Proceedings of the Seventh International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 15, Paper 10.5
Civil-Comp Press, Edinburgh, United Kingdom, 2026
ISSN: 2753-3239, doi: 10.4203/ccc.15.10.5

Influence of Outgoing Feeders on Natural Period of Overhead Contact Line Equipment at Traction Power Supply Facility

M. Tsunemoto[1], N. Fukushima[1], T. Saito[1], Y. Kondo[1] and H. Takahashi[2]

[1]Railway Technical Research Institute, Japan
[2]East Japan Railway Company, Japan

Abstract

In the Shinkansen, Japan's high-speed railway network, the supports of the overhead contact line equipment located at traction power supply facilities consist of multiple masts interconnected by beams. Outgoing feeders are installed between the traction power supply facilities and the overhead contact line equipment. If the supports at traction power supply facilities are fractured or otherwise damaged during an earthquake, they are difficult to replace because of the complex structural configuration. Consequently, the restoration time is lengthened from that of restoring general supports. The supports installed on viaducts are known to experience amplified seismic vibrations when their natural period approaches that of the viaduct. Therefore, accurately estimating the natural period of the supports is essential in the seismic design of overhead contact line equipment. However, the influence of outgoing feeders on the natural period of the supports has not been clarified. This study analyses vibration measurements collected at a full-scale test facility and clarifies the influence of the outgoing feeders on the natural period of the supports. The analysed natural period and seismic response of the supports agree with the measured values.

Keywords: electric railway, overhead contact line equipment, seismic performance, natural period, natural frequency, vibration analysis.

1 Introduction

In the Shinkansen, Japan's high-speed rail network, the supports of the overhead contact line equipment located at traction power supply facilities (such as traction substations and sectioning posts) consist of multiple masts interconnected by beams. Outgoing feeders (feeders, neutral wires and overhead ground wires) are installed between the traction power supply facilities and the overhead contact line equipment, as shown in Figure 1. If the supports at traction power supply facilities are fractured or otherwise damaged during an earthquake, they are difficult to replace because of the complex structural configuration. Instead, they are restored by jacking up the supports and repairing the damaged portion, substantially lengthening the restoration time from that of general-support restoration.

The supports installed on viaducts are known to experience amplified seismic vibrations when their natural period approach that of the viaduct [1]. Therefore, the natural period of the supports must be accurately estimated during the seismic design of overhead contact line equipment. However, the influence of outgoing feeders on the natural period of the supports at traction power supply facilities has not been clarified.

In this study, ambient and seismic vibrations of overhead contact line equipment at traction power supply facilities were measured using a full-scale test facility in order to investigate the influence of outgoing feeders on the natural period of the supports. The results clarified that the outgoing feeders little affect the natural period of the supports in the longitudinal direction to the track, but exert a larger effect in the lateral direction. Furthermore, an analysis model of the supports and outgoing feeders was developed based on the finite element method. The model accurately reproduced both the natural period and seismic response of the supports.

Figure 1: Example of Shinkansen overhead contact line equipment at a traction power supply facility.

2 Methods

2.1 Seismic-performance evaluation methods for overhead contact line equipment on viaducts

In Japan, the seismic design of overhead contact line equipment adheres to the seismic design guidelines for overhead contact systems [1]. The fundamental principles are prevention of support collapse and avoidance of harmful damage that could obstruct the train running space [2]. The evaluation method is overviewed in an annex to IEC 60913 [3]. As an example, Figure 2 shows an acceleration-response spectrum of the supports on a viaduct during an earthquake, as specified in the seismic design guidelines for overhead contact systems [1]. When the ratio of the natural period of the mast to the equivalent natural period of the viaduct approaches unity, the supports and viaduct vibrate at resonance and the response acceleration of the supports largely increases. Therefore, identifying the natural period of the supports is a vital part of the design process.

