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The nature frequency identification of tunnel lining based on the microtremor method

Yujing Jiang [a,*], Yang Gao [b], Xuezhen Wu [a,c]

[a] Graduate School of Engineering, Nagasaki University, Nagasaki 852-8521, Japan

[b] Key Laboratory of Structural Health Monitoring and Control, Shijiazhuang Tiedao University, Shijiazhuang 050043, China

[c] State Key Laboratory of Mining Disaster Prevention and Control Co-founded by Shandong Province and the Ministry of Science and Technology, Shandong University of Science and Technology, Qingdao 266510, China

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Abstract

Many tunnels all over the world have been in service for several decades, which require effective inspection methods to assess their health conditions. Microtremor, as a type of ambient vibration originating from natural or artificial oscillations without specific sources, has attracted more and more attentions in the recent study of the microtremor dynamic properties of concrete structures. In this study, the microtremors of the tunnel lining were simulated numerically based on the Distinct Element Method (DEM). The Power Spectra Density (PSD) of signals obtained from numerical simulations were calculated and the nature frequencies were identified using the peak-picking method. The influences of the rock-concrete joint, the rock type and the concrete type on the nature frequencies were also evaluated. The results of a comprehensive numerical analysis show that the nature frequencies lower than 100 Hz can be identified. As the bonding condition becomes worse, the nature frequencies decrease. The nature frequencies change proportionally with the normal stiffness of the rock-concrete joint. As the concrete grade decreases, the third mode of frequency also decreases gradually while the variation of the first two modes of frequencies can hardly be identified. Additionally, the field microtremor measurements of tunnel lining were also carried out to verify the numerical results.

Keywords: Tunnel lining; Frequency; Vibration intensity; Microtremor measurement; Numerical simulation

Introduction

Mountain tunnel structures are an important part of the road networks. To date, a great number of tunnels have been in service for more than 40 years and the persistent ageing of them causes many problems to the concrete linings, such as corrosion, buckling, fracturing, generation of internal voids and seepage induced by flaws (Malmgren, Nordlund, & Rolund, 2005). The deteriorations and damages of linings decrease the integrity of tunnels and subsequently affect the workability, serviceability and safety of tunnels (Aktan, Catbas, Grimmelsman, & Tsikos, 2000; Bhalla, Yang, Zhao, & Soh, 2005). Therefore, the maintenance of tunnel linings is essential to provide the required level of safety and serviceability to road users.

At present, the integrity of the mountain tunnel is commonly evaluated by using the ground penetrating radar (GPR) method, the ultrasonic method, the magnetic method, etc (Daniels, 2004; Jiles, 1990; Poranski, Greenawald, & Ham, 1996). However, only local information of the structure condition can be measured by highly-experienced operators, and the considerable time and cost are required to estimate the overall structural integrity in

* Corresponding author.
E-mail address: jiang@nagasaki-u.ac.jp (Y. Jiang).
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the most previous techniques (Park & Choi, 2008). Relatively, a more effective approach for evaluating the whole structural condition is to utilize the measured dynamic responses of a structural system to assess the physical properties of the structure (Choi, Park, Park, & Stubbs, 2006). There are two methods available for measuring the vibration response of a structure, including the forced vibration test and the ambient vibration test.

Unlike other structures, the mountain tunnels are subjected to rock-structure interaction of its surrounding rock masses. Hence, its dynamic behavior is controlled by the stiffness of the tunnel lining, the surrounding rock masses and the concrete-rock joints (Gao, Jiang, & Li, 2016; Wiehle, 1964). The forced vibration test is not applicable for the damage detection of large-scale structures, where the huge reaction mass shakers are necessary (Gao et al., 2016; Peeters, Maeck, & Roeck, 2001). With the development and application of the high sensitivity accelerometer, the low-cost ambient test has become the main test method for the structural damage identification. The ambient vibration measurement is a kind of output data-only dynamic testing and a modal analysis procedure is carried out based on the output data. Thus far, the ambient test has been applied to various types of structures including bridges (Magalhas, Cunha, & Cartano, 2009), buildings (Michel, Guéguen, & Bard, 2008), historical structures (Júlio, Rebelo, & Gouveia, 2008), and mechanical structures (Pierro, Mucchi, Soria, & Vecchio, 2008). Microtremor, as a type of ambient vibration originating from the natural or artificial oscillations without specific sources, has attracted lots of attentions in the recent study of the microtremor dynamic properties of concrete structures (Chatelain et al., 2000; Ikeda, Yoshitaka, & Yasutsugu, 2010; Tuladhar, Yamazaki, Warnitchai, & Saita, 2004). However, few attentions have been focused on the microtremor test on the damage identification of tunnel linings.

