Improvement effect of the infrasound and vibration due to repair of the bridge

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ABSTRACT

Recently, increasingly heavy traffic flow volumes have led to fatigue damage in the deck and pavement of bridges. Heavy trucks are a major contributor to such damage, causing environmental vibration problems such as infrasound and ground vibration. These vibrations are known to be transmitted through bridges to nearby houses. This study investigated bridges that caused such problems in nearby houses. Bridge repairs were performed to solve these problems. The improvement in infrasound and ground vibration upon bridge repair was investigated using a test truck and ordinary trucks. The ground vibration of the abutment with frequencies of 10 Hz or more decreased greatly as did the ground vibration outside the houses. Furthermore, infrasound with frequencies of 10–20 Hz decreased.

Keywords: Infrasound, Bridge vibration I-INCE Classification of Subjects Number(s): 40

1. INTRODUCTION

Matching of natural frequencies of heavy trucks, bridges and houses produce environmental vibration problems such as infrasound and ground vibrations (1, 2, 3). General trucks with rear leaf suspension in Japan have frequencies of about 3.0Hz. Also, the frequencies of the tire spring vibration appear at about 10-20Hz. The vibration of trucks' suspension springs (3 Hz) and/or tire springs (10–20 Hz) is known to be transmitted from bridges (4). Various measures (extended deck method (2, 3, 4), viscoelastic damper (4, 5) and structural modification (6)) have been employed to solve this problem. The road roughness of a pavement is found to be the most effective, though impermanent, measure.

Recently, increasingly heavy traffic flow volumes have led to fatigue damage in the deck and pavement of bridges. As a result, heavy truck vibrations were generated by the bad road roughness of the pavement, and large bridge vibrations were generated by the truck vibrations. These vibrations were transmitted to houses around the highway bridge as ground vibrations and as infrasound.

This study focused on bridges that had received several complaints of rattling sounds or vibrations in nearby houses owing to infrasound and ground vibrations. One of the present authors had previously investigated various measures (extended deck, viscoelastic damper, box structure, exchange for main girders from stringer, arch support) for complaints through a computer simulation using dynamic response analysis under a moving truck model (7). As the results of the investigation, the viscoelastic damper or extended deck and improvement of the road roughness were recommended in consideration of the construction cost and work difficulty.

Then, the extended deck and improvement of road roughness were employed as a permanent measure in these bridges. To investigate the improvement in infrasound and ground vibrations upon this repair, this study conducted investigations using a test truck and ordinary trucks before and after repair. The results of the improvement effect for ordinary moving trucks are presented.

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2. TARGETED HIGHWAY BRIDGES

2.1 Bridge specifications

The two highway bridges shown in Fig. 1 were targeted in this study. One, constructed in 1967, has two eastbound lanes and the other, constructed in 1971, two westbound lanes. The former has a simple steel composite girder with 25.2 m span (A1–P1), three spans of continuous steel composite girders each with 49.0 m span (P1–P4). The latter has a simple steel composite girder with 36.47 m span (P1–A1); three spans of continuous steel composite girders with 48.59 m, 49.09 m, and 49.09 m spans (P4–P1), respectively.

