

Study on Health Monitoring of Road Infrastructure Using Tires Mounted with Microphones

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1. Introduction

The deterioration of road infrastructure, including bridges and underground utilities, has become a growing concern as many structures continue to age. Conventional inspection methods rely on specialized equipment such as radar, cameras, ultrasonic sensors, or dedicated inspection vehicles. Although these methods provide reliable evaluations, they require considerable time, labor, and cost, making frequent monitoring difficult, particularly for local roads and small bridges. A practical alternative is to utilize ordinary vehicles that travel on roads every day as mobile sensing platforms for continuous infrastructure monitoring.

This study proposes a novel monitoring method using a microphone embedded inside a vehicle tire. Road vibrations generated at the tire-road contact patch excite the acoustic cavity inside the tire, producing characteristic cavity resonance. Because the resonance spectrum depends on the vibration characteristics of the road surface and supporting structure, changes in bridge conditions or subsurface structures may be detected through analysis of the microphone signal without installing sensors on the infrastructure itself.

2. Experimental Method

Two types of microphone-equipped tires were prepared: a light-truck tire for laboratory evaluation and a passenger-car tire for field measurements. MEMS microphones were mounted on the wheel inside the tire, and the cavity sound was recorded using a wireless oscilloscope. Fundamental characteristics were first investigated by hammering tests conducted on normal asphalt pavement and on pavement located above an underground sewer pipe. A cylindrical hammer was repeatedly dropped onto the pavement while the tire remained stationary under a controlled load and inflation pressure. The microphone signals were analyzed using FFT with a Hann window to obtain the resonance spectra. Field experiments were subsequently performed using the passenger car on ordinary roads and 13 bridges in Osaka City. The ratio of the third-order to first-order cavity resonance peak intensity was selected as an indicator of vibration characteristics and compared with the elapsed years since bridge construction or the most recent repair.

3. Results and Discussion

The hammering tests revealed clear cavity resonance peaks at approximately 278, 550–560, and 825–830 Hz. The first-order resonance peak gradually decreased as the hammering distance increased. This decrease was smaller for pavement above the underground sewer pipe than for normal pavement, suggesting that vibration attenuation was reduced because of differences in the subsurface structure. In contrast, the third-order peak trends showed relatively small differences between the two road conditions. Consequently, the ratio of the third-order to first-order peak intensity reflected changes in vibration propagation associated with the road structure. The field measurements also demonstrated a similar tendency as shown in Fig. 1. Although the measured peak ratios exhibited some scatter because vehicle speed was not corrected, the ratio generally decreased with increasing years since bridge construction or repair. This trend suggests that aging bridges tend to exhibit reduced high-frequency vibration components, which can be detected through tire cavity resonance. The proposed peak intensity ratio therefore provides a simple indicator of changes in structural vibration characteristics.

4. Conclusions

The results demonstrate that microphones embedded inside vehicle tires can be used to monitor road infrastructure by analyzing tire cavity resonance. Both laboratory and field experiments indicate that the ratio of the third-order to first-order resonance peak intensity reflects differences in subsurface conditions and bridge vibration characteristics. The proposed technique has the potential to transform ordinary vehicles, such as buses and delivery trucks, into low-cost mobile sensing platforms capable of continuously screening road infrastructure. Such a system could significantly improve the efficiency of infrastructure maintenance by identifying locations that require detailed inspection while reducing inspection costs and increasing monitoring frequency.

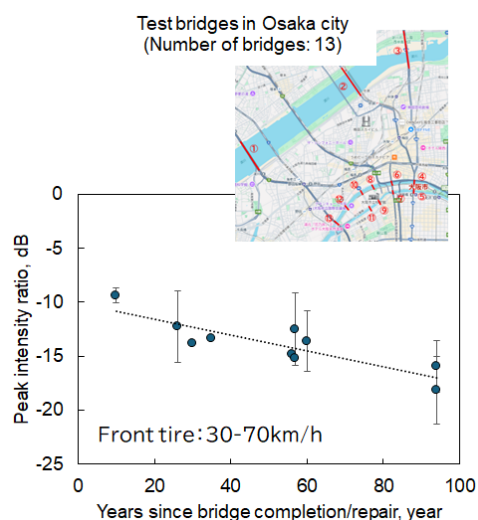


Fig.1 Peak intensity ratio dependence on time since the bridge's completion or repair.