Assessment of deteriorated reinforced concrete half-joint bridges

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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, but are notoriously hard to inspect, hence they require special attention. A revised inspection methodology for half-joint structures that provides more comprehensive information about crack details, and a greater alignment between defect information and indicators of structural measures, is proposed.

1 Introduction

National Highways (NH) is the government company responsible for operating, maintaining and improving England's motorways and major A (trunk) roads. The NH looks after the Strategic Roads Network (SRN) in England, which carries 1/3 of all traffic and 2/3 of all heavy goods traffic [1]. Data management systems are used by Asset Managers such as NH to support decision-making about structural assets. Examples include the Danish bridge management system DANBRO [2], AASHTOWare (formerly Pontis) developed by the US Federal Highways Administration and AASHTO [3] and Highways England's structure management information system [4]. The underlying source data includes inventory information, historical data regarding any interventions or loading events, and ongoing inspection and assessment data. As appropriate, in-service inspection data is gathered from visual observations, non-destructive testing and destructive testing. Visual inspections remain a central tenant of bridge inspection practice all over the world [5] even though they are known to have certain limitations [6], in particular, a reliance on the skills and expertise of the inspector [7]. To help provide a more unified reference framework for reinforced concrete structures, guidelines have been developed. The success of any guidance relies on a clear, common, and consistent definition of defects and damage [8,9] to help mitigate an inherent subjectivity due to different inspectors inspecting structures at different times and ages.

2 Highways England Reinforced Concrete Half-Joint Structures

Half-joints can simplify design and construction through the expedited placement of precast beams. A half-joint joint is characterised by a reduced depth of the beam or slab, referred to as a nib. The geometry of the nib means that the internal steel reinforcement must accommodate a load transfer from the supports through to the full-depth structure [10-11]. However, leakage through the joint can result in chloride-induced corrosion of the reinforcing bars and, as the inner faces of the nibs are largely hidden, inspections and repairs are challenging.

In 2004, The Highways Agency [12] published the document, Interim Advice Note 53 Concrete Half-Joint Deck Structures, to ensure that reinforced-concrete half-joint structures were recorded, properly inspected and well managed for the future. Inspection reports, design drawings, assessments, maintenance records and other related documents linked to individual half-joint structures [13] in the NH asset management database were studied. Based on this review, a total of 428 half-joint structures were identified on the NH network.

3 Classification of Defects

In the existing NH inspection approach, an inspector selects one of the following four predefined Defect Categories: Damage Causing; Appearance Related; Paint/Protective Systems; Affecting Adjoining Areas and chooses the most appropriate defect type from a list of 172 defects provided in the NH database. Some defects sit in several Defect categories.

An analysis of the half-joint data indicated that a new framework could be helpful to isolate common defect issues across half-joint structures and in the identification of criticalities. A new overarching 'Defect Class' (broad top-level grouping), associated with 'Defect Groups' (collections of defect types) linked to underlying Defect Types is proposed. The proposed Defect Classes are: Aesthetic, Structural and Deterioration, Constructional, Operational, and Other.

Within each of the Defect Classes, the Defect Types were collated into Defect Groups. The 'Cracking' Defect Group for half-joint structures contained 12 different individual defects, as will be discussed in the next section.

3.1 Defect Class/Group/Type Profiles of NH Half-Joint Structures

Using the proposed Defect Classes, the 252 half-joint related defects (note that a given bridge may have several half-joints) reported during at least one inspection were grouped. 'Structural and Deterioration' related issues (86.9%) and 'Aesthetic' defects (55.2%) were the most commonly reported.

It was also found that 'Constructional' defects rarely occurred in isolation and tended to occur in combination with other problems such as 'Aesthetic' and 'Structural and Deterioration' defects. This suggests good quality control during construction is necessary to help avoid issues at a later date. Within the 'Structural and Deterioration' Defect Class, the 'Cracking', 'Corrosion', 'Spalling' and 'Deterioration Mechanism' Defect Groups were the most common (Table 1).

Table 1. Most common structural & deterioration defects for half-joints (>20% occurrence)

Defects related to	No.	%
Cracking	134	61.2%
Corrosion	84	38.4%
Spalling	76	34.7%
Deterioration Mechanism	73	33.3%
Delamination	46	21.0%
Bond	46	21.0%

Defects from more than one Defect Group were observed within a given structure. About half of the structures with cracking related issues also tended to have corrosion defects. In 57.9% of structures with reported spalling, some form of corrosion is noted as well. The Defect Types found that were associated with the 'Cracking' Defect Group are summarised in Table 2. 'Crack of uncertain origin or a combination of causes' (61.2%) or 'Cracked' defect (21.6%) are most commonly noted. This suggests that it is difficult for inspectors to classify cracks in absence of other information and visual inspections can be inadequate as a means of specifying the crack origin.

