IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Analysis of dynamic accumulative damage about the lining structure of high speed railway's tunnel based on ultrasonic testing technology

To cite this article: Xiang-qiu Wang *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **81** 012127

Analysis of dynamic accumulative damage about the lining structure of high speed railway's tunnel based on ultrasonic testing technology

Xiang-qiu Wang[1*], Huojun Zhang[1],Wen-xi Xie[1],

[1]Dept. of Traffic and Civil Engineering, Foshan University, 528000, Foshan, China

*Email: tongji_wxq@163.com

Abstract. Based on the similar material model test of full tunnel, the theory of elastic wave propagation and the testing technology of intelligent ultrasonic wave had been used to research the dynamic accumulative damage characteristics of tunnel's lining structure under the dynamic loads of high speed train. For the more, the dynamic damage variable of lining structure of high speed railway's tunnel was obtained. The results shown that the dynamic cumulative damage of lining structure increases nonlinearly with the times of cumulative vibration, the weakest part of dynamic cumulative damage is the arch foot of tunnel. Much more attention should be paid to the design and operation management of high speed railway's tunnel.

1.Introductions

As we know, the lining structure of high speed railway's tunnel will produce cumulative damage effect under the long term vibration loads of high speed train. It has great theoretical and practical significance that how to detect and analyze the dynamic damage of concrete lining structure under dynamic loads of high speed train. At present, the research on the detection and analysis of dynamic accumulative damage of lining structure of high speed railway's tunnel is still rare at home and abroad. However, the research on ultrasonic testing of ordinary concrete is more mature, and the representative researching works are mainly as follows: based on the impact test of concrete prism specimens, the stress-strain curves of concrete specimens with different degrees of damage were obtained by using the drop hammer impact testing machine, and the influence of the test parameters on the damage performance was analyzed, by TIAN Yubin [1]. The fire damage characteristics of concrete were analyzed and the suggestions for improving the accuracy of concrete damage detection after fire were put forward, by LU Zhou-dao [2]. Based on the ultrasonic test of concrete specimens, the relationship among the propagation characteristics of ultrasonic wave and the damage parameters of concrete was obtained, by WANG Huai-liang, LIAO Jiehong et al [3-6]. In this paper, the damage characteristics of lining structure of high speed railway's tunnel was analyzed by using the ultrasonic testing technology of concrete.

2. The theory of ultrasonic damage detection

According to the theory of damage mechanics, the elastic modulus is usually used to express the continuity and damage variable, The relationship among them can be expressed as:

$$\psi = \frac{\tilde{E}}{E} = 1 - D \tag{1}$$

IOP Conf. Series: Earth and Environmental Science **81** (2017) 012127 doi:10.1088/1755-1315/81/1/012127

In which, E is initial elastic modulus of material, $\widetilde{E}$ is elastic modulus of material after damage, ψ is continuity of material, D is damage variable of material.

According to the theory of elastic mechanics, when the concrete is undamaged, the velocity of longitudinal wave, can be shown as following:

$$v_P = \sqrt{\frac{E}{\rho}\frac{1-\mu}{(1+\mu)(1-2\mu)}} \tag{2}$$

In which, μ is Poisson ratio, ρ is specific gravity of material, and the meanings of other parameters are as shown before.

It is assumed that the elastic modulus of concrete reduce to the value of $\widetilde{E}$, when it has been damaged, the velocity of longitudinal wave can be shown as following:

$$\widetilde{v}_P = \sqrt{\frac{\widetilde{E}}{\rho}\frac{1-\mu}{(1+\mu)(1-2\mu)}} \tag{3}$$

Simultaneous (2) and formula (3), the relationship between $\widetilde{\upsilon}_p$ and υ_p can be obtained as following:

$$\frac{\widetilde{v}_P}{v_P} = \sqrt{\frac{\widetilde{E}}{E}} \tag{4}$$

If the formula (4) has been substituted into the formula (1) , according to the assumption of equivalent strain, the relationship among the damage variable and continuity can be obtained as followings as:

$$\psi = 1 - D = \frac{\widetilde{E}}{E} = \left(\frac{\widetilde{v}_P}{v_P}\right)^2 \tag{5}$$

The value of damage variable in formula (5) can be obtained by measuring the velocity of longitudinal wave of concrete.

3. Test of dynamic cumulative damage for tunnel's lining structure

In order to study the dynamic accumulative damage characteristics of the lining structure of high-speed railway's tunnel under the vibration load of train. According to the design size of a tunnel on the high speed railway from Wuhan to Guangzhou, the scaled model of tunnel was made by using the particle concrete, the maximum height of model is 1.34m, the maximum width of model is 1.20m, and the lining thickness of model is 0.10m (as shown in Fig.1). By using the hydraulic servo loading system of MTS, the test of dynamic damage was carried out under the vibration loads of high speed train, in the meantime, the intelligent ultrasonic testing instrument was used to measure the velocity of ultrasonic wave for feature points of model SC1-SC4 (as shown in Fig. 2).

