Management of safety-critical fixings

Guidance for the management and design of safety-critical fixings

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WSP

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Summary

Fixings are widely used in construction and include those that are safety-critical and non safety-critical. The body of case studies in this guide provides evidence that incorrect performance of safety-critical fixings can contribute to structural failures, including several high-profile fatal accidents. This guide aims to improve the management of safety-critical fixings and to highlight how good design and installation can minimise risks in-service. Recommendations are made on the management process for existing fixings including cyclical stages of risk review, work planning and work implementation, and risk factors are identified. Recommendations are also made that complement existing industry standards and guidance for new design and installation, to facilitate effective future management of new fixings. This guide is aimed at competent practitioners responsible for the management of assets and those involved in design of structures and fixings.

Management of safety-critical fixings. Guidance for the management and design of safety-critical fixings

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	CONTENT	Guidance, case studies, recommendations
	STATUS	Author's opinion, committee-guided
	USER	Asset-owners, operators, facilities managers, project managers, manufacturers, suppliers, designers, specifiers, structural engineers, civil engineers, façade engineers, constructors, installers, supervisors, testers

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Foreword

As long-established civil and structural engineers there are issues that often keep us awake at night. For some while I have been aware that hidden structural components that are not easily inspectable fall into that category. A recently-published report by Collins *et al* (2017) identifies some of these structural challenges, and provides advice on how they should be managed. This guide to good practice on safety-critical fixings falls into this same area and is, to some extent, complementary to that earlier work. This companion guide to CIRIA C777 examines fixings used primarily in lower-risk environments such as facilities management.

Following notable fixings failures at Boston 'Big Dig' Tunnel, Massachusetts (2006), Sasago Tunnel in Japan (2012) and closer to home at Balcombe Railway Tunnel (2011), it is evident there are some gaps in practice, knowledge and guidance. While the design of fixings has been covered by publications such as George (2015) and elsewhere in manufacturer's literature, little is available to asset owners and consultants, in terms of their onward management (records, inspection, testing, repair etc). Although this guide focuses on the management of fixings, there are also lessons to be learnt in terms of improved design (the need for built-in redundancy, and accessibility for inspection, and selection of the most appropriate fixings to meet design considerations) and construction (need for quality throughout the process of installation, competency of installers, testing and the importance of records).

Many asset owners may be starting from a low point in the management of fixings:

- Do they know where safety-critical fixings have been used?
- What assets are being supported by the fixings?
- Are the records available?
- Have the fixings been inspected?

There is an opportunity for all infrastructure owners to instigate changes to their inspections and records to ensure that they have knowledge of where fixings have been used and their visual condition. The guidance produced will assist the onward management of those fixings deemed safety critical.

This guide should prove useful to the construction industry both in the UK and Ireland and further afield, and will plug a significant gap. Please read, and acknowledge the recommendations given. If in doubt look up at the office suspended ceiling above, and consider how it is supported.

Finally, thanks are extended to the primary authors at WSP, the collaborative funding partners and other project steering group members, CIRIA for publishing the guide, and Highways England assistant project manager Santosh Sansoa – without whose collective and supportive work the guide would not have been produced.

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Executive summary

Correctly designed and installed fixings, subject to an appropriate maintenance regime, have a significant role to play in the safe, efficient and cost-effective operation of transport infrastructure. However, in recent years a series of failures around the world has highlighted the potential risks associated with the use of fixings in safety-critical applications, where failure of the fixing can result in collapse of a structure, risk to human life or significant economic loss.

This guide aims to improve the management of safety-critical fixings and to highlight how good design and installation can minimise risks in-service. It makes 24 key recommendations for management of existing fixings and design and installation of new safety-critical fixings (see **Table 1**).

Management of existing fixings

The recommended management process for existing fixings is risk-based. It includes cyclical stages of risk review, work planning and work implementation. Risk reviews should occur periodically during steady state asset management and as required when triggered by events or incidents. Risk is assessed based on consequence and likelihood of failure, with likelihood determined qualitatively by considering applicability of a set of evidence-based risk factors.

Access to good quality information is fundamental to effective management of safety-critical fixings. Some information about installed fixings is difficult or even impossible to obtain. Sometimes it will be necessary to take decisions about the adequacy of fixings accepting some residual uncertainty.

Investigations may be carried out to gain more information about fixings. Investigations can include desk study, inspections, load tests and intrusive investigations. Additionally, steady-state management of fixings should include periodic inspections.

Interventions may be carried out to mitigate the risk from safety-critical fixings. Interventions can include removal of the fixing, improving robustness (such as by fitting a secondary restraint) and replacing the fixing. Interim measures can be required when it will take some time to mitigate the risk on a permanent basis.

It is important to recognise the limitations on resources and the need to prioritise asset management investment across all elements of an asset owner's stock. It may be necessary to implement a prioritised transition plan to manage safety-critical fixings, before a steady-state management regime can be reached.

Design and installation for effective future management

Fixings that are designed and installed in accordance with current industry standards and guidance can be expected to perform satisfactorily. This guide makes recommendations for design and installation of fixings to enable them to be managed effectively in future, linking with the recommendations of the previous section for management of safety-critical fixings.

Appropriate CE-marked fixings should be specified where possible. Safety-critical fixings should be designed to facilitate future management, including design for inspection, testing and replacement, and design to provide robustness.

The residual risks from new safety-critical fixings should be controlled by the asset owner through technical assurance processes including consideration of whether a safety-critical fixing is required in the first place. Full design records should be provided and retained to enable future management of the fixings.

Correct installation of fixings is essential for providing the performance that is expected by the design. Confidence in the installation will be achieved by following the manufacturer's instructions, having competent installers and by supervision. Full records of installation, supervision and testing should be provided and retained.

Table 1 *Summary of recommendations*

	Recommendation	Sections in this guide
Using the guidance		
1	Asset owners should produce an implementation plan for the recommendations of this guide, including defined timescales	4.5
2	Management responsibility for fixings should be defined	4.5.1, 4.5.2
3	An initial risk assessment should be undertaken to establish the overall level of risk presented by safety-critical fixings and identify priority actions	4.5.1, 5
4	Basic inventory information about the number and location of fixings should be captured as a priority	4.5.1, 5.2
5	Asset owner policies and processes should be updated to include requirements for managing safety-critical fixings	4.5.1
6	An asset information system which is capable of storing and retrieving adequate information about safety-critical fixings should be established	4.5.1, 10.2
7	Relevant staff and suppliers should be briefed on need for and approach to managing safety-critical fixings	4.5.1
Management of fixings in service		
8	A periodic and event-triggered risk review process should be used to determine actions to manage the risk from safety-critical fixings	5.1
9	A formal record should be retained of decisions taken about safety-critical fixings	5.7
10	Actions should be undertaken in a prioritised order with the objective of achieving a steady state where risk is tolerable	6.1
11	Fixings should be included in inspection activities and associated reporting	7.3.1
12	Interim measures should be undertaken when actions cannot be undertaken immediately and a fixing presents an unacceptable risk	9.1
13	Knowledge about the performance of fixings should be shared and, in particular, failures and near misses involving fixings should be reported	10.3
Design of new fixings		
14	New safety-critical fixings should be designed, specified, installed and tested in accordance with BS 8539	12.1, 13.2
15	Risk factors which apply to safety-critical fixings should be eliminated or mitigated by design, considering the fixing itself, the fixing system and the overall structural system so far as the design scope permits	12.2.3, 12.4.2
16	The design of new safety-critical fixings should facilitate future management, including inspection, future testing and replacement	12.5.1, 12.6.1
17	The design of new safety-critical fixing systems should incorporate robustness	12.6.1
18	New safety-critical fixings should be selected from those with an European Technical Assessment (ETA), unless there is no applicable ETA that covers the particular application	12.7
19	Full design records should be provided and retained for new safety-critical fixings	12.8
20	New safety-critical fixings should be included in technical assurance processes including Approval in Principle (AIP), design certification and design checks	12.9.1
Installation of new fixings		
21	Installation of new safety-critical fixings should be carried out and supervised by competent persons	13.2
22	Installation of new safety-critical fixings should be in accordance with the fixing manufacturer's instructions and the design specification	13.2
23	New safety-critical fixings should be tested to verify quality of installation	13.3
24	Installation and test records should be provided and retained for new safety-critical fixings	13.4

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Glossary

Anchor	Manufactured device for achieving a connection between a fixture and the base material. For this guide, this term is used to denote a designed anchor in accordance with BS 8539. 'Anchor' is considered a subset of the general term 'fixing'.
Anchorage	Assembly comprising a base material, an anchor or anchor group, and a fixture.
Asset owner	For this guide, the asset owner is the individual or organisation with daily responsibility for maintenance and decision making about the asset and fixings on the asset.
Base material	Material of a structure into which a fixing is installed. See also *Substrate*.
Base plate	Part of a fixture forming the direct contact between a fixing or group of fixings and the base material.
Basic inventory	Records of the number and location of fixings.
Design	Choice, configuration and sizing of structural members, materials and components including fixings. In this guide, design refers to the wider process including selection of structural system, fixing system and specific fixing. Note that BS 8539 uses a narrower definition of design and reserves the term for the specific process of determining the size of anchor required.
Family of fixings	A group of fixings that share the same characteristics and can be managed as a group rather than individually.
Fixing	Manufactured device for achieving a connection between a fixture and the base material, including safety-critical and non-safety critical applications. The term 'fastener' is used in industry synonymously with fixing. In this guide, the term fixing includes anchors.
Fixture	Component to be fixed to the base material.
Interim measure	A short-term action taken to mitigate an immediate risk from a safety-critical fixing, which is unacceptable at the present time, before the completion of an action that mitigates the risk on a permanent basis.
Near miss	An event not causing harm, but has the potential to cause injury or ill health.
Non safety critical fixing	A fixing which is used in an application which is not safety critical.
Post-installed fixing	Fixing that is inserted into concrete and masonry in a drilled hole, without cast-in components.
Proof test	Tests carried out on fixings to validate correct installation. They are intended to demonstrate that fixings to be used in service have a modest safety margin without risking their integrity.
Risk factors	Factors that affect the probability that intervention may be necessary, ie indicators based on past performance evidence that have been found to influence the likelihood of failure either adversely or beneficially.
Robustness	The ability of a structure to sustain adverse and unforeseen events and limit local damage to an extent that is not disproportionate to the cause.
Safety-critical application	Application in which the failure of a fixing can (BS 8539): ■ result in collapse or partial collapse of the structure ■ cause risk to human life ■ lead to significant economic loss. Significant economic loss includes disproportionate loss of function or availability of elements of the transport network.
Safety-critical fixing	A fixing used in a safety-critical application.
Screening	Initial differentiation between safety-critical and non-safety critical fixings.
Substrate	Material of a structure into which a fixing is installed. See also *Base material*.
Steady state	A state in the management of safety-critical fixings where it is not practicable or useful to gather more information about a fixing, and the risk is tolerable. Periodic reviews are carried out to confirm there are no significant changes that require action.

Tests to determine the allowable resistance	Used before the installation of fixings to validate that the type of the proposed fixing is suitable for use in the substrate and to determine the allowable resistance. The test fixings are not incorporated into the works.
Transition period	The initial period in the management of safety-critical fixings following the implementation of the recommendations in this guide, which reflects the increasing availability of information as investigations are carried out. During this time, the risk review will be an iterative process and will be revisited as more information becomes available.
Workbank	Set of proposed actions to be carried out to the asset, including actions to mitigate risks.

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Abbreviations and acronyms

ADEPT	Association of Directors of Environment, Economy, Planning and Transport
AIP	Approval in Principle
ALARP	As low as reasonably practicable
BIM	Building Information Modelling
CDM2015	Construction (Design and Management) Regulations 2015
CFA	Construction Fixings Association
DMRB	Design Manual for Roads and Bridges
DoP	Declaration of Performance
EAD	European Assessment Document
EOTA	European Organisation for Technical Approval
ETA	European Technical Assessment (formerly European Technical Approval)
ETAG	European Technical Approval Guideline
ETICS	External Thermal Insulation Composite System
EN	EuroNorm (European Standard)
HSE	Health and Safety Executive
M&E	Mechanical and electrical (equipment)
prEN	Pre-norm (draft European Standard, not yet issued)
ROGS	The Railways and Other Guided Transport Systems (Safety) Regulations 2006
SCF	Safety critical fixing
SCOSS	Standing Committee on Structural Safety
SFAIRP	So far as is reasonably practicable
TAB	Technical approval body

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Notation

This guide uses the following verbs to take particular meanings, in accordance with practice in European and British standardisation:

- **'Shall'** means a requirement strictly to be followed to conform to the guide and from which no deviation is permitted. This publication details guidance so 'shall' is seldom used.
- **'Should'** gives a recommendation, ie a particularly suitable possibility or a preferred course of action. This guide includes numerous recommendations expressed using 'should'. Subject to asset owner requirements and any relevant contractual provisions, alternative approaches could be appropriate where technically justified.
- **'May'** means that the method presented is permitted or is acceptable, but alternative methods could be adopted.
- **'Can'** is used for statements of possibility and capability. It is not used as an alternative to 'may' and the two verb forms are not interchangeable. It also means that something is possible or is factual, but does not indicate whether it is permissible.

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Part 1 Introduction and context

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1 Introduction

Summary

Fixings are widely used in construction and include those that are safety-critical and non safety-critical. The incorrect performance of safety-critical fixings contributed to a number of high-profile structural failures. This guide aims to improve the management of safety-critical fixings and highlight how good design and installation can minimise risks in-service.

1.1 SCOPE

This guide is targeted towards transport infrastructure, where fixings are widely used in construction. The principles given may also be used for other applications. A wide variety of fixings are available, but they all allow for the secure attachment of a fixture to the base material.

Fixings can be used in safety-critical and non-safety critical applications. Safety-critical applications of fixings are those in which the failure of fixings can:

- result in collapse or partial collapse of the structure
- cause risk to human life
- lead to significant economic loss, including disproportionate loss of function or availability of elements of the transport network.

Examples of safety-critical applications include attachment of ceiling panels in tunnel roofs, attachment of ancillary equipment including overhead signs and communications equipment to walls and structures, attachment of parapets and gantries, vehicle restraint systems, temporary applications where failure of the fixing could affect the safety of the public or the operation of the asset or transport network.

Applications that could be considered as non-safety critical include signs attached to walls, overhead cable trays with high redundancy, mammal ledges within culverts. CIRIA C777 provides information on general fixings for selection and management.

This guide covers post-installed anchors using resin or cement-based grouted systems and mechanical fixing systems, installed into concrete and masonry substrates. It does not cover rock bolts, cast-in attachments, fall-arrest systems and structural connections such as bolts and welds. Fixings installed into rock are not covered by the design requirements, but the management techniques that are proposed may be applicable.

This guide is applicable to the UK and Ireland. It is primarily intended for transport infrastructure, including highways, railways, light rail/metro/underground rail, canals and waterways. The principles may also be used for other applications.

1.2 BACKGROUND

Correctly designed and installed fixings, subject to an appropriate maintenance regime, have a significant role to play in the safe, efficient and cost-effective operation of transport infrastructure. However, in recent years a series of failures around the world has highlighted the potential risks associated with the use of fixings in safety-critical applications.

- On 10 July 2006 in Boston, Massachusetts a precast concrete tunnel ceiling panel fixed and supported with resin anchors collapsed and one person was killed.
- Part of an ancillary drainage structure inside Network Rail's Balcombe Railway Tunnel collapsed in 2011. Various aspects of the design, installation and management of the fixings into the tunnel structure were cited as causal factors. This has been reported by the Rail Accident Information Board (RAIB).

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- Part of a Japanese tunnel suspended ceiling collapsed in early December 2012. Anchor bolts holding suspended ceiling panels pulled out. About 500t of concrete panels fell over a length of 140 m, resulting in nine fatalities. Design errors, deterioration of the concrete and lack of inspections were noted as contributing to the failure.

The Standing Committee on Structural Safety (SCOSS) has also headlined the failure of various fixing and ceiling systems, in buildings and civil engineering structures.

The causes of failures involving fixings include combinations of some or all of the following factors:

- poor design
- selection of inappropriate materials
- bad installation practice
- poor installation supervision
- lack of testing
- overloading
- exposure to loading outside design parameters
- deterioration of fixings and substrates.

Lack of regular inspection and maintenance can also contribute in failing to detect and control causes of failures.

1.3 AIMS OF THE GUIDE

This guide aims to provide nationally applicable information that covers the management of safety-critical fixings and how activities at other life cycle stages, including the design of fixings, influence these management activities.

It is aimed at competent practitioners responsible for the management of assets, including those specifying the asset management regime, delivering maintenance activities and those involved in design of structures and fixings.

The objectives are to:

- improve the management of safety-critical fixings (on transport infrastructure)
- provide a framework to identify high-risk fixings
- suggest actions to manage the risk of failure of safety-critical fixings
- recommend the minimum information and records to be collected:
  - during operation of the asset
  - during design, installation and testing
- recommend the minimum information to be retained on the asset record to enable management decisions to be made
- highlight considerations in design that could reduce risks in service
- provide reference to other applicable standards and guidance.

Note that this guide provides good practice. It is not mandatory, unless specified by the asset owner, and should not be considered in isolation, but taken into consideration along with other published documents on the management of transport infrastructure assets.

1.4 NAVIGATION

The guidance is structured in three parts, and an outline of the content is provided in **Table 1.1**.

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Table 1.1 Chapter details

Chapter		Details
Part 1: Introduction and context		
1	Introduction	Sets out the background to the guide, aims, scope and navigation.
2	Types of fixing	Introduces common applications of fixings and the different types of fixings that are available.
3	Context	Presents the context within which fixings are managed, including legislative and statutory requirements, CE marking and further references and sources of information.
Part 2: Management of existing fixings		
4	Management context and concepts for existing fixings.	Describes the management process for existing fixings, including key concepts and guiding principles, implementation, managing assets in service and managing incidents.
5	Management process for existing fixings	Presents the risk review, with screening for safety-critical fixings, a framework for identifying high risk fixings and a model for determining appropriate actions to manage the risk associated with populations of fixings.
6	Risk review	Covers work planning and implementation and discusses prioritisation of works within fixings and between fixings and other asset types.
7	Investigations	Describes the types of investigation including desk study, inspections, load test and intrusive investigations. Many asset owners may initially have limited information regarding fixings on their asset stock and investigations are likely to be needed during the transition period. Inspection requirements should be incorporated into normal management of the asset.
8	Interventions	Describes the types of intervention which are available to mitigate risk from fixings, including removal of fixings, enhancing robustness and replacing fixings.
9	Interim measures	Describes interim measures which are required if there is an unacceptable risk after prioritisation and before an intervention can be undertaken.
10	Managing information	Discusses managing information about fixings including the information to be collected and stored for safety-critical fixings, how this can link with an asset information system, and feedback and improvement activities.
Part 3: Design and installation of new fixings		
11	Management context and concepts for new fixings	Introduces the design and installation process.
12	Achieving confidence in design	Covers design of new fixings. It discusses fixing design in the context of the overall structural system, the design of the fixing system and selection of a fixing. Recommendations are made for design to facilitate future management of the fixing and design for robustness. Confidence in design should be provided through technical assurance processes. Full design records should be provided to enable effective management of the fixings in future.
13	Achieving confidence in installation	Covers installation of fixings, including assurance of the installation through supervision and testing, and the records which are required. Quality of installation is vitally important to achieve satisfactory performance of fixings.
Appendices		
A1	Applications of safety-critical fixings	Categorises uses of fixings.
A2	Overview of fixing types	An overview of the different fixing types and their characteristics.
A3	Marking of fixings	Discusses CE marking of fixings and the system of ETAs.
A4	Risk factors	Details and examples of the risk factors that can influence the likelihood of failure of a fixing.
A5	Examples of screening	Screening of safety-critical and non-safety critical fixings.
A6	Content of asset information systems	Categories of asset information required to manage fixings effectively and how this could be structured in an asset information system.
A7	Inspections	Checklist of features to be included in inspections of fixings, and how these related to the risk factors.
A8	Sample model for assessment of risk	A sample scoring model for assessing risk numerically.

