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NOISE REDUCTION DUE TO VIBRATION DAMPING ESTIMATED BY MEASUREMENTS OF PARTICLE VELOCITY

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We proposed a new method to evaluate noise reduction due to damping treatment by using the particle velocity of sound measured directly in the vicinity of a vibrating object. Moreover, the proposed method was verified based on the comparison between vibration and particle velocity reductions. In Japan, a procedure to revamp old railway bridges, which had no specific fissure damages or serious corrosions, by applying to composite remodeling process have been widely used. During the process of such composite remodeling, we have often used magnetic rubber damper or rubber-latex mortar to reduce remarkable large power of structure-borne sound radiated from steel bridge of railway. This proposed method enables us to estimate precisely noise reduction of these countermeasures, because we grasp the behavior of sound radiated from the vibrating object in detail. In this paper, we present the results of laboratory and field experiments on the effects of noise reduction by using two magnetic rubber dampers, type-A and type-B. In the field measurement, the type-B more significantly reduced the sound radiated from vibrating beam. However, the reduction of radiated sound and that of vibration did not coincide. The reason was clarified from comparison between vibration and particle velocity, which occur due to vibrating a steel plate of simulated beam of bridge in laboratory experiment. Thus, the proposed method enables us to evaluate noise reduction precisely.

Keywords: Steel bridge, Magnetic rubber damper, Environmental countermeasures, Field measurement, Laboratory experiment.

1 INTRODUCTION

Steel railway bridges made up of members of both longitudinal and cross girders have centuries-old history, and many steel bridges have still existed in various places even nowadays. In recent years, steel bridges have also been shown to have long life-cycle costs. In addition, many of the steel members are both high quality and high reliability of factory products, so they have many advantages such as short construction period than concrete bridge. However, on the other hand, steel members with a thin structure are caused to vibrate easily, so there is a disadvantage that the steel bridge has a significantly larger radiated sound due to vibration than a concrete bridge. The residents in major urban areas have high level of consciousness to the surrounding environment, so there are tendencies that the number of complaints at areas along the steel bridge is larger than that at areas along the concrete bridge. Therefore, despite the various advantages such as long life-cycle cost and shortening of construction work, there are some cases where construction of a steel bridge is avoided in consideration of the sound environment along railway.

In order to deal with the urgent issue of reducing radiated sound due to vibration of steel members, magnetic-vibration damping (Masanori and Mifune 1998) and rubber-latex mortar (Lin *et al.* 2017) have been devised as countermeasures applicable to the existing steel railway bridge. Either countermeasures increase the internal loss of the steel member by adding the material, and result in reducing the energy of the vibration which causes structure-born sound. In many cases which such countermeasure is applied, there are often difference of reduction effect between the vibration and radiated sound (Taniguchi *et al.* 2011). The reduction effect of structure-born sound may be not precisely estimated from that of vibration as for countermeasure of steel railway bridge. Therefore, in this study, we propose a method to evaluate the reduction effect based on the particle velocity of the sound directly measured near the vibrating body. We verified the validity of the proposed method by comparing reduction among vibration velocity, particle velocity and intensity of sound due to the vibration (Hiroe and Taniguchi 2017).

2 METHOD OF MEASUREMENTS AND EVALUATION

2.1 Measurement Method

In this study, two kinds of magnetic-vibration damping (type-A and type-B) fixed with the magnetic force were used as shown in Figure 1. The measurement for the steel girder bridge was performed at the Kasukawa railway bridge of the Jomo Electric Railway Co., Ltd. as shown in left side of Figure 2. We implemented a countermeasure to five unit spaces bounded by adjacent intermediated stiffeners, and five pieces of magnetic-vibration dampers which were size of 0.45 m * 0.30 m were attached per one unit space. At the center of five unit spaces, we set 5 sensors of vibration acceleration ***a*** on inside of the plate girder and 1 sensor of sound intensity ***I***, that consists of 2 sensors of sound pressure ***p***, near outer side of the plate girder as shown in right side of Figure 2.

