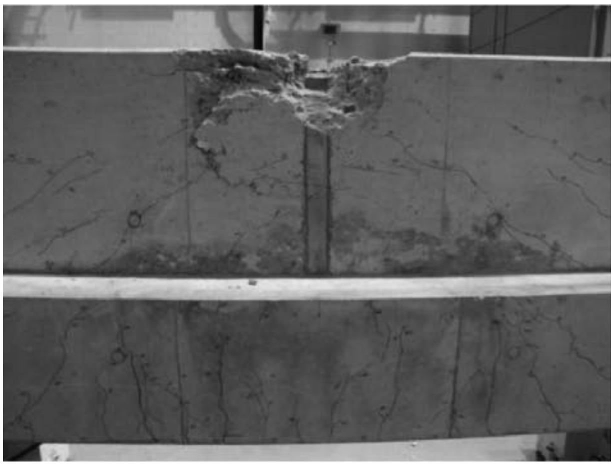


Fig. 5 Destruction of Sound Insulating Wall

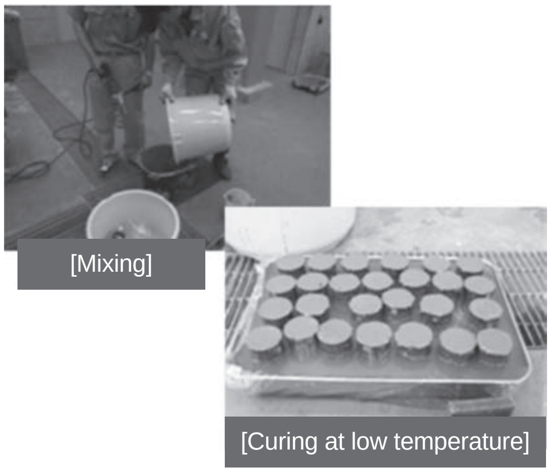


Fig. 7 Production of Non-shrinkage Mortar Specimen

3.2 Analysis of Test Results of Model Specimen

We studied the test results of the model specimen by the 3D nonlinear finite element method. The model specimen has a sound insulating wall on an RC girder and mortar is filled in the slit at the center. The filled mortar has a boundary with the concrete of the wall. Therefore, we decided to apply the 3D nonlinear finite element method since modeling of the total structure system would be needed for appropriate evaluation of the total behavior.

The constitutive law applied to analysis was the RC planar model based on the material structure model and expanded to 3D. The original material structure model that considers arbitrary load path dependence was developed at the Concrete Laboratory of the University of Tokyo[2]. There are many examples of application of this analysis method. Typical examples include verification of an RC column constantly applied with eccentric axial force in a cyclic load test[3].

Fig. 6 shows the analysis model used in the study. We placed bond elements around the filled mortar to prevent transmission of stress to the filled mortar even when tensile stress occurred on the boundary with the filled mortar. The analysis results are shown in Fig. 4. The analysis results that take into consideration the sound insulating wall in Fig. 4 are the simulation results of the test result. The analysis results could appropriately evaluate the maximum load, while the stiffness was slightly larger than in the actual test results. Fig. 4 shows results of analysis without a wall too. The analysis results in Fig. 4 clarified that the sound insulating wall contributed to improvement of bending stiffness.

4 Outline of Study at Trial Construction

4.1 Outline of Study at Each Construction Step

(1) Study of filling mortar to joint of sound insulating wall

The PC girders to which the construction method is applied are in a section that sees Shinkansen service, so construction has to be done in the period of time for track maintenance at night. As preparation for construction, we checked the placement of the reinforcement of the existing sound insulating walls using a nondestructive tester etc. Then we cut the joints of the sound insulating walls by the wall sawing method, installed steel forms, and cast non-shrinkage mortar of which strength expression time had been checked in advance.

The strength expression characteristics of the mortar to be used need particular consideration. In the study at the trial construction, we carried out material tests taking into consideration environmental conditions such as external temperature at filling the mortar.

In the material tests of the mortar, we made five column samples of 50 mm in diameter × 100 mm in length per type of non-shrinkage mortar after mixing the mortar for the specified mixing time per type. Assuming the site temperature at the time of construction, we cured the samples in mold cans in iced water (temperature 10–15°C). Compression strength tests were conducted every 30 minutes after casting, and changes over time were recorded. Fig. 8 shows the test results.

Considering the train service interval in the construction section (scheduled completion of mortar filling at 1:30 am and running of the first outbound train around 7:30 am), we selected a mortar material that can reach the required strength (24 N/mm^2) within six hours after filling.