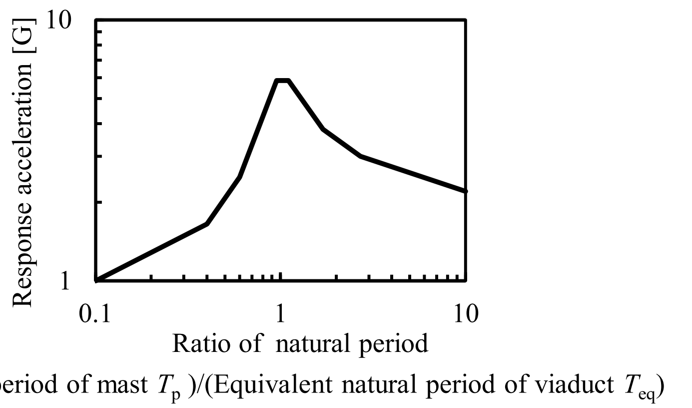


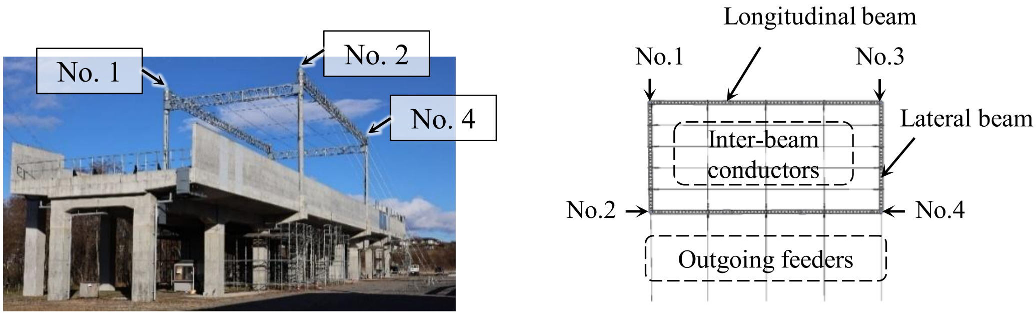
Figure 2: An acceleration response spectrum of supports on the viaduct.

2.2 Overview of vibration measurements at full-scale test facility

Ambient and seismic vibrations of overhead contact line equipment were measured using a full-scale test facility [4] shown in Figure 3. The conditions of the overhead contact line equipment are listed in Table 1 and the test conditions are schematised in Figure 4. The mast is a concrete pole with a span length of 25.7 m.

2.3 Overview of vibration analysis model

Figure 5 shows the finite-element vibration analysis model of the outgoing feeders, masts and beams at the full-scale test facility. Table 2 lists the parameters used in the analysis. The masts and beams were modelled as beam elements, whereas the outgoing feeders and inter-beam conductors were modelled as tensioned beam elements. Based on natural-period measurements of the beam alone, the moment of inertia of area of the beams was set to 0.9 times the specified value.

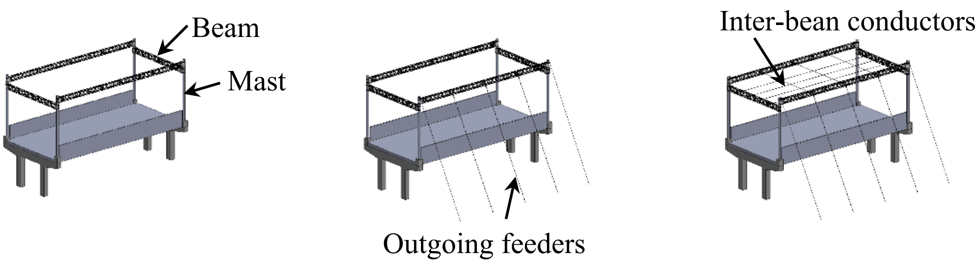


(a) Overall view (b) Top view of overhead contact line equipment

Figure 3: Photograph and schematic of full-scale test facility.

Item	Type
Mast	Concrete pole type 11-40-N150B Height from base = 10 m
Beam	Lattice, main angle 65 × 8 mm; Cross-section: height = 800 mm, width = 450 mm
Feeder, neutral wire (outgoing feeders installed beam, inter-beam conductors)	Hard-drawn aluminium stranded conductors HA1300 [5]
Ground wire (outgoing feeders installed on the mast)	Zinc-coated steel wire strands St55 [5]

Table 1: Conditions of overhead contact line equipment.



(a) Case 1: supports without outgoing feeders (b) Case 2: supports with outgoing feeders (c) Case 3: supports with outgoing feeders and inter-beam conductors

Figure 4: Schematic of test conditions.