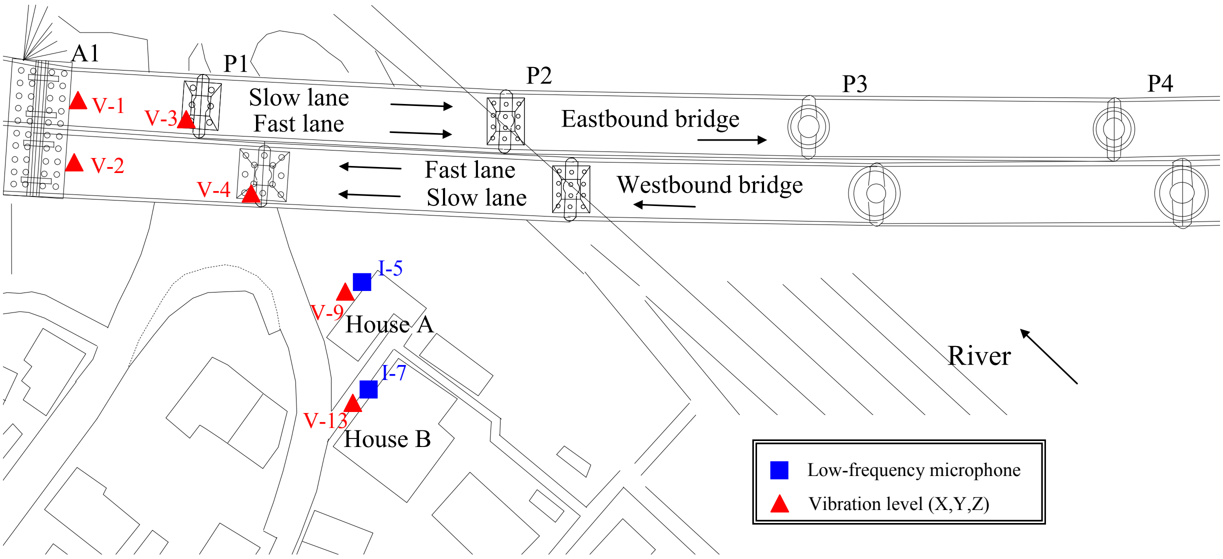


Figure 1 – Targeted highway bridges

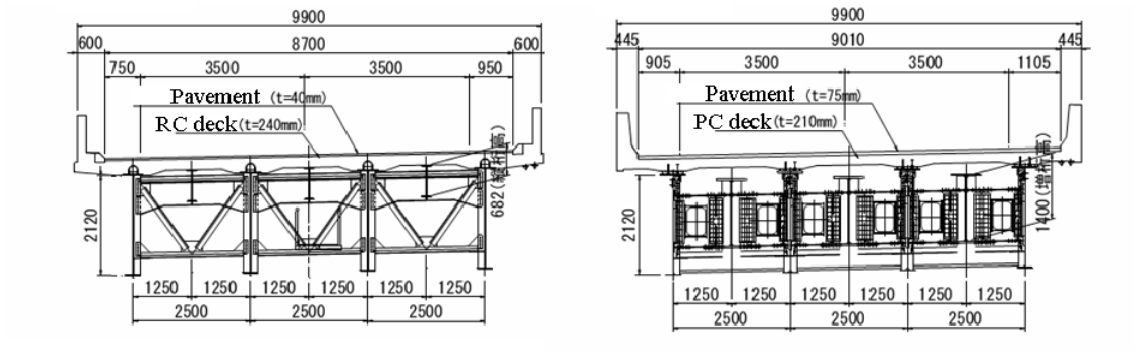
2.2 Measurement points

Houses A and B near the girder (P1–P2) suffered from infrasound and ground vibrations transmitted from the westbound bridge, as shown in Fig. 1. The infrasound and ground vibrations produced by moving trucks were investigated before and after bridge repair using low-frequency microphones and vibration level meters arranged in accordance with each propagation course.

3. REPAIR METHOD

Damaged reinforced concrete decks were replaced with pre-cast prestressed concrete composite decks. In the eastbound and westbound bridges, sections A1–P1 and P2–A1 were replaced, respectively. In particular, in section P1–A1 of the westbound bridge, stringers were replaced with new girders to reinforce the bridge stiffness, as shown in Fig. 2.

Moreover, the extended deck method (4) was applied to the A1 abutments of the eastbound and westbound bridges to reduce the impact force of tire spring vibrations (10–20 Hz) when heavy trucks pass over the roughness (faulting) at the expansion joint. In the extended deck method, the existing reinforced concrete deck is extended in the direction of the embankment, and the expansion joint is moved toward the approach embankment. The length of the extended deck was decided as 10 m in consideration of the damping time of the tire spring vibration.