The guide contains references throughout and a further reading section to help the reader.

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2 Types of fixing

Summary

Fixings are used in a wide range of applications and are available in many types. An understanding of the different varieties of fixing is important in understanding the risks presented. The two main categories of post-installed fixing are mechanical and bonded.

2.1 APPLICATIONS OF FIXINGS

Fixings can be used in a wide variety of applications (see **Figure 2.1** and **Appendix A1**), including:

- structural elements, such as gantries and connections using post-installed bars
- secondary elements, such as canopies and access walkways
- cladding systems
- support of ventilation equipment
- support of electronic equipment, such as communications and public display
- lighting
- services
- signage.

2.2 CATEGORISATION OF FIXINGS

There are many different types of fixing, which offer different characteristics and different installation requirements (see **Figures 2.2** and **2.3**). An understanding of the different types of fixing is important in understanding the risks presented by safety-critical fixings.

There are two main categories of post-installed fixing:

- Mechanical fixings rely on friction or mechanical interlock in order to achieve the anchorage. They include expansion, undercut, screw, plastic, driven.
- Bonded fixings consist of a structural element inserted into a pre-drilled hole which is filled with a bonding material. Bonding agents can include cementitious material and resins.

A more comprehensive description of the different types of fixing and their characteristics is provided in **Appendix A2**.

Where fixings can be grouped into families with common characteristics it can be most effective to manage them as a population. Relevant families of fixings may be defined based on fixings that share the same characteristics, for example, fixings of the same type in similar environmental conditions. Further information is provided in **Section 4.7**.

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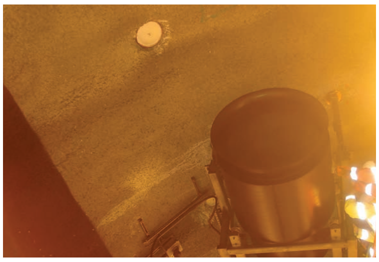
Tunnel ventilation and information systems


Tunnel ventilation fan


Gantry attached to bridge parapet


Post-installed parapet fixing


Bridge collision protection beam


Bridge fascia units


Sign fixed to bridge


Utility suspended from bridge deck


Infill panels on bridge soffit


Cable trays suspended from station canopy (could be non-safety critical)

Over-road advertising screen

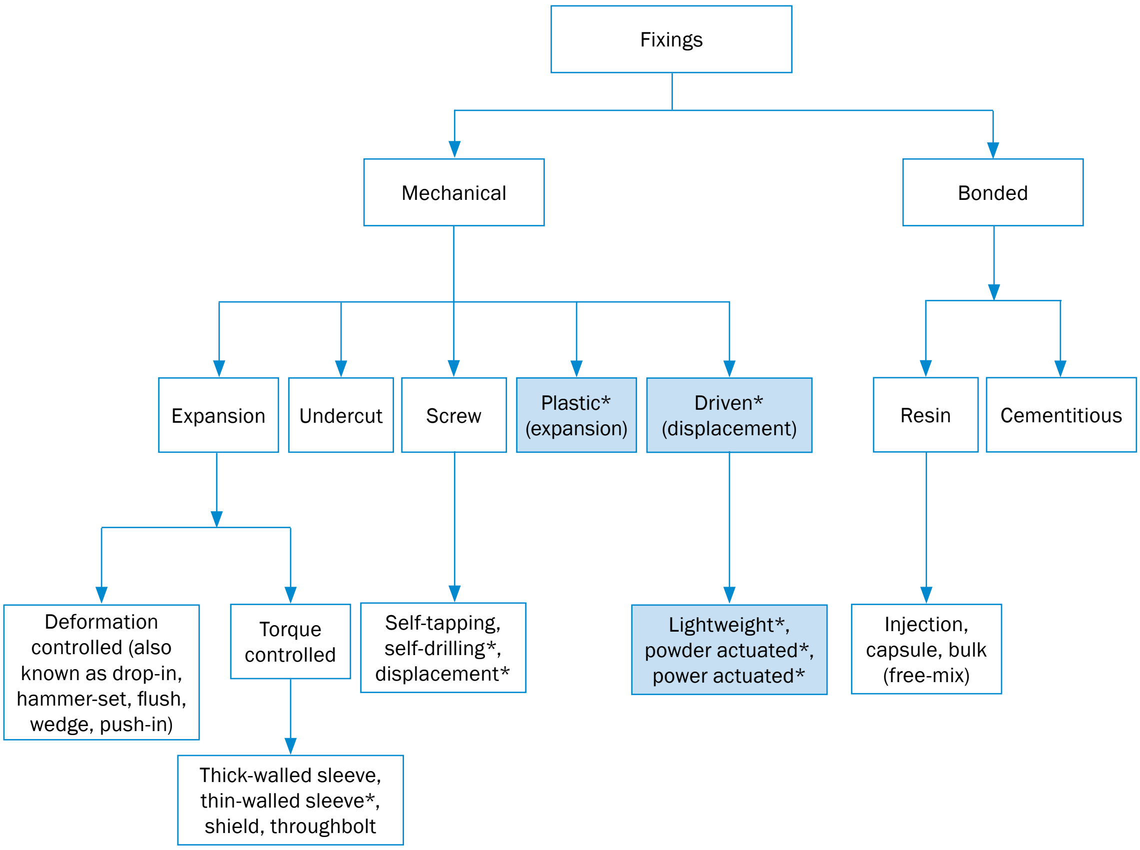
Suspended advertising panels


Lightweight sign, lighting and bracket fixed to bridge spandrel


Cladding system in underpass


Ventilation system in bus depot

Figure 2.1 Applications of safety-critical fixings



Note

* Fixing type unlikely to be used in safety-critical application.

Figure 2.2 Categorisation of fixing types

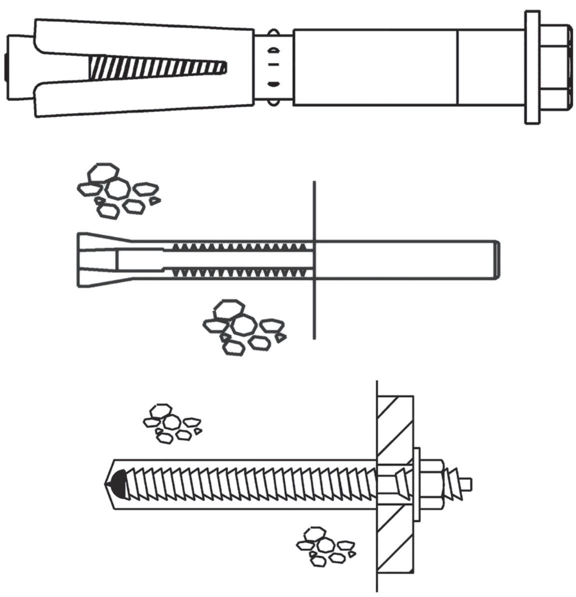


Figure 2.3 Examples of different types of fixing

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3 Context

Summary

Asset owners operate under general legal duties and specific duties and powers, which can include health and safety legislation, highway and railway legislation. Fixings are a construction product and are subject to the Construction Products Regulation 305/2011. CE marking indicates that a fixing has undergone a rigorous set of type-tests to demonstrate its performance, but care is still needed that an appropriate fixing is selected for a particular application.

3.1 LEGISLATIVE AND STATUTORY REQUIREMENTS

Asset owners typically operate under general legal duties and specific duties and powers. The applicable legal duties depend on the legal framework within a country. This section highlights generally applicable principles within which safety-critical fixings should be managed.

A general duty of care can exist under case law. Where a duty of care is demonstrated to apply and to have been breached, then a claim for negligence can be successful.

Specific legislation can place duties on asset owners. For example:

- Provide for a safe way of carrying out work. In Great Britain, the primary legislation is the Health and Safety at Work Act 1974.
- Make suitable arrangements for managing a project. Eliminate, reduce or control foreseeable risks that can arise during construction work (including maintenance) and use. In Great Britain, this comes under the Construction (Design and Management) Regulations 2015 (CDM2015).
- For railways in Great Britain, carry out risk assessments and put in place the measures identified as necessary to make sure that the transport system is run safely, under The Railways and Other Guided Transport Systems (Safety) Regulations (as amended) 2006 (ROGS 2006).
- Duty to maintain highways. In England and Wales, the Highways Act 1980 defines the main statutory duties of highway authorities, which includes a duty to maintain highways maintainable at public expense in a safe condition. Equivalents in other countries are the Roads (Northern Ireland) Order 1993, and the Roads Act (Scotland) 1984.
- Secure the expeditious movement of traffic. In England and Wales, the Traffic Management Act 2004 requires that traffic authorities secure the expeditious movement of traffic on the authority's road network.

A range of other legislation can be applicable and can cover matters such as health and safety, roads and street works, environmental protection, disability discrimination, wildlife and countryside, freedom of information etc.

A detailed summary of legislation applicable to highway infrastructure in the UK is provided by the UK Road Liaison Group (2016).

3.2 CE MARKING AND EUROPEAN TECHNICAL ASSESSMENTS

A CE mark on a product means that the manufacturer takes responsibility that the performance of the product is the same as the performance declared for the product in accordance with a particular European technical specification. Where a product is CE marked, public authorities cannot require any additional marking, certificates or testing of the product.

Fixings are a construction product and are subject to the Construction Products Regulations (Regulation (EU) 305/2011) (CPR 2011), which took effect from 1 July 2013, and includes provisions for CE marking.

Before CPR 2011 came into effect, fixings were subject to the Construction Products Directive 89/106/EEC. This Directive included similar provisions, but there were differences in terminology and detail.

There is no harmonised European technical standard for fixings, so fixings are covered by a series of European Assessment Documents (EADs) (formerly European Technical Approval Guidelines [ETAG]) which define the essential characteristics of the fixings and the methods and criteria for assessing the performance of the fixing against these characteristics.

A fixing, which is covered by a EAD can go through a process of ETA, which allows a manufacturer to issue a Declaration of Performance (DoP) for a fixing and apply a CE mark.

The significance of CE marking is that the fixing has undergone a rigorous set of type tests to demonstrate its performance under a variety of conditions, as defined in the EAD, and that the manufacturer operates a quality control system to verify that the fixing achieves the tested performance.

So, a higher degree of confidence can be placed in fixings that have a CE mark, than in those that do not. However, care is needed that the correct fixing is selected for a particular application, as it is entirely possible to select an appropriately CE marked fixing.

A more comprehensive description of CE marking and the means of achieving it is provided in **Appendix A3**.

Box 3.1 Identifying an incorrectly selected CE-marked fixing

A CE-marked fixing is selected for installation in the soffit of a reinforced concrete bridge slab, in order to suspend a sign. The fixing is qualified to the correct EAD for metal fixings in concrete (EOTA, 2016a).

An independent design review identifies that the wrong option for the fixing has been specified. The selected fixing is qualified to option 7 (see Table 1.1 of EOTA, 2016a), use in uncracked concrete. However, the bridge soffit will be cracked concrete, so an option applicable to cracked concrete (such as one of options 1 to 6) should have been chosen.

3.3 REFERENCES AND SOURCES OF INFORMATION

This guidance complements a wide range of published material covering design, installation, and testing of fixings, and broader guidance on the management of structures. It is not intended in this guidance to duplicate information, which is provided elsewhere.

Complementary documents and sources of information include the accompanying guide CIRIA C777 (2018), BS 8539:2012, CFA (2012), Collins *et al* (2017) and the Construction Fixings Association (CFA) website.

Construction Fixings Association: www.the-cfa.co.uk

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Part 2 Management of existing fixings

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4 Management process and concepts for existing fixings

Summary

The recommended management process for existing fixings includes cyclical stages of risk review, work planning and work implementation. The process is based on a set of guiding principles which describe the key issues in the management of safety-critical fixings. Risk reviews should occur periodically during steady state asset management and as required when triggered by events or incidents. An implementation plan should be established and the plan may include a transition to the recommended process and alignment with a framework for asset management.

4.1 IMPROVING THE APPROACH TO MANAGEMENT OF SAFETY-CRITICAL FIXINGS

The history of known failures involving safety-critical fixings indicates the need to improve the approach to management. A number of accident reports have been cited in NTSB (2006), Baxter (2012), RAIB, (2014), MLITT (2013), Cole (2017) and Simpkins (2016).

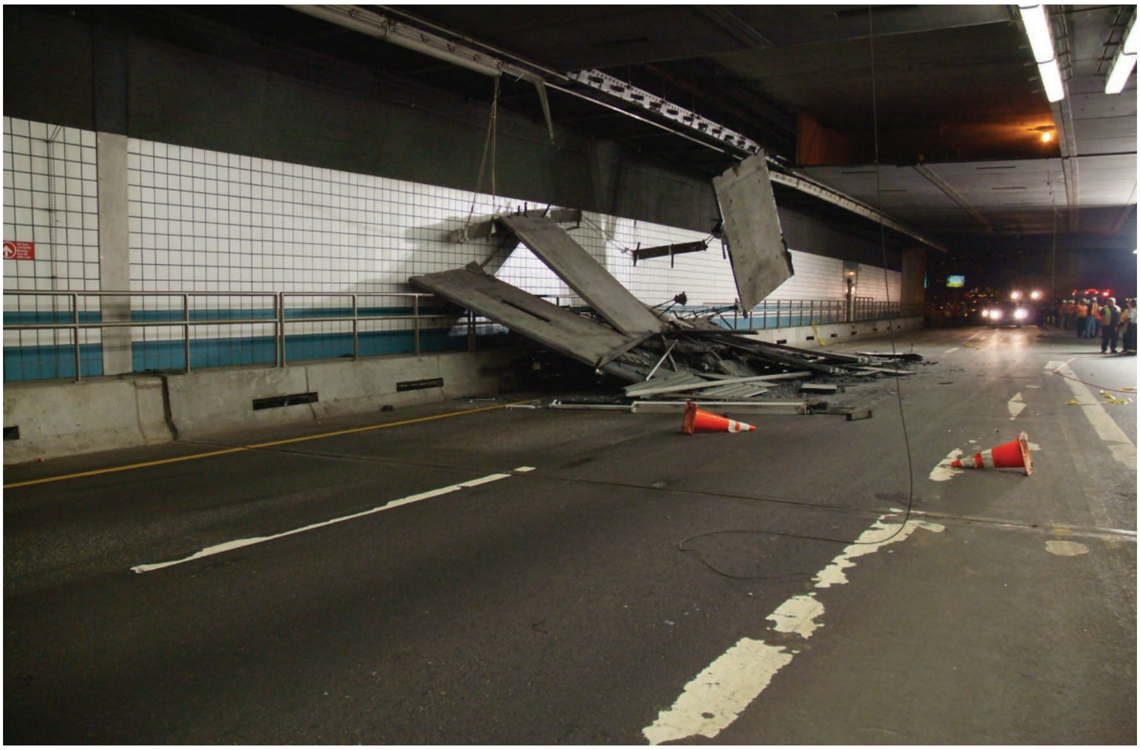

Figure 4.1 Collapse of a suspended ceiling, Boston USA (courtesy US National Transportation Safety Board)

In the past, post-installed fixings have been used on a 'fix and forget' basis, so information held about fixings can be limited. If there is a limited knowledge, it can be challenging to demonstrate that the risk presented from fixings is tolerable.

This guide provides recommendations to address specific issues for the management of safety-critical fixings.

An overview of the management process is shown in **Figure 4.2**, including navigation to the relevant sections of this guide, including topics on risk review (**Chapter 5**), work planning and implementation (**Chapter 6**), investigations (**Chapter 7**), interventions (**Chapter 8**), interim measures (**Chapter 9**) and asset information (**Chapter 10**).

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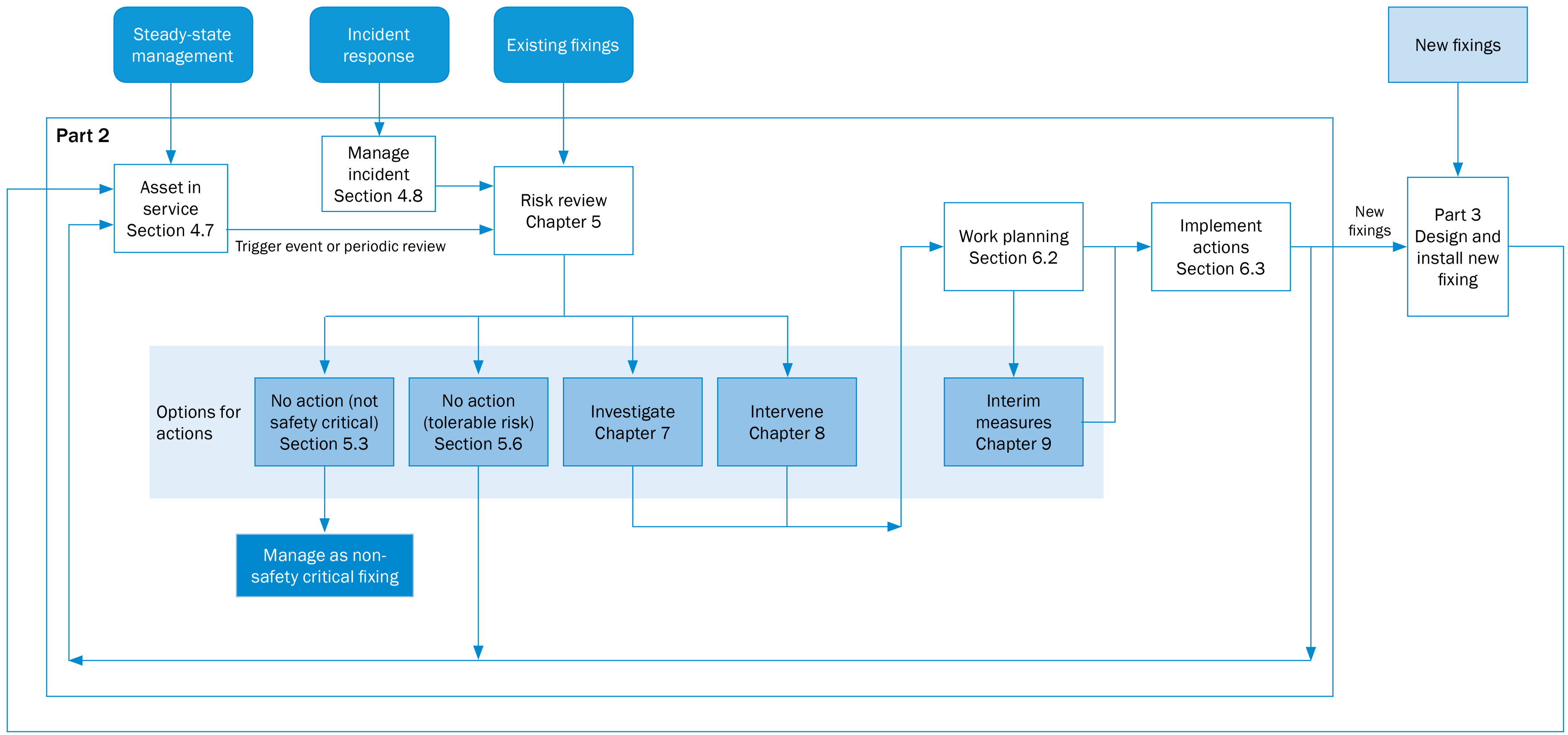

Figure 4.2 Overview of management process for safety-critical fixings

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4.2 SUMMARY OF RECOMMENDATIONS

This guide includes seven recommendations on how to apply the information and six key recommendations for fixings in service. The recommendations are summarised in **Tables 4.1** and **4.2** and are explained in more detail in relevant sections.

