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The effect of local reinforcing bar reductions and anchorage zone cracking on the load capacity of RC half-joints

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ABSTRACT

Half-joint beams, also referred to as dapped-end beams, have been the subject of several studies, primarily focussing on the design optimisation of new reinforced concrete beams and bridge decks. Existing half-joint structures, however, often show signs of deterioration and can exhibit improper reinforcement detailing. In order to gain a better insight into the impact of local corrosion, anchorage cracking, limited amounts of provided shear reinforcement, and improper reinforcement detailing, a test program was designed. Full-scale tests on nine half-joint beams were performed.

The results of the study show that even though the impact of an individual shortcoming on the load carrying capacity of reinforced concrete half-joint beams might not be substantial, inspectors and assessors should pay attention to the possibility of combined effects. When multiple deterioration processes are noted and/or questions are raised with respect to the reinforcement detailing, the impact on the load carrying capacity of the beam might be larger than the linear combination of the individual effects.

1. Introduction

The design of bridges incorporating half-joints (also known as dapped end beams) is characterised by local reductions in the overall depth of the beam at the supports as shown in Fig. 1. Half joints were particularly popular in the UK in the 1960s and 1970s, leading to over 400 concrete bridges with this type of joint being built on the existing UK Highways England network [1,2]. The main reason for their popularity was that the structural form was suitable for pre-cast bridge construction [3]. In addition, an overall reduced construction depth was achieved with a level running surface along the bridge deck and the support spans.

However, the design configuration of half-joints has certain disadvantages. One of the most commonly reported issues is linked to the water tightness of the joint itself [4,5]. In most bridges that are inspected, the water tightness is not fully achieved leading to seepage of chloride-rich water on to the nibs of the half-joint. Due to the half-joint layout, this water can stagnate on the lower nib of the joint creating a beneficial environment for corrosion.

Nicholas [6] reported the inspection details for two reinforced concrete half-joint bridges in Australia. In both bridges, severe signs of deterioration were noted. In the first bridge, a lack of water tightness in the small movement joints (and hence seepage onto the steel bearings and spreader plates) led to severe corrosion of the bearings and surrounding concrete. In the second bridge, cracks were noted in the concrete on both the upper and lower half-joint nibs. These cracks were partly attributed to the improper placement of the bearings and partly to reinforcement corrosion. In both cases, extensive interventions were required to repair the bridges. Similar problems were reported by Santhanam [7] in a bridge inspected in New South Wales where all the half-joint beams located on the outside of the bridge showed visible signs of cracking and water ingress.

The corrosion of the nib reinforcement can sometimes be severe as shown by Smith [8]. During the refurbishment of the old Medway Bridge in the UK, inspections revealed reinforcement section losses of up to 50% for the front-face hanger reinforcement. In addition, some bars showed insufficient anchorage and poor reinforcement detailing. However, it should be emphasized that despite these shortcomings no visible signs of distress were noted by Smith [8].

One of the most well-known examples of a bridge designed with half-joints is de la Concorde Overpass in Quebec (Canada). In 2006, the overpass collapsed killing five people [9]. The investigation following the collapse revealed that the bridge had collapsed due to the simultaneous occurrence of a number of different aspects, where none of these on their own would have led to the collapse [10]. Some of the contributing factors were

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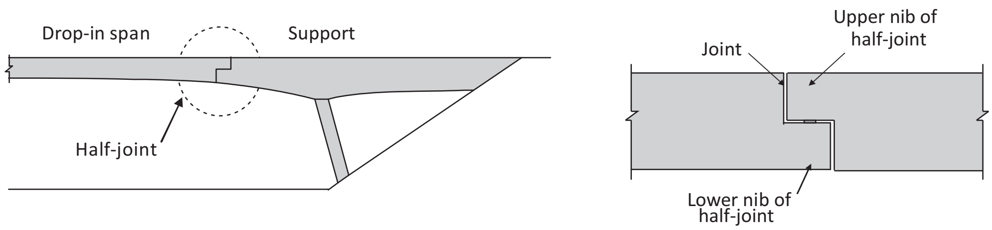

Fig. 1. Half-joint principle for reinforced concrete bridges.

the misalignment of certain reinforcing bars, improper repair methods and crack initiation due to deterioration along the top reinforcing bars.

Given the vulnerability of half-joints to deterioration, the development of maintenance strategies for half-joints is further hampered by the difficulty in inspecting half-joints due to limited access [7,11]. The only faces available for inspection are the outer vertical faces. The interior and transverse vertical faces can either be inaccessible or only conducive to limited access e.g. using snake eye cameras.