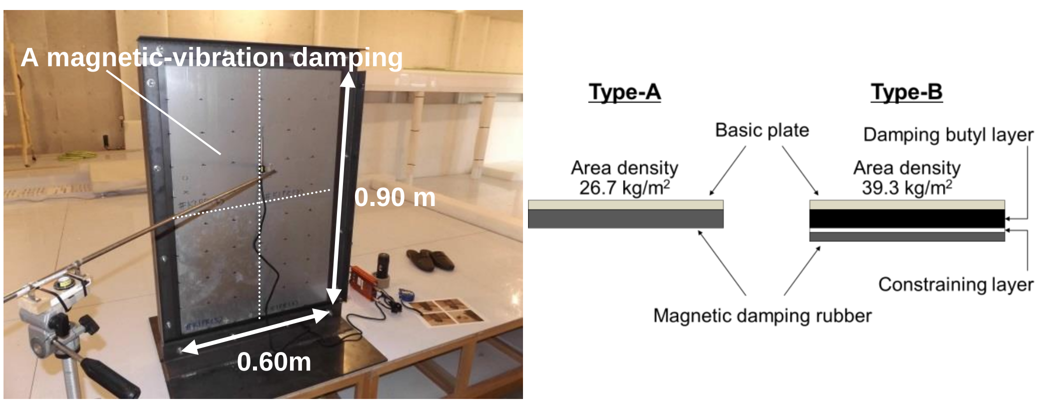


Figure 1. A photograph and structures of magnetic-vibration damping.

Figure 3 shows an overview of a steel plate and the arrangement of both 3 exciting points (x-mark) and 70 measurement points (black circle) on/near the plate in a primary experiment. The steel plate used in the primary experiment was size of 1.055 m * 0.740 m, and attached to 4 pieces of magnetic-vibration dampers. As shown in Figure 3, the particle velocity ***u*** (m/s) in the vicinity of site for attachment of magnetic-vibration dampers was measured, and the vibration acceleration ***a*** (m/s^2) was measured on the opposite side of the particle velocity.

We used an impact hammer PH-51 with a hard tip (Figure 3), sensors of vibration acceleration PV-85/86 (Figures 2 and 3) and an intensity microphone SI-34 (Figure 2) for the field measurement at steel girder bridge. For the primary experiment using the steel plat, PH-51, PV-86 and a sensor of particle velocity KIT-PA-SP0 (Figure 3) were used. All output signals caused by excitation force of the impact hammer were recorded using a data recorder LX-110 for the field measurement (sampling frequency f_s = 24.0 kHz) or DA-20 for the primary experiment (f_s = 25.6 kHz). We secured the effective data which exceed 10 dB of signal to noise substantially of more than 5 for each combination of excitation point and measurement point.

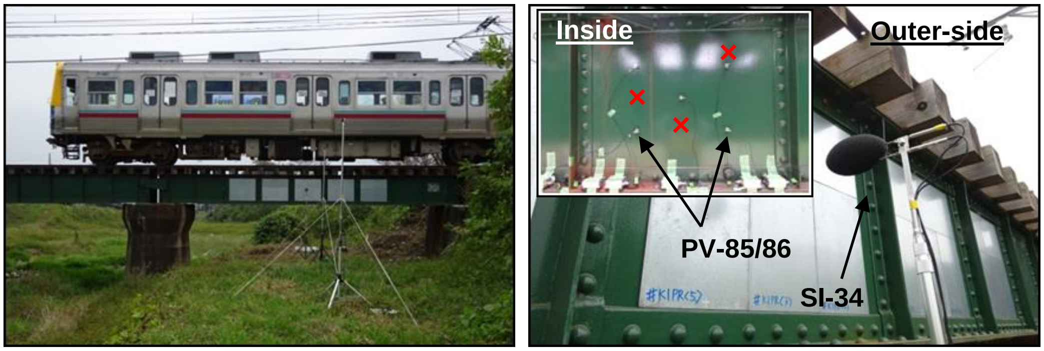


Figure 2. An overview of deck-type plate girder bridge and the arrangement of point excitations (x-mark) and measurement points on/near the girder.