Table 4.1 Recommendations on how to use this guidance

Recommendation		Sections
1	Asset owners should produce a plan based on the recommendations of this guide, including defined timescales	4.5
2	Management responsibility for fixings should be defined	4.5.1, 4.5.2
3	An initial risk assessment should be undertaken to establish the overall level of risk presented by SCF and identify priority actions	4.5.1, 5
4	Basic inventory information about the number and location of fixings should be captured as a priority	4.5.1, 5.2
5	Asset owner policies and processes should be updated to include requirements for managing SCF	4.5.1
6	An asset information system, which is capable of storing and retrieving adequate information about SCF, should be established	4.5.1, 10.2
7	Relevant staff and suppliers should be briefed on need for and approach to managing SCF	4.5.1

Note
SCF = safety-critical fixings

Table 4.2 Recommendations for fixings in service

Recommendation		Sections
8	A periodic and event-triggered risk review process should be used to determine actions to manage the risk from SCF	5.1
9	A formal record should be retained of decisions taken about SCF	5.7
10	Actions should be undertaken in a prioritised order with the objective of achieving a steady state where risk is tolerable	6.1
11	Fixings should be included in inspection activities and associated reporting	7.3.1
12	Interim measures should be undertaken when actions cannot be undertaken immediately and a fixing presents an unacceptable risk	9.1
13	Knowledge about the performance of fixings should be shared and, in particular, failures and near misses involving fixings should be reported	10.3

Note
SCF = safety-critical fixings

4.3 GUIDING PRINCIPLES TO MANAGE SAFETY-CRITICAL FIXINGS

This guide is based around a series of guiding principles, which are related to and expand on the recommendations in **Tables 4.1** and **4.2**. In contrast to the recommendations, which describe 'what' should be done, the guiding principles explain 'why' issues exist for safety-critical fixings.

1 Post-installed fixings have often been used at the interfaces between different asset classes, with different 'owners' either in the same or in different organisations. There is potential for ambiguity, so it is important that it is clear who has responsibility for the management of all safety-critical fixings.

2 It is important to recognise the limitations on resources and the need to prioritise asset management investment across all elements of an asset owner's stock. It may be necessary to adopt a prioritised transition plan to manage safety-critical fixings, before a steady-state management regime can be reached.

3 Where fixings can be grouped into families with common characteristics it can be most effective to manage them as a population, for example so that destructive load testing on a sample of fixings could be used to inform a risk review for the rest of the family, taking account of statistical aspects.

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4 The load-carrying capacity of fixings can reduce in time due to deterioration or there can be external changes affecting the fixing, so they should be examined within a regular cycle of inspections. Significant observed changes should trigger a review of risk and possible investigations or intervention.

5 Decision making on the adequacy of installed fixings should be risk based, considering the consequence and likelihood of failure.

6 Safety-critical fixings are those with a high potential consequence of failure.

7 Before making a decision on the adequacy of an installed safety-critical fixing it can be appropriate to undertake investigations to gain more information about it, particularly when the information held is limited.

8 Some information about installed fixings is difficult or even impossible to obtain. Sometimes it will be necessary to take decisions about the adequacy of fixings accepting some residual uncertainty.

9 If the risk of allowing a fixing to remain in service is considered too high, a remedial intervention will be required to reduce the risk to a tolerable or broadly acceptable level.

10 If the time required to carry out further investigation or an intervention will pose an unacceptable level of risk, interim measures should be implemented.

4.4 ASSET MANAGEMENT FRAMEWORK

Asset management is defined in BS ISO 55000:2014 as the co-ordinated activity of an organisation to realise value from assets.

Where asset owners already operate a framework for asset management, or parts of such a framework, then the recommendations for managing safety-critical fixings should be incorporated within the framework for asset management. Similarities between the processes, information requirements and actions taken for safety-critical fixings and for other asset types can lead to efficiencies in adopting the recommendations.

Where asset owners do not have well-developed frameworks for asset management, then the recommendations for managing safety-critical fixings should be adopted in their own right.

The recommendations are aligned with the general principles of asset management and could be incorporated into an existing or future framework for asset management.

This guide deals solely with fixings. However, it is recognised that asset owners will have various organisational objectives and that other asset types, components or risks will present demands on the asset owner. The asset owner should establish the relative priority of investing to manage safety-critical fixings compared with investing to manage risk from other sources. Prioritisation can occur within the framework for asset management, where such a framework is present.

Further information for asset management is given in UK Roads Liaison Group (2013 and 2016).

4.5 IMPLEMENTATION

Recommendation 1. Asset owners should produce an implementation plan for the recommendations of this report, including defined timescales.

4.5.1 Implementation plan

The implementation plan should describe:

- the required actions and those responsible for their completion
- a communication strategy to inform affected staff and suppliers

- a programme
- funding required.

Initial steps in the implementation plan should include **Recommendations 2 to 7**:

Recommendation 2. Management responsibility for fixings should be defined (see Section 4.6.2).

Recommendation 3. An initial risk assessment should be undertaken to establish the overall level of risk presented by safety-critical fixings and identify priority actions (see Chapter 5).

Recommendation 4. Basic inventory information about the number and location of fixings should be captured as a priority (see Section 5.2).

Recommendation 5. Asset owner policies and processes should be updated to include requirements for managing safety-critical fixings.

Recommendation 6. An asset information system which is capable of storing and retrieving adequate information about safety-critical fixings should be established (see Section 10.2).

Recommendation 7. Relevant staff and suppliers should be briefed on need for and approach to managing safety-critical fixings.

The asset owner should update relevant policies and processes, for example:

- inspection requirements
- asset information requirements
- instructions on the risk review process
- prioritisation requirements for fixings
- instructions for transition tasks under the implementation plan.

New policies and processes should be disseminated to relevant staff and the supply chain.

4.5.2 Management responsibilities for fixings

Post installed fixings have often been used at the interfaces between different asset classes, with different 'owners' either in the same or in different organisations. There may be some ambiguity, so it is important to be clear who has responsibility for the management of all safety-critical fixings.

The management responsibility should include:

- ownership of policies and processes covering safety-critical fixings
- confirming that the basic inventory of fixings is complete and, if necessary, undertaking further investigations where information is incomplete
- screening of fixings to determine if they are safety critical
- making decisions about the level of risk presented by fixings and taking actions to mitigate those risks
- inspections of fixings on a periodic basis
- asset records for fixings.

The owner for fixings can be different to the owner of the fixture or the underlying asset, and can belong to a different organisation. For example:

- The fixings of a highway height restriction sign on a railway overbridge are usually the responsibility of the highway authority even though the substrate is usually a railway asset.
- A fixture (such as an information display or ventilation fan) is owned by a mechanical and electrical (M&E) team, but inspection responsibility rests with the structures team under the same overall asset owner because the fixture is fixed to a structures asset.

Responsibility for fixings may be subdivided by the asset owner, for example, based on asset type such as bridges and tunnels. The asset owner should make sure there is no ambiguity about their ownership, for example, in the case of 'unknown' fixings where their presence may not be recorded.

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4.5.3 Transition and steady state

In recognition of limitations on resources and the need to prioritise asset management investment across all elements of an asset owners stock, it may be necessary to adopt a prioritised transition plan to manage safety-critical fixings, before a steady-state management regime can be reached.

Actions can be broadly classified into two groups:

1 Gathering information (ie investigations, see **Chapter 7**).

2 Addressing unacceptable risks (ie interventions, see **Chapter 8**).

The transition period reflects the increasing availability of information about fixings. Initial actions during this time may be concerned with gathering information. During the transition period, the risk review will be an iterative process and will be revisited as more information becomes available.

A steady state is reached when it is not practicable or useful to gather more information about a fixing, and the risk is tolerable. Once a steady state is achieved, the risk review should be regularly revisited to confirm there are no significant changes that require action. Significant changes can include those to condition or new information that alters the understanding of risk factors.

4.6 FAMILIES OF FIXINGS

Where fixings can be grouped into families with common characteristics it can be effective to manage them as a population, for example so that destructive load testing on a sample of fixings could be used to inform a risk review for the rest of the family, taking account of statistical aspects.

The risk review process may be undertaken either for families or individual fixings. For brevity, the terminology 'fixings' and 'a fixing' is used in the following sections, but the approach should be taken equally as applying to 'family/families of fixings'.

Relevant families of fixings may be defined based on fixings that share the same characteristics, ie fixings of the same type in similar environmental conditions. The concept of families of fixings can provide useful simplification and avoid repetition. However, care should be taken not to over-simplify, for example, where a small number of high-risk fixings could be overlooked.

The composition of a family of fixings may vary during the transition period depending on the level of information available. Family groupings may become more refined as more information becomes available. The example at the end of **Chapter 6** illustrates how this refinement can occur.

Where actions are required for a family of fixings, then it can be appropriate to take action as a programme of work rather than managing as individual work items.

4.7 ASSET IN-SERVICE

The asset owner should define maintenance processes and activities for safety-critical fixings in-service, including inspection, awareness and risk review.

The load carrying capacity of fixings can reduce in time due to deterioration or there may be external changes affecting the fixing, so they should be examined within a regular cycle of inspections. Significant observed changes should trigger a review of risk and possible investigations or intervention. Guidance on inspections and on significant changes is provided in **Section 7.3**.

Asset owners should take steps to remain aware of industry practice regarding fixings and of external events, incidents or failures, which can lead to updates of good practice regarding fixings. Further guidance is provided in **Section 10.3** (asset information).

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Risk reviews (see **Chapter 5**) should be undertaken on a periodic basis and when triggered by an event. Trigger events can include:

- availability of further information, for example, following completion of investigation work
- poor condition or defects identified during an inspection
- an incident involving fixings
- external events, incidents or failures involving fixings
- updated knowledge about risk factors affecting fixings, for example, industry alerts produced by SCOSS or circulated through industry bodies.

4.8 MANAGING INCIDENTS INVOLVING SAFETY-CRITICAL FIXINGS

Where an incident occurs involving a safety-critical fixing, then the asset owner should respond to the incident. The specific response will depend on the location of the incident and the asset owner's incident procedures. Typical steps include:

- make safe the asset which was affected by the incident
- understand the causes of the incident
- review locally whether other safety-critical fixings on the same asset could be affected by similar causes
- review whether other safety-critical fixings on similar asset types could be affected by similar causes
- review whether there is a need to update the risk factors used in the risk review
- consider undertaking a general or targeted risk review for safety-critical fixings that could be affected by new information about applicable risk factors
- share knowledge about the cause of the incident with other asset owners (see **Section 10.3**).

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5 Risk review

Summary

The risk review lies at the heart of managing risk from existing fixings and is assisted by the availability of adequate records of the fixings. The risk review includes a screening stage to identify fixings that are safety critical. Risk is assessed based on consequence and likelihood of failure, with likelihood determined qualitatively by considering applicability of a set of evidence-based risk factors. The type of action to be taken should follow from the level of risk and whether the risk is tolerable to the asset owner.

5.1 OVERVIEW OF THE RISK REVIEW PROCESS

Recommendation 8. A periodic and event-triggered risk review process should be used to determine actions to manage the risk from safety-critical fixings.

The risk review for safety-critical fixings (see **Figure 5.1**) is the process of identifying and assessing risks to make informed decisions and determine appropriate actions. Further detail on each of the steps is provided in the following sections.

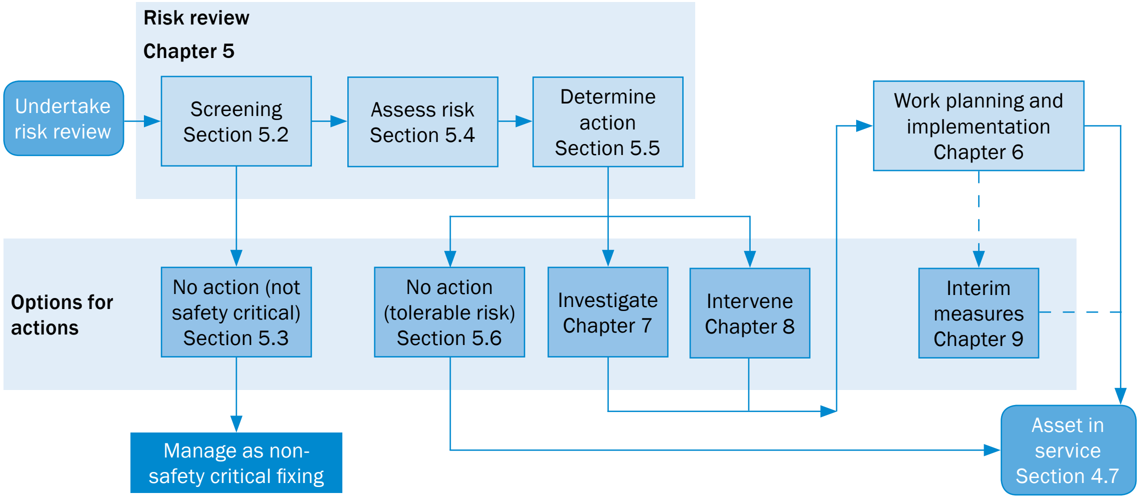

Figure 5.1 Risk review process

5.2 SCREENING

5.2.1 Purpose of screening

Screening has the following objectives, so that effort can be focused on safety-critical fixings:

- filter out non safety-critical fixings.
- identify areas where further investigation is required/is not required.

5.2.2 Basic inventory of fixings

Holding basic inventory information of the number and location of safety-critical fixings is a prerequisite for their management. Basic inventory information is also necessary to manage non-safety critical fixings.

Where this inventory is not complete, for example during the transition period, then screening may be used to prioritise likely higher risk safety-critical fixings, as follows:

1. Where fixings are known to be present, the screening classifies known fixings as safety-critical or non-safety critical.
2. Where it is unknown whether records are complete, the screening provides direction to complete the basic inventory of safety-critical fixings.

An example of an approach to develop the basic inventory of fixings is provided in **Box 5.1**.

Box 5.1 Example of approach to develop basic inventory of fixings

A particular asset owner has not historically held asset records about fixings and is concerned about the number of fixings that are present on its assets.

The owner chooses to focus its initial efforts on gathering information about safety-critical fixings, such as fixings supporting overhead signs. The owner conducts a desk study including review of virtual earth footage to identify the inventory of this type of safety-critical fixing.

The owner is aware that other non-safety critical fixings are present, such as those supporting wall-mounted information panels and suspended ceilings in buildings. The owner intends to gather inventory about these and other fixings, but as a low priority and through the course of normal scheduled inspections.

5.2.3 Classification as safety-critical/non-safety critical

Where basic inventory information is available for a fixing, then the screening questions in **Table 5.1** may be used to classify it as safety-critical or non-safety critical.

Where the answer is 'yes' to one or more questions, then the fixing should be classified as safety critical.

Where insufficient information is available to provide a definitive 'yes/no' answer then by default the fixing should be classified as safety critical. Actions should be undertaken, where possible, to gather relevant information and allow the screening exercise to be revisited.

Where more information becomes available later, then it can be possible that the result from the initial classification is downgraded.

Appendix A5 provides examples of applying **Table 5.1** to classify fixings as safety critical or non-safety critical.

Table 5.1 Screening questions

Question		Response
If the fixing failed…		
1	…is there potential for one or more people to be killed or seriously injured?	Yes/no
2	…is there potential for severe damage to one or more road vehicles/rail vehicles/floating vessels?	Yes/no
3	…is there potential for structural failure of one or more structural members?	Yes/no
4	…could failure of a single fixing lead to progressive failure of a larger area?	Yes/no
5	…would it cause closure of any of the following? ▪ road ▪ railway ▪ commercial waterway ▪ a principal pedestrian access to a building or facility ▪ a significant utility service.	Yes/no
6	…taking into account investigation and access arrangements, would it take longer than one week to restore normal operation of the network?	Yes/no

Note

Where the answer is 'yes' to one or more questions, then the fixing should be considered as 'safety critical'. The questions reflect the definition of a safety-critical fixing, which includes structural collapse, risk to human life, or significant economic loss.

Appendix A5 provides examples of the completion of this table.

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5.2.4 Identify further investigations

Where it is unknown whether records are complete, then investigations should be targeted at the likely locations of safety-critical fixings based on the asset owner's knowledge of their stock. Initially, this can be accomplished by considering broad families of fixings, based on the types of fixture supported. The classification of fixings given in **Appendix A1** may be used as a starting point, but should be supplemented to suit the types of asset managed by the asset owner.

Three questions may be used to identify appropriate actions, as shown in **Table 5.2**.

1 Is the family of fixings safety critical?

2 Are some of these fixings present somewhere on the asset stock?

3 Is basic inventory information available for these fixings?

An example showing the use of **Table 5.2** is provided in **Box 5.2**.

Table 5.2 Actions to complete basic inventory information about safety-critical fixings

Is the family of fixings safety critical?	Are some of these fixings present somewhere on the asset stock?	Is basic inventory information available for these fixings?	Action
✓	Not known	✗	No knowledge currently available about whether this type of fixing is present on the asset stock and could present a risk. Carry out general programme of investigation to determine whether this type of fixing is present and obtain basic inventory information.
✓	✓	✗	Some of these fixings are present on the asset stock, but locations are not known. Carry out targeted investigation to collect specific data on this type of fixing.
✓	✓	✓	Basic inventory information is available for this family of safety-critical fixings. Carry out more detailed risk review. Further investigation/intervention may be required to mitigate risk.
✗	Not known	N/A	No knowledge currently available about whether this type of fixing is present on the asset stock, but even if it is present then it is not safety critical. No need to collect data on this type of fixing to manage the risk of safety-critical fixings. However, information about the fixing is still necessary and relevant for the management of non-safety critical fixings.
✗	✓	N/A	This type of fixing is present on the asset stock, but is not safety critical. No need to collect further data on this type of fixing to manage the risk of safety-critical fixings. However, information about the fixing is still necessary and relevant for the management of non-safety critical fixings.

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Box 5.2 Example of determining actions to complete the basic inventory of safety-critical fixings

A particular owner has incomplete records of fixings on the network. A screening will be carried out for groups of fixings based on the type of fixture supported. Table 5.2 was applied for post-installed fixings supporting vehicle restraint systems. (Note that parapets can also be supported by cast-in bolts, which are outside the scope of this guide).

Figure 5.2 Post-installed parapet fixing

	Question	Response	Justification
1	Is the family of fixings safety critical?	Yes	Failure of the fixing could cause a serious injury
2	Are some of these fixings present somewhere on the asset stock?	Yes	Based on the asset owner's knowledge of their stock
3	Is basic inventory information available for these fixings?	No	

Action from the second line of Table 5.2:

- Some of these fixings are present on the asset stock, but locations are not known.
- Carry out targeted investigation to collect specific data on this type of fixing.

The owner needs to determine which structures have vehicle restraint systems and which of these systems have post-installed fixings. The first step may be completed by a desk study. The second step can require a programme of special inspections to confirm which structures have post-installed fixings rather than cast-in fixings. Once this information is available, the risk review should be revisited to determine the level of risk and decide on appropriate actions.

5.3 NON-SAFETY CRITICAL FIXINGS

An outcome of the screening can be that the fixing is classified as non-safety critical. A fixing previously classified as safety critical can be reclassified based on new information which has become available since a previous risk review.

Where a fixing is non-safety critical, then the fixing should be managed in accordance with good practice guidance such as CIRIA C777.

The management procedures for non-safety critical fixings should include a review following significant changes affecting the fixing and a mechanism for a fixing to be re-classified as safety critical. It is possible that circumstances can change and a non-safety critical fixing can become safety critical. Examples of such changes include:

- the fixture is changed and the new fixture applies larger actions
- change in use of the area surrounding the fixing, for example a change from limited maintenance access to open public access
- evidence of failures of similar types of fixings, which cause injury, death or significant economic loss, for example, a report of a significant new failure involving fixings.

5.4 ASSESSING RISK

5.4.1 Methods of assessing risk

Decision making on the adequacy of installed fixings should be risk based. Risk is assessed as the product of likelihood and consequence.

There is little statistical data on the likelihood of failure of fixings in service, so it is difficult to calculate the risk of failure quantitatively. A qualitative assessment of risk is recommended, for example, using a high/medium/low designation.

Various methods are available to determine the level of risk. The asset owner should select a method which is consistent with its overall approach to risk. The method shown in **Figure 5.3** based on a modified 3 x 3 matrix may be used.

The effort involved in the risk assessment method should be proportional to the risk and to the level of information that is available. Greater effort should be focused on the most significant risks.

Safety-critical fixings are those with a high potential consequence of failure, ie where failure of the fixing could lead to collapse of the structure, risk to human life or significant economic loss. Where these criteria do not apply and the consequence of failure is low, then the fixing is classified as non-safety critical as shown in **Figure 5.3**.

