Research on Health Assessment Technique of Mountain Tunnel Lining Based on the Microtremor Method

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Japan is a country surrounded by sea and 70% of its land is covered by mountains. A large number of tunnels have been constructed during the last several decades. To date, a great number of tunnels have been in service for more than 50 years. The persistent ageing of tunnels causes many problems on the lining of tunnel, such as corrosion, spalling, fracturing, generation of internal voids and seepage. Deteriorations and damages of lining concrete decrease the integrity of tunnel lining and subsequently affect the workability, serviceability and safety reliability of tunnels. From the pioneering attempt on civil engineering structures in 1930s by Carder, the ambient test has attracted more and more attentions for assessing the health state of civil structures in operational conditions due to its easy testing & data understanding, low cost and multiple-input. Hereby, this dissertation mainly investigates the relationship between the tunnel lining healthy state and its vibration behaviors.

First of all, the vibration characters of tunnel lining shells built with poling-board method was analyzed based on the analytical solutions. Both the Love-Timoshenko shell theory and Donnell-Mushtari shell theory are adopted and extended to the elastic boundary conditions to analyze the vibration characters of tunnel lining, and the rock-concrete contacts were treated as elastic boundaries represented by the distributed springs. The void between concrete linings and rock masses was treated as the additional load and its influence on the natural frequency was estimated by the modal expansion approach. The validity and the accuracy of the proposed theory were verified by the numerical results of the Distinct Element Method (DEM) code of UDEC.

Secondly, the in-situ microtremor measurements were carried out on three spans of Satomi tunnel (the seriously damaged span S1, the moderately damaged span S2 and the healthy span S3). The microtremors were analyzed at the frequency domain (i.e., power spectral density (PSD)). The modal parameters including nature frequencies and damping ratios were extracted from the measured data. The relation between microtremor characteristics and the health conditions of tunnel was discussed. As an initial step, the in-situ measurements give clear evidence that the microtremor vibration characteristics have strong relation with the health conditions of lining concrete.

Moreover, a horse shoe shaped tunnel lining, of which the lining shape and the physico-mechanical properties of the surrounding rock mass and lining concrete are in accordance with the tested tunnel, was modeled by the code of UDEC to verify the in-situ measurements and to give a better understanding about the microtremor vibration behaviors. The relationship between the stiffness of rock-concrete interface and the peak frequency was analyzed. The influences of the voids and their geometrical parameters, rock type and concrete type on frequency response of tunnel lining were studied. The relationship between the peak frequency and the stress state of the tunnel lining were also discussed based on the numerical results.

A void delineation method based on the vibration intensity of microtremors was also discussed. In this method, the vibration modal parameters (natural frequencies, mode shapes and dampings) are unnecessary to obtain by the modal identification procedure. The mean values of PSD were adopted to represent the vibration intensity of microtremors. The vibration intensity ratios of the microtremors in different directions were analyzed. In the numerical simulations, not Gaussian while noise but the microtremors measured at the healthy span were chosen as far-field vibration sources. Influences of the properties of rock-concrete interfaces, the voids and their geometrical parameters, and the mechanical properties of rock and concrete on the vibration intensity ratio of tunnel linings were also studied.