Suggestions for improved reinforced concrete half-joint bridge inspection in England

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Abstract. Asset management databases play a crucial role in the management of existing infrastructure assets. Highways England (HE) has a long history of using bridge management software to record the current state of bridges and to guide maintenance schemes and interventions. Reinforced concrete half-joints are amongst the most challenging structures to inspect and repair due to their susceptibility to deterioration and construction type. Hence, they require particular attention within asset management programmes. An Interim Management Strategy was developed by HE to identify all the structures on the Highways England road network with half-joint elements. These half-joint structures were then subjected to a special inspection regime. Out of the 428 half-joint structures with inspection data, 252 structures had defects associated with four existing HE defect classes. A review of the inspection database with a focus on half-joints led to an alternative classification of half-joint related defects based on a revised set of Defect Classes, the introduction of Defect Groups and the extraction of Defect Types specifically observed in half-joints. Using this new classification, the most common half-joint Defect Groups were found to be cracking, corrosion, spalling and deterioration mechanisms. In about half of the structures cracking and corrosion tended to be observed together. Correlations were also shown to exist between structural and deterioration, and constructional Defect Classes, emphasising the need for quality control and proper workmanship. Recommendations to address shortcomings in current inspection practice are proposed. Clearer defect definitions and decision-tree guidance for inspectors could enhance the consistency and repeatability of inspection data gathering thereby overcoming some of the limitations of subjective classifications. Acquiring additional information about the observed crack details including zonal information, crack patterns, crack extent, crack orientations and widths combined with local and global pictorial evidence would also be advantageous. This could then provide the basis for the automatic processing and identification of structures with specific half-joint related defects. In this way, asset managers would be better able to allocate limited resources to the most critical structures.

1 Introduction

Highways England (HE), formerly known as the Highways Agency, is the government company responsible for operating, maintaining and improving England's motorways and major A (trunk) roads. The HE 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 HE 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 in the UK [8–11], [12] and abroad [13,14]. The success of any guidance relies on a clear, common, and consistent definition of defects and damage [15,16] to help mitigate an inherent subjectivity due to different inspectors inspecting structures at different times and

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ages. A further desirable outcome is for the acquired data to reveal, and be associated with, indicators of criticalities to thereby enhance decision-making.

In the following, the basis for a new set of defect definitions and damage indicators are proposed for reinforced concrete half-joint bridges. The study builds on the outcomes of the Concrete Half-Joint Deck Structures Programme managed by Highways England, and a recent research investigation on the influence of detailing and deterioration in reinforced concrete half-joints [17,18].

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 (see Fig. 1), 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. 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.

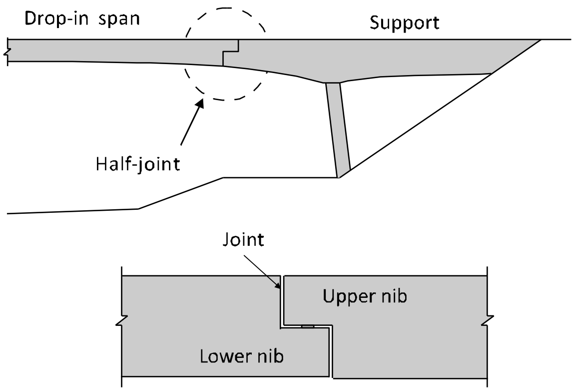

Fig. 1. Reinforced Concrete Half-joints

In 2004, The Highways Agency [19] 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 [20] in the HE asset management database were studied. Based on this review, a total of 428 half-joint structures were (Fig. 2) identified on the HE network. These vary from highway underpasses or overpasses to footbridges and include single span and multi-span structures. Most of the existing half-joint structures date from the late 1960s and 1970s. The first bridge on record was built in 1940 and the most recent one in 1989.

With respect to the construction type, reinforced, post-tensioned, pre-tensioned structures and combined pre/post-tensioned bridges are in service, as shown in Fig. 3.

