SeeBridge Information Delivery Manual (IDM) for Next Generation Bridge Inspection

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Abstract

Innovative solutions for rapid and intelligent survey and assessment methods are required in maintenance, repair, retrofit and rebuild of enormous numbers of bridges in service throughout the world. Motivated by this need, a next-generation integrated bridge inspection system named SeeBridge is proposed. To frame the system, an Information Delivery Manual (IDM) was compiled to specify the technical components, activities and information exchanges in the SeeBridge process. The IDM supports development of the system by rigorously defining the information and data repositories that structure bridge engineers' knowledge. The SeeBridge process is mapped, parts of the data repositories are presented and the future use of the IDM is discussed.

Keywords –

Information Delivery Manual, Bridge inspection, Building Information Modelling, Semantic enrichment, Remote sensing.

1 Introduction

Highway asset owners face severe problems acquiring status data for their bridges. There are not enough experienced bridge engineers for the extensive work required for inspection of a large number of bridges; bridge inspections mean interruption of transportation and are potentially dangerous activities; and the data available in many Bridge Management Systems (BMS) does not meet the standard of information needed for subsequent bridge repair, retrofit and rebuild work.

Remote sensing technologies are attracting increasing research interest for inspection for health monitoring and valuation for bridges [1-5]. Among the remote sensing technologies, both laser scanning technology and photo- or videogrammetry can produce point clouds from which 3D primitives can be derived. However, the challenge that must be overcome for implementation of remote sensing in bridge inspection is to enable automatic recognition of bridge components from point clouds and make the model semantically rich [6].

To address the challenges, a Semantic Enrichment Engine for Bridges (SeeBridge) is proposed, targeting the development of a comprehensive solution for rapid and intelligent survey and assessment of bridges. The SeeBridge concept is the subject of an EU Infravation research project comprising seven partners in the US, UK, Germany and Israel. In the SeeBridge approach, various advanced remote sensing technologies are used to rapidly and accurately capture the state of a bridge in the format of point cloud data. A bridge model is automatically generated by a point cloud processing system, an expert system that encodes bridge engineers' knowledge for classification of bridge components, and a damage measurement tool that associates the identified defects with the bridge model.

In order to guide and connect the subsystems in the system as a whole, an Information Delivery Manual (IDM) [7] was compiled to formally specify the user requirements and to ensure that the final model would be sufficiently semantically meaningful to provide most of the information needed for decision-making concerning the repair, retrofit or rebuild of a bridge. The IDM approach is outlined in the US National BIM Standard [8] and has been used in numerous BIM interoperability research projects [9-12].

The IDM includes:

- A detailed process map defining the Seebridge process, its component processes and its information exchanges.
- A list of typical bridge elements classified by structure types, their function, shape representation and relative importance in the structure.
- Definition of the possible logical connections between the elements in a bridge structure type.
- A defect table for defects modelling and classification.
- Definition of the required information contents of the exchanges specified in the process map.

The following sections describe the overview and the systematic process of SeeBridge framed by the IDM, explain the information exchange between the component processes, and present parts of the data repositories compiled in the IDM. The conclusion section discusses the need for extensions to the IFC Schema [13] for bridges and the value of the IDM approach to research and development of this kind.

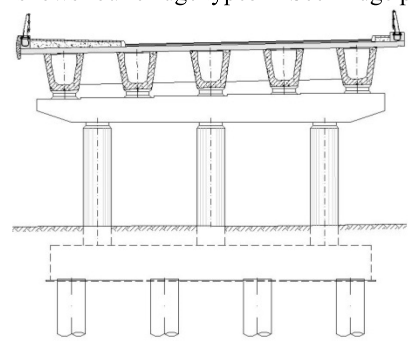
2 SeeBridge Inspection Process

Bridge inspection and management is a part of the bridge life-cycle and is related to the operational and maintenance stage. The data needed for managing the bridge stock within a given defined road network is used for decision making regarding the maintenance, repair, retrofit and rebuild/replacement of the bridges. Bridge inspections are the main source of data regarding the actual condition of a bridge during its life cycle.