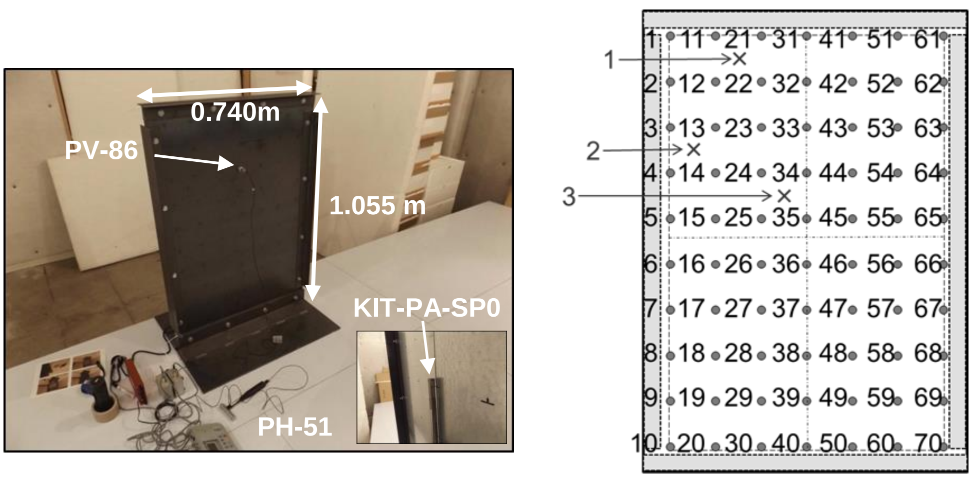


Figure 3. A photograph of the steel plate and the arrangement of 3 point excitations (x-mark) and 70 measurement points (black circle) on/near the plate.

2.2 Evaluation Procedure

Firstly, the electrical signals recorded were converted to those of excitation force $\boldsymbol{F}$ (N), sound pressure $\boldsymbol{p}$ (Pa), vibration acceleration $\boldsymbol{a}$ (m/s^2) and particle velocity $\boldsymbol{u}$ (m/s). Then, we converted the signal of vibration acceleration $\boldsymbol{a}$ to that of the vibration velocity $\boldsymbol{v}$ (m/s) by pass through the filter in the inverse ratio of frequency. The signal of sound intensity $\boldsymbol{I}$ (Watt/m^2) was calculated according to the formula from two signals of the sound pressure $\boldsymbol{p}$ by directly using digital integrators (Tachibana and Yano 1988).

Secondary, we calculated the time-integrated energy value of each variable $\boldsymbol{Q}$ which indicated $\boldsymbol{F}^2$, $\boldsymbol{v}^2$, $\boldsymbol{u}^2$ and $\boldsymbol{I}$ as shown in the following equation (1).

$$P_{ijk} = \int_{-\infty}^{+\infty} Q_{ijk}(t)dt \tag{1}$$

where, subscripts of $\boldsymbol{i}$, $\boldsymbol{j}$ and $\boldsymbol{k}$ mean excitation position (N_i=3), measurement position (N_j=5 in the field measurement / N_j=70 in the primary experiment) and iteration count (N_k=5). After normalizing by excitation force $\boldsymbol{F}$ according to the equation (2), the averaged value $\boldsymbol{P_{ij/F}}$ of each variable $\boldsymbol{P_{ijk/F}}$ was calculated according to the equation (3). Further, the area-averaged value $\boldsymbol{P_{i/F}}$ of each variable $\boldsymbol{P_{ij/F}}$ was calculated according to the equation (4).

$$P_{ijk/F} = P_{ijk}/F_{ijk} \tag{2}$$

$$P_{ij/F} = \left(\sum_{k=1}^{N_k} P_{ijk/F}\right)/N_k \tag{3}$$

$$P_{i/F} = \left(\sum_{j=1}^{N_j} P_{ij/F}\right)/N_j \tag{4}$$

Finally, in accordance with the equation (5), the level ratio of the standardized exposure value for vibrating body between with damper (type-A or type-B) attachment $\boldsymbol{P_{i/F}^{(A,B)}}$ and without damper attachment $\boldsymbol{P_{i/F}^{0}}$ was calculated as reduction effect $\boldsymbol{\Delta P_{i/F}^{(A,B)}}$. Finally, we calculated the difference of reduction $\boldsymbol{\Delta P_{i/F}^{B/A}}$ between type-B $\boldsymbol{\Delta P_{i/F}^{(B)}}$ and type-A $\boldsymbol{\Delta P_{i}^{(A)}}$ in according to the equation (6).

$$\Delta P_{i/F}^{(A,B)} = -10 \times log_{10}\left(P_{i/F}^{(A,B)}/P_{i/F}^{0}\right) \tag{5}$$