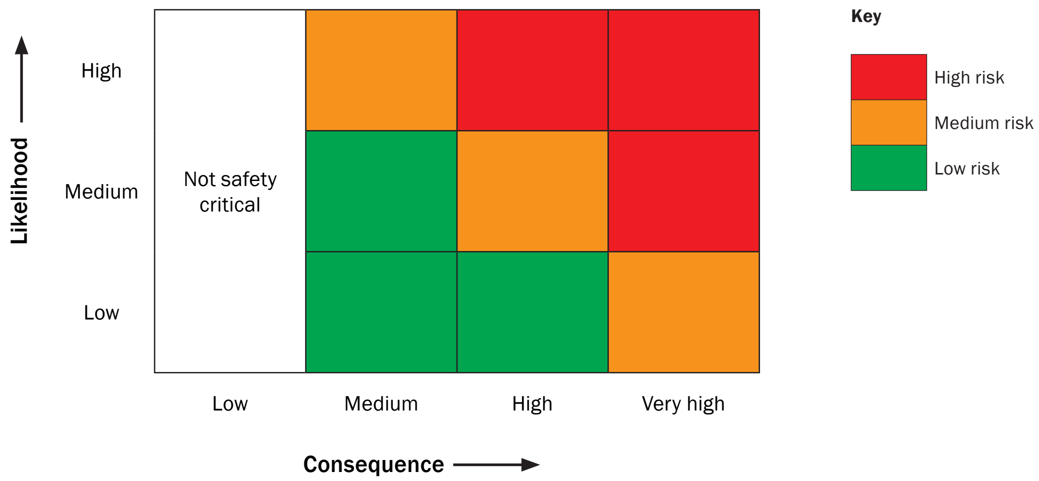

Figure 5.3 Risk matrix based on likelihood and consequence

During the risk assessment, it may become obvious that a specific fixing presents an immediate risk, for example, due to its condition or the presence of particular risk factors. Where there is an immediate risk, then the need to take action should be escalated. The required action may need to be undertaken as an emergency measure rather than waiting on completion of the full risk review and prioritisation process.

Some information about installed fixings is difficult or even impossible to obtain, and it may be necessary to take decisions about the adequacy of fixings while accepting some residual uncertainty. This can include having limited information on either likelihood or consequence or both, which can affect the risk assessment as outlined in this section.

Where incomplete information is available, then credible worst-case assumptions should be made and the precautionary principle should be adopted. Further guidance is available in HSE (2001a), which highlights that lack of scientific certainty should not be used as a reason for not taking preventative action.

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5.4.2 Information available for consequence but not likelihood

The consequence typically depends on the location of the fixture in relation to people and traffic (see **Section 5.4.4**) whereas likelihood depends on a more detailed understanding of the fixing and substrate materials (see **Section 5.4.5**). So, it can be easier to obtain information about consequence than likelihood.

Where information is available about consequence, but not likelihood, then it is possible to undertake a screening of the fixing as safety critical or non-safety critical. Limited prioritisation based on the consequence may also be possible, but the prioritisation may need to be refined once further information is available. **Figure 5.4** indicates how the risk matrix reduces where information is available about consequence, but not likelihood.

Figure 5.4 Reduction of risk matrix with limited information about likelihood

5.4.3 Information available for neither consequence nor likelihood

Where information is available neither for consequence nor likelihood, then the fixing should be treated as high risk. Action should be taken to gather further information such that a screening can be undertaken and a better understanding of risk obtained. **Figure 5.5** indicates how the risk matrix reduces where information is available neither for consequence nor likelihood.

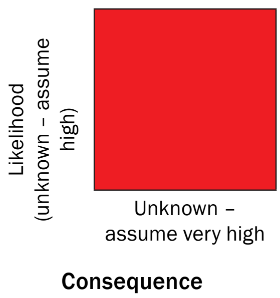

Figure 5.5 Reduction of risk matrix with limited information about likelihood and consequence

5.4.4 Assessing consequence

Consequence is the potential for harm if a fixing fails. It follows from the definition that failure of any safety-critical fixing has at least a significant consequence (ie collapse of the structure, risk to human life or significant economic loss).

Within this overall designation of significant consequence, it can be helpful to establish degrees of severity (ie medium, high, very high) to allow a gradation in the level of risk. Effort can then be targeted at the highest risk fixings.

The assessment of consequence depends mainly on the relative position of the fixture and people or traffic that may be affected by a failure. Information about the fixture position can be relatively straightforward to gather through desk study, photographic records or visual survey.

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Likelihood and consequence both include an evaluation of probability (see **Box 5.3**). The distinction between the two is:

- **Likelihood** is the probability of the failure occurring (ie the probability that the fixing fails).
- **Consequence** is the probability of harm arising from the failure (assuming the failure occurs).

Box 5.3 Example of differentiating between consequence and likelihood

> The consequence of failure of a fixing over a motorway should be assessed as higher than the consequence of failure of the same fixing over a rural road. This is because there is a greater volume of traffic using the motorway so a greater probability that harm will be caused if the fixing fails.
>
> If the fixings are the same (ie identical fixings supporting identical fixtures in the same circumstances) then the likelihood of failure is the same. There is an equal probability of failure whether they are over a motorway or over a rural road.
>
> If the circumstances are different, for example where there are greater buffeting actions due to faster and more frequent high vehicles (eg HGVs) using the motorway, then the actions applied to the fixings are different, so the likelihood can be different.

The level of effort expended on assessing consequence should be proportional to the benefit to be gained from the exercise. Greater effort may be beneficial where the following apply (conversely, lesser effort may be appropriate where the opposites apply):

- there are a large number of fixings
- information is available to assess likelihood and consequence
- there is a mature risk assessment process for fixings
- decisions on prioritisation are needed
- results need to be compared with other asset types.

A variety of factors may be included in the assessment of consequence. The asset owner should select the factors to align with their organisational strategic objectives and their overall framework for asset management.

Table 5.3 contains suggested factors that may be adapted as required to suit the needs of the asset owner, depending on the degree of complexity to be merited.

Appendix A8 presents a fuller numerical scoring system for consequence that may be used and adapted by asset owners. Note that other systems can be used or developed by the asset owner.

Table 5.3 Sample factors for assessing consequence

Topic area	Possible measures
Safety	■ number of people killed or seriously injured ■ potential damage to vehicles ■ potential damage to utilities and other services ■ proximity of fixture to people/vehicles ■ potential for fixing failure to lead to structural failure ■ potential for disproportionate collapse.
Functionality	■ nature/classification of route (eg strategic/local) ■ availability and length of diversion route ■ volume of traffic ■ length of time to restore normal network operation ■ political and reputational damage.
Environment	■ potential for pollution incident arising from fixing failure.
Financial	■ direct cost of remedial works ■ direct costs of access for remedial works ■ indirect costs of disruption to the network (overlaps with functionality topic) ■ third-party costs and claims.

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5.4.5 Assessing likelihood using risk factors

The likelihood of failure of a fixing is difficult to establish numerically because there are limited statistical records. Some failure modes of fixings are sudden with no warning, so the absence of previous failures does not necessarily provide assurance of future performance.

Evidence from known fixing failures has suggested a series of risk factors which affect the probability that intervention is necessary (see **Table 5.4**). The risk factors are based on past performance evidence that has been found to influence the likelihood of failure either adversely or beneficially. Further description of the risk factors is provided in **Appendix A4**.

The list of risk factors may be adapted based on the experience of the asset owner, in particular, considering problems previously experienced with specific combinations of fixture, fixing, actions and environment.

The assessment of likelihood should include judgement where there is uncertainty. In some cases it may be obvious that a risk factor applies. In other cases, it may not be possible to confirm based on available information. Judgement should be used as to whether a risk factor could apply.

It is not possible to provide guidance on the relative severity of the different risk factors due to the low number of recorded failures. However, all of the risk factors have contributed to some failures. Where a greater number of risk factors apply, then there is more cause for concern.

The effect of each risk factor on the overall likelihood may be assessed based on the available information using the following questions (see **Table 5.5**):

- Is information available about the fixing type, substrate and condition?
- Does the information provide positive confirmation about the risk factor?

Many of the risk factors require information about the behaviour of the fixing and substrate subjected to the applied actions, environmental conditions and potential long-term degradation.

Where available, design records can provide confirmation that certain risk factors do not apply or have been taken into account in the design. Further information may be needed to clarify other risk factors, for example, an inspection to confirm that a change in loading or condition has not occurred.

Even where formal technical approval is available, such as an ETA, the risk factors should be reviewed and it should be confirmed that the options set out in the technical approval fully cover the particular circumstances of the fixing.

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Table 5.4 Summary of risk factors on existing fixings

Risk factor		Likelihood (I/D)	Type of fixing
Design	Formal technical approval (eg ETA) including applicable actions	D	All
Installation	Poor quality of installation	I	All/resin anchor
	Overhead installation	I	Resin anchor
	Substitution	I	All
	Certification of installation	D	All
Actions	Shear rather than tension	D	All
	Sustained tension	I	Resin anchor
	Cyclic loading	I	All
	Vibrations	I	All/mechanical anchor
	Accidental/shock load	I	All
	Change in fixture/change in use	I	All
Environment	Wet/damp	I	All/polyester resin
	Corrosive environment	I	All
	Chlorides/marine environment	I	All
	High/low temperature including fire	I	All/resin anchor
	Masonry substrate	I	All/resin anchor
Robustness	High degree of redundancy	D	All
	Secondary restraint	D	All
	Exposure to sources of damage	I	All
Degradation	Not recently inspected/hidden	I	All
	Missing/failing fixings	I	All
	Distortion/movement	I	All
	Substrate degradation	I	All
	Fixing/fixture corrosion	I	All

Note

Further information is given in Appendix A4.

I = increase

D = decrease

Table 5.5 Effect of availability of information in assessing likelihood

Is information available about the fixing type, substrate and condition?	Does the information provide positive confirmation about the risk factor?	What does the information tell us about the risk factor?	Effect on likelihood	Potential action
✗	✗	No information	Assume high likelihood	Undertake general investigation. Target fixings where there is a greater probability that risk factors apply.
✓	✗	Uncertain whether risk factor applies	Make credible worst-case assumption about whether risk factor could apply and whether there is increased likelihood	Undertake targeted investigation on these fixings to confirm risk factors, or undertake intervention to mitigate unacceptable risks.
✓	✓	Risk factor applies	Increased likelihood	Undertake intervention to mitigate unacceptable risks. Further investigation is not beneficial for this risk factor.
✓	✓	Risk factor does not apply	Reduced likelihood	Confirm the absence of other risk factors, for example due to change in condition, degradation over time, poor installation quality.

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5.5 DETERMINING ACTIONS

The type of action to be taken for a fixing, or family of fixings, should be selected based on the level of risk. The following options for types of action are available:

- manage as non-safety critical fixing
- no action (tolerable risk)
- investigate (gain more information)
- intervene (action to mitigate unacceptable risk).

Actions (see **Figure 5.5**) may be selected based on the following questions:

- Is the fixing safety critical?
- Is the risk tolerable?
- Is the risk level increased because of cautious assumptions made due to lack of information?
- Is it viable to gain more information, which could reduce the risk level?

Before making a decision on the adequacy of an installed safety-critical fixing it may be appropriate to undertake investigations to gain more information about it, particularly when the information held is limited. For example, investigations could positively eliminate (or confirm) the presence of risk factors and reduce (or confirm) the risk level.

The benefit of obtaining further information should be identified before undertaking the investigation. For example, if there are significant access costs and a small number of fixings, then it may prove more cost effective to replace the fixings rather than expend significant effort attempting to gather further information.

Some information about installed fixings is difficult or even impossible to obtain. So, it may be necessary to take decisions about the adequacy of fixings accepting some residual uncertainty.

If the risk of allowing a fixing to remain in service is considered too high, a remedial intervention will be required to reduce the risk to a tolerable or broadly-acceptable level.

Further detail of potential investigation actions is provided in **Chapter 7** and of interventions in **Chapter 8**.

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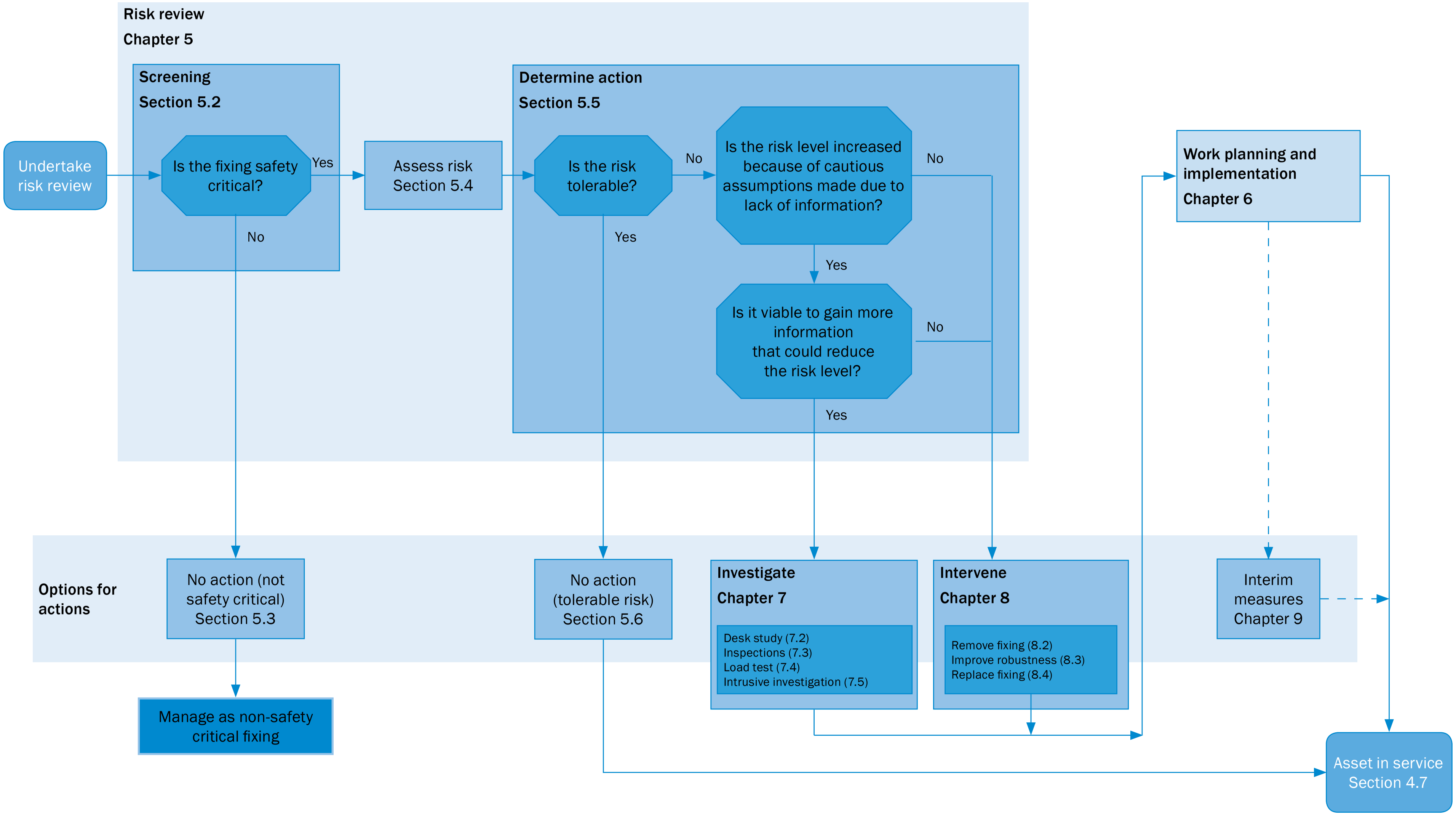

Figure 5.6 *Flow chart for determining the type of action*

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5.6 DETERMINING TOLERABLE LEVELS OF RISK

Where a fixing is classified as safety critical it is important to decide whether the level of risk is tolerable. This should be determined by the asset owner, based on the organisation's strategic objectives, risk appetite and overall framework for asset management. Judgement will be required due to the qualitative nature of the risk assessment.

Low-risk fixings may be characterised as having lower consequence and having low likelihood of failure, by the demonstrated absence of risk factors. Asset owners may consider low-risk fixings to be tolerable, although the viability of further practicable mitigating actions should be considered.

High-risk fixings may be characterised as having higher consequence and having one or more confirmed risk factors. Asset owners should consider high-risk fixings to be unacceptable and interventions should be undertaken. Further detail of potential intervention actions is provided in **Chapter 8**.

Where fixings are classed as (intermediate) between low and high risk, then mitigating actions should be undertaken to reduce the risk level as low as reasonably practicable (ALARP). The viability and cost of potential actions should be established to assess whether the mitigation is reasonably practicable. An action is not considered reasonably practicable when the effort involved is disproportionate to the benefits of risk reduction that would be achieved. Guidance on ALARP is provided in HSE (2001b).

When considering the practicability of actions, the following should be noted:

- There are limits on what information can reasonably be obtained, for example, missing original design information can be irretrievable.
- There are a limited number of actions that can be taken and the ultimate recourse is to replace a fixing where the risk cannot be demonstrated to be tolerable.

5.7 RECORDS OF RISK REVIEWS

Recommendation 9. A formal record should be retained of decisions taken about safety-critical fixings.

The outcome of the risk review should be recorded. The formal record of the risk review can be important evidence to justify what action is taken by an asset owner. The record should describe the information that was considered and the assessment and tolerability of risk, and outline the rationale for the decisions taken.

The records should include:

- information available during the risk review
- level of risk
- proposed action
- changes compared with previous risk review, where applicable.

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6 Work planning and implementation

Summary

The work identified to mitigate risk from safety-critical fixings should be prioritised and planned. Prioritisation can occur among fixings, and between fixings and other asset types. If proposed work to address the risk from fixings is deferred, it may be necessary to undertake interim measures for the fixings.

6.1 GENERAL

Recommendation 10. Actions should be undertaken in a prioritised order with the objective of achieving a steady state where risk is tolerable.

The output from the risk review is a set of proposed actions (sometimes termed the 'work bank') to investigate or to mitigate risk from safety-critical fixings. Asset owners may undertake work planning as part of the risk review process, or may have separate processes that involve service providers.

In recognition of limitations on resources, actions should be prioritised. The prioritisation can include all elements of an asset owners stock and not just safety-critical fixings. Where work on these fixings is deferred during the prioritisation process, or where there is an immediate unacceptable risk, then interim measures should be undertaken.

The application of a generic process for work planning and how it is applied to safety-critical fixings is shown in **Figure 6.1**. **Box 6.1** provides an example of the overall application of the risk review and work planning process.

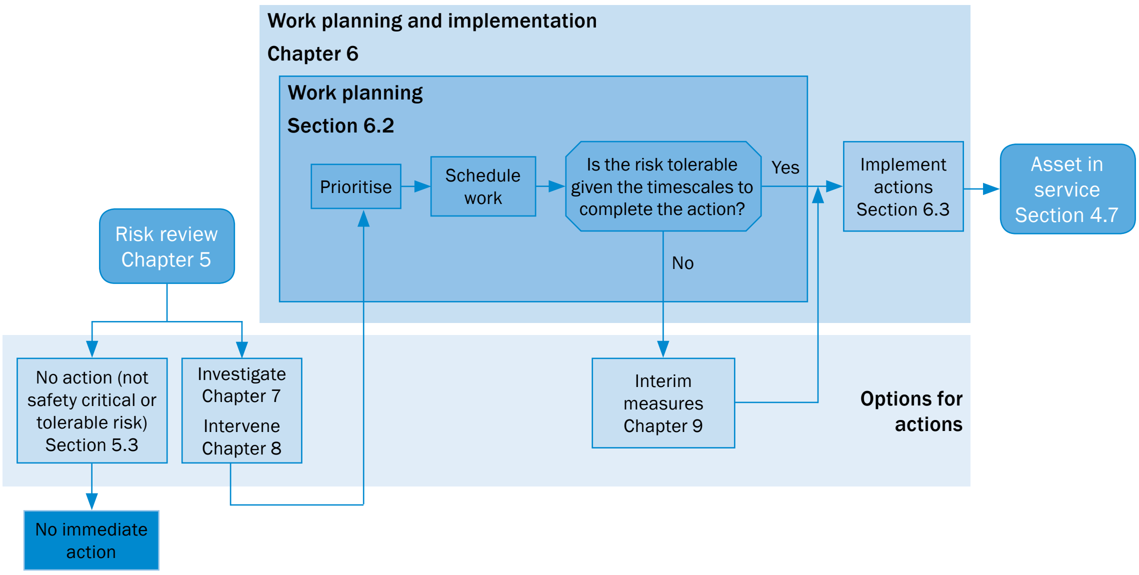

Figure 6.1 Application of work planning and implementation to safety-critical fixings

6.2 WORK PLANNING

6.2.1 Prioritisation

Prioritisation of work on fixings can occur at two levels:

1 Among fixings (**Section 6.2.2**).

2 Between fixings and other asset types (**Section 6.2.3**).

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The risk review can identify some fixings as needing immediate action to address an unacceptable risk, for example due to poor condition or the presence of risk factors similar to known failures. Where immediate action is necessary, then the action may need to be carried out as emergency works or emergency interim measures, outside of the normal prioritisation process.

