Effects of long-term time-dependent behaviour on dynamic properties of cable-stayed bridges

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Cable-stayed bridges have become very popular over the last four decades not only because of their structural efficiency but also their aesthetic appearance. Structural health monitoring systems are often installed on such bridges to provide the necessary data for engineers to evaluate their integrity, durability and reliability through the observation of changes in bridge properties caused by any damage or deterioration. However, the time-dependent behaviour of construction materials such as concrete and steel cables also causes changes in structural characteristics. If these are not taken into account properly, false positive or false negative alarms may result. So it is necessary to investigate these long-term effects on the structural characteristics of cable-stayed bridges.

This paper presents a systematic and efficient method to study the effects of long-term time-dependent behaviour due to concrete creep, concrete shrinkage and cable relaxation on the dynamic properties of cable-stayed bridges.

The finite element model of a cable-stayed concrete bridge is built up by a combination of Bernoulli-Euler beam elements for the bridge girders and towers, and truss elements with equivalent Ernst moludi for the stay cables (Curley and Shepherd, 1996; Au et al., 2001) to account for cable sag. The geometric nonlinearities are considered by adopting the geometric stiffness matrix of each element (McGuire et al., 2002) to modify its elastic stiffness matrix. The resulting total stiffness matrix is an efficient way to take into account the “P-delta effect”.

The equivalent creep coefficient is introduced to establish the *relaxation-adjusted elasticity modulus* for each cable (Si et al., 2009). Then an efficient single-step finite element method is adopted for analysis of long-term time-dependent behaviour of the cable-stayed bridge using the *age-adjusted elasticity modulus* (Ghali et al., 2002) and *shrinkage-adjusted elasticity modulus* (Au et al., 2007) for concrete and the *relaxation-adjusted elasticity modulus* for cables.

With the updated internal forces from long-term analysis and geometric nonlinearity of the bridge members properly taken into account, the necessary element stiffness matrices and mass matrices can be calculated using the instantaneous moduli of elasticity. After building up the global stiffness matrix and the global consistent mass matrix, free vibration analysis of the cable-stayed bridge is carried out using the subspace iteration method (Cook et al., 2001).

Numerical examples are presented to illustrate the application of the proposed method as well as to investigate the behaviour of typical cable-stayed concrete bridges. Results from these investigations show that the natural frequencies, whether accounting for geometric effects or not, increase with time due to concrete ageing effect alone, its interaction with creep and shrinkage of concrete, and cable relaxation, or their combined effects. However the natural frequencies tend to decrease slightly with time when cable relaxation is considered alone. These results also indicate that concrete ageing has the most important influence on the dynamic properties among various time-varying factors. The
interaction between concrete ageing effect and effect of concrete creep, cable relaxation or their combined effect are greater than their individual effects. The interaction between ageing effect and concrete shrinkage is negligible. Hence the interaction among time-varying factors should be considered carefully during long-term dynamic analysis of concrete structures. Besides, the effect of time-dependent behaviour on dynamic properties varies from mode to mode. Therefore, the long-term dynamic characteristics due to time-dependent behaviour should be investigated in detail in order to ensure reliable damage identification in vibration-based structural health monitoring systems.

References