(2) Study at adding steel covers

Steel covers are added after filling the mortar. The steel covers are U-shaped and cover the top of the sound insulating wall. The purpose of installing the steel covers is to prevent rainwater infiltration from the boundary with the filled mortar, thus securing durability. If the covers too are of a structure that contributes to the increase of the bending stiffness of the sound insulating wall, the stress borne by the wall may become too large and lead to stress cracking. We thus made the steel covers of a structure that can minimize the increase of the bending stiffness of the wall.

The steel covers were installed within the maintenance time. They were installed to a 15 m-long area at the center of the girders, taking into account distribution bending moment when train load is applied (Fig. 9).

The steel covers were fixed with bolts through the steel covers and the sound insulating wall. The gaps around the through bolts and around the steel covers were filled with resin.

As the steel covers are U-shaped, air pockets are often generated at the corners while filling the resin, causing improper filling. For proper filling, it is thus important to appropriately position air vents. Furthermore, installation of the steel covers to the sound insulating wall and filling the resin cannot be completed within one maintenance time slot. We thus decided to place a synthetic rubber backup partition in the steel covers. Placement tests using a full-scale sample were conducted to check its structure and performance, and a method of on-site installation was established. Fig. 10 shows the placement of the filling pipes and the ventilation pipes for filling the resin into the gaps around the steel cover.

4.2 Development of Construction Method Using Hollow Through Bolt

Resin is filled into the gaps around the through bolts too. Usually, resin is filled around the through bolt using resin filling pipes and ventilation pipes set after installing the through bolt. However, this method of filling resin by individual through bolts takes time, so it is thus not reasonable for filling many resin gaps around through bolts within the short maintenance time at night.

To make filling of resin around the through bolts more reasonable, we developed a construction method using hollow through bolt and applied that to the trial construction. Fig. 11 shows an outline of the method.

In this method, we first drilled holes for filling resin in the through bolt. Preparation for filling resin is complete when those bolts are set. Resin is injected from the bottom near the center of the hollow through bolts. The injected resin concentrically spreads due to its own viscosity, fills the gap, and overflows from the air vent at the washer. The overflow from the air vent confirms proper filling of resin and it is useful for checking construction management.

