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In-situ methods to determine residual prestress forces in concrete bridges

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ABSTRACT

Levels of residual prestress forces are key parameters when assessing the structural behaviour of existing prestressed concrete bridges. However, these parameters are often unknown and not easy to determine. To explore them, two existing non-destructive and destructive approaches have been further developed for practical application and demonstrated on a multi-span continuous girder bridge. The evaluation of the prestress forces was part of an extensive experimental programme aimed to calibrate and develop assessment methods. Due to the pursuit of practical applications for existing bridges, the main focus was on non-destructive methodology, combining experimental data and finite element modelling to obtain the residual prestress forces. Assuming that the initial prestress force corresponded to 85% of the characteristic 0.2% proof strength of the reinforcing steel, estimated losses in investigated sections ranged between 5 and 70%. However, determined residual prestress forces were generally higher than theoretically based estimates accounting for friction and time-dependent losses in the prestressing system. In addition to describing in detail the methods for prestress evaluation, this paper presents suggestions for improvements and further studies, based on experiences from the field tests.

1. Introduction

Accurate determination of residual prestress forces is essential in assessments of existing prestressed concrete bridges because they strongly influence their responses and capacities at both serviceability and ultimate limit states. In addition to stiffening, prestressing reduces exposure and thus increases resistance of such structures in aggressive environments by preventing cracks or limiting their growth.

Several studies, e.g. [1–4], on existing prestressed concrete elements taken out of service have found appreciable deviation between measured prestress losses and losses predicted by models provided in codes. However, others [5,6] have reported good agreement between predicted and empirically determined losses. All of the cited studies focused on members that had been in service between 25 and 40 years. Furthermore, an investigation of 30 full-scale, prestressed girders during the first three years after casting showed that most prestress losses occurred during the first four months, and code-based predictions generally agreed well with the test results, although they were very conservative in some cases [7]. Thus, there are clearly difficulties in determining residual prestress forces using code models. These difficulties are related to factors including (*inter alia*) assumptions about the properties of the prestressing system and time-dependent phenomena, such as steel relaxation, both shrinkage and creep of concrete and also degradation processes [1–7]. Uncertainties associated to the prestressing system have for several bridges even yielded in collapse of the structure [8,9].

Although there are uncertainties in code models, leading to deviations from reality, few empirical methods are available to assess the actual condition of prestressing systems, and their applicability in complex conditions may not have been confirmed. Examples of destructive methods are moment, decompression load and strand-cutting tests [5]. In a cracking moment test (Fig. 1a) the external load causing the first crack to appear in a member is determined and used to calculate the prestress force. Several techniques can be used for this [7], but the results may be inaccurate due to uncertainties about the tested member's tensile properties. In decompression load tests (Fig. 1b), regarded as generally more accurate, an existing crack is monitored under repeated loading and the load causing reopening is used to calculate the prestress force [7]. In a strand-cutting test a strand is exposed then a strain gauge is installed and used to measure strains that develop when the strand is cut (Fig. 1c). The corresponding prestress force in the strand can then be determined.

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Nomenclature

Notations

A	cross-section area
E_c	concrete modulus of elasticity
I	second moment of inertia
P	prestress force
P_0	prestress force in the active tendon end before anchorage
P_x	prestress force taking into account prestress losses due to friction
M_G	moment due to dead load
M_R	secondary moment due to restraint forces
M_Q	moment due to external load
e	natural logarithm (2.71)
e_P	eccentricity of the prestress force
$f_{p0.2k}$	characteristic value of the reinforcing steel 0.2% proof strength
f_{tk}	characteristic value of the reinforcing steel tensile strength
k	friction coefficient due to unintended angle change (wobble)
x	distance from the tendon end of the section for prestress force determination
y	position of the neutral axis
α	cumulative angle change
ε_{cr}	creep strain
μ	friction coefficient due to intended curvature
φ	creep coefficient
σ	stress