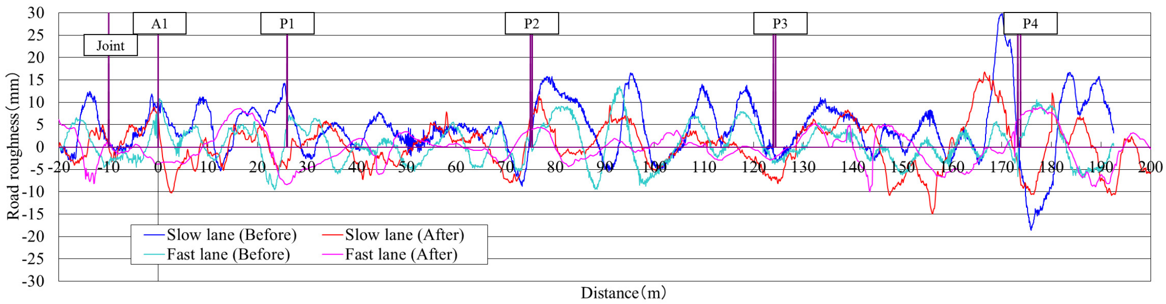


(a) Before repair (b) After repair

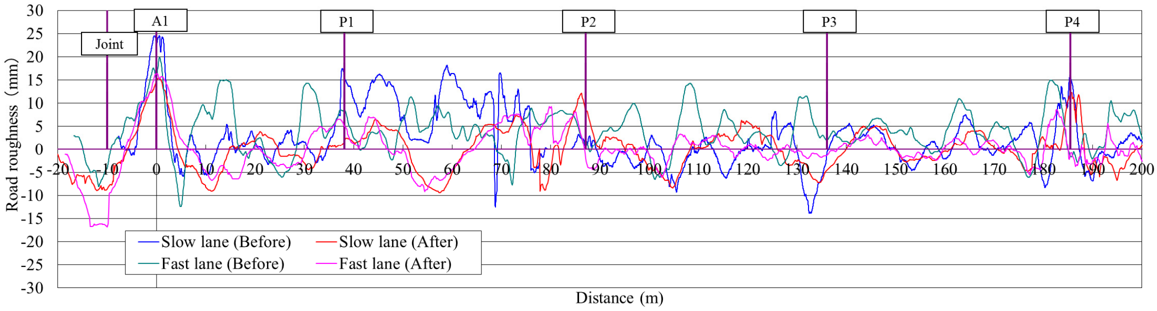
Figure 2 – Outline of repair method (P1–A1 of westbound bridge)

4. ROAD ROUGHNESS OF PAVEMENT

To compare the road roughness of the pavement before and after repair, Figs. 3 (a) and (b) show the road roughness of the pavement in each lane on the eastbound and westbound bridges, respectively. Bad road roughness is clearly observed in the eastbound (P2–P3) and westbound (P1–P2) bridges before repair, and it is reduced after repair.