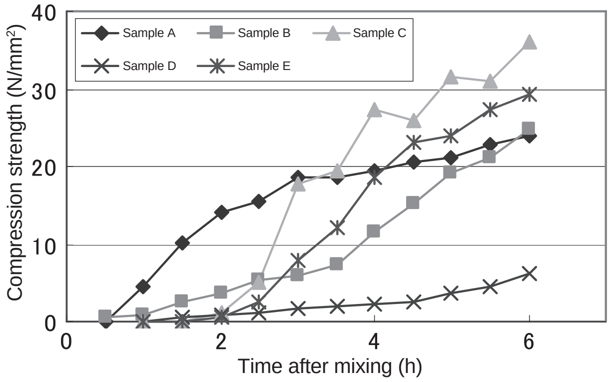


Fig. 8 Non-shrinkage Mortar Strength Expression Test Results

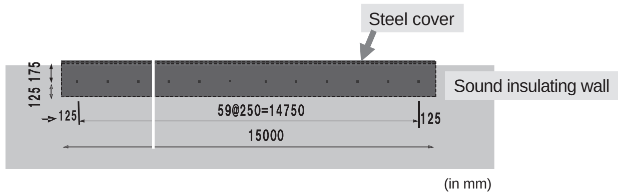


Fig. 9 Area to Which Steel Cover is Attached

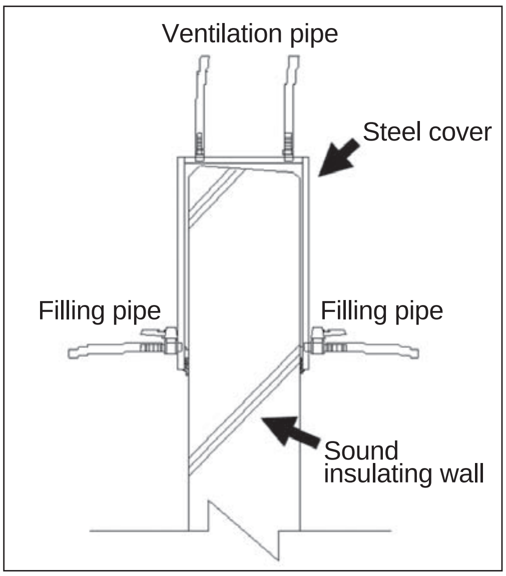


Fig. 10 Placement of Filling Pipes and Ventilation Pipes on Steel Cover

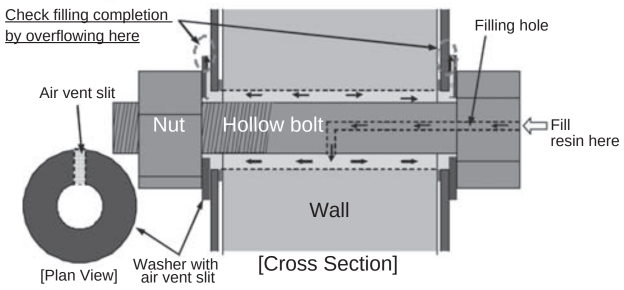


Fig. 11 Outline of Filling Method Using Hollow Through Bolt

5 Deflection Measurement Results After Construction

(1) Deflection measurement results at running of the current trains in service

Fig. 12 shows the plotted measurement data of the maximum deflection at the center of the girder when a Shinkansen train in service passed before and after the construction. The data proved that the construction reduced girder deflection to approx. 1/2 of that before the construction. Check of the mortar filling in the joints of the sound insulating walls at a year and two months revealed no problems.

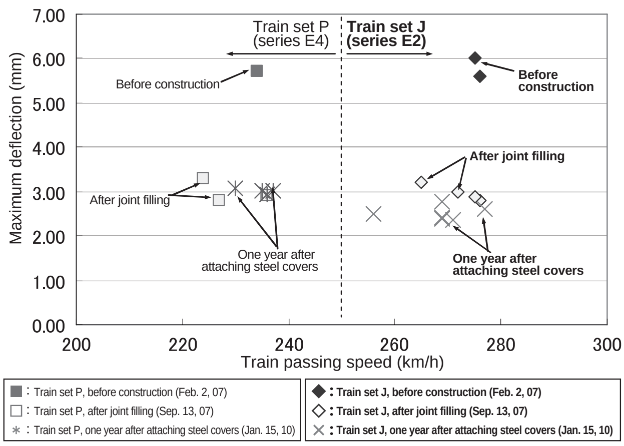


Fig. 12 Deflection Measurement Results at Passing of Shinkansen Train in Service

(2) Measurement results of actual bending stiffness

To identify the actual bending stiffness of the PC girder before and after the construction, we carried out impact vibration tests and examined the actual bending stiffness from the measurement values of the natural frequency of the PC girder. Fig. 13 shows the change in natural frequency based on the impact vibration tests at each construction stage. For calculation of actual bending stiffness from the actual natural frequency, we applied the Bernoulli-Euler beam equation.

6 Analysis Results of Train Speed and PC Girder Deflection

We studied train speed and deflection of PC girders based on train running analysis using a running train model and actual bending stiffness of a PC girder. The results are as follows.

(1) Outline of the analysis method[4)]

Fig. 14 shows an outline of the analysis method. The running train analysis has as substructures dynamic system models representing the running train and the structure, and deformation and forces are transmitted between the dynamic system models at their joint nodes. Sequential calculation is conducted to make both models satisfy the compatibility conditions of deformation and force.

For train running, sequential move of the joint nodes of the dynamic system models from start of analysis reproduces the condition where a train runs at a set speed.

(2) Outline of train model

Fig. 15 shows an outline of the dynamic system model of a running train ("train model"). The train model was given nodes and beam elements that model the car bodies, bogies and axles, and it was given spring elements and damper elements that model the vibration characteristics and attenuation characteristics between the car body and bogies and between the bogie and axles. Cars are connected with the vertical spring elements and damper elements, and car coupling conditions are considered.

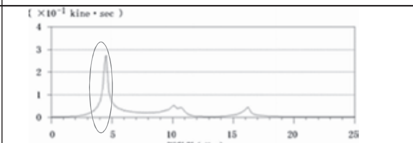
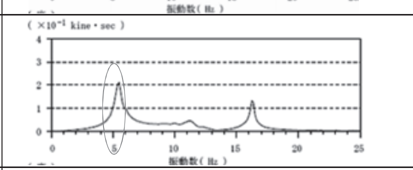
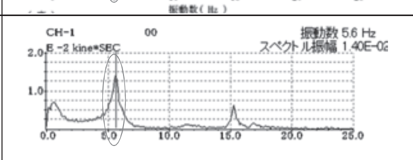
Impact vibration test	Spectrum diagram (impact and measurement at the girder center)	Natural frequencies (primary mode)
Before construction		**4.5** (Conversion: EI = 2.40 × 10^7kN · m^2)
After filling joint		**5.5** (Conversion: EI = 3.59 × 10^7kN · m^2)
After attaching steel cover		**5.6** (Conversion: EI = 3.75 × 10^7kN · m^2)

Fig. 13 Change of Natural Frequencies in Impact Vibration Test

(3) Outline of analysis method

As the numeric analysis method, we applied the Newmark β method with a 0.005 sec. analysis interval. In the attenuation characteristics of the structure, the attenuation constant is 2%, and attenuation proportional to stiffness is considered.