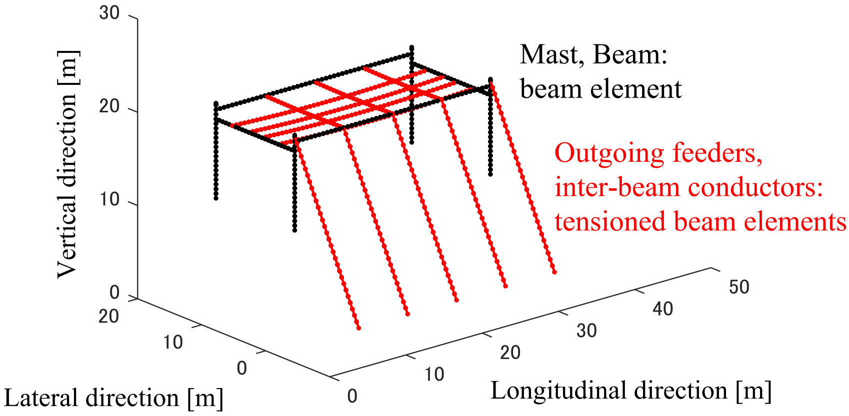


Figure 5: Vibration analysis model of the full-scale test facility.

(a) Mast

No.	Type	Line density [kg/m]	Flexural rigidity [Nm^2]	Comment
1	Concrete pole 11-40-N150B	192.0	4.57×10^7	-

(b) Beam

No.	Line density [kg/m]	Moment of inertia of area [m^4]	Modulus of longitudinal elasticity [N/m^2]	Mast band [kg]	Comment
1	51.75	1.68×10^{-4} (horizontal dir.) 5.69×10^{-4} (vertical dir.)	2.06×10^{11}	161.6	Moment of inertia of the area = 0.9 times the specified value

(c) Outgoing feeder and inter-beam conductor

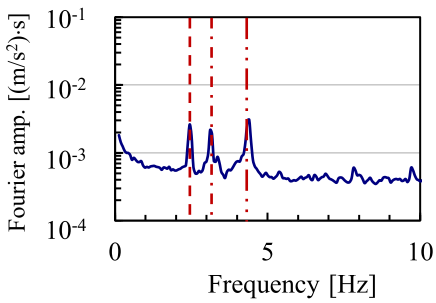
No.	Type	Cross-sectional area [mm^2]	Line density [kg/m]	Modulus of longitudinal elasticity [N/m^2]	Comment
1	HAl300	297.6	0.8201	6.18×10^{10}	-
2	St55	56.3	0.4460	1.96×10^{11}	-

Table 2: Equipment specifications used in analysis.

3 Results

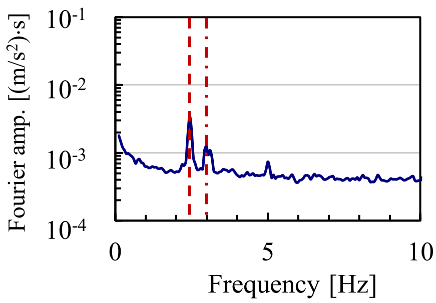
3.1 Natural period and natural vibration mode of supports

Figure 6 shows various Fourier amplitude spectra of the mast-top acceleration obtained from the ambient vibration measurements. The natural periods were estimated from the peaks of the Fourier amplitude spectra and the natural vibration modes obtained using the frequency domain decomposition (FDD) method [6] from the ambient vibration measurement data. In the Fourier amplitude spectra, three peaks in the lateral direction and two peaks in the longitudinal direction appear below 5 Hz.



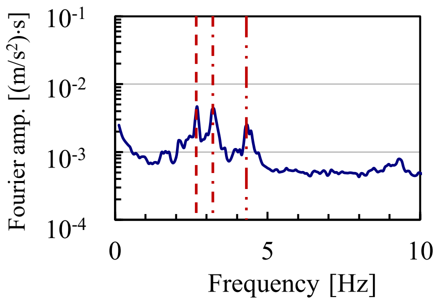
Estimated values of natural frequency (natural period):
2.4 Hz (0.41 s), 3.1 Hz (0.32 s), 4.4 Hz (0.23 s)

(a) Case 1, lateral direction



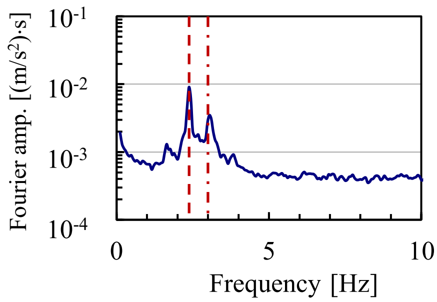
Estimated values of natural frequency (natural period):
2.4 Hz (0.41 s), 3.0 Hz (0.34 s)

(b) Case 1, longitudinal direction



Estimated values of natural frequency (natural period):
2.7 Hz (0.37 s), 3.2 Hz (0.31 s), 4.3 Hz (0.23 s)

(c) Case 3, lateral direction



Estimated values of natural frequency (natural period):
2.4 Hz (0.42 s), 3.1 Hz (0.33 s)

(d) Case 3, longitudinal direction

Figure 6: Fourier amplitude spectra of the mast-top accelerations obtained from ambient vibration measurements. Vertical lines highlight the peaks of the Fourier amplitude spectra, identified as the natural periods of the mast.

