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GROUND VIBRATION ACCOMPANYING INFRA-SOUND GENERATED BY A HIGHWAY BRIDGE

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ABSTRACT
Residents near a highway bridge complain about vibration caused by traffic on the highway. We have made a series of measurements including pressure and ground vibration around the house. The house and the surrounding ground were shaken strongly at a frequency of about 4 Hz. The level of infra-sound was on the order of 110 dB at the maximum. The contours of level were roughly concentric around the midpoint of a span of the bridge suggesting the source to be the oscillation of the bridge girder. However, it was unlikely that the ground vibration was interacting with the ambient infra-sound.

1 - INTRODUCTION
Residents by a bridge of state highway #2 in Hiroshima, Japan, complain that they suffer severe shaking of their house by traffic on the bridge. We examined the noise and vibration at the site and found that the house and the surrounding ground altogether were shaken strongly at a frequency of about 4 Hz. The levels of sound pressure were highest beneath the bridge girder and attained the order of 110 dB at the maximum.
From an experience of similar case in Nara, Japan, we were confident that the bridge was the source of the infra-sound [1]. In the present paper I have investigated the relationship between the infra-sound and ground vibration.

2 - MEASURED RESULTS OF INFRA-SOUND AND GROUND VIBRATION
We have deployed two sets of sensors in every set of measurements and placed one of which at a reference point and another at an arbitrary measuring point to determine the sound and/or ground-vibration fields under question.
The fluctuations of infra-sound at two points measured in the same time periods roughly synchronized suggesting that the sound was propagating from a point to another. The spatial distribution of infra-sound at an instant, at which the levels at the reference point beneath the bridge girder was high, is given in Fig. 1. This demonstrates clearly that the level is the highest just below the mid-point of the span of the bridge and attenuated gradually as the distance is increased from the point. Ground vibration was measured in the same time periods at the same locations at which infra-sound was measured. The peaks of fluctuation of vibration levels also exhibited the temporary coincidence with those of the infra-sound.
Octave-band spectra of the infra-sound and the ground vibration are given in Fig. 2. The spectra of the ground vibration are very similar to those of the infra-sound with a peak in the 4 Hz band suggesting a positive correlation between the both.
By these results and from experience in a previous study [1] it may be assumed that the infra-sound was generated by bending oscillation of a bridge girder which constituted a dipole source and the pressure was propagated from the point toward the surrounding area.
Even admitting the foregoing postulate the relationship between the infra-sound and the ground vibration deserves a further investigation: Is the ground vibration propagated independently of the infra-sound or is it interacting with the latter? We will examine the question in the next section.

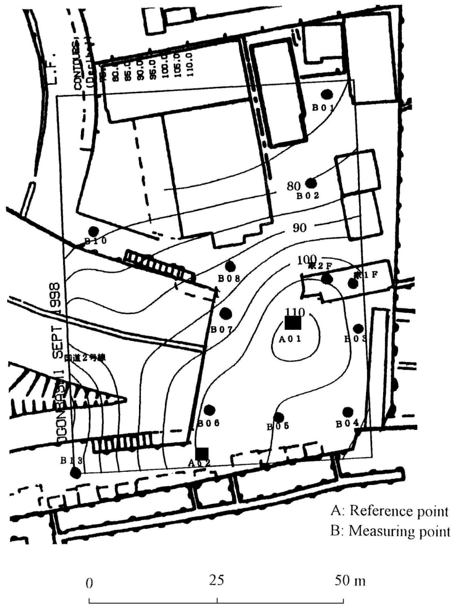

Figure 1: Contours of level of infra-sound around the bridge; the highest level is located beneath the 1st span of the bridge.

3 - DISTANCE ATTENUATION OF INFRA-SOUND AND GROUND VIBRATION AND THE CORRELATION OF THEIR LEVELS

First, I have computed dispersion-curves for Rayleigh waves that may be propagated under the estimated ground condition of the site, and found that the phase velocity of the fundamental mode of the wave at the frequency of 4 Hz can be about 340 m/s. It is possible that the ground vibration were the air-coupled Rayleigh wave [2].

Next, I have made a diagram of the distance attenuation of levels of infra-sound and ground vibration (z-component) from contour maps such as in Fig. 1 (Fig. 3). Attenuations of them are -12 to -15 dB/(double distance) and -3dB/(double distance) over the range of 8 to 30 meters, respectively: they correspond to $1/r^2 \sim 1/r^{5/2}$ and $1/r^{1/2}$, respectively. Attenuation proportional to $1/r^2$ is consistent with our findings that a bridge girder behaved as a dipole source of infra-sound [1]. In the present case the attenuation seems to be stronger than -12dB/(d.d.). Surrounding houses may have played a role in this over attenuation of infra-sound. In contrast, attenuation of ground vibration proportional to $1/r^{1/2}$ is reasonable if it were a surface wave. The different rates of attenuation are unfavorable to the air-coupled Rayleigh-wave postulate.

