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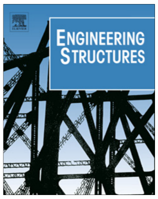

Anchorage and residual bond characteristics of 7-wire strand

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ABSTRACT

The periodic assessment of our existing concrete infrastructure is a crucial part of maintaining appropriate levels of public safety over long periods of time. It is important that realistic predictions of the capacity of existing structures can be made in order to avoid unnecessary and expensive intervention work. Assessment is currently undertaken using codified models that are generally readily applied to infrastructure with simple geometric and reinforcement details that conform to design methods for new structures.

This approach presents two significant challenges for prestressed structures: (1) design and construction practice has changed significantly in the past 50 years, and modern codified approaches can be incompatible with historic structures; and (2) deterioration of exposed soffits can lead to reduced cover to internal prestressing strand. Unless appropriate reductions are used in assessment of a structure with such problems, unnecessary load restrictions, or major strengthening or reconstruction work may be required, despite having carried a full service load since its construction.

There are currently no widely accepted methods for the prediction of peak and residual capacities in prestressed concrete beams with inadequately detailed 7-wire strand. This paper presents a completely new prediction methodology, validated against new experimental results from 31 novel semi-beam tests. The proposed models for peak load, residual load, and bond stress-slip modelling provide reliable, accurate, and conservative results. Their results demonstrate feasible and appropriate capacity reduction factors for use in the assessment of existing concrete infrastructure.

1. Introduction

The periodic assessment of existing infrastructure is crucial to maintain appropriate levels of safety over long periods of time. Changes in loading, material properties, design, detailing, and construction practices mean that some infrastructure, when assessed today, is deemed to be structurally inadequate. Assessment methods that can properly and accurately predict the behaviour of such structures are therefore crucially important to avoid unnecessary and expensive reconstruction works.

Road infrastructure provides a crucial economic pathway, and trunk route road closures have significant economic impacts. Minimising closures to bridges and other infrastructure for repair can therefore provide economic benefits. In the USA, 67,000 (11%) of bridges have been deemed as structurally deficient with load restrictions or closures, and the ASCE estimates $76 billion is required for their repair or replacement [1]. In the UK road infrastructure investment of £15 billion is already planned for the period to 2021 [2]. Such levels of repair and refurbishment are significant, and must be supported by the provision of appropriate assessment methodologies.

1.1. Half joint bridges

Half joints (Fig. 1) have historically been used to simplify the design and construction of bridges. However, due to inspection, construction, and maintenance problems with such designs BD 57 [3] cl.2.2 now notes that half joints should not be used for new bridges unless there is absolutely no alternative. The structural assessment of structures containing half-joints at the serviceability and ultimate limit states in the UK is undertaken using strut and tie models in accordance with BD 44 [4] and BA 39 [5]. Such approaches are readily applicable to cases with simple geometric and reinforcement detailing and when the reinforcement is appropriately anchored.

If reinforcement in existing structures does not provide theoretically sufficient anchorage to be fully utilised in a strut and tie model, reduction factors are applied by the assessing engineer. Common issues where this may arise include (1) loss of cover

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Nomenclature

Notation

ø	nominal strand diameter (mm)
d	effective depth to flexural reinforcement (mm)
c	cover to strand (mm)
b	breadth (mm)
L	length (mm)
δ_1	modification factor accounting for reduced cover
δ_2	modification factor accounting for confinement from cover and/or transverse reinforcement
δ_3	modification factor accounting for confinement from transverse reinforcement
δ_4	modification factor accounting for confinement from cover
F	force (N)
σ_{pd}	strand stress (MPa)
A_{ps}	cross sectional area of strand (mm^2)
l_{bpd}	total anchorage length for anchoring a tendon with stress σ_{pd} (mm)
l_{pt2}	120% of the basic transmission length (mm)
σ_{pd}	prestress after all losses (MPa)
σ_{pm0}	tendon stress just after release (MPa)
f_{bpd}	bond strength of the concrete at the test date (MPa)
f_{bpt}	bond stress at transfer (MPa)
$f_{ctd(t)}$	axial tensile strength of the concrete at release (MPa)
f_{ctd}	axial tensile strength of the concrete (MPa)
$f_{ctm(te)}$	mean axial tensile strength at the test date (MPa)
$f_{ctm(tr)}$	mean axial tensile strength measured at transfer
$\tau_{b,\max}$	maximum value of bond stress (MPa)
s	slip (relative displacement of strand and concrete) (mm)
L_b	bonded length (mm)
R_m	strand tensile strength (MPa)