6.2.2 Prioritisation among fixings

The prioritisation among the population of fixings (the fixings work bank) follows directly from the risk level obtained from the risk review. As a general principle, higher risk fixings should be prioritised over lower risk fixings.

Where more sophisticated risk scoring systems are used, such as the example in **Appendix A8**, then the risk scores should be used as a starting point and judgement applied to the prioritisation.

Where there are different levels of information available then care and judgement is needed in comparing risk levels. For example, the risk from a known fixing can be well defined and actions readily identifiable, but there could be a greater risk from unrecorded fixings that should be addressed first.

A weighting should be applied to the relative risks based on the sizes of the families of fixings that are being considered.

Depending on the needs of the asset owner, actions for fixings can be managed either as specific tasks or as programmes of work.

6.2.3 Prioritisation between fixings and other asset types

Asset owners can prioritise between work to address the risk due to fixings, and work to address risk from other sources (the overall work bank). Decisions about the priority of fixings compared with other asset types should be carried out within the scope of the overall framework for asset management (where such a framework exists).

The asset owner can already have established methods of prioritisation for other asset types, and it can be beneficial to adapt and use a similar system for fixings. The intended actions to address risk from fixings should be processed through the asset owner's systems for prioritisation and work planning.

The qualitative nature of the risk assessment for fixings means it can be difficult to compare the risk from fixings directly against risk from other sources.

6.2.4 Timescales for actions

The work should be scheduled, taking into account the prioritisation. The likely timescales for undertaking the proposed action should be established. Factors influencing the timescale can include:

- timings of periodic prioritisation/value management sessions
- compliance with corporate governance processes including budget authorisation
- procurement/instruction of the works
- time to plan the works, including any necessary design work
- interaction of the works within an overall works programme
- time to carry out the works.

The exposure to risk should be assessed during the intervening period before anticipated completion of the action.

Where the interim risk is unacceptable, then measures should be undertaken to reduce the risk to a tolerable level or the works should be brought forward. Possible interim measures are described in **Chapter 9**. These could include measures that, for example, result in a loss of functionality of the network, which is acceptable as a temporary measure, but not as a permanent one.

6.2.5 Input to asset works programme

Work and budget planning can require information to be produced on a 'top-down' and 'bottom-up' basis:

- **Top-down** presents the overall risk from fixings and an estimate of the works budget required to mitigate this risk. For this approach, a risk review should be completed across the whole population of safety-critical fixings. The top-down information can inform an overall budget allocation between work on fixings and other asset types.
- **Bottom-up** shows the detailed work plan to address the risk from fixings. This information is likely to be generated from the specific identified actions for particular fixings, and tends to be focused on the highest risk fixings. It can be used to inform the detailed short-term prioritisation and work planning.

6.3 IMPLEMENT ACTIONS

Carrying out the proposed actions can include design, delivery planning and installation/construction.

Delivery planning should include identification of a safe working method, necessary access arrangements and a realistic programme.

The fixing asset records should be updated with records of the work carried out.

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Box 6.1 Example of an iterative risk review and work planning process

Figure 6.2 Highway sign supported by post-installed fixings

Initially, an asset owner has no information about fixings supporting signs from structures above roads. The owner knows that there are fixings like this on the network.

A 'family' is defined as all fixings of supporting signs from structures above roads, with an unknown number of fixings.

The first iteration of screening identifies that a targeted investigation should be carried out to gather information on this family. The asset owner undertakes a desk study.

As a result of the desk study, the asset owner gains basic inventory information about the fixings. The family is refined into three new families to reflect the characteristics of the fixings. The new families are:

1 Small signs.
2 Large signs supported by vertical fixings.
3 Large signs supported by horizontal fixings.

This grouping was based on knowledge of the risk assessment, where family 1 has a lower consequence and families 2 and 3 have higher consequence and family 2 has particular risk factors due to the sustained tension in the fixings.

In the second iteration of the risk review there is sufficient information to make an initial assessment of risk.

- **Family 1 (small signs)** is considered to present a tolerable risk, because it includes no particular risk factors and has a low consequence due to the small size of sign. No further action will be undertaken for this family.
- **Family 2 (large signs with vertical fixings)** is found to have the highest risk due to the risk factor presented by vertical fixings. The asset owner decides that the risk for Family 2 is not tolerable based on the currently available information, but further investigation is viable and useful. The asset owner decides to undertake special inspections of this family to confirm the type of fixing, condition and any evidence of movement.
- **Family 3 (large signs with horizontal fixings)** is not yet considered to have tolerable risk based on the available information. Similar special inspections are proposed to confirm whether there is any evidence of distress. However, this is accorded a lower priority than Family 2 due to the lower risk, and due to competing demands from other assets these inspections will not be undertaken in the current financial cycle. Interim measures comprise normal scheduled inspections and annual review to confirm there are no changes of condition.

In the third iteration of the risk review, the special inspections for Family 2 (large signs with vertical fixings) have been completed.

Further information about condition has been provided by the special inspections. The family is further subdivided. In most of the locations there is no evidence of distress. This group, Family 2a, is now deemed to present a tolerably low risk. No further action will be carried out and the family will be included in future risk reviews to verify whether there are any significant changes.

At a small number of locations, cracking has been found in the concrete substrate around the fixings. The risk level for this group, Family 2b, has increased because there was no evidence from the available general inspection reports to suggest the concrete was in poor condition. The asset owner decides to undertake proof testing of a small number of the fixings in Family 2b to verify performance.

The proof testing will take some time to arrange. From a review of the structural arrangement of the sign, the asset owner concludes that there is sufficient structural redundancy such that failure of one fixing would not lead to collapse of the sign. No further specific interim measures are proposed.

The proof testing is undertaken and shows that, despite the cracking in the concrete substrate, the fixings provide adequate resistance. Family 2b is considered to present tolerably low risk and is accepted. A note is made in the asset information to confirm during inspections that there is no progression of the cracking.

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7 Investigations

Summary

Investigations may be carried out to gain more information about fixings. Investigations can include desk study, inspections, load tests and intrusive investigations. Additionally, steady-state management of fixings should include periodic inspections. The benefit of obtaining new information from an investigation should be balanced against the cost of obtaining the information and the cost of alternative actions such as interventions.

7.1 TYPES OF INVESTIGATIONS

The purpose of undertaking investigations is to gain more information about fixings. Actions to investigate fall into the following categories:

- desk study (**Section 7.2**)
- inspections (**Section 7.3**)
- load tests (**Section 7.4**)
- intrusive investigations (**Section 7.5**).

Objectives should be established for each investigation. The effect of the target information on the risk assessment should be understood before undertaking the investigation. Where the new information is unlikely to affect the risk assessment, then the decision on actions should be revisited, because there may be little value in undertaking the investigation.

Some information can be unobtainable, such as original designs that were not recorded. If the risk is anticipated to remain unacceptable even with maximum achievable information, then it may not be beneficial to progress an investigation.

The costs and benefits of undertaking the investigation should be weighed against those of undertaking an intervention. An investigation is likely to be most beneficial when one or more of the following apply:

- The costs of the investigation (such as a desk study) are low in comparison to costs of intervention. Costs should include enabling works such as access and traffic closures.
- The results of the investigation apply to a large family of fixings (for example, where test results on a small number of fixings can be used to provide confidence in the performance of many similar fixings).
- It is viable to gain more information, which will reduce the level of risk for a family of fixings (for example, where a conservative assumption has been made, but where it is suspected that further information will demonstrate the absence of a particular risk factor).
- It will provide positive confirmation that risk factors apply (or not), before undertaking an expensive intervention.

7.2 DESK STUDY

A desk study comprises a review of available records and can include searches for supplementary records. It can be cost effective and relatively quick in obtaining results, where records exist.

A desk study can include searches of non-categorised information to provide initial information about fixings, for example, examination of photographs from inspection reports, or using virtual world image data.

Asset owners can have data about fixings which is stored as part of other asset records, but has not been organised and categorised to provide systematic information about fixings. For example, data about primary structures assets, such as structures drawings, can include details of fixings, but may not be searchable without human interpretation.

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A desk study can be valuable during the initial stages of a transition, particularly to provide basic inventory information about fixings. However, a desk study is unlikely to provide more detailed information necessary to assess likelihood. A desk study may need to be supplemented by other means of gathering information to allow for a full risk assessment.

Results from a desk study should be treated with caution until confirmed by inspection on site, because records can be incomplete or modifications could have been made. For example, records may not be available for all structures, or there may have been unrecorded changes on site.

A desk study can include requests for manufacturers' data or testing records, but such data should be related to the fixings that are installed.

7.3 INSPECTIONS

7.3.1 General

Recommendation 11. Fixings should be included in inspection activities and associated reporting.

The purpose of inspection is to provide information about the observable features of the asset based on a physical visit to the asset.

Where a regular inspection regime is already in place as part of an overall framework for asset management, then there is potential to gather and update information about fixings from the normal scheduled inspections. Information from these inspections may need to be supplemented by specific investigations targeted at fixings.

This section describes:

- types of inspection and information that can be obtained for fixings (Section 7.3.2)
- inspection requirements (Section 7.3.3)
- inspections in the steady state (fixings in service) (Section 7.3.4)
- inspections during the transition period (Section 7.3.5)
- hidden fixings (Section 7.3.6)
- inspection records (Section 7.3.7).

7.3.2 Types of inspection

Table 7.1 shows the types of inspection that are commonly used in the management of transport infrastructure and the information on fixings that can be obtained from these types of inspections. See also Appendix A7 for guidance on inspections.

Table 7.1 Information that can be obtained for fixings from different types of inspection

Scope of inspection	Common names	Details that can be obtained for fixings
Visual inspection without special access equipment or traffic management	General inspection, visual examination	■ inventory ■ basic information about a fixture to allow for screening and assessment of consequence ■ significant changes since previous inspection ■ changes or defects that need urgent attention ■ limited information on condition of fixing.
Close examination from touching distance	Principal inspection, detailed examination	■ as 'visual inspection', plus condition of fixing, substrate, fixture and attachment ■ may not provide details on hidden fixings.

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Scope of inspection	Common names	Details that can be obtained for fixings
Targeted investigation of a particular element	Special inspection, additional examination	■ as for 'visual inspection', plus condition of fixing, substrate, fixture and attachment ■ can include exposure of hidden fixings.
Inspection by other disciplines	Mechanical and electrical inspection, facilities inspection	■ inventory ■ basic details about fixture to allow for screening and assessment of consequence ■ significant changes since previous inspection ■ changes or defects that need urgent attention.

7.3.3 Inspection requirements

Asset owners should incorporate requirements to inspect fixings within their processes for inspection.

Inspections should be undertaken by suitably-experienced and competent staff. Training and briefing of relevant teams may be required to establish suitable competencies, which include:

- knowledge of how to identify different fixing types
- knowledge of risk factors associated with fixings
- experience of identifying defects relevant to fixings.

Where inspections are undertaken by teams responsible for different assets, then the asset owner should establish processes to share relevant information about fixings. The different teams should all have the competencies required to inspect fixings.

Case study 7.1 Partial failure of a water catchment structure in Balcome Tunnel

A steel water catchment structure over the railway in Balcombe tunnel, between London and Brighton, became partially detached overnight on 23 September 2011. The sagging of the structure over a 12 m length was observed and reported by an engineering train. The route was closed for 24 hours to allow for emergency remedial works, significantly affecting rail traffic.

A series of fixing studs were found in the tunnel by track patrollers in the seven months before the failure. However, there was a lack of appreciation by the track patrollers of the significance of the fallen studs and a failure to communicate with the structures asset owner. The owner had incomplete information about the issues affecting multiple fixings so did not appreciate the overall level of risk and took no action.

Figure 7.1 Missing studs that had fallen to the ground and were found by track patrollers over a seven-month period before the failure (courtesy RAIB)

7.3.4 Inspections in the steady state

In the steady state, the asset owner should operate a periodic inspection regime, which updates the available information about fixings. In common with other asset types, the purpose of the inspection regime is to detect in good time any changes that may cause an unacceptable risk and to enable an appropriate intervention to be taken.

Guidance on what should be included in the inspection regime is provided in **Appendix A7**. Examples of the types of changes that should be detected are provided in **Table 7.2**.

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Table 7.2 Types of changes to be detected by an inspection regime

Type of change	Example of change
Change in condition of fixing, substrate, fixture, attachment	Cracking and rust staining noticed in the substrate close to a fixing, or deformation or elongation of fixing (see Figure 7.2).
Change in environment	Dampness detected in a tunnel lining where previously dry
Change in fixture/change in use	New fixture has different centre of gravity and different weight, so a change in loads on the group of fixings supporting the fixture
Change in actions	Use of hard shoulder on a frequent basis by high vehicles means that a fixture is more commonly subjected to buffeting actions

Note

See Appendix A7 for full guidance on aspects to include in inspections of fixings.

Figure 7.2 Deformation of fixings, Boston, USA (courtesy US National Transportation Safety Board)

The frequency of inspection should be determined such that it provides sufficient warning to allow for intervention before failure. The frequency may depend on a variety of factors including rate of deterioration, potential for external change and level of risk presented by the fixing.

Where specific information is not available for fixings then it may be reasonable to apply the principle of analogy. For example, assuming that the rate of deterioration of fixings is similar to that of other steel and concrete elements in similar environmental conditions and a similar inspection frequency is suitable.

Care should be taken that the analogy is appropriate. For example, many steel and concrete structural elements exhibit ductile failure modes where deformation precedes ultimate failure but in contrast, fixings can exhibit failure modes that display no warning.

Where an inspection identifies a change or defect that requires urgent attention, then the concern about that fixing should be highlighted as urgent and if necessary escalated. As soon as practicable, the asset owner should undertake a risk review of the fixing, and review the potential for the defect to apply to similar fixings. This may need to be done sooner than the next scheduled risk review. The asset owner should establish whether further investigation, intervention or interim measures are required.

Examples of defects requiring urgent attention include:

- missing, distorted or elongated fixings
- movement of fixing or fixture
- gaps between fixing and attachment
- poor condition or rapid degradation of condition of fixing or substrate.

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Case study 7.2 Defect in road tunnel: gap between anchor plate and substrate

Figure 7.3 Steel ruler inserted into gap between anchor plate and concrete substrate of tunnel lining

A road tunnel has ventilation equipment supported from the concrete tunnel lining using post-installed resin-bonded anchors.

During a routine inspection of the tunnel, a gap was noticed around the perimeter of the anchor plate between the plate and the concrete surface. A steel ruler could be inserted up to 40 mm into the gap, as indicated in Figure 7.3. A concern was raised that the gap could indicate possible movement of the fixing.

A risk review was carried out that considered the potential for creep to occur in the resin and determined that further detailed investigation should be undertaken of the fixings and base plates.

Investigations were carried out during a series of night closures of the tunnel. The ventilation equipment was removed temporarily to inspect the concrete surface below the anchor plate. Detailed measurements of the surfaces were made.

Following discussions and inspections over a period of months, it was concluded that the gap resulted from a combination of tolerances in the manufacture of the anchor plate and the milling to prepare the concrete lining. A slight convex profile to both surfaces led to the visible gap at the edge. There was no evidence of movement of the fixing itself.

Although the initial concern was closed out, the convex profiles created the possibility that bending moments could be induced in the fixing and that a greater than expected proportion of fatigue capacity could have been used. Further investigations and interventions were ultimately required to address these issues.

7.3.5 Inspections during the transition period

During the transition period, inspections can be an effective method for gathering and supplementing information about fixings. Depending on the information already available, this may include basic inventory information, information to assess consequence of failure, and detailed information to inform risk factors such as condition and detail of fixing. Guidance on information that should be identified during inspections is provided in **Appendix A7**.

The urgency of obtaining the information should be established based on the level of risk following the initial risk review. The strategy for inspections should be based on the urgency and this may be different for different families of fixings (see **Box 7.1**).

Where there is greater urgency to gather information about a family of fixings, then special inspections may be required. Where there is less urgency, then a cost-effective approach may be to rely on normal scheduled inspections.

Box 7.1 Example of using different types of inspection depending on urgency

The owner has identified from an initial desk study of installation records that it has a family of high-risk fixings, consisting of polyester resin-bonded anchors in damp conditions. The owner decides to undertake a programme of special inspections of this family to gather condition information.

The owner is confident that it has no other families that present a high risk, based on general knowledge of its asset and a review of the potential risk factors. The owner decides to collect condition information about its other fixings using its normal scheduled inspections, acknowledging that this will take a full cycle of inspections to obtain the information for all its fixings.

7.3.6 Hidden fixings

Where inspections only record information about observable features, then further targeted investigation may be necessary to identify and manage hidden fixings. Extensive guidance about hidden defects is provided in Collins *et al* (2017).

Locations with the potential for hidden fixings should be identified. Further investigation may be required to confirm their presence or eliminate the possibility of hidden fixings. The further investigation may need to comprise targeted investigations including removal of panels or exposure of hidden elements.

Intervention may be necessary to manage the risk of hidden fixings. Interventions to mitigate the risk can include improvement of access, for example, installation of removable panels to allow for periodic inspection of a representative set of fixings.

The lack of regular inspection of hidden fixings was noted as a contributory factor by the US National Transportation Safety Board in its accident investigation report on the failure at the Boston tunnel and by the Ministry of Land, Infrastructure, Transport and Tourism on the failure at the Sasago tunnel.

Case study 7.3 Defects to hidden fixings

A road tunnel has a secondary internal cladding system attached to the primary concrete tunnel lining. The cladding is supported by a secondary steel frame arrangement. The steel frame is secured to the tunnel lining by post-installed fixings.

During work to install new fire detection equipment, a number of cladding panels were removed.

The secondary framing and the fixings are normally hidden behind the cladding. Following removal of the cladding panels, some of the framing and fixings were found to be suffering from severe corrosion.

Further investigation was undertaken to establish the extent of the defects and remedial works were undertaken.

Figure 7.4 Cladding panels removed

Figure 7.5 Close-up of corrosion affecting support framework and fixing

7.3.7 Inspection records

Inspection records should include the relevant information which is identified during inspections (see the checklist in **Appendix A7**).

Inspection records should include photographs of fixings, which can be particularly valuable in allowing changes over time to be identified and tracked.

It is important that inspection records are retained and can be accessed. The asset information system should allow for identification and retrieval of the inspection records, which are relevant to particular fixings. See **Chapter 10**.

Where inspection records are held by different teams (for example, M&E and structures teams), then the asset information system should allow for relevant records about fixings to be identified and reviewed by the fixing owner regardless of where the records are held.

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7.4 LOAD TESTS

7.4.1 Purpose and applicability of load tests

The purpose of load tests is to provide information about the resistance of a fixing. Load testing is one of the few available actions that can provide definitive information about the resistance of a fixing. Load testing can be costly and disruptive, so the outputs from and benefits of undertaking the testing should be established and weighed against the costs.