Figure 7 compares the five measured natural periods of the supports with those obtained from the eigenvalue analysis of the vibration analysis model. The first lateral natural period is approximately 0.03 s shorter in Cases 2 and 3 than in Case 1, indicating influence by the outgoing feeders. The other natural periods differ by approximately 0.01 s at most among the cases, indicating negligible influence of the outgoing feeders. In addition, the analysed natural periods of the supports generally agree with the measured values.

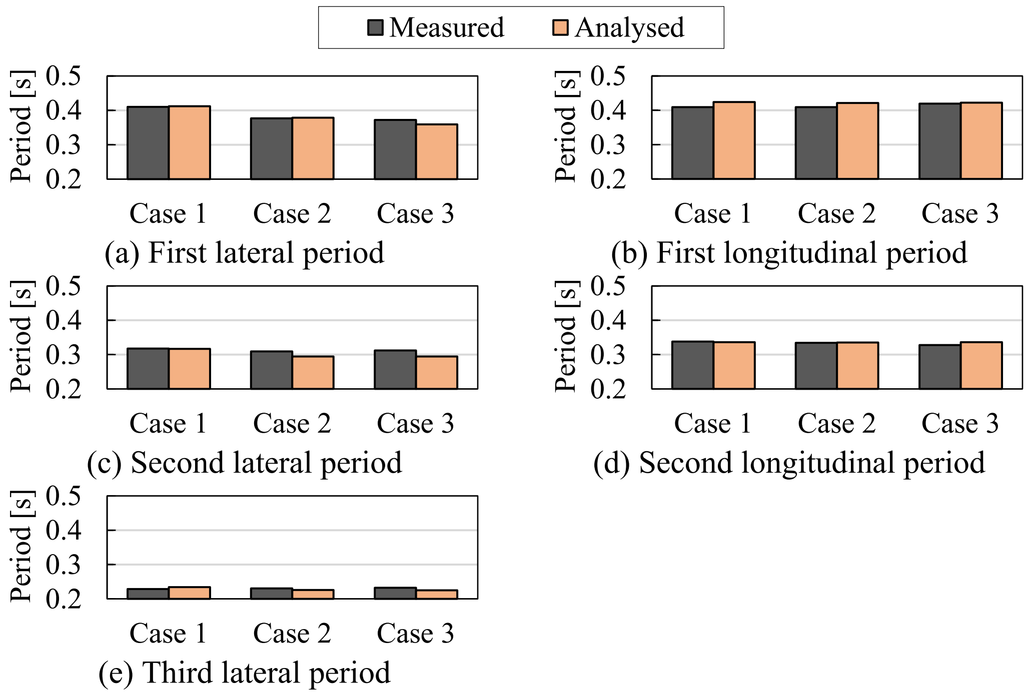


Figure 7: Comparison of measured and analysed natural periods.

Figures 8 and 9 show the natural vibration modes of the supports in Cases 1 and 3, respectively, identified using the FDD method from the ambient vibration measurement data. The corresponding modes obtained from the eigenvalue analysis of the vibration analysis model (Figures 10 and 11) generally agree with the measured results. The characteristics of the five natural vibration modes below 5 Hz are summarised as follows:

• Lateral direction
In the first natural vibration mode: all masts and longitudinal beams oscillate in phase.
In the second natural vibration mode: masts No. 1–2 and No. 3–4 oscillate out of phase.
In the third natural vibration mode: all masts oscillate in phase while the longitudinal beams oscillate out of phase with the mast oscillations.

• Longitudinal direction
In the first natural vibration mode: all masts oscillate in phase.
In the second natural vibration mode: masts No. 1–3 and No. 2–4 oscillate out of phase.