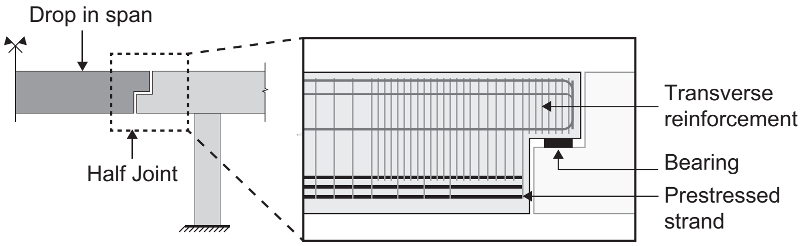

Fig. 1. Half joint bridges.

due to environmental deterioration; (2) inadequate cover from design detailing; and (3) transverse reinforcement that does not enclose longitudinal reinforcement. A modern assessment of a structure with such problems, which may have carried the full service load since its construction, could lead to load restrictions, strengthening or reconstruction work, if realistic and appropriate assessment methods, including consideration of reliability and reduction factors, are not known and used.

Some half joint bridges assessed using BD 44 [4] and BA 39 [5] have recently been rated as provisionally substandard. Although such bridges are now being traffic managed using BD 79 [6], they had previously been carrying unrestricted traffic loading since their construction in the 1970s.

This paper investigates the effect of loss of cover on bond, peak load, and residual behaviour for specimens with 7-wire strand as flexural reinforcement. A series of semi-beam pull out tests were undertaken utilising both unstressed and pretensioned strand to develop new guidance on appropriate reduction factors for the assessment of half-joint bridges and, in general, prestressed concrete elements containing theoretically inadequate 7-wire strand detailing.

2. Bond and anchorage

2.1. Bond tests

Tests are required to determine the bond characteristics of concrete reinforcement in order to effectively predict required transmission (transfer) and anchorage (development) lengths. Simple cube pull out tests are commonly used (see for example RILEM [7] and ASTM [8] methods) and considerable data for these exists [9–12]. Such tests, however, provide very localised data over small bonded lengths. BS 4449 [13] overcomes this limitation through the use of a half-beam test setup, similar to the ‘beam end test’ of ASTM A944 [14].

A simplification of the half-beam test method was proposed by Perera et al. [15] in which one half of the specimen is tested, whilst retaining the correct state of stress in the end zone. This approach has numerous advantages, including a simpler test set up, and the ability to keep the bar straight rather than deforming it under loading. This method was adopted in this paper for testing unstressed specimens (Fig. 4).

2.2. Strand bond

2.2.1. Unstressed strand

The majority of previous studies of bond of prestressing strand, has been on unstressed samples. Unstressed 7-wire strand achieves bond with the surrounding concrete through adhesion and mechanical interlock. Once slip occurs, adhesion is no longer present and bond will therefore rely only on the mechanical interlock provided by the helical shape of the strand. Unlike for plain and deformed passive reinforcement [16], there is no well-established bond stress-slip model for prestressing strand, yet such a model is crucial for the realistic assessment of existing structures.

To determine the bond-slip performance of steel wire strand, Moustafa [17] developed a pull out test in which multiple strands are pulled from a large concrete block, while the Post-Tensioning Institute (PTI) Bond Test uses a single strand pulled from a cement mortar cylinder. The North American Strand Producers (NASP)