Thus, in order to examine quantitative relation between the ground vibration and infra-sound I have calculated the air pressure with particle velocity that is equal to that of vertical ground vibration. They are plotted in the ordinate in Fig. 4 against the measured values of infra-sound at 1.2 m above every location where the vibrations was measured. The correlation is poor and the values of vibration-related pressures are much lower than those of measured infra-sounds. (The correlation coefficient is 0.57 if we expressed the relation by Y=57 +0.14X where Y is vibration-compatible air pressure and X is infra-sound.) This suggests again that the ground vibration is propagated independently of infra-sound at every point.

This naturally does not deny the fact that the ground vibration is generated in the source area by over-pressure by infra-sound.

4 - CONCLUSIONS

Correlation between infra-sound and ground vibration is investigated near a highway bridge where a strong infra-sound at about 4 Hz is generated from a bridge girder. Spectra of infra-sound and ground vibration were quite similar. Dispersion characteristics of Rayleigh waves in the site suggest a possible interaction between the infra-sound and the ground vibration. However, the distance attenuations of the infra-sound and the ground vibration were more than -12dB/(double distance) and -3dB/(double distance), respectively; and the quantitative correlation between the levels of measured infra-sound and the computed ones from vertical component of ground vibration was poor. The inconsistent attenuation and the poor correlation implies that the infra-sound and the vibration are propagated independently

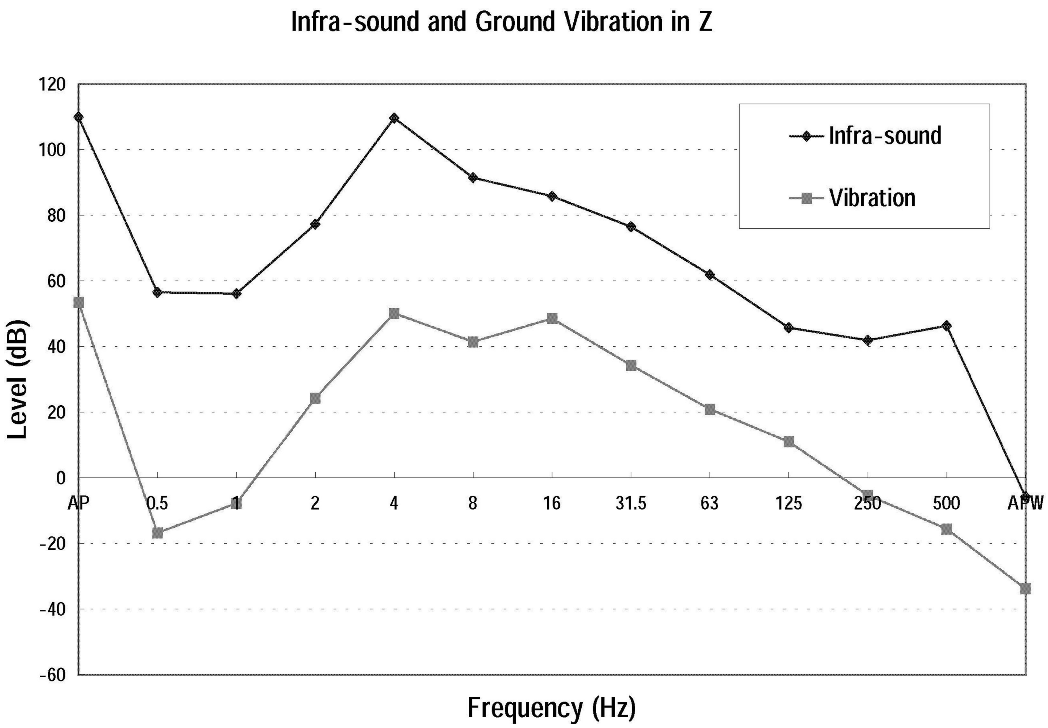

Figure 2: Octave-band spectra of infra-sound and ground vibration (z-component); both exhibit a peak in the 4 Hz band.

from each other. This does not necessarily contradict to that the ground vibration was generated by infra-sound in its source area.