Fig. 2. Locations of the RC half-joint structures on the HE road network

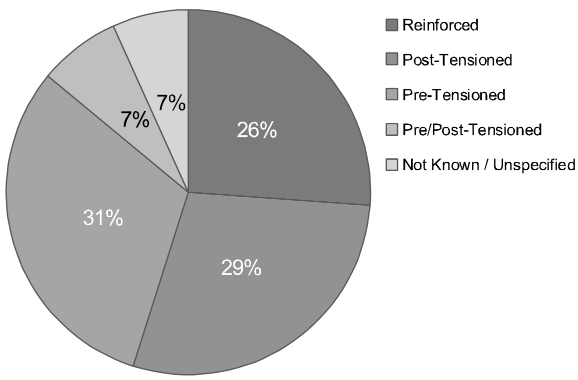

Fig. 3. Construction type of Half Joint Structures in HE database

3 Classification of Defects

In the existing HE 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 HE 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. The philosophy behind the newly developed approach was as follows:

1) Only defect types found in the asset management database half-joint records would be considered thereby reducing the number of defect types to analyse.
2) The emphasis would be on defects most likely to relate to structural consequences for half-joints.
3) In the interests of continuity, the existing defect type terminology would be maintained although, where evident, the scope for rationalisation was noted. Cracking-related defects were of particular interest in half-joints.

A new overarching 'Defect Class' (a 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: defects that affect the appearance but do not impact the structural integrity (analogous to the existing 'Appearance-Related' category).
- Structural and Deterioration: defects that can be linked to a structural deficiency developed during the lifetime of the structure or having an impact on the structural behaviour/capacity of (an element) of the structure, as well as defects that can be clearly linked to a deterioration process.
- Constructional: defects that have arisen due to improper construction or flaws in the construction process
- Operational: defects that have an impact on the operational aspects of the structure only
- Other: defects not covered by the previous categories e.g. foreign objects.

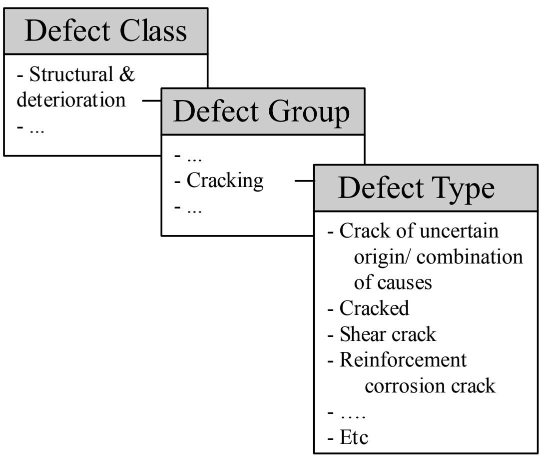

Fig. 4. Class/Group/Type classification for 'Cracking' Defect Group associated with 'Structural and Deterioration' Defect Class

Within each of the Defect Classes, the Defect Types were collated into Defect Groups. An example for the 'Cracking' Defect Group within the 'Structural and Deterioration' Defect Class is shown schematically in Fig. 4. 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 HE 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 in Table 1. 'Structural and Deterioration' related issues and 'Aesthetic' defects were the most commonly reported.

Table 1. Number of structures with defects at the half-joint within each Defect Class (252 bridges)

Defect Class	No.	%
Structural & Deterioration	219	86.9%
Aesthetic	139	55.2%
Operational	57	22.6%
Constructional	36	14.3%
Other	2	0.8%

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 2).

Table 2. Most common structural & deterioration defects for half-joints (219 bridges) (>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 in the studied half-joint bridges that were associated with the 'Cracking' Defect Group are summarised in Table 3. '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 3. 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.

a. 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 [21]. 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. 5 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

