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Accurate time-dependent analysis of concrete bridges considering concrete creep, concrete shrinkage and cable relaxation

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ABSTRACT

This paper proposes a new relaxation model for steel tendons based on the equivalent creep coefficient to enable the accurate estimation of losses of cable forces. The equivalent creep coefficient works not only in the case of intrinsic relaxation but also under various boundary conditions. Based on the proposed relaxation model, an accurate finite element analysis of the time-dependent behavior of concrete bridges considering concrete creep, concrete shrinkage and cable relaxation is devised based on the time integration method. Concrete members are modeled by beam elements while tendons are modeled by truss elements with nodes connected to the beam axis by perpendicular rigid arms. Then the individual and combined effects of concrete creep, concrete shrinkage and cable relaxation on the long-term performance of concrete structures are investigated. It is found that the proposed relaxation model and time integration method can provide a reliable method for time-dependent analysis. The numerical results obtained indicate that the interactions among these factors should be considered carefully in analyzing the long-term performance of concrete bridges.

1. Introduction

A long time has elapsed since the first observation of concrete shrinkage and the discovery of concrete creep [1]. Since then, engineers and researchers have been aware of the time-dependent behavior of concrete structures [2–4], and steel–concrete composite structures [5,6] because the creep and shrinkage of concrete and the relaxation of cables interact with one another during the construction and service stages, resulting in additional deflections, cracking, reduction of prestress and redistribution of internal forces, which in turn affect the long-term structural performance. Therefore the time-dependent effects are significant considerations for serviceability limit states under which deflections, stresses and crack widths should be limited [7–10].

A reliable method for time-dependent analysis of concrete structures is the finite element method combined with time integration [11]. In the method, the concrete members are usually modeled by frame elements and the tendons are treated as truss elements connected to the structural nodes with rigid arms [12–15]. In the time-dependent analysis of prestressed concrete structures, the interactions among concrete creep, concrete shrinkage and cable relaxation are often considered approximately by introducing relaxation reduction coefficients taken from charts or tables [16–18]. It is therefore desirable to develop better methods for modeling the interaction between cable relaxation and other sources of time-dependent deformations.

This paper first introduces a convenient technique to model curved tendons using rigid arms. Then a new equivalent stress relaxation model for steel tendons is developed. An accurate finite element method is then devised for accurate time-dependent analysis of concrete structures with time integration taking into account all three time-varying factors. Numerical investigations are then carried out to demonstrate the versatility of the proposed method.

2. Modeling of tendons using rigid arms connected to a beam

The common assumptions for analysis of concrete girder bridges are made. The concrete, steel reinforcement and steel cables are modeled separately, ignoring their interaction within the element. It is also assumed that plane sections remain plane after bending. The present analysis is mainly for the time-dependent behavior under working conditions before any cracks are formed. The tendons are assumed to be perfectly bonded to the structural concrete members. Each tendon of an arbitrary shape is modeled by a series of truss elements with nodes connected to the beam axis by perpendicular rigid arms [12,14]. However, to avoid an unduly large number of degrees of freedom (DOFs) for curved tendons, the rigid arms are modeled by the master–slave transformation technique rather than using physical nodes.

Fig. 1 shows a spatial beam elements 1–2 of length L_c aligned with the beam axis and a spatial tendon element a–b of true

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