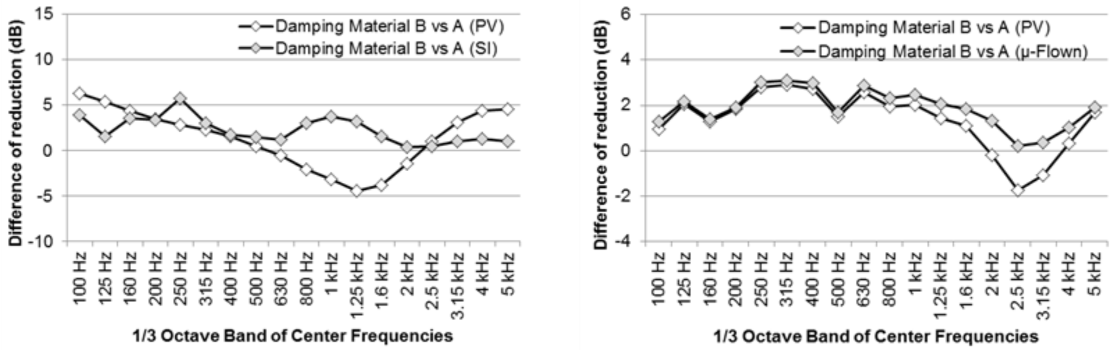
$$\Delta P_{i/F}^{B/A} = \Delta P_{i/F}^{(B)} - \Delta P_{i/F}^{(A)} \tag{6}$$

3 RESULTS AND DISCUSSIONS

3.1 The Result in the Field Measurement at a Deck-Type Steel Girder Bridge

Figure 4 shows a comparison of reduction effects $\boldsymbol{\Delta v^{B/A}_{/F}}$ between (a) the field measurement and (b) the primary experiment. The left side figure (a) shows two kinds of reduction difference, $\boldsymbol{\Delta v^{B/A}_{/F}}$ for vibration velocity and $\boldsymbol{\Delta I^{B/A}_{/F}}$ for sound intensity in the field measurement at the deck-type steel girder bridge. The right shows two kinds of difference reduction, $\boldsymbol{\Delta v^{B/A}_{3/F}}$ for vibration velocity and $\boldsymbol{\Delta u^{B/A}_{3/F}}$ for particle velocity in the primary experiment using the steel plate for No.3 of excitation position.

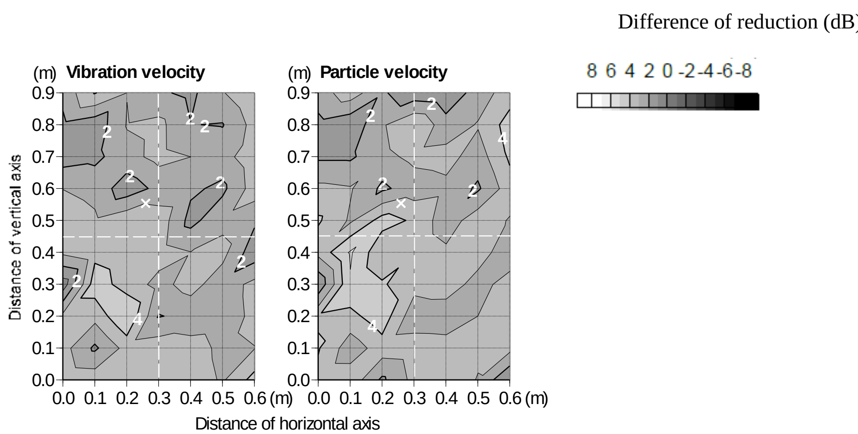
As shown in Figure 4(a), there is a clear difference between the sound intensity $\boldsymbol{\Delta I^{B/A}_{/F}}$ and the vibration velocity $\boldsymbol{\Delta v^{B/A}_{/F}}$ in the reduction effect at the frequency range from 630 Hz to 2 kHz. We notice that there is discrepancy between the vibration of girder plate and the radiated sound due to the vibration with magnetic-vibration damper attachment at the frequency range from 630 Hz to 2 kHz. On the other hands, as shown in Figure 4(b), the result of the primary experiment shows that there is a clear difference between the particle velocity $\boldsymbol{\Delta u^{B/A}_{3/F}}$ (μ-Flown) and the vibration velocity $\boldsymbol{\Delta v^{B/A}_{3/F}}$ (PV) in the reduction effect at the frequency range from 2 kHz to 4 kHz. Similarly to the result in the field measurement, as far as it relates to the particle velocity of sound radiated from vibrating body ($\boldsymbol{\Delta u^{B/A}_{3/F}}$), the reduction of type-B is larger than that of type-A in all frequency range, despite the fact that the damper of type-A has large reduction in the vibration than the damper of type-B near the frequency of around 2.5 kHz ($\boldsymbol{\Delta v^{B/A}_{3/F}}$).