(a) Eastbound bridge



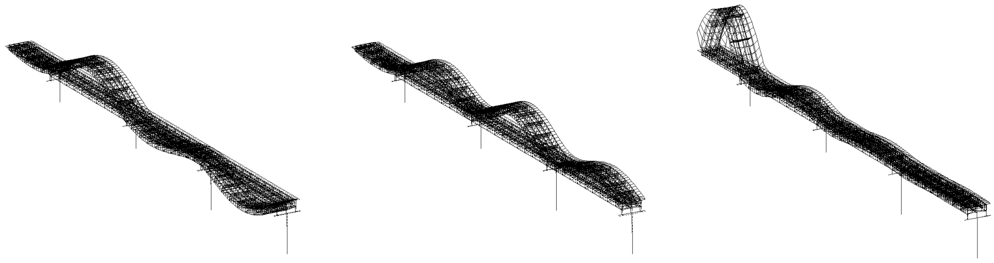
(b) Westbound bridge

Figure 3 Road roughness of the pavement

5. BRIDGE VIBRATION CHARACTERISTICS

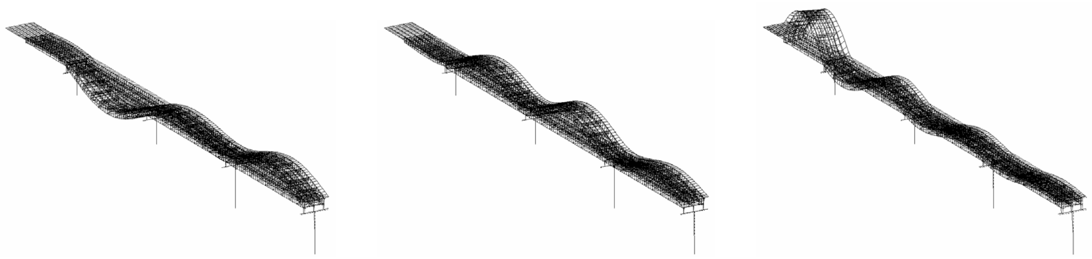
To compare the vibration characteristics of each bridge before and after repair, eigenvalue analysis was carried out using a finite element (FE) model. Figures 4 and 5 show the results of the vibration modes of the eastbound and westbound bridges, respectively.

A comparison of the frequencies before and after repair for the same vibration mode showed little change. These bridges show many similar vibration modes at frequencies of 2–5 Hz. Bending vibration modes with the same phase in each span of the westbound bridge at a frequency of 2.5–4.0 Hz clearly affect Houses A and B.



Bending 2nd: 2.4 Hz Bending 3rd: 3.0 Hz Bending 4th: 5.4 Hz

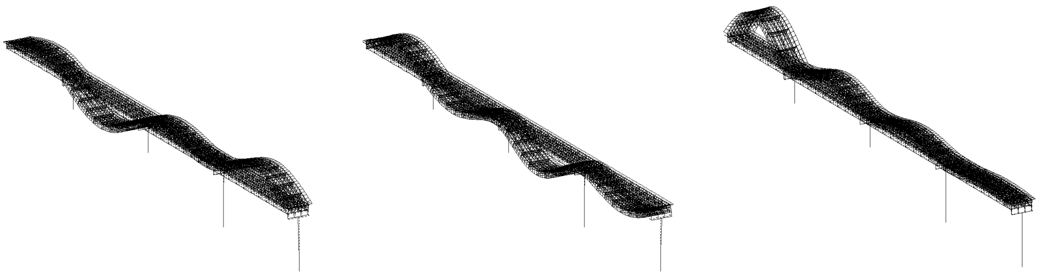
(a) Before repair



Bending 2nd: 2.4 Hz Bending 3rd: 3.1 Hz Bending 4th: 6.2 Hz

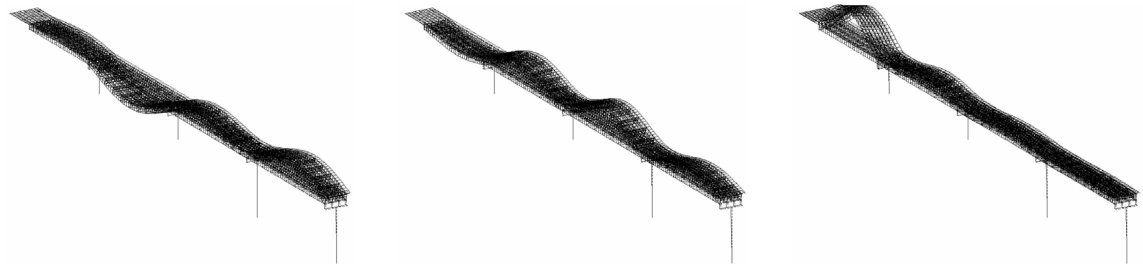
(b) After repair

Figure 4 – Vibration modes (Eastbound bridge)