The test programme should be designed such that the outputs from the testing will provide useful information to mitigate risks. A phased approach to testing may be helpful in exploring performance in a cost-effective manner.

The costs of testing should be assessed against the costs of interventions such as replacement. Testing is most likely to be beneficial where the performance of a large family of fixings can be confirmed by tests on a smaller representative number of fixings.

The practicalities of the testing should be understood at an early stage (**Figure 7.6**). In particular, testing may require some or all of:

- temporary removal of the fixture
- closures of the asset or network to carry out the testing
- physical space/temporary works to fit the testing rig, which will most likely include a jack and load-spread arrangement
- connection of the testing gear to the fixing, for example, using a coupler or adapter.

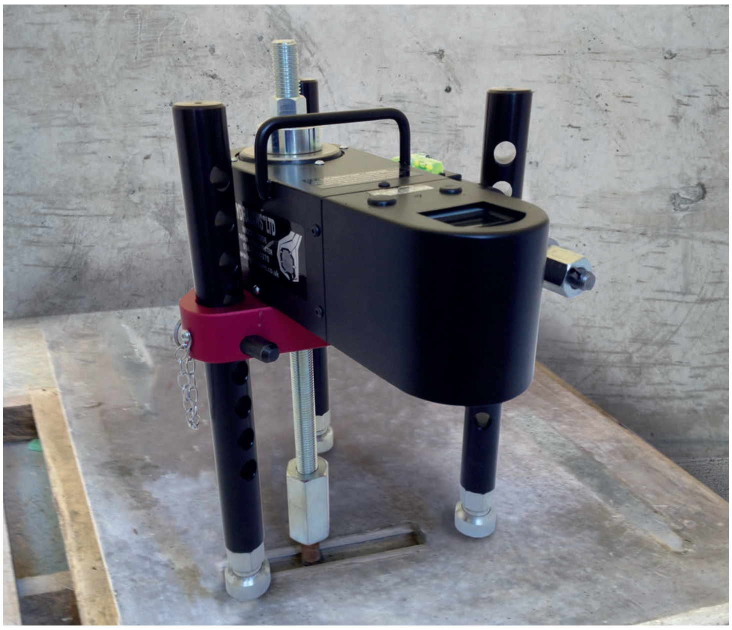

Figure 7.6 Arrangement to apply test load to a fixing (courtesy Hydrajaws)

The acceptability of damage to the substrate and to the fixing should be established. All tests present some risk that the fixing will fail. Some types of testing (such as tests to failure, see **Section 7.4.2**) will result in the destruction of the fixing or present a high risk of damage to the fixing or substrate.

Where damage to the substrate is not acceptable or where the fixture is required to remain in service following the testing, then a strategy should be developed considering the following:

- Select a test that presents less risk of causing damage (but reconfirm the test will provide information which will achieve the test objectives):
  - choose a different location or fixing for the test

- choose a test that requires a lower test load to be applied
- use an off-site test of similar fixings (if fixing type is known).

- Develop contingency plans for:
  - repair of the substrate
  - new location for the fixture, if the substrate is damaged
  - replacement of the fixing, including selection of an appropriate new fixing.

It can be more practicable to apply the test load indirectly through the fixture, rather than directly to the fixing. For example, a pushover force could be applied directly to a parapet upright. Where the test load is applied indirectly, the relationship between the test load and the fixing load should be established.

If design information is available, it can confirm the intended resistance of the fixing, for example, if an ETA is provided. If the design resistance is available, then testing can be beneficial if there is doubt that the design resistance has been achieved, for example, due to poor quality of construction.

7.4.2 Types of load test

Requirements for testing fixings for new installation are provided in BS 8539. The types of test described in the BS can also be applied to provide information about existing fixings.

There are two main types of test:

- to determine the allowable resistance (see Section 9.2 of BS 8539), including:
  - tests to failure
  - preliminary tests (to a particular test load)
- proof tests (see Section 9.3 of BS 8539).

Tests to determine the allowable resistance are used in new installations before the installation of fixings. Their purpose is to validate that the type of the proposed fixing is suitable for use in the substrate and to determine the allowable resistance. Specific test fixings are installed for these tests and subsequently removed. The test fixings are not incorporated into the works.

Where applied to existing fixings, tests to determine the allowable resistance can establish the failure load with reasonable confidence or demonstrate that the intended design factor of safety has been achieved. However, a test to determine the allowable resistance may result in the destruction of the fixing.

Proof tests for new installations are intended to validate the quality of installation. They are carried out on fixings that will be used in service, and demonstrate that the fixings have a modest safety margin, with a low risk of damage during testing.

Provided premature failure does not occur, a proof test will give confidence that the fixing can carry the test load. It does not indicate how large a margin is available above the test load.

Key features of the different types of load test are summarised in **Table 7.3**.

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Table 7.3 Key features of different types of load test

	Tests to determine allowable resistance: test to failure	Tests to determine allowable resistance: preliminary test	Proof test
Section of BS 8539:2012	Annex B.2.3.1	Annex B.2.3.2	Annex B.3
Indicative ratio between characteristic action and test load	2.5 (see BS 8539 Equation B.10, factor for static actions)	3 (see BS 8539 Table B.1, value for long-term loading)	1.5 (see BS 8539 Section B.3, assuming 2.5 per cent of fixings are tested)
Number of fixings tested	≥5 Increasing the number of tests to 10 or 15 is likely to demonstrate a higher resistance due to greater statistical certainty.	≥5	≥3 Minimum proportion of 2.5 per cent of all fixings recommended for new installations. 100 per cent proof testing used in some applications, such as suspended access.
Risk of damage	Test to failure, so fixing cannot be reused. Depending on failure mode, damage may occur to substrate. Such damage may not be visible, eg cracking around the fixing within the concrete.	Risk of damage to fixing and substrate. Where this method is used in new installations, the test fixings are for testing only and should not be used in-service.	Low risk of damage. Proof tests are intended to be carried out on installed fixings to show they have been installed correctly. Failure of the proof test indicates that fixing is inadequate and should be replaced.

7.4.3 Determining test objectives

The main objectives for testing should be established before any tests are commissioned. These should include actions to be taken in the event of a pass or a fail of the tests, ie actions in the event of positive and negative outcomes should be decided before undertaking the test.

The type of test selected should consider the balance between the level of certainty required for the resistance, compared with the risk of damage, as indicated in **Table 7.3**.

The load that the fixing has to withstand should be determined. Generally, it should be taken as the characteristic value of the action (the unfactored load) applied to the fixing. In proof tests and preliminary tests, the test load equals the characteristic action multiplied by an appropriate factor. The characteristic action may be obtained from record information or by calculation based on knowledge of the fixture and actions applied to the fixture.

The direction of the test should be determined, based on the orientation of the action in relation to the fixing. It is most common to undertake tests for fixings in tension. Tests for fixings in shear in concrete are less commonly undertaken, as noted in Section 9.4 of BS 8539.

Some types of fixings are subject to the phenomena of load relaxation and creep. Load relaxation and creep both results in a loss of preload over time. Manufacturer's installation instructions, including torque settings where applicable and initial proof test loads, are expected to account for these effects. However, results from a test after some years in service should not be expected to match results from initial testing.

Further information on these phenomena is provided in CFA (2011), Salmon (2011) and Salmon (2013).

7.4.4 Undertaking the testing

Tests should be undertaken in accordance with relevant industry guidance including BS 8539 and CFA (2012).

Asset owners should ensure that testing is carried out by suitably-experienced and competent persons. Competency requirements for testers are listed in Section 9.1 of BS 8539. An independent accreditation scheme for testers is available through the CFA.

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7.4.5 Test records

Test records should be produced in accordance with the relevant industry guidance listed above, specifically Section 9.5 and Annex B.4 of BS 8539.

The asset information system should allow for identification and retrieval of test records, which are relevant to particular fixings. See **Chapter 10**.

It is important that test records are retained and can be accessed over the life of the fixing.

7.5 INTRUSIVE INVESTIGATIONS

7.5.1 Types of intrusive investigation

Intrusive investigations provide information about the non-observable characteristics of the fixing and substrate within the substrate material. Similar to load testing, these investigations can be expensive and disruptive, so the outputs from and benefits of undertaking the investigation should be established and weighed against the cost, disruption and potential damage.

Intrusive investigations can be valuable for high-risk fixings where confidence cannot be gained by any other means. Similar considerations apply as for load testing (see **Section 7.4.1**), in particular:

- determine objectives of the investigation
- understand practicalities of investigation
- consider the costs and benefits of the investigation and compare against alternatives such as replacement
- confirm potential for and acceptability of damage to fixing and substrate
- plan for repair/replacement of fixing and substrate.

Intrusive investigations can include destructive and non-destructive techniques. Examples are provided in **Table 7.4**.

Further guidance on intrusive investigations is provided in Highways Agency (2007).

7.5.2 Intrusive investigation records

Records should be retained of the results of intrusive investigations, and they should include photographs of exposed elements.

Table 7.4 Examples of intrusive investigations and information that may be obtained

Type of intrusive investigation	Destructive/non-destructive	Information obtained
Remove fixing (where possible)	Destructive	Size and type, condition
Remove concrete around fixing	Destructive	Embedment depth, condition of fixing, bond condition
Core around fixing	Destructive	Embedment depth, condition of fixing, bond condition
Concrete/masonry core	Destructive	Substrate strength
Rebound test	Non-destructive	Concrete strength
Ultrasound	Non-destructive	Fixing length, condition

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Case study 7.4 Intrusive investigation of failed anchors on a bridge parapet

An intrusive investigation was undertaken following movement of a concrete parapet unit follwing a vehicle impact. The concrete parapet was attached to the bridge deck by a series of vertical resin anchors. Concrete cores were taken around the fixings to try to investigate the cause of the fixings having low resistance under impact load.

***Figure 7.7** A section of dowel that came out clean upon breaking the core open, indicating that the bond between dowel and concrete was ineffective (courtesy Southampton City Council)*

Case study 7.5 Non-destructive investigation of bolt length and condition on a bridge parapet

Concerns were raised about the performance of post-installed anchors functioning as holding-down bolts for a vehicle restraint system on a series of parapets on structures.

Initial intrusive investigations removed a number of bolts from parapets and found that the bolts could be of different length and types with varying condition, some with extensive corrosion or through-shank cracks.

An ultrasonic test method was developed and verified by a specialist supplier. The test method measured the ultrasonic signal from a probe on the head of the bolt reflected by the end of the bolt. The test method was calibrated against samples of removed bolts and was successful in identifying changes in length and condition of the bolts.

The test method was capable of producing and documenting results for about 40 bolts per hour. 640 bolts on seven structures were tested over 1.5 shifts during the daytime. Bolt lengths were found to vary between 68 mm and 110 mm.

***Figure 7.8** Ultrasound testing of bolt length and condition (courtesy Mistras Group Ltd)*

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8 Interventions

Summary

Interventions may be carried out to mitigate the risk from safety-critical fixings. Interventions can include removal of the fixing, improving robustness (such as by fitting a secondary restraint) and replacing the fixing. Some interventions involve new design of either the fixing or the support arrangement, and such new designs should seek to eliminate risk factors so far as possible.

8.1 TYPES OF INTERVENTIONS

The purpose of undertaking an intervention is to mitigate the risk from a fixing. Where the risk is not tolerable and intervention is required, then there are only a limited number of possible options for interventions. The actions to intervene fall into the following categories, which are explained in more detail in the sections below:

- remove fixing (**Section 8.2**)
- improve robustness (**Section 8.3**)
- replace fixing (**Section 8.4**).

A hierarchy of decisions may be followed to determine the type of intervention, considering whether the fixing can be eliminated, whether practicable robustness measures can allow the risks from the existing fixing to be mitigated, and whether it is viable to eliminate the safety-critical fixing (for example, by reconfiguring to provide an alternative non-safety critical fixing).

An intervention is likely to be required when one or more of the following apply:

- the risk of failure is unacceptable (due to the combination of consequence and likelihood of failure)
- there is positive confirmation that one or more risk factors apply to the fixing
- it is not practicable to gain more information that could reduce the level of risk
- intervention is more cost effective than prolonged (and possibly inconclusive) investigations.

Interventions should be subject to technical approval procedures. Further guidance is provided in **Section 12.7**.

8.2 REMOVE FIXING

Removal of the fixing typically also requires removal of the fixture. Removal of the fixing can eliminate the risk of failure. Elimination of risk is typically placed at the top of risk control hierarchies so this approach should be considered. However, there can be cases where it is not practicable to remove the fixing or fixture.

The purpose and need for the fixture should be reviewed to determine whether it is possible to eliminate the need for the fixing. This can occur, for example, where equipment has become redundant.

Where the fixture needs to be retained, it may be possible to reconfigure the support arrangement so that the fixings provided are not safety critical. Further guidance is given in **Section 12.2**.

Where removal of a fixture is proposed, then a review should be carried out to determine whether there is any consequential safety, or operational impacts.

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8.3 IMPROVE ROBUSTNESS

8.3.1 General

Measures to improve robustness can mitigate the risk of failure of a fixing and allow an existing fixing to be retained. Such measures can be relatively quick to install so it can be effective in mitigating immediate risks, and can be more cost effective than replacing fixings.

These measures can fall into the following categories:

- add secondary restraint (improve redundancy)
- improve load distribution (and redundancy)
- reduce loads (provide excess capacity)
- protect fixing (reduce exposure of fixing).

There are similarities between robustness measures applied retrospectively and robustness measures incorporated during new design. Further guidance on design for robustness for new fixings is provided in **Section 12.6**.

8.3.2 Secondary restraint

The purpose of secondary restraint is to prevent the fixture from falling if the primary fixing fails. Examples of secondary restraint include:

- lanyard
- safety chains
- corbel or other structural device to 'catch' the fixture
- crash deck.

Secondary restraint does not necessarily address the point of failure of a primary fixing. Secondary restraint can reduce the consequence of a failure, but it does not affect the likelihood of a failure of the primary fixing. So, further work can still be required in future to address the primary fixings, particularly where there are cases of the secondary restraint being mobilised.

The provision of a secondary restraint can require the installation of additional new fixings to support the secondary restraint. Where the fixing can fall for a distance before mobilising the secondary restraint (for example, where safety chains are used), then the secondary fixings should be designed for the dynamic load required to arrest the movement of the fixture.

Recommendations for the design of secondary restraint are provided in **Section 12.6.3**.

8.3.3 Improve load distribution

The purpose of improving the load distribution is to allow load to be transferred to adjacent fixings in the event of a failure of one fixing. Similar to secondary restraint, improving the load distribution does not reduce the likelihood of failure of a primary fixing, but reduces the consequence of the failure.

Improved load distribution can be difficult to retrofit to existing assets. Options can include new secondary support framing, strengthening of existing framing, and providing an anchor plate to link a group of fixings.

Load distribution typically requires a support framework to be provided. The support framework should be designed for the loss of a fixing or fixing group. The support framework should be designed for the loads generated by the envisaged failure mechanism. For example, a sagging mechanism can generate additional components of force due to a catenary tension effect.

The resistance of the remaining fixings should be sufficient to carry the load shed from a failed fixing, to avoid an 'unzipping' progressive failure. The load applied to the remaining fixings should include for any geometric effects arising from the assumed failure mechanism, such as eccentric forces, prying actions, shear components and twist.

Information about the resistance of the fixings is required in order to establish that the fixings can carry the additional distributed load. This can be provided from the original design information, or can be obtained from testing. Where design information is not available, then testing can provide resistance information (see **Section 7.4**).

Where an enhanced load distribution is proposed compared with the original structural system, then the design load to be carried by the existing fixings in the failure case can be increased compared with the original design assumptions. Where it is proposed to retain existing fixings, then the acceptability of the new factor of safety against failure should be confirmed.

Subject to the requirements of a particular asset owner, a lower factor of safety under a load distribution design situation compared with new design can be acceptable where, for example, the:

- 'failed' support arrangement involving the lower factor of safety will be a temporary situation, with action taken within a defined time period to replace the failed fixing
- failure is detectable, for example, by deformation of the support framework or visual identification of a failed fixing
- failure will be detected through the operation of asset management processes, for example, regular inspections or defects hotline.

If it is not possible to establish or justify the resistance of existing fixings to carry increased loads because of the distribution effect, then improving the load distribution can require new fixings to be installed. Where the resistance of the existing fixings is not known and new fixings are provided, they should be designed to take the entire load without reliance on the existing fixings.

In some cases it can be possible to justify improved load distribution by reviewing the performance of the complete structural system, for example, taking into account the strength of the fixture in addition to any anchorage or framing arrangement. Where reliance is placed on the strength of the fixture, then checks should be made that the fixture is satisfactory under this load arrangement.

8.3.4 Reduce load

Reducing the load applied to a fixing can improve the factor of safety against failure, and can be achieved by:

- reducing the applied actions
- increasing the number of fixings, together with appropriate load distribution.

The permanent loading can be decreased by reducing the self-weight of the fixture, for example, by substituting lightweight materials or a lower-weight fixture.

It can be difficult to reduce other types of action at source, for example, buffeting loads from traffic or cyclic loads from wind or traffic. It can be possible to fit shielding to minimise wind and aerodynamic effects, although shielding may itself require new fixings to be fitted.

A reduction in the design load for the fixing can be achieved by increasing the number of fixings that carry the load. An enhancement of the load distribution system can be required in order for the increased number of fixings to be effective in reducing the design load (see **Section 8.3.3**).

Where the resistance of the existing fixings is not known and new fixings are provided, they should be designed to take the entire load without reliance on the existing fixings.

Information about the resistance of the fixings is required to quantify the benefit of the reduced design load on the fixing, and can be obtained from original design information or by testing (see **Section 7.4**).

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Where the resistance of the fixing is not known, then a reduction in load does not provide certainty against failure of the fixing. However, confidence can be gained by considering the known loads that the fixing has historically carried, for example, the permanent actions. If the design load is reduced below this level of historic loading, then there is a known margin to carry other loads, for example combined permanent and variable actions.

8.3.5 Protect fixing

Protecting a fixing can mitigate the likelihood of failure. Protection measures tend to be effective only against specific risk factors. **Table 8.1** provides examples of protection measures.

Table 8.1 Examples of protection measures for fixings

Risk factor	Example	Protection measure
Exposure to sources of damage	Fixings on bridge deck surface supporting fascia panels	Mass concrete placed over fixing heads, eg to protect against accidental damage during planing and resurfacing
Wet/damp	Water running over fixing	Improved water management measures
Corrosive environment	High relative humidity causing corrosion	Dehumidification measures

Case study 8.1 Accidental damage to fixings holding fascia panels

A highway overbridge has fascia panels to conceal the outside face of the precast concrete beams. The panels are fixed to the deck with fixings on the top surface of the deck. The fixing heads were buried in the footway surfacing.

Accidental damage was caused to the fixings during a resurfacing operation and the road was closed while remedial action was carried out.

Mitigation could have included covering the fixings in a layer of mass concrete.

Figure 8.1 Damaged fixings to suspended fascia panels

8.4 REPLACE FIXING

Replacement involves installing new fixings to support the fixture. The new fixings should be designed and installed in accordance with **Part 3**. The recommendations of **Part 3** are intended to minimise the future risk due to new fixings.

Where access costs are significant (including for traffic closures) and there are a small number of fixings, then the costs of replacement may be comparable to investigation options, so replacement can be preferred over investigation.

The configuration of the fixture and fixings should be reviewed to determine constraints on the replacement and opportunities to amend it. Constraints can dictate that a like-for-like replacement is undertaken. However, there can be opportunities to alter the configuration to reduce the consequence of failure or eliminate particular risk factors.

The possibility of eliminating the safety-critical fixing should be examined. It can be possible to adjust the configuration such that there is a low consequence of failure, resulting in the replacement fixing being classified as non-safety critical. Where the fixture has a safety-related function then the safety impact of changing the fixture location should be reviewed.

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Box 8.1 ***Decision making for the replacement of high-risk fixings***

A fixing supporting a sign over a carriageway has been assessed as high risk. Initial review suggested that this particular sign could be relocated to a position next to the carriageway, which would have a lower consequence of failure.