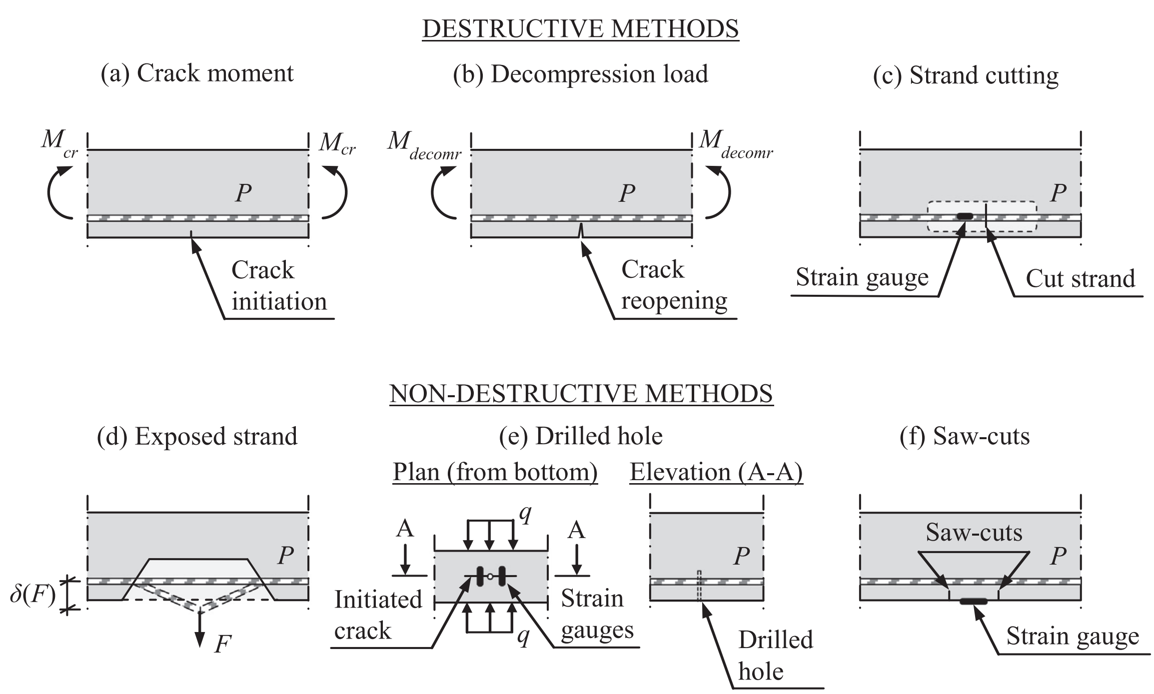

Fig. 1. Methods to determine residual prestress force P.

As the destructive approaches inevitably cause damage they are not suitable for application to bridges in service, consequently non-destructive approaches have also been developed. For exposed strands (Fig. 1d) the residual prestress forces can be derived by comparing responses to lateral forces applied to the strands with calibration data [10]. The drawbacks of this method are the needs for exposed strands in the structure and calibration data covering the specific conditions (for instance, the strand's dimensions, type and exposed length). For embedded strands, measurements of stresses around a drilled hole (Fig. 1e) adjacent to the prestressed reinforcement can be used to quantify the residual prestress forces [1]. Another method is to calculate prestress force from responses of a concrete block isolated from the force by introducing saw-cuts (Fig. 1f) in the member's concrete cover adjacent to the prestressed reinforcement [11]. These methods can be regarded as non-destructive as they have negligible impact on the structure, provided local damage they cause is properly repaired. The two approaches that do not require exposed strands—measuring stresses around a drilled hole and isolating a concrete block (Fig. 1e and f)—have only been applied to, and confirmed for, relatively simple members (in terms of support conditions, member geometry and prestressed reinforcement) in controlled environments. Thus, none of the mentioned non-destructive testing methods have been applied to continuous members reinforced with parabolic post-tensioned cables. There are also some other techniques that require installation of monitoring equipment before casting, but they are very rarely utilized in bridges and thus can rarely be used for assessment.

Clearly, there is a need to develop rigorous practical approaches for in-situ quantification of residual prestressed forces in concrete bridges due to the importance of prestressing in a proper assessment of the structural behaviour [12]. Thus, both destructive