Bending 2nd: 2.5 Hz Bending 3rd: 3.3 Hz Bending 4th: 4.0 Hz

(a) Before repair



Bending 2nd: 2.5 Hz Bending 3rd: 3.3 Hz Bending 4th: 4.4 Hz

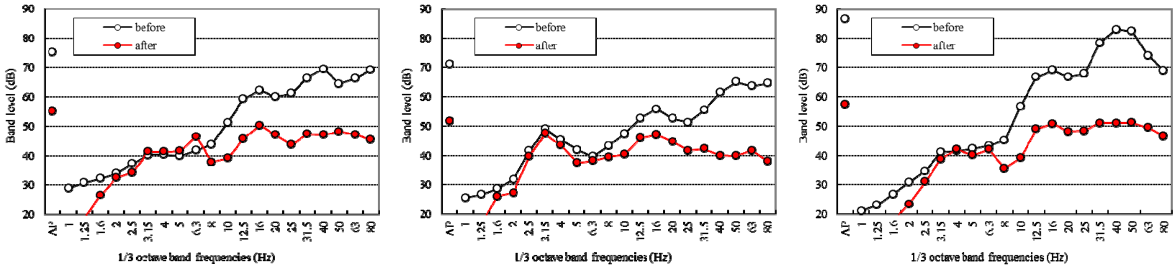
(b) After repair

Figure 5 – Vibration modes (Westbound bridge)

6. VIBRATION LEVEL

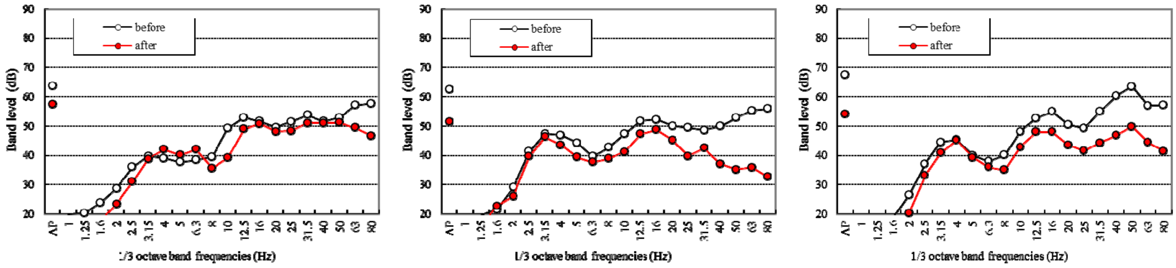
To compare the effect of repair, the ground vibration caused by ordinary trucks was measured for 10 min per hour from 9:00 PM to 9:00 AM. The vibration levels (band levels) of every 1/3 octave band frequency at each measurement point are compared. Here, these are the averages of the peak levels for each 10 min per hour period.

Figures 6 and 7 show the results of the A1 abutment in the eastbound and westbound bridges, respectively. Trucks approach from the A1 abutment of the eastbound bridge. Because the extended deck method was applied at this A1 abutment, frequencies of 10–80 Hz caused by the trucks' tire spring vibration at the A1 joint decreased greatly. On the other hand, at the A1 abutment of the westbound bridge, the extended deck method had a small effect because this abutment was not the approach side. Figures 8 and 9 show the results of the P1 pier in the eastbound and westbound bridges, respectively. All frequencies in the eastbound bridge reduced after repair. In contrast, frequencies of 10–80 Hz decreased greatly in the westbound bridge. Figures 10 and 11 show the outsides of Houses A and B on the ground, respectively. Houses A and B are affected by frequencies of 3.15–4.0 Hz and 10–20 Hz from the westbound and eastbound bridges. Repair showed a pronounced effect for frequencies of 10–20 Hz, whereas other frequencies decreased slightly. Repair showed greater effect at House B than at House A.



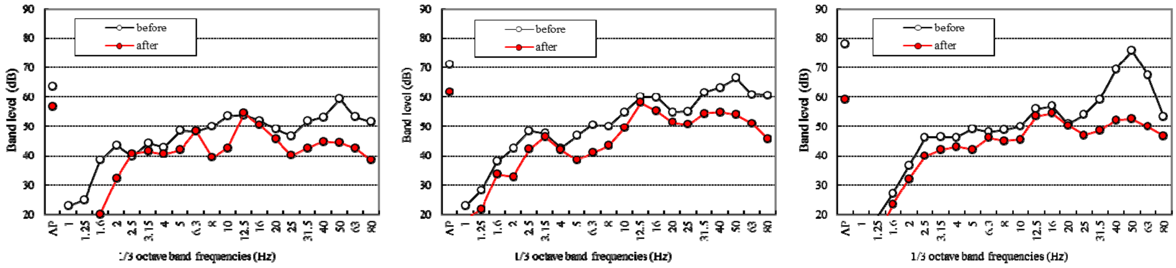
(a) Longitudinal (b) Transverse (c) Vertical