However, a risk assessment carried out by the the road safety team highlighted that by changing the position of the sign, it had become less visible to drivers. The asset owner's in-house risk guidance was applied and indicated that increase in risk due to the change in sign position outweighed the benefit of removing the safety-critical fixings. So, the sign was retained in its existing location. The actions on the sign were calculated and new fixings selected accordingly and installed. The new fixings were covered by an ETA, which was appropriate to the applied actions.

The design of the new fixings should seek to eliminate the risk factors, which led to the assessment of the existing fixing as high risk. Where it is not possible to eliminate the risk factors, then the selection of the new fixings should be suitable given the risk factors. For example, it can prove impractical to eliminate environmental risk factors such as dampness in a tunnel lining, or applied actions such as cyclic loads.

The new fixings should be installed in new holes with the appropriate edge distances to any old holes. So, the new fixings will be in different positions to the old fixings. Where it is acceptable for the fixture to be moved a small distance, then it can be possible to retain existing anchor plates, if applicable and subject to condition. Where it is not acceptable for the fixture to be moved, then a new anchor plate or support framework can be required to suit the new hole positions.

The residual life or likely replacement date of the fixture should be established. Where the fixture is likely to need replacement in the short term, then a strategy to avoid rework should be developed. Rework may be avoided by bringing forward the installation of the new fixture to coincide with the new fixing, or where the new fixture is known, by selecting the new fixings to be suitable for both the existing fixture and the intended new fixture.

Mobilisation costs can be significant compared to the unit installation cost, so it can be more cost-effective to determine the overall replacement needs and procure as a small number of work packages, rather than as multiple smaller work packages.

8.5 RECORDS OF INTERVENTIONS

Records should be retained of the intervention.

Where physical work is undertaken to improve robustness or to replace a fixing, then design records should be produced and retained as for a new design. Guidance on design records is provided in **Section 12.8**.

9 Interim measures

Summary

Interim measures can be required when it will take some time to mitigate the risk on a permanent basis. Interim measures can include the same types of investigation and intervention as for permanent measures, including those that may be acceptable on a temporary basis but not a permanent basis, for example due to loss of function.

9.1 GENERAL

Recommendation 12. Interim measures should be undertaken when a fixing presents an unacceptable risk in the period before completing a planned action.

The purpose of undertaking interim measures is to mitigate an immediate risk from a safety-critical fixing that is unacceptable at the present time, and before completion of an action that mitigates the risk on a permanent basis. Interim measures can have the following characteristics:

- quicker to implement than a permanent measure
- cause disruption or loss of function, which is acceptable as a temporary measure, but not as a permanent measure
- reduce the risk to a level that is tolerable over a defined short-term period, but is not acceptable on a permanent basis.

A specific measurable time should be established during which the interim measure is required. This may be until:

- a permanent intervention is completed, including the possibility that planned access such as a route closure becomes unavailable
- results of an investigation are available and a further risk assessment undertaken
- the next periodic review of the risk assessment.

9.2 TYPES OF INTERIM MEASURES

The types of action that may be taken as an interim measure belong to the same categories as the permanent actions. Other options within these categories can be possible for interim measures, due to the temporary nature of the measure. A summary of the applicability of the generic types of action as an interim measure is provided in **Table 9.1**.

The interim measure should be selected such that the risk level is tolerable or broadly acceptable after implementing the interim measure.

Table 9.1 Applicability of the generic types of action as an interim measure

Type of action		Relevant as interim measure?	Application as interim measure
Investigate	Desk study	✗	More likely to be a step in the transition period rather than an interim measure to mitigate unacceptable risk
	Inspect	✓	Inspection strategy to gather continued evidence of satisfactory performance/of changes affecting fixing
	Load test	✗	More likely to be a step in the transition period rather than an interim measure
	Intrusive investigation	✗	More likely to be a step in the transition period rather than an interim measure
Intervene	Remove	✓	Remove fixture (could cause loss of function) Remove traffic (lane closure/route closure/prohibition of pedestrian access)

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Type of action		Relevant as interim measure?	Application as interim measure
Intervene	Enhance robustness	✓	Secondary restraint Crash deck Reduce load, eg by propping
	Replace	✗	Replacement typically provides a permanent solution

Box 9.1 Decision making for interim measures to support a customer information screen

A fixing supporting a customer information screen has been assessed as high risk. It is not considered viable to gain further information about the fixing, which would improve the risk assessment. The provision of this customer information is important to the asset owner, so the long-term plan is to replace the fixing.

This work item has been placed into the asset owner's prioritisation process and is likely to be done in the following financial year.

The high risk is due to the numbers of people who use the area below the information screen and the risk is unacceptable in the short term before the replacement is undertaken. Other screens are available within a close distance, so the asset owner decides to remove the customer information screen on a temporary basis, until a replacement is made in the following financial year.

9.3 RECORDS OF INTERIM MEASURES

The following should be recorded for an interim measure:

- description of the interim measure
- justification that applying the interim measure reduces the risk to a tolerable or broadly acceptable level
- the maximum acceptable duration for interim measure to be in place
- latest date of next risk review.

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10 Managing information

Summary

Access to good quality information is fundamental to effective management of safety-critical fixings. Information about fixings should be stored in an asset information system. The asset data collected for safety-critical fixings should include records of the primary asset, fixture and fixing, which can be generated during all life cycle stages of the fixing, including design, installation, testing, in-service and decommissioning. Information should be captured about the performance of safety-critical fixings, and information on near-misses or failures should be shared within the construction industry.

10.1 ASSET INFORMATION SYSTEMS

Information relating to fixings is fundamental in enabling asset owners to assess risk and make informed decisions about management actions and communicate with stakeholders.

Information about safety-critical fixings should be stored in an asset information system. Where the asset owner operates a framework for asset management, then this system should be part of such a framework.

Asset information systems can include paper-based systems, spreadsheet records, databases, sophisticated asset management suites and other systems. Some systems can include more complex processing and analysis functions.

These systems can support the asset owner in achieving external information objectives, for example, embedding and increasing the use of digital technology including Building Information Modelling (BIM) Level 2 as set out in IPA (2016).

10.2 ASSET DATA

Recommendation 6. An asset information system that is capable of storing and retrieving adequate information about safety-critical fixings should be established.

Guidance on relevant content for safety-critical fixings within the asset information system is provided in **Appendix A6**. The content should include fields for the records identified elsewhere in this guide to enable management of safety-critical fixings, and also data for the primary asset, fixture and fixing, which can be generated during all life cycle stages of the fixing, including design, installation, testing, in-service and decommissioning. The suggested content provided in **Appendix A6** may be adapted depending on the features of the asset information system.

The volume of information required for safety-critical fixings can appear to be large. The benefit of collecting and maintaining these records for safety-critical fixings is that the risk due to the fixing can be determined with greater certainty. Where records are not available, then further investigation and intervention can be required to manage the risk and these actions can be costly.

The volume of information to be recorded can be reduced by using index or a database. For example, only a single copy of a EAD can be stored, but can be referenced using indexing links from multiple individual fixing records.

The asset owner should establish and operate processes to check the quality of the data recorded for safety-critical fixings. Quality checks should be carried out at a time when identified errors can be rectified. For example, a check of handover data for a new fixing installation should be made while the designer, supplier and installer are still available to correct any omissions or errors. Where data quality checks are not made contemporaneously with data entry, then relevant information can be lost irretrievably.

10.3 FEEDBACK, IMPROVEMENT AND KNOWLEDGE SHARING

Recommendation 13. Knowledge about the performance of fixings should be shared and, in particular, failures and near misses involving fixings should be reported.

Good practice in asset management (and more generally in management processes) includes for feedback and continual improvement. For example, both ISO 55000:2014 and ISO 9001:2015 discuss performance evaluation and continual improvement.

Feedback on performance can assist in updating and refining the basis of the risk assessment. As noted in **Section 5.3**, there is little statistical data on the likelihood of failure of fixings in service and so a qualitative risk assessment is recommended. The risk factors defined in **Table 5.4** and **Appendix A4** are based on current evidence of known failures.

Asset owners should capture information about the performance of safety-critical fixings. Performance data can include failures, near misses, design life information, performance under particular environmental or loading conditions. Information about near misses can assist in identifying risk factors before a failure occurs.

Where near misses or failures of safety-critical fixings have occurred, then the asset owner should establish the risk factors that contributed to the near miss or failure. Risks can include new factors not included in **Table 5.4** and **Appendix A4**, for example, identification of a previously-unseen mechanism of failure.

Reports of near misses and failures should be shared within the construction industry. For example, an industry confidential reporting facility is provided by Structural-Safety incorporating CROSS and SCOSS. Newsletters and alerts are produced and made available to the industry based on reports received.

Structural-Safety (incorporating CROSS and SCOSS) www.structural-safety.org

The asset owner should establish a mechanism for remaining up to date with industry information on fixings. For example, this could be by membership of a community of organisations such as the Bridge Owners Forum, ADEPT and the UK Bridges Board or by receipt of industry alerts. The asset owner should update relevant policies and procedures when the current state-of-art knowledge and practice for safety-critical fixings changes.

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Part 3 Design and installation for effective future management

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11 Management process and concepts for new fixings

Summary

Fixings that are designed and installed in accordance with current industry standards and guidance can be expected to perform satisfactorily. This guide makes recommendations for design and installation of fixings to enable them to be managed effectively in future, linking with the recommendations of the previous section for management of safety-critical fixings.

11.1 IMPROVING THE APPROACH TO DESIGN AND INSTALLATION

Considerable effort has been invested by the construction industry in producing standards and guidance for design and installation of safety-critical fixings, including BS 8539. Fixings designed and installed in accordance with relevant standards and guidance can be expected to perform satisfactorily.

The quality of installation, including workmanship, is a major factor affecting performance of a fixing and likelihood of failure. Confidence in the quality of installation should be provided through assurance, with positive confirmation that what was designed was built correctly.

Part 2 provides guidance on the management of safety-critical fixings. The management process depends on the availability of information about fixings. From the design and installation, high quality, comprehensive and accurate information describing what has been installed, should be obtained and retained to enable the future management of the fixing.

Design and installation of a new fixing should be carried out to minimise the whole-life risk presented by the fixing. It can be achieved by considering the applicable risk factors during the concept design of structures and fixings, and designing-out or mitigating the residual risk factors.

Design decisions about the overall structure (for example, the configuration of ventilation ducts or structural connections) can have a significant effect on the arrangement of safety-critical fixings. Where possible, it is important to consider the overall structural design process in addition to the selection and design of fixings.

11.2 MANAGEMENT PROCESS FOR DESIGN AND INSTALLATION OF NEW FIXINGS

The relationship between design, installation and management in-service is shown in Figure 11.1.

Further detail is provided in the Chapter 12 (design) and Chapter 13 (installation).

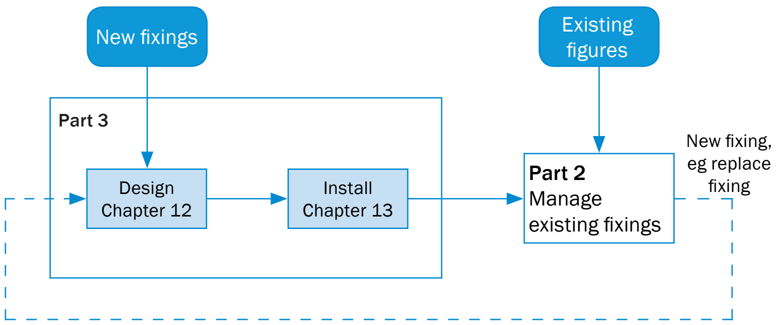

Figure 11.1 Links between design, installation and management in-service

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11.3 SUMMARY OF RECOMMENDATIONS

This guide includes 11 key recommendations for design and installation of safety-critical fixings. The key recommendations are summarised in Table 11.1 and are explained in more detail in relevant sections of the guide.

Table 11.1 Recommendations regarding design and installation of safety-critical fixings

	Recommendation	Section ref
Design of new fixings		
14	New safety-critical fixings should be designed, specified, installed and tested in accordance with BS 8539	12.1, 13.2
15	Risk factors that apply to safety-critical fixings should be eliminated or mitigated by design, considering the fixing, the fixing system and the overall structural system so far as the design scope permits	12.2.3, 12.4.2
16	The design of new safety-critical fixings should assist future management, including inspection, testing and replacement	12.5.1, 12.6.1
17	The design of new safety-critical fixing systems should incorporate robustness	12.6.1
18	New safety-critical fixings should be selected from those with an ETA, unless there is no applicable ETA that covers the particular application	12.7
19	Full design records should be provided and retained for new safety-critical fixings	12.8
20	New safety-critical fixings should be included in technical assurance processes including AIP, design certification and design checks	12.9.1
Installation of new fixings		
21	Installation of new safety-critical fixings should be carried out and supervised by competent persons	13.2
22	Installation of new safety-critical fixings should be in accordance with the fixing manufacturer's instructions and the design specification	13.2
23	New safety-critical fixings should be proof-tested to verify quality of installation	13.3
24	Installation and test records should be provided and retained for new safety-critical fixings	13.4

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12 Achieving confidence in design

Summary

The potential risk factors affecting the future performance of a fixing depend not only on the selection of the fixing itself, but also on decisions taken, possibly by other parties, on the concept of the structure as a whole and the arrangement of the fixing system. Appropriate CE-marked fixings should be specified where possible. Safety-critical fixings should be designed to facilitate future management, including design for inspection, testing and replacement, and design to provide robustness. The residual risks from new safety-critical fixings should be controlled by the asset owner through technical assurance processes including consideration of whether a safety-critical fixing is required in the first place. Full design records should be provided and retained to enable future management of the fixings.

12.1 DESIGN PROCESS

Recommendation 14. New safety-critical fixings should be designed, specified, installed and tested in accordance with BS 8539.

Correct design should result in fixings that present a low risk throughout their life and that require a minimal amount of effort to manage. Conversely, incorrect design can result in a legacy of intervention and effort for the life of the fixing.

New safety-critical fixings should be designed and specified in accordance with BS 8539. This guide aims to provide supporting information to that given in BS 8539 on how new fixings should be designed to enable effective future management.

'Design' of a fixing can mean many different things. BS 8539 reserves the term 'design' for the specific process of determining the size of fixing required. In this guide, the term includes design of the structural system, the fixing, and the fixing system. Also, it recognises the influence that wider design considerations of the entire structural system can have on the need for, and performance of, both the fixing system and an individual fixing, and the role of technical assurance in providing confidence in the integrity of the fixing. These relationships are shown in **Figure 12.1**.

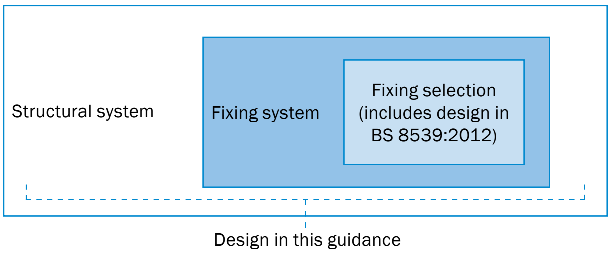

Figure 12.1 Relationships between design of the fixing and the structural system

This guidance is intended to be used for a range of applications of safety-critical fixings. Some of the steps may be more or less relevant depending on the application and design scenario. For example, the design of a new road or rail tunnel may include ventilation and M&E requirements, and the potential for associated fixings can be considered at the start of structural design. In contrast, the requirement to install a new CCTV camera can afford little opportunity to reconsider the structural system.

The design process generally starts from consideration of the structural system and moves into the fixing system then the selection of the fixing. There can be benefit in iteration between the stages. The design process is shown in **Figure 12.2**.

Design of safety-critical fixings should be undertaken by a competent designer, ie a designer that can demonstrate knowledge of the issues and experience in the design of safety-critical fixings.

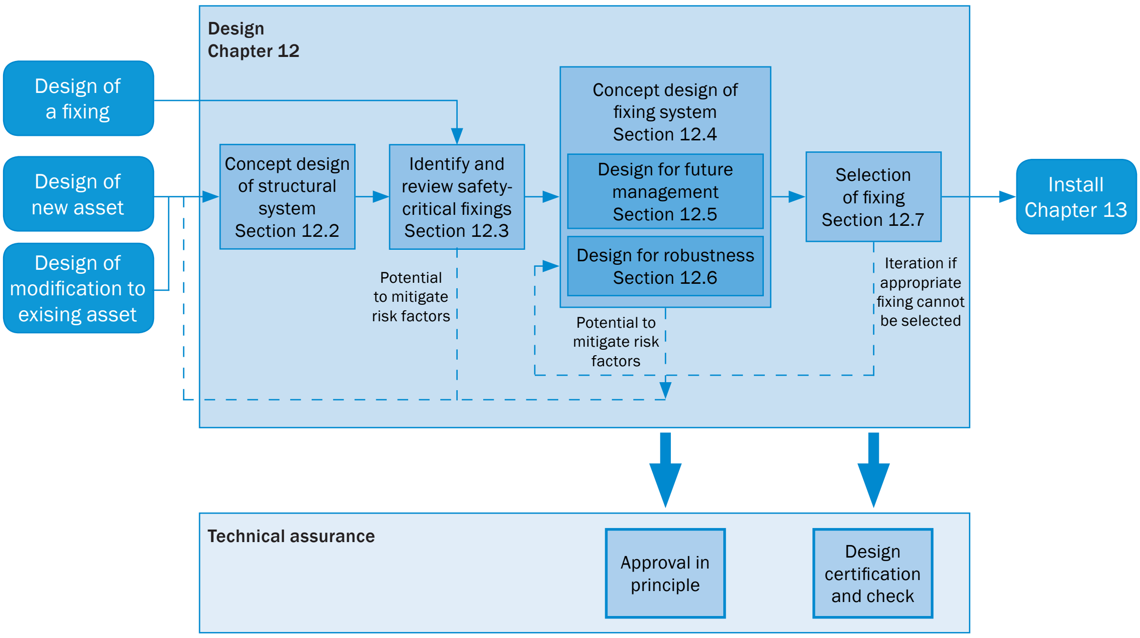

Figure 12.2 Design process for safety-critical fixings

12.2 CONCEPT DESIGN OF THE STRUCTURAL SYSTEM

12.2.1 Scope of structural system concept design

The structural system concept design may determine that a fixing is needed at a particular location.

Decisions made during the concept design can have a profound effect on the selection of fixings. Early consideration of fixings in the overall structural design process can provide opportunities to minimise the residual risk presented by fixings or to consider eliminating safety-critical fixings. However, where fixings are considered later in the overall design process or are an after-thought, there can be little flexibility to optimise the fixing arrangement.

Concept design can involve a balance between multiple constraints while satisfying project requirements. The designer should aim to minimise the residual risk due to safety-critical fixings, subject to the project constraints and requirements.

The ability of the designer to realise opportunities to reduce residual risk can depend on how tightly defined the design task brief is. Where a designer recognises a potential opportunity for a preferential fixing arrangement, which requires changes outside their design scope, then they should explore whether such changes can be made.

The designer of the structural system should have an understanding of the risk factors that can apply generally to fixings and be competent in the subject, because conceptual design decisions can have a considerable influence on the fixing selection.

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Box 12.1 The influence of concept design on fixing selection

The concept design of a new tunnel is being undertaken. Ancillary items, which can require fixings, include the ventilation system, lighting, M&E and signs. There are opportunities at this design stage to make fundamental design decisions that affect the need for fixings, such as whether to include false ceilings and cladding systems, and to consider alternatives to fixings, such as cast-in anchors.

There is a requirement to install a new traffic camera. The location of the camera is constrained by the requirement to cover a particular field of view. However, there is an opportunity to consider how this coverage is provided, for example, whether the camera is mounted on a pole or by fixing to a nearby structure. If it is decided to mount the camera on the structure, there is an opportunity to define the support bracket arrangement, and to influence the configuration and actions on the fixings.

A new (replacement) fixing is required for a suspended sign. The position of the sign is fixed by visibility requirements and cannot change. So, the orientation of the fixing is set by the support structure, and the location can only be varied within a small tolerance.

12.2.2 Interfaces and fixings

Interfaces, which could result in the need for safety-critical fixings, should be identified during the concept design of the structural system.