The occurrence of damage and deterioration in a structure causes changes in the nature frequencies of the structure. The most widely used parameter in dynamic tests is the predominant frequency due to that the nature frequency can be acquired conveniently. Especially in some large-scale civil structures, other model characteristics (e.g., the model shapes) would be economically unfeasible to measure. In this paper, the microtremors of the tunnel lining were simulated using the Distinct Element Method (DEM). The nature frequency of the concrete lining was identified from the acceleration data of ambient vibration. The influences of the rock-concrete joint, the rock type and the concrete type on the nature frequencies were also investigated. For the purpose of verification, a field test was also carried out.

The principle of microtremor method and simulation method based on distinct element

Comparing with theoretical and experimental studies, the numerical simulation provides a convenient and low-cost approach to study the dynamic problems of engineering, especially when theoretical solutions are difficult to be obtained. In this study, the tunnel was simplified as a plane strain model and the dynamic properties in the cross section were investigated. The numerical simulations were performed by using the DEM code of UDEC to investigate the microtremor vibration behavior of the tunnel lining.

In the old tunnels that were built using the poling-board method, shotcrete was not used and incomplete contact usually exist between the rock mass and the lining concrete. In numerical simulations, the unbonded contact can be simplified as weak joints with low normal and shear stiffness, which are treated as interfaces between distinct bodies (i.e., the discontinuity is treated as a boundary condition in the DEM) (UDEC, 2000). The Mohr-Coulomb model and Coulomb slip model were adopted to represent the mechanical behavior of rock masses and joints, respectively. Those types of elements can effectively simulate the dynamic deformational behavior of rock mass, lining concrete and joints. The shape and size of the numerical model are shown in Fig. 1. It is a semicircular arch with a radius of 4.5 m. The height of springing line is 2.5 m. The thickness of the concrete lining is 0.7 m. The physic-mechanical properties of the surrounding rock mass, lining concrete and concrete-rock joints are listed in Table 1, which are determined according to the typical properties of concrete and the laboratory tests on a kind of granite located in the Kyushu area, Japan. Since the microtremor will not cause the failure of the rock mass and lining concrete, the tensile strength, cohesion and friction angle

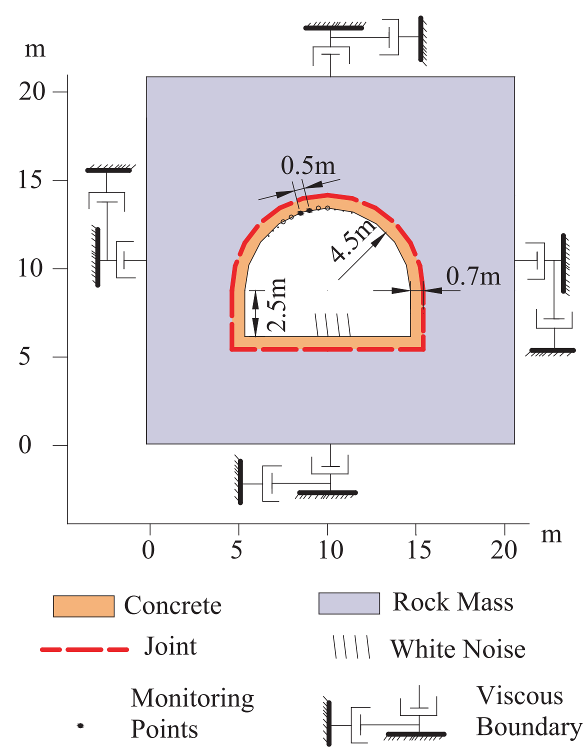

Fig. 1. Model of numerical simulation.