Figure 6 – Abutment A1 (Eastbound bridge)



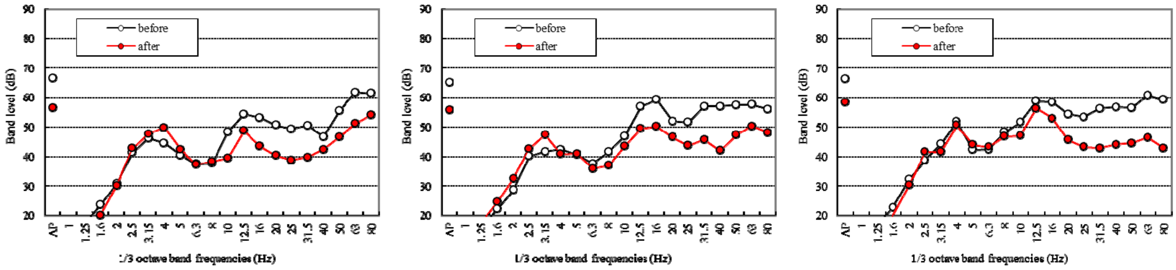
(a) Longitudinal (b) Transverse (c) Vertical

Figure 7 – Abutment A1 (Westbound bridge)



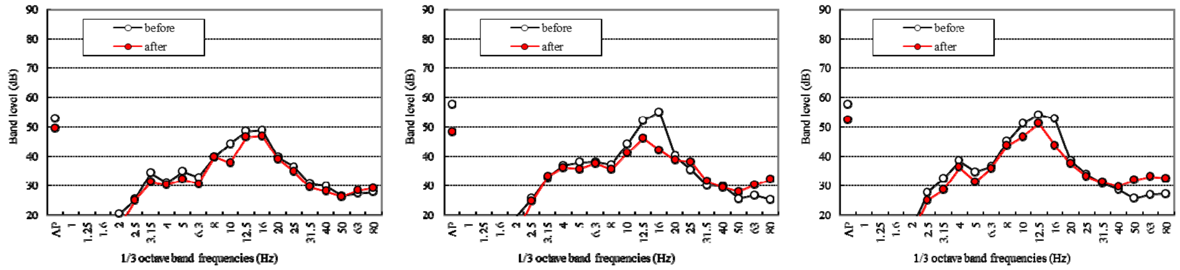
(a) Longitudinal (b) Transverse (c) Vertical

Figure 8 – Pier P1 (Eastbound bridge)



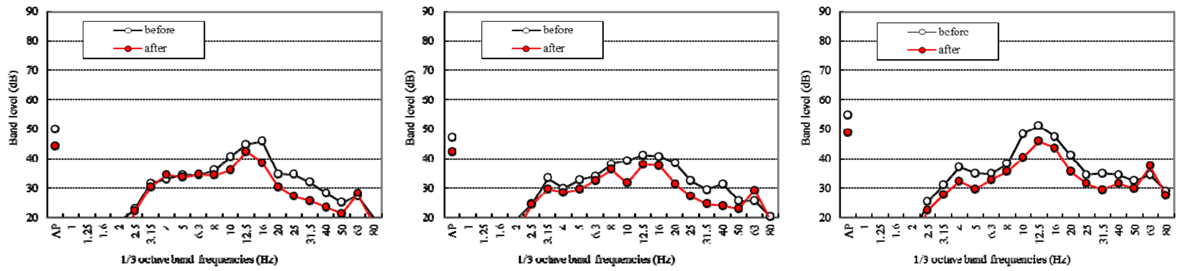
(a) Longitudinal (b) Transverse (c) Vertical

Figure 9 – Pier P1 (Westbound bridge)



