Predictive maintenance of tunnels based on real-time acceleration registers on the concrete revetment

Fran Ribes Llario[1], Clara Zamorano Martín[2], Beatriz Baydal Ginerl[3], José Luis Velarte González[4]*

[1, 3, 4] Institute of Multidisciplinary Mathematics, Polytechnic University of Valencia, Camino de Vera, 46022 Valencia, Spain

[2] Universidad Politécnica de Madrid. Calle Ramiro de Maeztu, 7, 28040 Madrid

**Corresponding author. E-mail: frarilla@cam.upv.es. Telephone: +349638770000*

Properly scheduling maintenance and conservation tasks of a tunnel is a matter of utmost importance in order to ensure its adequate functioning, safety and reliability. In this regard, the most usual maintenance strategy is preventive maintenance, where cyclic conservation tasks are scheduled based on the analysis of historical repair data [1]. However, such approach cannot prevent unexpected system failures and generally implies unnecessary maintenance, since it does not take into account the current health state of the structure, which considerably increases maintenance costs. On the other hand, corrective maintenance is another widely used strategy, where the scheduling of repair and conservation tasks is done after a failure has been detected. Such technique usually involves significant costs and reduces the capacity of the infrastructure, since major repair tasks may be expensive and even require the closure of the tunnel.

Therefore, with the aim of overcoming the drawbacks of the aforementioned methodologies, predictive maintenance arises as a more efficient technique accounting for the real-time health state of the structure. It consists of a continuous monitoring of the tunnel, which allows to evaluate its health state and thus the need of maintenance before the occurrence of a failure. Furthermore, it should be taken into account that the conservation of the concrete revetment is one of the most important tasks among those composing tunnel maintenance, since this region of the structure is more vulnerable to critical failures [2].

In this regard, a methodology has been developed within this research project for the predictive maintenance of tunnels based on acceleration registers measured on the concrete revetment of the structure. For this purpose, tri-axial accelerometers should be placed on the most vulnerable locations (to be determined depending on the typology of the tunnel section) of each instrumented section. Then, the time history of accelerations is transformed into the frequency domain by means of a discrete form of the Fast Fourier Transform (FFT, see eq.(1)) and the *peak picking method* can be applied.

$$x(\omega)=\sum_{r=1}^{n}x(t)\cdot e^{\frac{2\pi i(r-1)(s-1)}{n}} \tag{1}$$

Where coefficients r and s vary from 1 to n; and n is the total number of points in the data series. Once in the frequency domain, a low-pass filtering of the signal is performed with the aim of removing high frequencies out of the range of interest (0 – 100 Hz).

The next step is the application of the *peak picking method*, a technique based on the hypothesis that the dynamic response of the resonance peaks is determined by a single mode, which is valid for low damping structures (*e.g.*, concrete) and sufficiently separated modes [3]. Hence, the Power Spectrum Density (PSD) is obtained from the data series in the frequency domain and the average normalized PSD value (ANPSD) is calculated for every instrumented section of the tunnel. According to the method, if a variation is detected on the first frequency peak of a certain tunnel section, it can be concluded that such section presents damage.

Once the damaged sections have been identified, the PSD ratio (RPSD) is calculated, which permits the classification of the damage into four different categories depending of its variation: i) no defect if the variation is close to zero; ii) presence of cavities or lack of thickness if it is constantly negative; iii) perimeter crack if it is constantly positive; and iv) radial crack if the variation does not present a clear trend and oscillates around zero.

Finally, the location and magnitude of the damage can be determined by comparing the acceleration measurements on the studied section with the results provided by a 2D Distinct Element Method (DEM) numerical model. To this aim, a variety of cases comprising different damage typologies, magnitudes and positions should be executed and analysed prior to the implementation of the method, thus creating a wide damage catalogue valid for any section of the tunnel.

Such numerical technique considers materials as a group of individual particles, thus permitting independent displacements and rotations of each one, as well as the occurrence of new contacts/loss of contact between them. Therefore, it constitutes an excellent tool for the numerical modelling of cases where discontinuities appear on the material as a consequence of the deformation process. The Mohr-Coulomb criteria and the Coulomb sliding criteria have been adopted for the modelling of the mechanical behaviour of the rock and the rock-revetment interface, respectively. Moreover, a Rayleigh damping coefficient of 1-2% and viscous boundary conditions have been considered in order to accurately reproduce real materials and avoid boundary reflections.

References

[1] Lee, D. and Pan, R. Predictive maintenance of complex system with multi-level reliability structure. International Journal of Production Research, 2017: p. 1-17.

[2] Yuan, Y., Jiang, X., and Liu, X. Predictive maintenance of shield tunnels. Tunnelling and Underground Space Technology, 2013. 38: p. 69 - 86.

[3] Freire, C. Implementación y validación del método mejorado de descomposición en el dominio de la frecuencia (EFDD) para la identificación de los parámetros modales de estructuras genéricas utilizando ruido ambiente. Estudio del rango de aplicabilidad en función del modelo estructural y las condiciones de uso, 2011, Universidad de Las Palmas de Gran Canaria: Spain.