Comparing the natural vibration modes in Cases 1 and 3, one observes different deformations of the longitudinal beams on the sides of masts No. 2–4, where the outgoing feeders are installed. This difference is particularly obvious in the first lateral natural vibration mode (Figures 8 (a), 9 (a), 10 (a) and 11 (a)). As the natural vibration modes in Case 2 are similar to those in Case 3, the observed effects are probably attributable to the outgoing feeders, not to the inter-beam conductors.

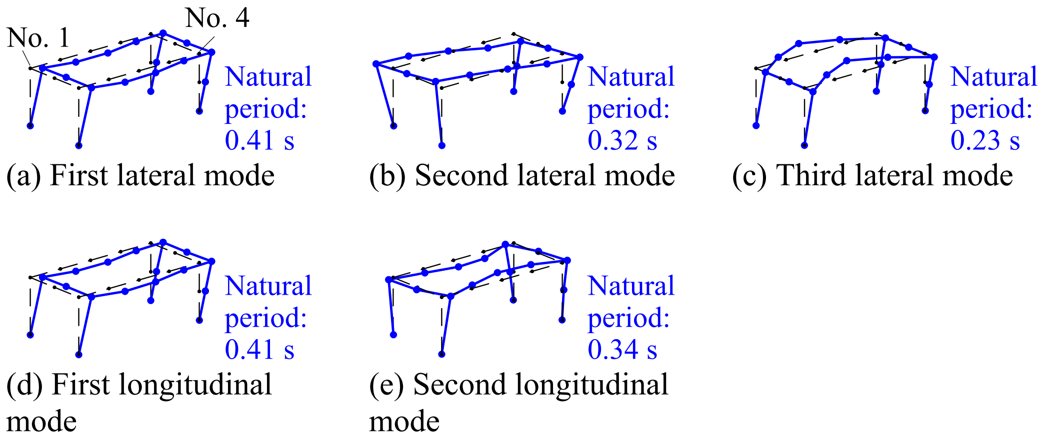


Figure 8: Natural vibration modes identified using the frequency domain decomposition (FDD) method (Case 1).

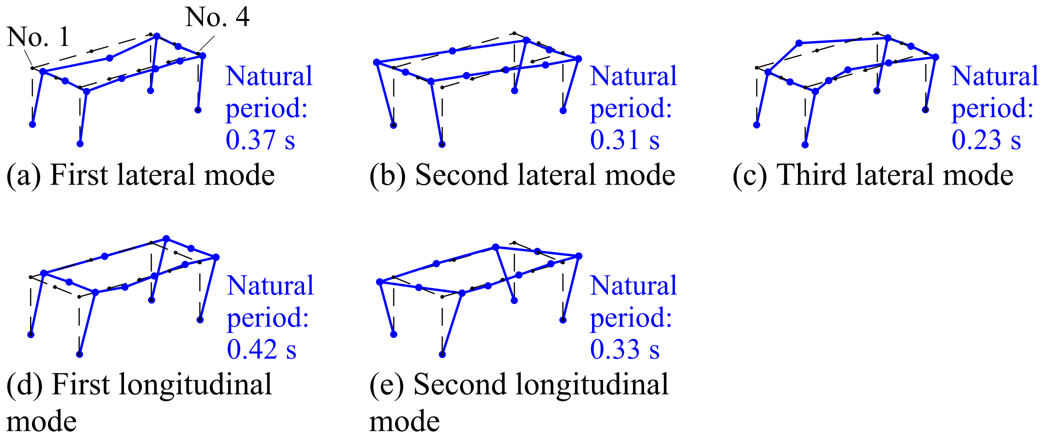
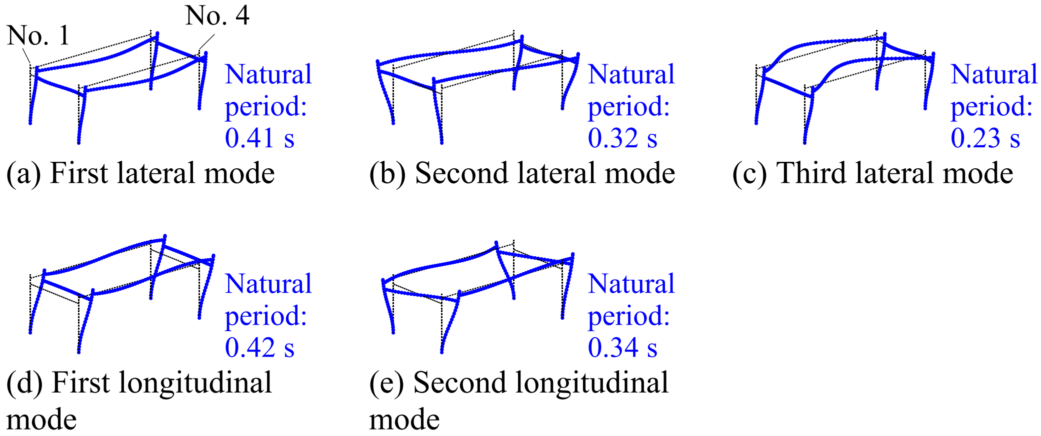