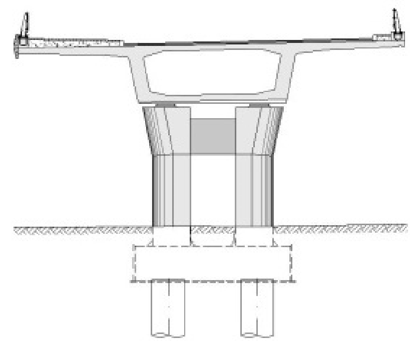
Bridge inspection and management methods differ among Departments of Transport (DOT) and authorities in different countries, yet the core innovations of the SeeBridge process are applicable to most if not all. The system integrates four novel technical components to upgrade the traditional bridge inspection process and produce semantically rich BIM models for the inspected bridges. The new components are:

- A bridge data collection system using remote sensing techniques such as terrestrial/mobile laser scanning and photogrammetry/videogrammetry.
- A bridge object detection and classification software for automated compilation of 3D geometry from the remote sensing data using both parametric shape representation and boundary representation.
- A semantic enrichment engine for converting the 3D model to a semantically rich BIM model using forward chaining rules derived from bridge engineers' knowledge.
- A damage detection tool for damage identification, measurement, classification and integration of this information in the BIM model.

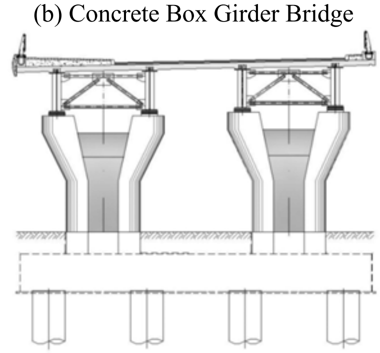
Figure 1 shows four bridge types in SeeBridge project.