Fig.1 Test model of full section tunnel

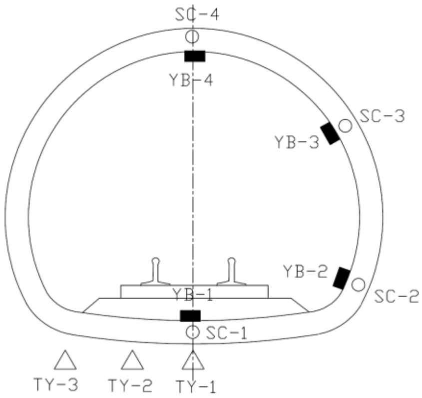


Fig.2 Points of ultrasonic detection

4.Analysis of dynamic cumulative damage

In the process of dynamic loading test, the ultrasonic velocity of feature points (SC1-SC4) ,which on the inverted arch, foot of arch, side wall and vault of tunnel are measured synchronously, and the attenuation law of ultrasonic wave velocity of feature points with the vibration times is shown in Fig.3. Based on the correlation between the changing rate of ultrasonic velocity and the damage variable of material, it can be seen that the accumulative damage of lining structure on the inverted arch, foot of arch, side wall and vault is similar. However, the cumulative damage of the inverted arch and the foot of arch is larger than that of the side wall and vault. This results are consistent with the results of theoretical analysis and engineering practice.

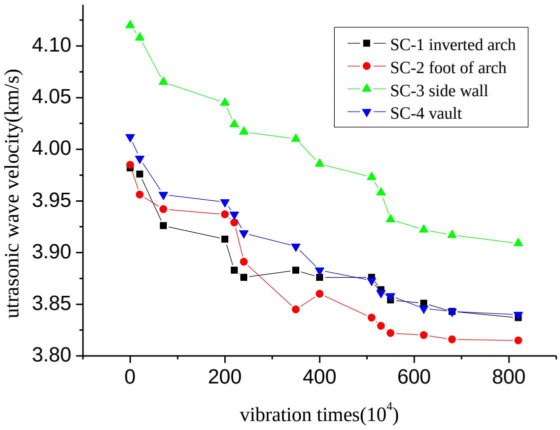
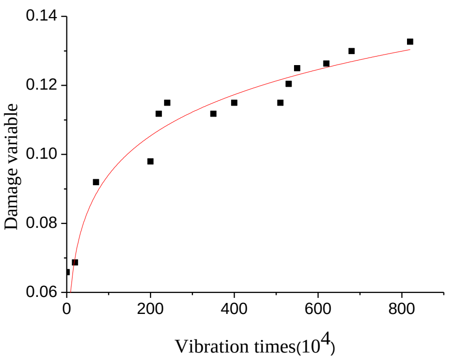


Fig.3 Variation trend of ultrasonic wave velocity

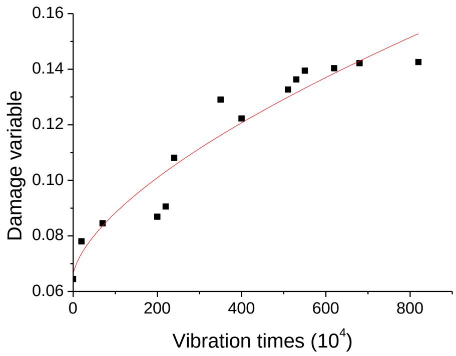
According to the ultrasonic test, the initial velocity of ultrasonic wave is 4.12km/s. Based on the testing data of ultrasonic wave for the lining structure of tunnel, the damage variable of feature points can be calculated by formula (5) and it has been shown in Tab.1. According to the calculated values of the dynamic damage variable of feature points under different vibration times, by using the fitting method of exponential function, the dynamic accumulation damage law of the lining structure can be obtained as shown in Fig. 4.