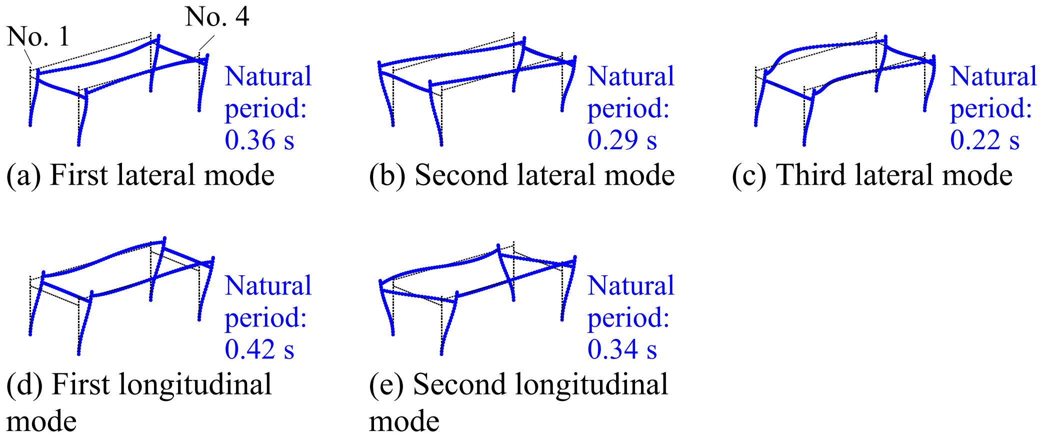
Figure 9: Natural vibration modes identified using the FDD method (Case 3).



(a) First lateral mode (b) Second lateral mode (c) Third lateral mode

(d) First longitudinal mode (e) Second longitudinal mode

Figure 10: Natural vibration modes derived through eigenvalue analysis (Case 1).



(a) First lateral mode (b) Second lateral mode (c) Third lateral mode

(d) First longitudinal mode (e) Second longitudinal mode

Figure 11: Natural vibration modes derived through eigenvalue analysis (Case 3).

3.2 Seismic response of the supports

Figure 12 compares the earthquake measurements at the full-scale test facility with the dynamic-response analysis results. In the dynamic response analysis, the earthquake-induced vibration waveforms were measured at the bases of the masts and at the ground surface and then applied to the vibration analysis model.

The acceleration responses at the tops of masts No. 1 and No. 3 oscillated in phase (Figure 12). Following the increase in vibration amplitude between 1 and 2 s, the vibrations gradually decayed while exhibiting a beating phenomenon. Similar trends were observed in the measured results. Again, the vibration periods of the mast-top accelerations are generally consistent between the measured and analysed results.

The maximum and minimum mast-top accelerations are summarised below. The measured and analysed results differ by approximately 0.01 m/s² at most, validating the seismic response estimates of the vibration analysis model.

• Mast No. 1:
Measured: approximately +0.12 m/s² and −0.12 m/s²
Analysed: approximately +0.12 m/s² and −0.12 m/s²

• Mast No. 3:
Measured: approximately +0.12 m/s² and −0.11 m/s²
Analysed: approximately +0.11 m/s² and −0.12 m/s²