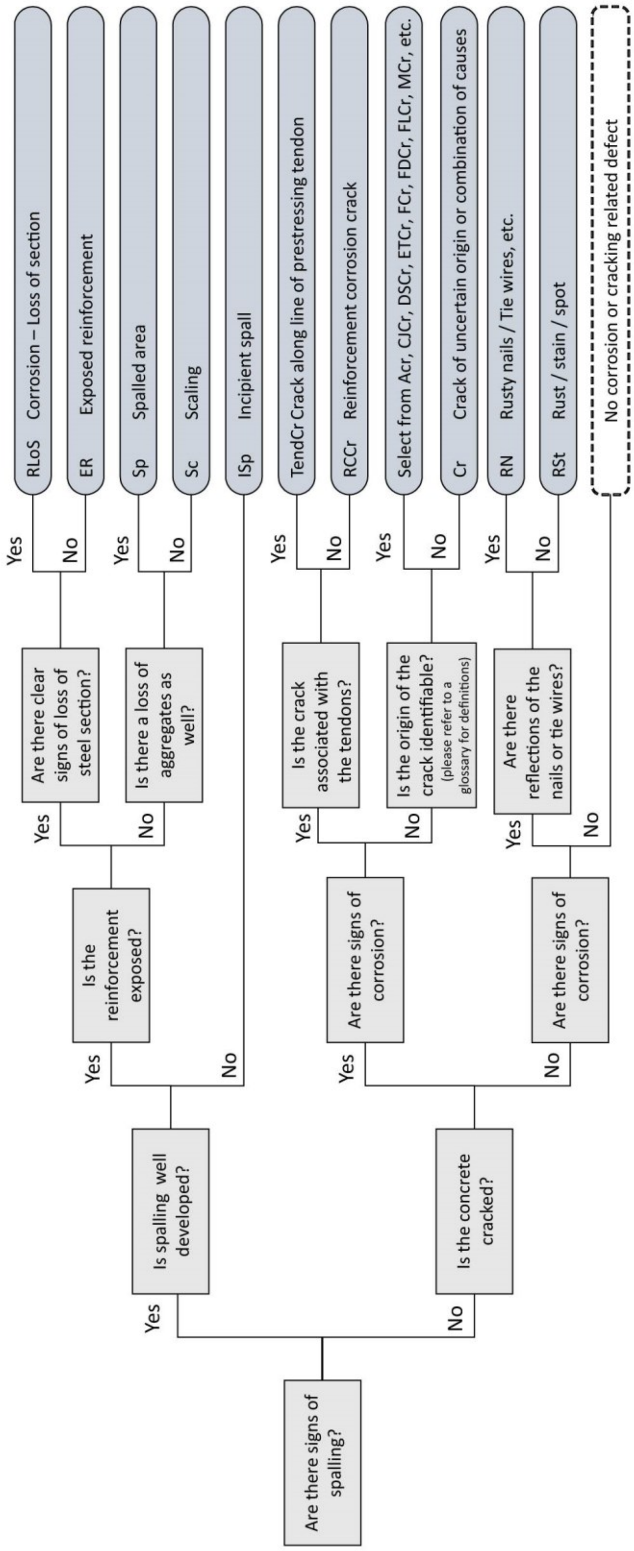

Fig. 5. Decision tree for identifying the defect type of corrosion/cracking/spalling related defects in RC half-joints

b. 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. 6. 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.

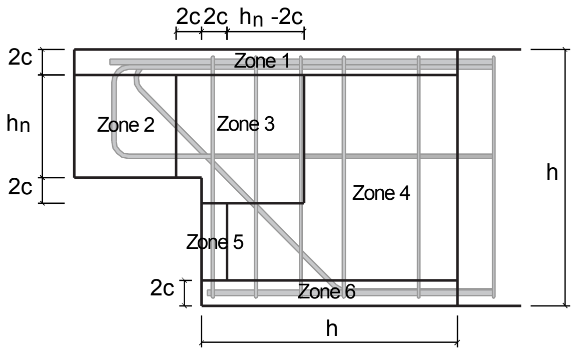

Fig. 6. Example of zonation within a half-joint detail to facilitate inspections

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 including inspection reports and maintenance logs is gathered.

In England, an Interim Management Strategy was developed to identify all structures on the Highways England road network with half-joint elements. Most of England's concrete half-joint structures were built 40 to 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. These four classes are Damage Causing, Appearance Related, Paint/Protective Systems, and Affecting Adjoining Areas. 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. The proposed Defect Classes are 'Structural & Deterioration', 'Aesthetic', 'Constructional', 'Operational' and 'Other'. 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 the causes of cracking. The gathering of more comprehensive crack data provides additional insight into the location and orientation of cracking defects.

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. By obtaining improved insight, asset managers can then take more informed decisions and allocate limited resources accordingly.

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