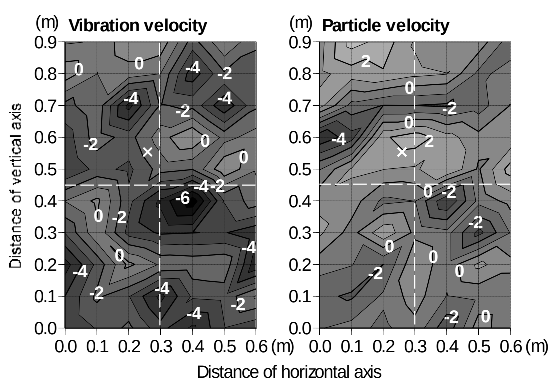
(a) The field measurement (b) The primary experiment

Figure 4. The reduction effects in (a) the field measurement: vibration velocity PV and sound intensity SI in the frequency characteristic at the steel girder bridge, and (b) the primary experiment: PV and particle velocity μ-Flown for excitation position No.3 at the steel plate.

3.2 The Result in the Primary Experiment Using a Steel Plate



(a) Frequency 315 Hz: $\Delta \boldsymbol{v}^{B/A}_{3/F}$ vs $\Delta \boldsymbol{u}^{B/A}_{3/F}$



(b) Frequency 2 kHz: $\Delta \boldsymbol{v}^{B/A}_{3/F}$ vs $\Delta \boldsymbol{u}^{B/A}_{3/F}$

Figure 5. Comparisons of reduction effect between vibration velocity $\Delta \boldsymbol{v}^{B/A}_{3/F}$ and particle velocity $\Delta \boldsymbol{u}^{B/A}_{3/F}$ for excitation position 3 in the primary experiment.

Figure 5 shows contour maps of difference reduction compared type-B with type-A for both particle velocity $\Delta \boldsymbol{u}^{\mathbf{B/A}}_{\boldsymbol{3/F}}$ and vibration velocity $\Delta \boldsymbol{v}^{\mathbf{B/A}}_{\boldsymbol{3/F}}$. Figure 5(a) is the contour maps in the frequency band of 315 Hz, and Figure 5(b) shows those in the frequency band of 2.5 kHz.

These contour maps make clear that the consistency or discrepancy of reduction effect between particle velocity $\Delta \boldsymbol{u}^{\mathbf{B/A}}_{\boldsymbol{3/F}}$ and vibration velocity $\Delta \boldsymbol{v}^{\mathbf{B/A}}_{\boldsymbol{3/F}}$ appear over the entire surface of the steel plate. In regard to the reduction effect caused by the magnetic-vibration damper attachment, the behavior of particle velocity in the vicinity of the vibrating plate seems to differ with that of its vibration velocity above the middle frequency of around 500 Hz. As shown in Figure 5(a), because the wavelength of bending wave on the steel plate becomes larger than the size of a piece of magnetic-vibration damper below the frequency of 500 Hz (in the frequency band of 315 Hz), each piece of the magnetic-vibration damper express similar behavior to the vibrating steel plate. On the other hands, at the frequency range far higher than 500 Hz (in the frequency band of 2.5 kHz), there are a few peaks and troughs for reduction effect of vibration velocity in each piece of the magnetic-vibration damper. As shown in Figure 5(b), at such frequency range, the behavior of steel plate seems to differ from that of the magnetic-vibration damper. Therefore, our proposed method to evaluate based on the particle velocity near a vibrating body is superior to the method based on vibration velocity of the body in determining noise reduction of a countermeasure precisely.

4 CONCLUSIONS

In this study, we propose a method to evaluate reduction effect based on the particle velocity of sound measured directly near the vibrating body. Through both the field measurement at the deck-type steel girder bridge and the primary experiment using the steel plate, we verified the validity of the proposed method. In regard to two magnetic-vibration dampers, the behavior of particle velocity seems to differ with that of vibration velocity above the middle frequency of around 500 Hz. Thus, it is necessary to evaluate reduction effect based on the particle velocity rather than vibration velocity in order to determine noise reduction of a countermeasure precisely.

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