(4) Analysis results

Fig. 16 shows the analysis results after taking measures with this construction method. The results proved that deflection can be less than the deflection standard defined by ride comfort up to a train speed of 360 km/h.

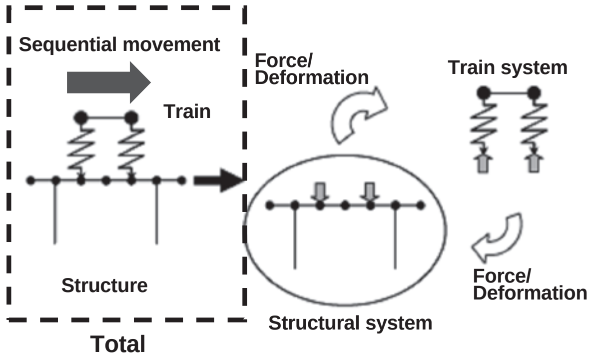


Fig. 14 Outline of the Train Running Analysis

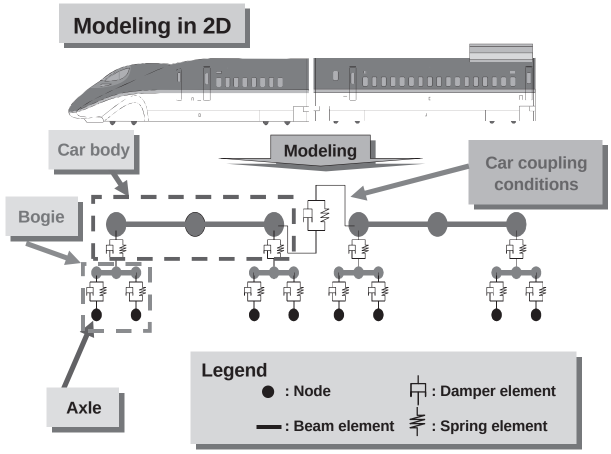


Fig. 15 Outline of the Train Model

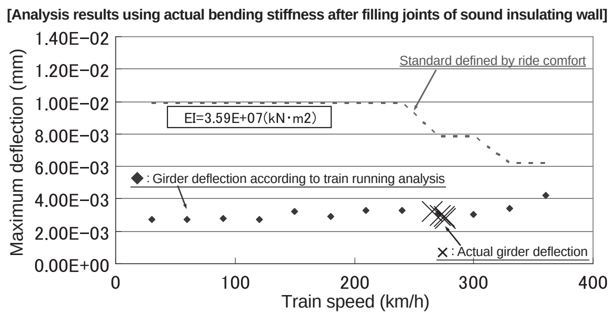


Fig. 16 Train Running Analysis Results Using Actual Bending Stiffness after Filling Joints of Sound Insulating Wall

7 Conclusion

The advance study of dynamic characteristics of concrete girders for Shinkansen speed increase revealed that some measures were needed to secure the ride quality at three PC girders. As that measure, we developed a construction method utilizing binding of existing sound insulating walls to reduce deflection of PC girders.

A summary of the effects of this method and study in this development is as follows.

(1) Based on the results of load tests using a model specimen and 3D nonlinear finite element analysis, we have concluded that it is possible to utilize existing sound insulating walls to increase the bending stiffness of the girders.

(2) Since the mortar filling the joints of existing sound insulating walls must reach the required strength within the maintenance time slot, we have to select mortar material according to construction conditions.

(3) When filling resin in gaps around the steel covers, air vents need to be placed at appropriate locations.

(4) To ensure proper filling of resin in gaps around through bolts, we developed a filling method that uses hollow through bolts.

(5) Applying this construction method can reduce deflection by the load of running trains by approx. 50%. Analysis of train running using bending stiffness of actual girders demonstrated that deflection can be less than the deflection standard defined by ride comfort even at a train speed of 360 km/h.

Reference:

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