Table 2. Number of structures with crack-related defects at the half-joint (134 bridges)

Defect	No.	%
Crack of uncertain origin or a combination of causes	82	61.2%
Cracked	29	21.6%
Shear crack	10	7.5%
Reinforcement corrosion crack	7	5.2%
Tension crack	6	4.5%
Flexural crack	5	3.7%
Construction joint crack	4	3.0%
Drying shrinkage crack	4	3.0%
Map cracking	4	3.0%
Early thermal crack	2	1.5%
Frost damage crack	1	0.7%
Crack in mortar only	1	0.7%

4 Recommendations for improved inspections and data gathering

The Class/Group/Type data architecture reveals a more transparent picture of recurring issues with half-joint structures and highlights some of the challenges when collecting and interpreting visual inspection data. A number of recommendations relating to improving the quality of the data and expanding the data collected are proposed.

Data quality

Each half-joint specific component or element should be defined separately to allow inspectors to allocate detected defects to a specific half-joint. Defect Groups could provide a framework for a more consistent classification of defects, supported with clearer definitions of Defect Types e.g. the International Concrete Repair Institute's Concrete Repair Terminology [14]. Decision trees can be used to guide inspectors towards more repeatable conclusions rather than relying on individual inspectors' interpretations. For example, the decision tree in Fig. 1 can be used to make a distinction as to whether a crack falls within the 'Corrosion', 'Spalling' or 'Cracking' Defect Groups where these are defined as: Corrosion: Exposed reinforcement, Corrosion with loss of section, Rusty nails/Tie wire etc., Rust/stain/spot; Spalling: Incipient spall, Scaling, Spalled area; Cracking: Impact (accident) damage crack, Construction joint crack, Crack of uncertain origin or a combination of causes, Drying shrinkage crack, Early thermal crack, Fatigue crack, Frost damage crack, Flexural crack, Formwork movement crack, Mapping crack, Plastic settlement (displacement) crack, Plastic shrinkage crack, Reinforcement corrosion crack, Shear crack, Settlement crack, Tension crack, Crack along line of prestressing tendon, Torsion crack.

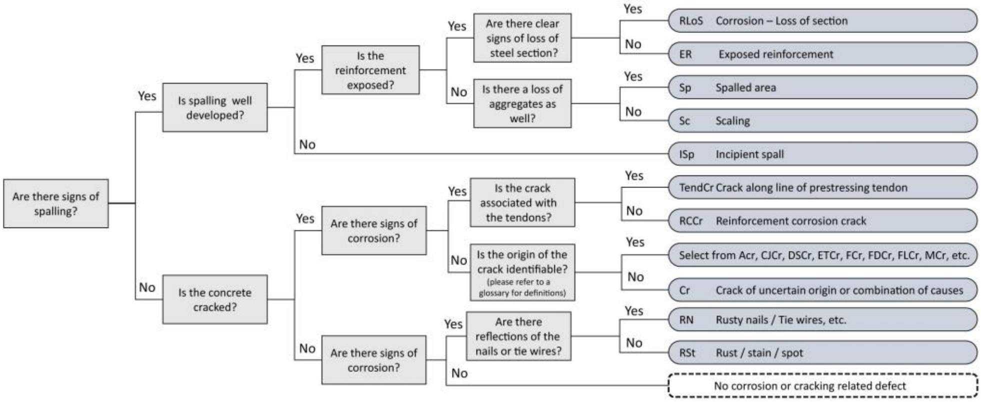

Fig. 1. Decision tree for the defect type of corrosion/cracking/spalling related defects in RC half-joints

Additional data

Overview photos and sketches give an indication of the general condition of the entire half-joint. For a given structural form, construction type and reinforcement layout, the presence of cracks within particular regions can be indicators of specific issues. An example of a zonal layout for a reinforced concrete half-joint with internal diagonal and transverse reinforcement is shown in Fig. 2. Knowledge of the zone in which cracks occur and the crack locations, crack patterns, crack orientations, crack extent, and crack widths would inform improved decision making. Additional comments and pictorial evidence to link the local crack pattern to the overall half-joint condition is also important to understand issues such as whether a single crack progresses through several zones or several cracks occur in different zones.

5 Conclusions

The use of bridge management software is an essential part of the asset management decision-making process. Over the years, an extensive set of data is gathered.