Tab.1 Calculation values of lining structure's damage

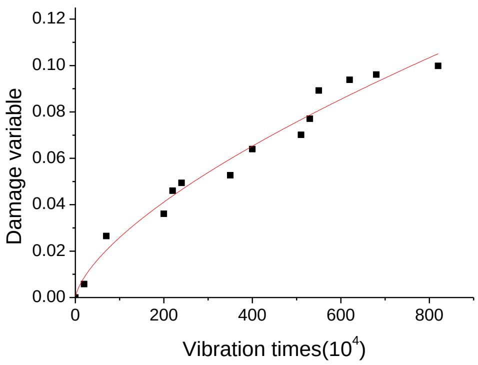
Vibration times (10^4)	SC-1(inverted arch)		SC-2(foot of arch)		SC-3(side wall)		SC-4(vault)	
	Wave velocity (km/s)	Damage variable	Wave velocity (km/s)	Damage variable	Wave velocity (km/s)	Damage variable	Wave velocity (km/s)	Damage variable
0	3.982	0.066	3.985	0.064	4.120	0.000	4.012	0.052
20	3.976	0.069	3.956	0.078	4.108	0.006	3.991	0.062
70	3.926	0.092	3.942	0.085	4.065	0.027	3.956	0.078
200	3.913	0.098	3.937	0.087	4.045	0.036	3.949	0.081
220	3.883	0.112	3.929	0.091	4.024	0.046	3.937	0.087
240	3.876	0.115	3.891	0.108	4.017	0.049	3.919	0.095
350	3.883	0.112	3.845	0.129	4.010	0.053	3.906	0.101
400	3.876	0.115	3.860	0.122	3.986	0.064	3.883	0.112
510	3.876	0.115	3.837	0.133	3.973	0.070	3.873	0.116
530	3.864	0.120	3.829	0.136	3.958	0.077	3.861	0.122
550	3.854	0.125	3.822	0.139	3.932	0.089	3.858	0.123
620	3.851	0.126	3.820	0.140	3.922	0.094	3.846	0.129
680	3.843	0.130	3.816	0.142	3.917	0.096	3.843	0.130
820	3.837	0.133	3.815	0.143	3.909	0.100	3.840	0.131



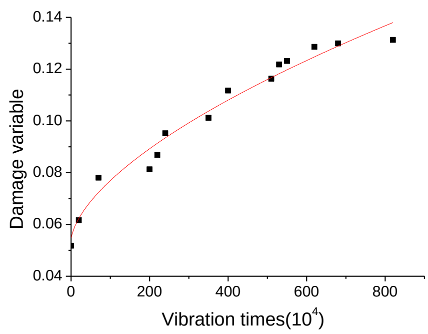
a） SC1- inverted arch



b） SC2 -foot of arch



c） SC3 -side wall



d） SC4 - vault

Fig.4 Fitting curves of damage variable for lining structure

It can be seen from Fig.4, the dynamic cumulative damage variable of the tunnel's lining structure has similar changing law. With the increasing of vibration times, the damage variable increases nonlinearly, but the degree of dynamic damage of feature points is different. When the cumulative times of vibration up to 8,200 thousand times, the damage variable of the foot of arch achieves 0.143, value of the inverted arch and vault is about 0.130, but the damage variable of the side wall is only 0.10. Based on those results, the foot of arch is regard as the weakest part of dynamic accumulation damage on the whole section of tunnel, and much more attention should be paid to the design and operation management of the high-speed railway's tunnel.

5.Conclusions

Based on the model test of tunnel with full section and the detection method of intelligent ultrasonic wave, the dynamic cumulative damage characteristics of concrete lining structure can be researched effectively, under the vibration loads of high speed train.

Dynamic cumulative damage of the lining structure of high-speed railway's tunnel increases nonlinearly with the times of cumulative vibration of high-speed train. The degree of dynamic damage in different parts of the lining structure is not the same, and the foot of arch is the weakest part of tunnel.

If only consider the effect of vibration loads in operation period of high speed railway, the damage failure of tunnel's lining structure will not be occurred. If there are cracks of initial damage and coupled with the action of groundwater pressure, the dynamic damage could not be ignored ,which induced by the vibration loads of high speed train.

Acknowledgements

This work was financially supported by the project of National Natural Science Fund(51278121) and the major project of Guangdong province (2014KTSCX155).

References

[1] TIAN Yubin, HUANG Tao, LIU Jia,2014. Damage detection and compressive behavior of concrete after impacting. *Journal of Building Structures*, **35(S1)** 58-64.

[2] LU Zhoudao, YU Jiangtao, Li Cancan,2006. Discussion on detection of damaged concrete after fire. *Industrial Construction*, **36(1)** 88-90.

[3] LIAO Jiehong, LU Zhoudao,YU Jiangtao,2012. Ultrasonic test on damage of concrete members under cyclic loading. *Structural Engineers*, **28(5)** 149-153.

[4] WANG Huailiang, SONG Yupu,2007. Ultrasonic pulses behavior in various-size concrete specimens under compression. *Journal of Dalian University of Technology*, **47(1)** 90-94.

[5] Nogueira, Carnot L,Willam Kaspar J,2001. Ultrasonic testing of damage in concrete under uniaxial compression. *ACI Materials Journal*, **98(3)** 265-275.

[6] LI Gang, CHEN Zheng-han, XIE Yun,2007. New tri-axial test equipment combined with ultrasonic apparatus and its application. *Chinese Journal of Geotechnical Engineering*,**29(5)** 657-663.