(a) Longitudinal (b) Transverse (c) Vertical

Figure 10 – Outside House A



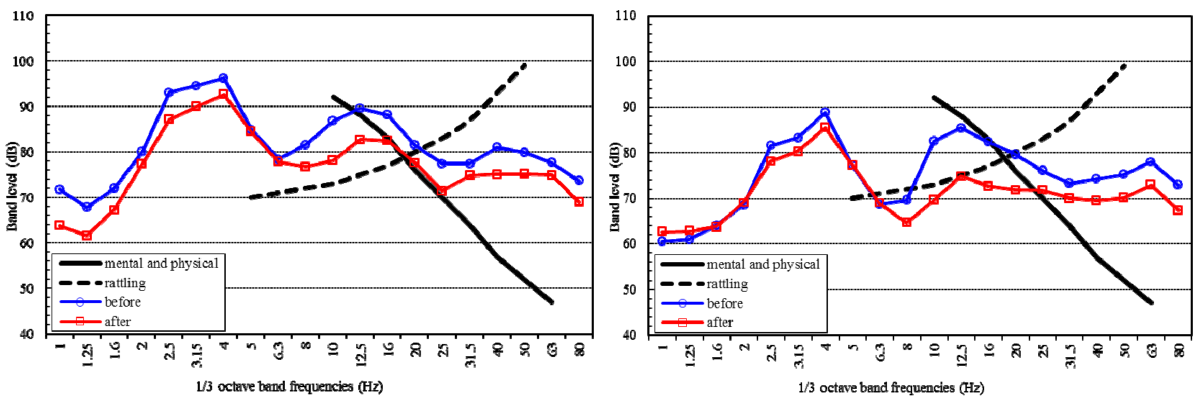
(a) Longitudinal (b) Transverse (c) Vertical

Figure 11 – Outside House B

7. INFRASOUND

To investigate the effect of repair for infrasound and to measure the vibration level, infrasound produced by conventional trucks was measured for 10 min per hour from 9:00 PM to 9:00 AM before and after repair. The infrasound (band level) of every 1/3 octave band frequency (averages of the peak levels for each 10 min per hour period) at each measurement point are shown in Fig. 12. Here, the dotted line indicates the threshold level at which windows begin to rattle and humans perceive a rattling sound and the solid line, the threshold level at which humans experience mental and physical discomfort. These curves are defined by the Ministry of Environment in Japan as reference values of the 1/3 octave band frequency for complaints about rattling sounds and mental and physical discomfort (8).

Figures 12 (a) and (b) show the infrasound (band level) of every 1/3 octave band frequency at the outside of Houses A (I-5) and B (I-7), respectively. Though Houses A and B are affected by frequencies of 2.5–4.0 and 12.5 Hz, each peak band level is decreased. In particular, the peak band level at a frequency of 12.5 Hz for House B is below the dotted line.



(a) Outside House A (I-5) (b) Outside House B (I-7)

Figure 12 – Infrasound (band level) of every 1/3 octave band frequency before and after repair

8. CONCLUSIONS

Repairs were conducted to solve the environmental vibration problem in target bridges. Investigations were conducted using a test truck and ordinary trucks before and after repair. The improvements realized through repairs were determined. The following conclusions were derived from this study.

(1) Before repair, bad road roughness of the pavement was observed on the eastbound (P2–P3) and westbound (P1–P2) bridges. The roughness was reduced after repair.

(2) A comparison of the frequencies before and after repair for the same vibration mode showed little change.

(3) A comparison of every 1/3 octave band frequency of the band level (vibration level) at the A1 abutment of the eastbound and westbound bridges showed a gentle decrease in frequencies of 10–80 Hz caused by the trucks' tire spring vibration at the A1 joint. The extended deck method used to reduce the impact of the truck's vibration when passing over the expansion joint was applied at this abutment.

(4) Repairs had a pronounced effect on the vibration level (band level) of every 1/3 octave band frequency in Houses A and B for frequencies of 10–20 Hz, whereas other frequencies decreased slightly. Repairs had a greater effect at House B than at House A.

(5) From the infrasound (band level) of every 1/3 octave band frequency outside Houses A (I-5) and B (I-7), each peak band level at frequencies of 2.5–4.0 and 12.5 Hz decreased. In particular, the peak band level at a frequency of 12.5 Hz at House B is below the dotted line.

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