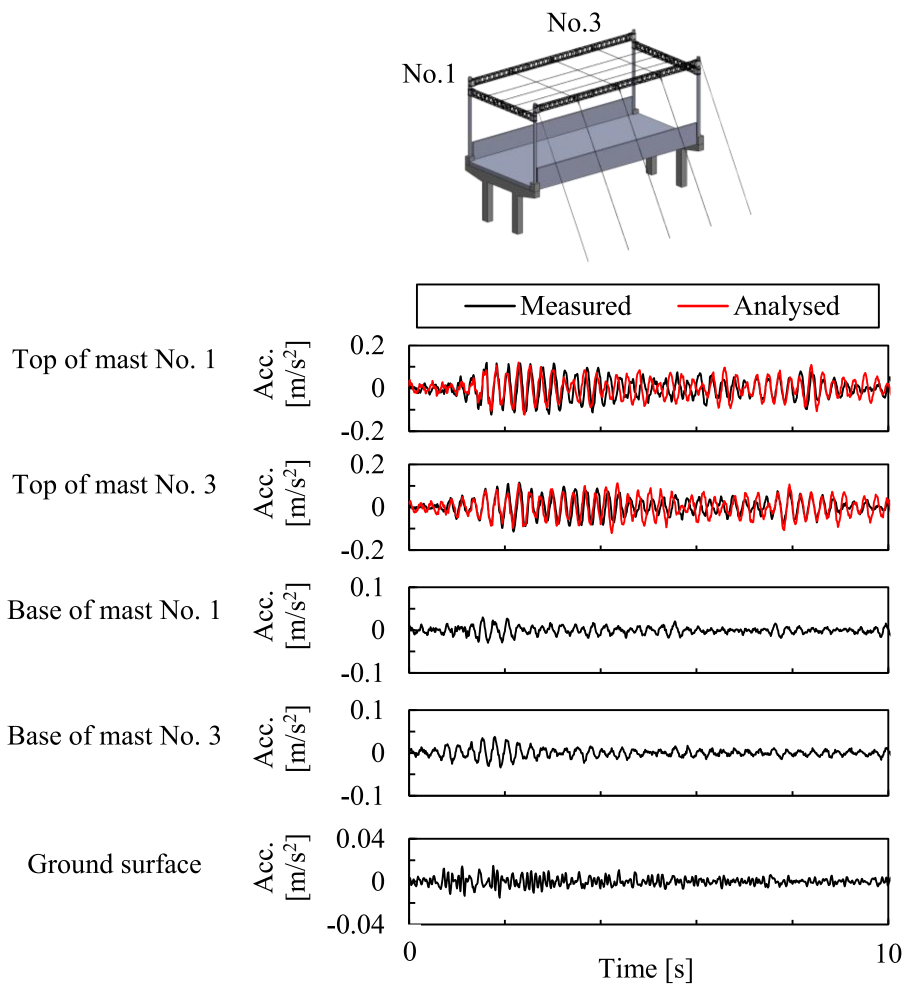


Figure 12: Comparison of measured and analysed acceleration responses of the masts during an earthquake, obtained in the longitudinal direction of Case 3.

4 Conclusions and Contributions

In this study, vibrations of the overhead contact line equipment at traction power supply facilities were measured at a full-scale test facility. The authors investigated the influence of the outgoing feeders on the natural period of the supports and the accuracy of the vibration analysis model.

The main findings are below:

(1) A vibration analysis model of the masts, beams and outgoing feeders was developed based on the finite element method. The analysis results were validated by comparing them with the measured results at the full-scale test facility.

(2) Both the modelled and measured results clarified that the outgoing feeders little affect the natural period of the supports in the longitudinal direction but exert non-negligible effects in the lateral direction.

(3) Comparing the measured results at the full-scale test facility with the corresponding results of the vibration analysis model during an earthquake, it was found that the model reasonably estimates the seismic vibration responses of the supports.

References

[1] Railway Technical Research Institute, "The Seismic Design Guideline for Overhead Contact Systems", 2013 (in Japanese).

[2] Y. Kondo, M. Shimizu, S. Harada, "Exposition of Revision of Seismic Design Guideline for Overhead Contact Systems", Proc. of STECH 2015, 3E23, 2015.

[3] IEC 60913:2024, "Railway applications - Fixed installations - Electric traction overhead contact line systems", International Electrotechnical Commission, 2024.

[4] K. Kuribayashi, M. Uochi, "Technology development for large-scale Shinkansen renovation utilizing full-scale simulated structures", JR EAST Technical Review, No.67, 31-34 2022 (in Japanese).

[5] JERS 2010, "Installation standard of overhead contact line systems in high speed rail", Japan Railway Electrical Engineering Association, 2025 (in Japanese).

[6] R. Brincker, L. Zhang, P. Andersen, "Modal Identification from Ambient Response Using Frequency Domain Decomposition", Proceedings of 18th International Modal Analysis Conference, 625-630, 2000.