In England, an Interim Management Strategy was developed to identify all structures on the National Highways road network with half-joint elements. Most of England's concrete half-joint structures were built 40-50 years ago and are pre-tensioned, post-tensioned or reinforced (in almost equal shares).

Traditionally, a list of 172 defects grouped in four different classes is used for the identification of shortcomings. However, an analysis of the data showed that introducing a new classification of defects using Defect Classes, Defect Groups and Defect Types could provide a better means to identify common half-joint specific issues. It was found that 'Constructional' defects rarely occurred in isolation, indicating that construction issues will often lead to more structural defects or enhanced deterioration later on. Grouping the Defect Types in Defect Groups further revealed that, in many cases, cracking and corrosion are noted simultaneously. The 'Cracking', 'Corrosion', 'Spalling' and 'Deterioration Mechanism' Defect Groups were the most common within the 'Structural and Deterioration' Class.

Based on the results from an analysis of the asset management database using the new classification scheme, recommendations for the improved gathering of half-joint specific defect data are made. A decision-tree approach tries to overcome the shortcomings of a subjective classification of cracking.

Although further development, benchmarking and validation is required, the proposed methodology could be extended to provide the basis for the automatic processing and identification of structures with cracks at specific locations and flag structures with critical issues.

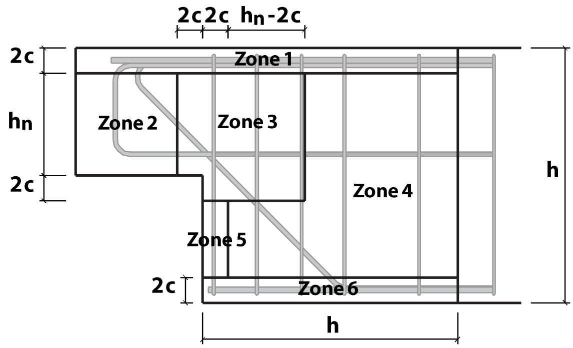

Fig. 2. Example of zonation within a half-joint detail to facilitate inspections

6 Acknowledgements

The authors would like to acknowledge the financial support of EPSRC (UK) – through the IAA Knowledge Transfer Fellowship 'Strategic Roads Network Infrastructure Alliance'.

7 References

[1] Highways England, Highways England - Annual Report and Accounts 2015-2016, Highways England, Guildford, UK, 2016.

[2] J. Lauridsen, B. Lassen, The Danish Bridge Management System DANBRO, in: The Highways Agency (Ed.), Manag. Highw. Struct., Thomas Telford, London, UK, 1999: pp. 61–70.

[3] V. Patidar, S. Labi, K.C. Sinha, P. Thompson, NCHRP Report 590: Multi-Objective Optimization for Bridge Management Systems, Washinton DC, USA, 2007.

[4] Z. Mirzaei, B.T. Adey, L. Klatter, J.S. Kong, The IABMAS Bridge Managment Committee Overview of Existing Bridge Management Systems, IABMAS, 2012.

[5] M. Enright, D. Frangopol, Condition prediction of deteriorating concrete bridges using Bayesian updating, J. Struct. Eng. 125 (1999) 1118–1125.

[6] D. McCann, M. Forde, Review of NDT methods in the assessment of concrete and masonry structures, NDT E Int. 34 (2001) 71–84.

[7] B.M. Phares, et al, Routine Highway Bridge Inspection Condition Documentation Accuracy and Reliability, J. Bridg. Eng. 9 (2004) 403–413.

[8] A. Tarighat, A. Miyamoto, Fuzzy concrete bridge deck condition rating method for practical bridge management system, Expert Syst. Appl. 36 (2009) 12077–12085.

[9] B.A. Graybeal, B.M. Phares, D.D. Rolander, M. Moore, G. Washer, Visual inspection of highway bridges, J. Nondestruct. Eval. 21 (2002) 67–83.

[10] P. Desnerck, J.M. Lees, C.T. Morley, Impact of the reinforcement layout on the load capacity of reinforced concrete half-joints, Eng. Struct. 127 (2016) 227–239.

[11] P. Desnerck, J.M. Lees, C.T. Morley, The effect of local reinforcing bar reductions & anchorage zone cracking on the load capacity of RC half-joints, Eng. Struct. 152 (2017) 865–877.

[12] N. Loudon, IAN 53/04 - Concrete Half-joint Deck Structures, (2004) 18.

[13] SMIS, SMIS Half-Joint Dataset, (2016).

[14] International Concrete Repair Institute, Concrete Repair Terminology, June 2015, International Concrete Repair Institute, Saint Paul, MN, USA, 2015.