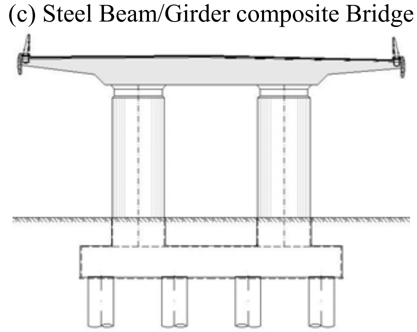
(a) Concrete Beam/Girder Bridge



(b) Concrete Box Girder Bridge



(c) Steel Beam/Girder composite Bridge



(d) Concrete slab Bridge

Figure 1 SeeBridge Bridge Types

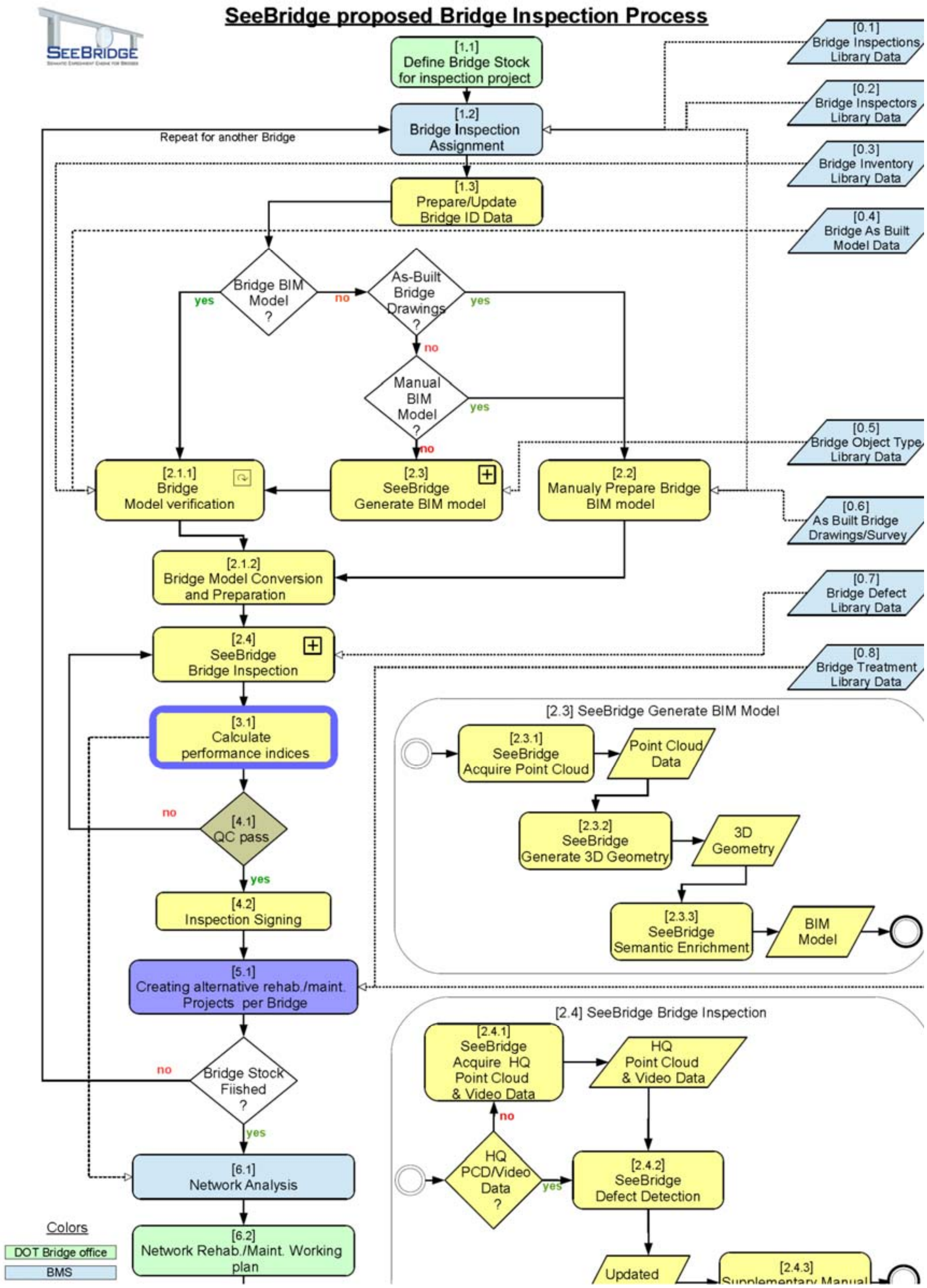


Figure 2 Workflow diagram of proposed SeeBridge Bridge Inspection process.

The workflow of the SeeBridge system is shown in Figure 2 (on the previous page). Incorporating the suggested SeeBridge technical components into an existing bridge inspection and management process should be done with great care as the impact on the existing workflow and on the way the BMS is used to manage the bridge stock may be significant. One of the major changes is the introduction of a BIM model as a database for the bridge inspection and management process. There are three options/situations for incorporating BIM models into the process:

- Using the 'as-built' BIM models of bridges if and where they exist.
- Automatic creation of 'as-is' BIM models of bridges using the SeeBridge technical components numbered 1-3 above (activities 2.3.1, 2.3.2, and 2.3.3 in Figure 2).
- Preparation of 'as-built' BIM models of bridges manually based on drawings.

The second option is the major solution that SeeBridge provides, since most of the existing BMS have not incorporated BIM models. The SeeBridge solution of this aspect should greatly reduce the effort and costs required for BIM model integration into the BMS.

A detailed SeeBridge process map was developed in the IDM using Business Process Modelling Notation (BPMN), which defines the information exchange, including Non Model Exchanges (NME) and BIM Exchange Models (EM), between the activities. Part of the process map is shown in Figure 3.