Limited guidance is available for the assessment of concrete half-joints [1,2,12]. These documents mainly relate to the effects of corrosion and crack widths. Fib bulletin 10 [13] identifies three different effects caused by corrosion: a reduction in the steel reinforcement bar diameter, the formation of a weak layer of corrosion products between the reinforcing bar and surrounding concrete, and cracking of the concrete surrounding the reinforcing bar. Both the weak layer at the concrete-steel interface and concrete cracking (due to the expansive nature of the corrosion products) result in a reduction in bond strength.

BA51 [14] provides guidance on the assessment of concrete structures affected by steel corrosion. A distinction is made between local and general corrosion. In the case of local corrosion, the steel section loss is identified as the main consequence. Assessors are advised to ignore locally corroded steel flexural and shear reinforcement which should be assumed to have no strength. Due to a reduction in ductility, these bars should also not be considered effective in plastic analyses. In addition, BA38 [15] points out that a reduction in fatigue life can be expected in reinforcing bars with deep pits caused by corrosion.

General corrosion often leads to only minor reductions in the bar cross-sectional area. In BA51 [14] it is advised, in cases where significant reductions are noticed, to account for general corrosion in a manner similar to local corrosion. However, the main effect of general corrosion tends to be the loss of bond strength due to the appearance of cracks along the bars. In this case, it is advised to reduce the bond strength of reinforcing bars associated with longitudinal cracks by 30%. In cases where spalling or delamination has occurred, the bond with the bars in the plane of delamination should be ignored. A reduction in fatigue life is less of a concern for general corrosion cases [15].

BA39 [16] specifically addresses the assessment of reinforced concrete half-joints. A distinction is made between serviceability checks (which are mainly based on crack width control) and ultimate limit state calculations which take into account actual reinforcement layouts. The guideline addresses deterioration effects by accounting for the loss of the cross-sectional area of reinforcing bars when evidence of corrosion is present. Specific reference is made to BD38 [15] when fatigue checks are required. However, a possible reduction in anchorage capacity due to corrosion is not explicitly addressed.

As design codes and standards are developed primarily for new construction, assessors of existing structures have to rely on the documents such as those previously mentioned to obtain guidance about how to account for corroded reinforcing bars in existing reinforced concrete structures. Although extremely useful, these documents have been developed based on a limited amount of data. Furthermore, none of the guidelines directly address the potential synergistic effects that might occur when e.g. concrete deterioration, corroding reinforcing steel and/or improper detailing are simultaneously present in a structure.

Reinforcement layout and detailing deficiencies can exist in older half-joint structures, as shown in the past by inspections that revealed discrepancies between as-designed and as-built reinforcement layouts [7]. These inconsistencies may include missing reinforcing bars, relocated reinforcement and/or improper execution of reinforcement detailing (e.g. anchorages). Over the last decades, provisions with respect to detailing have changed significantly as well, resulting in structures which were considered properly detailed at the time of construction but are questionable based on the current knowledge and requirements [17]. The effect of the omission of specific rebars was the subject of a previous study by the authors [18], while anchorage defects are of particular interest in current work. In order to identify the impact that anchorage conditions can have on the behaviour of half-joint beams, bars where hooked ends are present or not, as well as prematurely curtailed longitudinal bars, were considered.

A further challenge with existing structures is that they have potentially been in service for decades and there is difficulty in recreating time-dependent deterioration processes. Corrosion, for example, causes in the first instance corrosion products to be formed leading to a reduction in the local reinforcement bar diameters. Over time the expansive nature of the corrosion process also leads to cracking and potentially spalling of the concrete [13]. Temperature loading on the other hand, especially in cases with frost-thaw cycles combined with the use of de-icing salts, may result in micro-cracking of the concrete and hence concrete strength reductions [19]. Rather than trying to recreate and accelerate the deterioration processes themselves, in the current work, the approach was to look at deterioration outcomes and hence to incorporate reinforcing bars with reduced sections or surrounded by cracked concrete.

After identifying the impact of these commonly found individual shortcomings, the next stage is then to look at the combination of deterioration and detailing deficiencies and start to provide the basis for guidance to assessors.

2. Experimental design

To provide data on the effect of deterioration mechanisms and to evaluate synergistic effects, an experimental program was designed. A total of nine full-scale reinforced concrete half-joint specimens were tested to failure to determine their load-carrying capacity and detailed behaviour. The results of the program are discussed in this paper.