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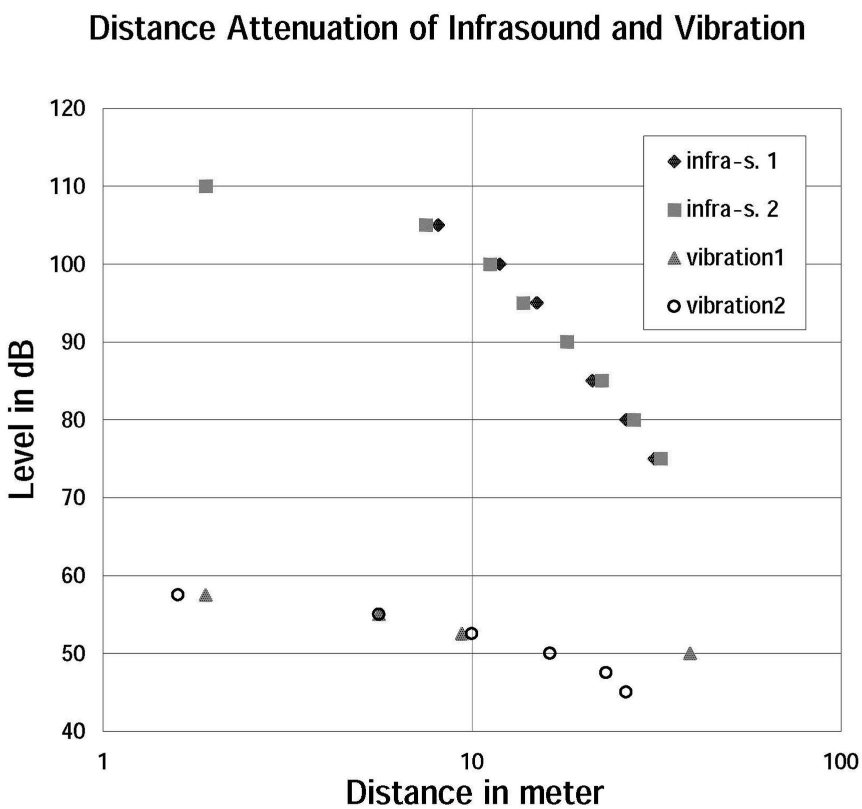

Figure 3: Distance attenuations of infra-sound and ground vibration along two measuring lines; infra-sound exhibit more than -12dB/(double distance) while ground vibration does about -3dB/(double distance).

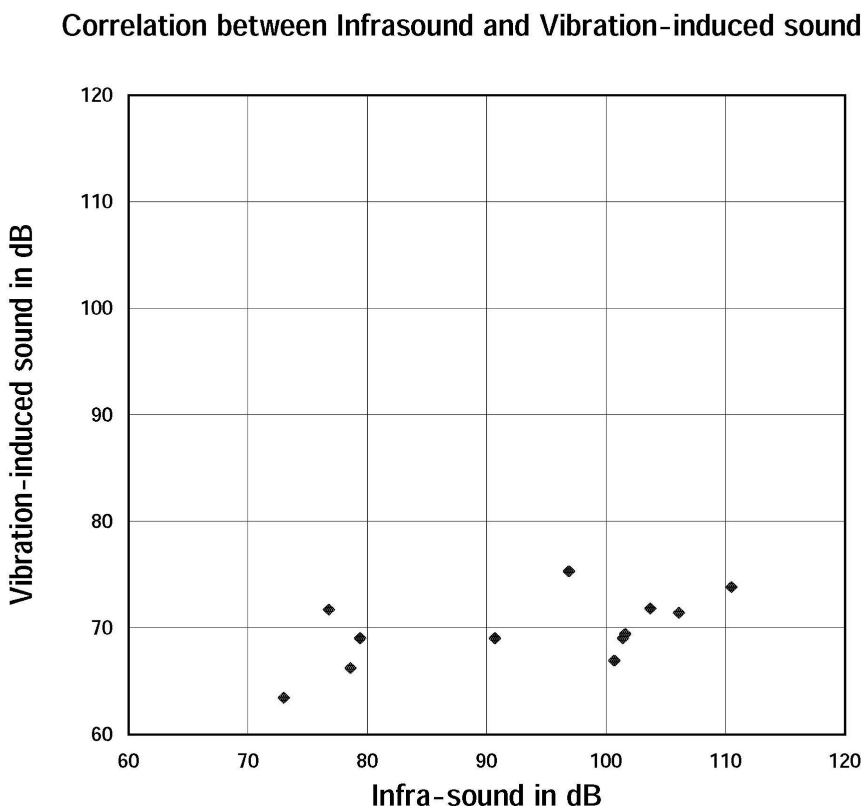

Figure 4: Correlation between measured infra-sound levels and estimated sound levels from vertical component of ground vibration at the same sites; correlation is poor suggesting that the infra-sound and ground vibration are propagated independently.