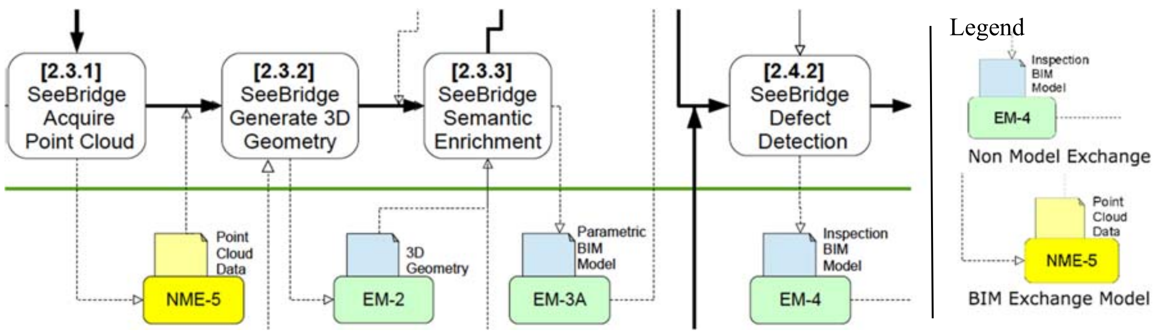


Figure 3 Part of the SeeBridge Bridge Management Process Map

3 Activities and Information Exchange in SeeBridge

The four major activities (technical components) in the SeeBridge system are advanced in the area of survey technology, computer vision, information interoperability and modelling of bridges defects.

3.1 Remote Sensing Technology

The use of these technologies for capture of existing structures is the topic of much research [3, 4]. In activity 2.3.1 shown in Figure 2, the bridge inspector, depending on the bridge type and inspection criteria, selects a proper 3D scanning approach. The options are terrestrial/mobile laser scanning and video/photogrammetry.

In case of laser scanning, the inspector evaluates the site and designs the laser scanning set-points so that they collectively cover the entire bridge structure. The laser scanner is then set at every set-point and a 3D point cloud is captured at each set-point. The individual point clouds are then registered to each other using automated software or manually.

In case of video/photogrammetry, the inspector selects a proper camera resolution based on the project criteria, distance of the camera to the bridge surfaces, and required point cloud resolution. Once the camera is selected, the inspector captures video or takes photographs from the bridge. The important point here is to cover every surface of the bridge from multiple viewpoints. The video or photographs are then input to the processing software. The software automatically estimates camera parameters and trajectory which will lead to the generation of a dense point cloud data (PCD), i.e. the NME-5, as the input of the 2.3.2 activity (as shown in Figure 3).

3.2 Reconstruction of 3D Model from PCD

Current practice for the generation of as-built models from PCD involves manual conversion through user-guided specification of components combined with automated fitting of the components to specified subsets of the point cloud data. In activity 2.3.2 in the SeeBridge process (as shown in Figure 2), the 3D geometry generation engine processes the PCD created in 2.3.1 and generates a geometric model of the infrastructure associated to the PCD. The engine segments the main bridge components by matching the data with a repository of predefined bridge element shapes defined in the IDM. The techniques used employ a surface primitive extraction algorithm and a component detection and classification algorithm. As the detection and classification is based on machine learning, training data is required for learning the proper relationships between surface primitives and integrated components.

Most of the bridge components can be modelled using extruded, prismatic solid shape representations, while others require a BREP approach. To support component detection of extruded area solid elements, a comprehensive set of parametric cross-sections were defined in the IDM, including all of the typical concrete box, double T and girder sections. An example of the SeeBridge Generic Girder Parametric Cross-Section is shown in Figure 4. The parameters are specified in Table 1.

The output of this activity (2.3.2) is a simplified building information model of the sensed bridge with the main bridge components identified and modelled, but with no relationships or other information. Elements that are occluded or that are too small to be discerned due to insufficient scan resolution are not provided. The level of detail satisfies or is superior to LoD 300, but is inferior to LoD 400 [14]. The data format of the output model will be an IFC or equivalent BIM model file with the component objects and their full geometry (defined as EM-2 in Figure 3).

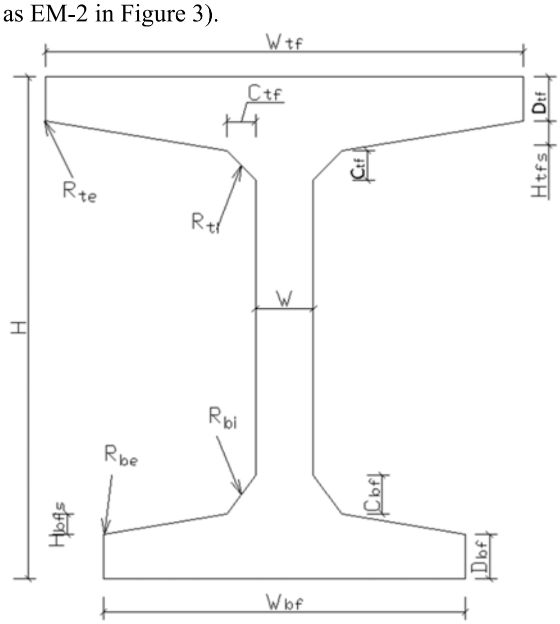


Figure 4 SeeBridge generic girder parametric cross-section

Table 1 Definition of parameters for generic girder parametric cross-section

Parameter	Label	Notes
Height	H	
Top flange depth	D_{tf}	
Top flange slope height	H_{tfs}	
Bottom flange slope height	H_{bfs}	
Top flange chamfer	C_{tf}	Chamfers are all 45°
Bottom flange chamfer	C_{bf}	
Bottom flange depth	D_{bf}	
Top flange width	W_{tf}	
Bottom flange width	W_{bf}	
Web width	W	
Top flange inner filet radius	R_{ti}	These values are only relevant for a small group of bulb tees (e.g. North East and for California bulb tees).
Top flange edge filet radius	R_{te}	
Bottom flange inner filet radius	R_{bi}	
Bottom flange edge filet radius	R_{be}	

3.3 Semantic Enrichment of the 3D Model

In activity 2.3.3, the semantic enrichment engine parses the 3D model and extracts the geometric, topologic and functional characteristics from the model. It then progressively creates, updates or deletes semantically rich model entities (including tangible objects, virtual aggregation containers and objectified relationships of them) following a chain of predefined rules. The rule sets capture the knowledge of bridge engineers concerning the characteristics of the 3D model objects that represent bridge components, including their geometric features (e.g., the parametric cross-sections), their occurrence and the topological and other relationships among them. The general approach to semantic enrichment follows that derived by Belsky et al. [15, 16].

The information derived is structured in the IDM. Some of the examples are shown in Table 2 and Table 3. The output of this activity is a bridge "Pre-Inspection BIM Model" (EM-3A in Figure 3), usually in IFC format, with explicit geometry representation and property sets in a verified LoD similar to LoD 350, but the data must represent 'as-is' conditions (in the same sense as LoD 500 calls for a ‘field-verified’ model).

Table 2 Part of the IDM Table of Bridge Elements and Occurrence

Element Type: Bridge type	Description	Primary Girders	Slab	Box	Transverse Beam/Diaphragm
Concrete Beam/Girder Bridges	At/Below deck surface	+			+
	Box Girder (exterior & interior)			+	+
Steel Beam/Girder Composite Bridges	At/Below deck surface	+			+
Slab Bridges	Monolithic Slab Bridges	+			

Note:
+ means that this element type always exists in this type of bridge

Table 3 Part of the IDM Table of Spatial Relationships between Elements

Element description		Primary Girders	Box (Box girder)	Slab	Transverse Beam/Diaphragm
Deck/Superstructure	Primary Girders	■			E
	Box (Box girder)		■		E
	Slab			■	
	Transverse Beam/Diaphragm	E	E		■
	Deck Slab - (Concrete Slab)	E	E		P

Note:
E = Exists: normally the elements are in physical contact
P = Possible: the elements may or may not be in physical contact

3.4 Bridge Defects Modeling

A pre-process activity of the damage detection (2.4.2 activity in Figure 3) process is to enable all the elements in the BIM model generated from 2.3.3, i.e., EM-3A, to have boundary shape representation (BREP), because it is much easier to represent defects on the bridge surface when using BREP, which is a composite of faces. Any bridge elements that were only modelled using solid extrusions and CSG in EM-3A maintain both their original representations and BREP in the resulting model - EM-3B. The objects also have high resolution imagery registered with them at this stage (note that EM-3B is not shown in Figure 3 due to space limitations).

The damage detection algorithm (activity 2.4.2 in Figure 3) iterates over every BIM element in EM-3B and analyses the imagery, shape and function in the structure. First, imagery is used solely to localize visually detectable damage groups. Subsequently, these findings are further refined to a specific damage type (structural crack, non-structural crack, spalling, scaling, efflorescence, corrosion, other) using additional extracted properties such as element type, damage position and damage location. The defects' types and possible occurrence in bridge elements are listed in bridge defect occurrence tables that are compiled in the IDM; some examples are shown in Table 4.

Meaningful damage parameters (damage type, absolute and relative size measurements, etc.) are extracted from the findings and embedded into the BIM model. The result is an 'Inspection BIM Model' (EM-4) with defect data attached and located on bridge component surfaces.

The 'Inspection BIM Model' enables automatic calculation of performance indicators of the bridges and automatic classification of the defects based on the defect classification tables, which are compiled in the IDM according to the DOTs/Highway Authorities' regulations. An example of severity levels is shown in Table 5.

4 Conclusion

The proposed IDM establishes the professional knowledge basis of the domain of highway bridges in order to ensure the correct development of the technical components in the proposed SeeBridge system. It specifies the data collection process; details the activities for 3D model reconstruction and the geometric shape representations needed; presents the process of semantic enrichment and the required structured knowledge; and it specifies the defect identification and modeling activities and the defect classifications that facilitate the process.

The proposed IDM was developed and validated with a network of domain experts representing highway departments and DOT's in four countries. It captures general data exchange scenarios relevant to the bridge inspection process in the SeeBridge system, as well as country-specific aspects. It also forms a sound basis for the development of a Model View Definition (MVD), which can be used as an evaluation tool to rigorously validate the comprehensiveness of the bridge information instance models generated when the SeeBridge process is used in the future.

Development of the MVD will also enable review of the currently proposed IfcBridge [17] data model extension. Specification of any new entities, relationships or properties that may be found lacking in the IFC schema will depend heavily on the IDM for their content. For example, there is currently no accepted, consistent or thorough way to represent the defects that may occur in bridges. Definitions for objects that represent defects, defect patches and similar objects will need to be added to the IFC schema.

Use of the IDM approach to modeling the data exchanges has proven to be an effective way of establishing a common basis for the activities of the different research teams engaged in the SeeBridge project. In addition to providing the basis for a Model View Definition (MVD), its development forced the researchers to rigorously confront and solve a range of issues concerning questions of data modeling and the coherence of the process as a whole. As such, the IDM is a central component for R&D of this type.

Table 4 Part of the Bridge Defect Occurrence Table in the IDM

	Defect Group	02 Reinforced & Prestressed Concrete				
				Cracks in reinforced concrete		
	Defect Description	Spalls	Delamination	Cracks likely to affect the stability of the element/ structure	Cracks which do not affect the stability of the element/structure	Cracks in prestressed concrete
Deck/Superstructure	Primary Girders (Concrete Beam/Girders)	+	+	+	+	+
	Primary Girders (Steel Beam/Girders)					
	Box (Box girder)	+	+	+	+	+
	Slab	+	+	+	+	+
	Secondary Deck element - Transverse Beam/Diaphragm	+	+	+	+	+
	Deck Slab (Concrete Beam/Girders, Box Girder, Composite)	+	+	+	+	+

Note: + means normally this type of defect may be identified in this element

Table 5 Part of the Defects Classification Table in the IDM

02 Reinforced & Prestressed Concrete					
	Severity				
Defect	**1**	**2**	**3**	**4**	**5**
Spalls	No spalling	Slight, but clear, local spalling. Partial exposure of the outer reinforcement layer (stirrups in beams, external reinforcement in slabs) usually accompanied by signs of corrosion	Large, discrete spalls, exposing the cross-section of the shear stirrups and/or longitudinal reinforcing bars. Usually accompanied by general corrosion of the exposed bars, with possible local reduction in cross-section of longitudinal bars	Delamination in regions of low bending or shear, with no influence on the stability of the element	The element is no longer structurally functional, as a result of developments described under “Degree of severity 4”

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