Where the detail of fixings is not known, for example during early scheme design, then the need for fixings can be inferred from the fixtures that are required. Examples of typical fixtures that need safety-critical fixings are provided in **Appendix A1**.

The need for fixtures can arise from multi-disciplinary requirements, for example, M&E cabling, architectural cladding, ventilation systems, lighting, signs, communications etc. The designer of the structural system should establish reasonable foreseeable requirements for fixtures from other disciplines. Input from other disciplines can depend on how the design input has been procured and timing can vary between disciplines.

Where possible, the size and weight, anticipated location and orientation of the fixing, should be established for the fixture(s).

Where there are multi-disciplinary design requirements, the procurement strategy for design work can influence the opportunity to reduce risk from safety-critical fixings. Possible strategies that encourage deeper consideration of multi-disciplinary interfaces include:

- following a staged design process, with outline design including input from relevant disciplines
- sourcing input from relevant disciplines such as communications systems, either in-house or from an external designer
- appointing a design organisation with multi-disciplinary design responsibility.

12.2.3 Minimising residual risk from safety-critical fixings

Recommendation 15. Risk factors that apply to safety-critical fixings should be eliminated or mitigated by design, considering the fixing itself, the fixing system and the overall structural system so far as the design scope permits.

The residual risk should be minimised by designing-out risk factors, so far as is reasonably practicable (SFAIRP). The risk factors and relevant design activity are shown in **Table 12.1** with further information provided in **Appendix A4**.

Confirmation of the risk factors applicable to the fixing can require iteration between the structural system design and the fixing design. See **Section 12.4** for information on the fixing design.

For example, BS 8539 states that anchorages working in shear often have a greater robustness compared to anchors working in pure tension. It suggests that options can be explored for 'top fixings' such as fixing into a vertical rather than a horizontal surface where the fixing operates in shear rather than tension.

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If a risk factor cannot be designed-out, for example, where it is due to the local environmental conditions or the applied action, then the fixing should be selected to be suitable given the particular risk factor.

Elimination of risk is typically placed at the top of risk control hierarchies so elimination of safety-critical fixings is an approach that should be considered. However, there can be cases where a safety-critical fixing is the only practicable solution, for example, when retrofitting signs to an existing structure. Possible strategies to eliminate safety-critical fixings are shown in Table 12.2, and include designing the fixing to become non-safety critical.

Table 12.1 Summary of risk factors in design

	Risk factor	Likelihood (+/-)	Type of fixing	Relevant design activity
Design	Formal technical approval (eg ETA) which covers applicable actions	D	All	Fixing selection/design assurance
Installation	Poor quality of installation	I	All/resin anchor	Fixing type/installation/supervision
	Overhead installation (which could lead to poor quality of installation)	I	Resin anchor	Structural system/fixing concept/ installation/supervision
	Substitution	I	All	N/A (installation)
	Certification of installation	D	All	N/A (installation)
Actions	Shear rather than tension	D	All	Structural system/fixing concept
	Sustained tension	I	Resin anchor	Structural system/fixing concept/ fixing selection
	Cyclic loading	I	All	Fixing selection
	Vibrations	I	All/mechanical	Fixing selection
	Accidental/shock load	I	All	Fixing selection
	Change in fixture/change in use	I	All	N/A (maintenance) – but consider future uses of fixing
Environment	Wet/damp	I	All/polyester resin	Fixing selection
	Corrosive environment	I	All	Fixing selection
	Chlorides	I	All	Fixing selection
	High/low temperature including fire risk	I	All/resin anchor	Fixing selection
	Masonry substrate	I	All/resin anchor	Structural system/fixing concept
Robustness	High degree of redundancy	D	All	Fixing concept
	Secondary restraint	D	All	Fixing concept
	Exposure to sources of damage	I	All	Structural system/fixing concept
Degradation	Not recently inspected/hidden	I	All	Fixing concept (inspection access)
	Missing/failing fixings	I	All	N/A (maintenance)
	Distortion/movement	I	All	N/A (maintenance)
	Substrate degradation	I	All	N/A (maintenance)
	Fixing/fixture corrosion	I	All	N/A (maintenance)

Note

See Appendix A4 for more information.

Table 12.2 Indicative strategies to eliminate safety-critical fixings from the structural system

Strategy	Example	Possible issues
Eliminate the fixture	Review whether fixture is necessary given that it will introduce a safety-critical fixing	Fixture can be vital to satisfy project requirements
	Review whether project requirements can be satisfied using alternative solutions	Inclusion of fixings can be the best compromise given the project constraints and requirements
	Mount the fixture elsewhere, eg supported from the ground	Constraints can dictate the fixture location

Strategy	Example	Possible issues
Make non-safety critical	Reduce the consequence of failure by changing the location of the fixture, eg away from a traffic lane	Constraints can dictate the fixture location
	Make sufficiently robust that it is inconceivable that failure of a fixture will lead to collapse	Can require more fixings Can require an extensive support arrangement Need care to design against a common cause failure
Alternatives to post-installed fixings	Cast-in fixings	Requires knowledge of fixture details at time of construction of main structure Potential tolerance issues Requires more planning for precast elements
	Alternative support, eg built-in beam	Can require 'pocket' in main structure, could be appearance issues Built-in support can also generate issues of tolerances and bearing area

12.3 IDENTIFICATION AND REVIEW OF SAFETY-CRITICAL FIXINGS

Where a need for a fixing(s) has been identified, then a screening should be undertaken to either confirm if the fixing is safety critical or review if it is possible to eliminate it.

The screening questions, which are the same as those used for the management of existing fixings (see **Section 5.2.3**), are repeated in **Table 12.3**. The classification as safety critical or non-safety critical depends only on the consequence of failure, ie whether failure of the fixing could lead to collapse of the structure, risk to human life or significant economic loss.

The possibility of reasonably foreseeable changes of use should be considered in the classification as safety critical or non-safety critical. For example, a fixing proposed over a non-trafficked area can be classed as non-safety critical, but a future modification to the road layout could result in the fixing becoming safety critical.

Where a fixing is non-safety critical, then it should be managed in accordance with good practice guidance such as CIRIA C777.

Table 12.3 Screening questions

	Question	Response
	If the fixing failed...	
1	...is there potential for one or more people to be killed or seriously injured?	Yes/no
2	...is there potential for severe damage to one or more road vehicles/rail vehicles/floating vessels?	Yes/no
3	...is there potential for structural failure of one or more structural members?	Yes/no
4	...could failure of a single fixing lead to progressive failure of a larger area?	Yes/no
5	...would it cause closure of any of the following? ■ Road ■ Railway ■ Commercial waterway ■ A principal pedestrian access to a building or facility ■ A significant utility service	Yes/no
6	...taking into account investigation and access arrangements, would it take longer than one week to restore normal operation of the network?	Yes/no

Notes

Where the answer is 'yes' to one or more questions, then the fixing should be considered as safety critical. The questions reflect the definition of safety-critical fixings, which includes for structural collapse, risk to human life or significant economic loss.

Appendix A5 provides examples of the completion of this table.

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12.4 CONCEPT DESIGN OF THE FIXING SYSTEM

12.4.1 Scope of fixing system concept design

The concept design of the fixing system includes determining the type of fixing (see **Appendix A2**) and any supporting framework or baseplate. Concept design occurs before the detailed selection of a specific fixing product or anchor size. It should be undertaken in accordance with BS 8539, referring in particular to **Sections 5.1 to 5.3**, which include:

- information to be assembled
- preliminary design considerations, including robustness
- factors determining anchor type:
  - reliability
  - base material
  - actions
  - environmental parameters
  - practicalities.

In addition, the concept design should include the following:

- design for future management (see **Section 12.5**)
- design for robustness (see **Section 12.6**).

The outcome of the concept design should be a fixing arrangement that is compatible with the structural system and minimises the residual risk from the fixing.

Once more understanding has been established of the applicable risks and potentially suitable fixings, it can be beneficial to revisit and refine the structural system concept design to improve the fixing concept design.

12.4.2 Designing-out risk factors

Recommendation 15. Risk factors that apply to safety-critical fixings should be eliminated or mitigated by design, considering the fixing itself, the fixing system and the overall structural system so far as the design scope permits.

Risk factors should be reviewed and designed-out, so far as practicable. The factors relevant to the fixing concept design stage are shown in **Table 12.4**. Further information is provided in **Appendix A4**.

Table 12.4 Implications of risk factors on the concept design of fixings

Factor	Specific aspect of factor	Implication for concept design of fixing
Base material	Reinforced concrete	Likelihood of hitting reinforcement during drilling, and specification of action to take if reinforcement is hit
	Shotcrete	Interface between fixture connection and rough surface finish
	Prestressed concrete	Potential unsuitability of post-installed fixings due to risk of destroying structural prestressing strand/tendons during drilling of holes
	Masonry	Potential variation in masonry and mortar strength, and possible voids Check against pull-out of section of masonry
	Cladding	Potential for fixings to be hidden

Factor	Specific aspect of factor	Implication for concept design of fixing
Actions	Sustained tension	Suitability of fixing type (risk of creep). Note that resin fixings with an appropriate ETA are suitable for use under sustained tension.
	Cyclic loading, shock load, exposure to vibration	Potential restriction of fixings that is suitable for these actions. Some of these actions are not covered by standard European assessments (see Appendix A3). Supplementary justifications and test results from fixing suppliers should be sought.
Environment	Water management (eg in tunnels)	Likelihood of fixing being exposed to damp conditions
	Exposure to severe chemical pollution, eg exhaust fumes in road tunnels, de-icing salts	Selection of fixing material type and grade (special alloys of stainless steel required in these conditions)
	Damp, corrosive, temperature extremes, fire risk	Selection of fixing material type and grade Unsuitability of some resins (do not use polyester resin in damp conditions) Potential for loss of concrete cover during fire
	Chlorides (eg marine environment, de-icing salts)	Potential for stress corrosion of stainless steel
Practicalities	Time available for installation (eg due to restricted access periods)	Susceptibility of fixing type to poor quality of installation Curing time for resin before loading Likelihood of satisfactory supervision
	Installation conditions (eg night work, lighting conditions, working conditions including weather and temperature)	Susceptibility of fixing type to quality of installation
	Installation position (eg overhead working)	Susceptibility of fixing type to quality of installation Need for full penetration of vertical hole by resin systems
	Achievable tolerances	Ability of fixture connection to accommodate realistically achievable tolerances

12.5 DESIGN TO FACILITATE FUTURE MANAGEMENT

12.5.1 General

Recommendation 16. The design of new safety-critical fixings should facilitate future management, including inspection, future testing and replacement.

The purpose of designing to facilitate future management is to make provisions in design that will enable an appropriate management regime to be followed. This will give confidence that a tolerably low level of risk is maintained throughout the life of the fixing.

Chapters 4 and 5 of Part 2 recommend active management of safety-critical fixings through a process of periodic risk review. A 'fix and forget' approach to safety-critical fixings should be avoided because there can be unforeseen degradation, changes, performance issues or external events during the life of the fixing.

Design for future management of a fixing should include inspection, future testing and end of life planning.

It can be possible to include measures at the start at low cost, which can avoid the need for expensive investigations or interventions later on.

The measures provided should be based on an understanding of the risk factors that could apply to the fixing. The proposed measure should be an effective control for the risk factor. For example, inspections can be effective at detecting changes such as movement in fixings that have a high proportion of permanent actions, but can be ineffective where fixings are subject to accidental or shock loading.

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Where the fixing is subject to effects that could give higher potential for degradation over time or working loose, then it can increase the need to provide effective control measures for the in-service phase. This can apply to fixings in harsh environmental conditions, or subject to cyclic loading or vibrations.

Where the long-term performance of a fixing cannot reasonably be assured based on measures taken in design, then the decision to use a safety-critical fixing for the particular application should be reconsidered. However, this may require reconsideration of the concept for the structural system.

12.5.2 Design for inspection of fixing

Legislation such as CDM2015 places a legal obligation on designers to eliminate, reduce or control foreseeable risks that can arise during construction work (including maintenance).

Safety-critical fixings should be designed such that the fixings are accessible, can be inspected without the need to remove panels or structural elements, and can be inspected at close distance using a viable means of access. However, ill-considered placement of fixings in relation to bulky fixtures such as tunnel ventilation fans can restrict the reach of mobile access platforms and prevent close inspection.

Where it is unavoidable that the fixing is hidden or concealed, then a means of access to the fixing should be provided. Examples include an access hatch into a ceiling area, a removable panel, or boroscope access. Further guidance on hidden critical defects is provided in Section 7.3.4 of Collins *et al* (2017).

Section 7.3 of this guide provides information on inspections, and **Section 7.3.4** for inspections during steady-state maintenance. Inspections should be able to detect:

- changes:
  - in fixture/use
  - in actions
  - in environment
  - in condition of fixing, substrate, fixture, attachment.
- defects:
  - in missing, distorted or elongated fixings
  - in movement of fixing or fixture
  - in gaps between fixing and attachment
  - poor condition or rapid degradation of condition of fixing or substrate.

Box 12.2 Limitations on inspections as a contributory factor to failures

> Several of the failure case studies highlight that limitations on inspection had a role in the failures.
>
> The Balcombe tunnel investigation report (RAIB, 2014) states: *"To reach the upper parts of the tunnel, examiners worked from rail-mounted mobile tower scaffolds, which needed to be erected, put on the track, and pushed into position before work could start. This means that short duration or interrupted possessions were not an adequate substitute for long possessions with uninterrupted access… staff found that Balcombe tunnel was a particularly difficult location to gain sufficient access for examination work. The long possessions required for tunnel examination were seldom available… Inadequate access meant that tunnel examinations were not undertaken in accordance with Network Rail standards".*
>
> The Sasago Tunnel report (MLITT, 2013) state: *"There was no close visual inspection or hammer testing of the ceiling bolts in the L cross section for 12 years, because of a change of inspection plan without first clarifying the condition of the ceiling adhesive bolts."*

12.5.3 Design to enable future testing

Load testing can provide assurance that a fixing continues to achieve a certain resistance over time. There can be benefit in including provision for testing even where it is not initially intended to undertake testing at defined intervals. The extra costs of including measures to enable testing can be relatively low if included from the start.

Designing for future load testing can be beneficial where, for example:

- Permanent actions carried by the fixing are a low proportion of the design load, for example, where the fixing is intended to carry accidental or shock loading.
- The fixing is subjected to a type of loading that is not covered by formalised test regimes (such as the ETA, see **Appendix A3**), for example, cyclic loading.
- There is high potential for degradation of the substrate or aspects of the substrate performance or strength are unknown.
- There is a high consequence of failure of the fixing.
- There are many similar fixings.

Analogy can be made with other types of fixing for which periodic testing is required, for example, anchors for suspended access.

Where a fixing is covered by a formal test regime (such as the ETA) and other factors listed above do not apply, then future testing is not likely to provide significant additional confidence in the fixing.

Section 7.4 provides guidance on load tests. Where future testing is envisaged in the design, the design records should include a documented future testing strategy that includes:

- type of test (eg proof test or to determine the allowable resistance)
- test load (see **Section 7.4.3**, noting that the test load can be significantly lower than the design load, and that over time the fixing arrangement can be subject to load relaxation and creep)
- frequency of testing (for example, five-yearly, 10-yearly, or mid-design-life)
- planning in the event that the test load is not achieved.

Physical measures to manage future testing can include:

- Extra fixings included specifically for future testing, potentially sited advantageously to minimise the access requirements during testing.
- Fixture/connection designed to enable testing, for example, having an extended thread to allow for attachment of a test rig, or allowing for testing without removal of the fixture
- Space to allow for the testing rig, which can include a spreader beam.

Where extra fixings are provided for future testing, the fixings should be in locations and conditions that are representative of the other fixings. The testing strategy should recognise the possible differences between the fixings tested and those in use.

12.5.4 Design for end of life

The design should establish and record the assumptions made about the end of life of the fixing. There should be at least one viable safe method for removing the fixture. Assumptions about the method of removal should be recorded.

Fixings should have a design life at least as long as the fixture. Proprietary fixings typically have a maximum design life of 50 years.

Where a fixture is critical to network operations or to the performance of the structure, then it can be beneficial to provide redundancy to allow replacement of fixings while the fixture remains in service.

Improved redundancy is discussed further in **Section 12.6**. Options for improving redundancy to allow replacement of fixings include:

- Making provision for fixings to be installed at other locations along a support framework, where one is present.
- Allowing for progressive replacement of fixings while the fixture remains in place (with assumptions about number of fixings that may be removed at any time during replacement).

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12.6 DESIGN FOR ROBUSTNESS

12.6.1 GENERAL

Recommendation 17. The design of new safety-critical fixing systems should incorporate robustness

Design for robustness is one of the basic requirements for structural design set out in BS EN 1990:2002, and for anchors in BS 8539.

Robustness is the ability of a structure to sustain adverse and unforeseen events and limit local damage to an extent that is not disproportionate to the cause. It includes the behaviour of a system of fixings, in addition to the performance of individual ones.

In basic terms, the fixing system should be designed such that the failure of any one fixing does not result in overall collapse.

Provision of sufficient robustness can mean that the fixing becomes non-safety critical, for example, where it is inconceivable that failure of a single fixing would lead to structural failure, risk to human life or economic loss.

Possible strategies to design for robustness include:

- improve redundancy
- provide excess capacity
- segmentation
- reduce exposure of fixing.

The potential for systematic errors leading to common-cause failures should also be considered in design for robustness.

There are similarities between robustness measures incorporated during new design and robustness measures to manage the risk from existing fixings. Guidance on retrospective measures to improve robustness is provided **Section 8.3**, drawing on the framework outlined in this section.

12.6.2 Improve redundancy

Methods can include:

- design against single point of failure
- distribute actions between more fixings
- provide alternative load paths to distribute loads in the event of failure
- provide secondary restraint.

Systems of safety-critical fixings should be designed to avoid a single point of failure. The fixing system should be designed to accommodate a failure of one fixing. For example, a fixture can be fixed using two fixings rather than a single one, with each designed to carry the full load.

In general, distributing the actions between a greater number of fixings provides an increasing degree of redundancy. However, there is a balance between the cost of installation and benefit obtained and installation practicalities such as maintaining edge and centre distances.

The effect of indeterminacy should be included in the design, as well as geometrical installation tolerances. For example, a uniform support arrangement of four fixings can result in more than one

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quarter of the load being attracted to one fixing if they have not been installed in the same plane, or if the base plate has to be forced into place. Design for loss of one fixing can result in similar load effects being designed for.

Load distribution can be provided through a support framework, and through the strength of the fixture. Where reliance is placed on the strength of the fixture, then it should be designed or checked for the assumed load distribution mechanism.

The load distribution system should be designed for the loss of a fixing or fixing group. The support framework or fixture should be designed for the loads generated by the envisaged failure mechanism. For example, a sagging mechanism can generate additional components of force due to a catenary tension effect.

The resistance of the remaining fixings should be sufficient to carry the load shed from a failed fixing, to avoid an 'unzipping' progressive failure. The load applied to the remaining fixings should include any geometric effects arising from the assumed failure mechanism, for example, eccentric forces, prying actions, shear components or twist.

The mobilisation of a load distribution mechanism should be designed to be detectable. This could occur through visual inspections identifying a missing fixing or detecting deformation of a support framework.

Case study 12.1 Partial failure of a water catchment structure in Balcome Tunnel

The Balcombe tunnel investigation report (RAIB, 2014) notes that the design of the water catchment tray incorporated redundancy.

The continuous longitudinal beams and the strengthening effect provided by fixing the deck to the supporting steelwork meant that the structure could accommodate the accidental loss of several wall fixings without immediate catastrophic collapse.

Although there were economic consequences due to the incident, with train services suspended for some time to allow for remedial work, the sag of the structure was detected and remedial measures taken before any damage to vehicles or injury to people occurred.

Figure 12.3 View of water catchment tray showing longitudinal beams (from RAIB, 2014)

Box 12.3 Example of design for improved redundancy

For a regular linear arrangement of fixings, it is assumed that fixings at one location can fail.

By simple statics, the support framework needs to be designed to span twice the fixing spacing. Each fixing should carry 1.5 times the characteristic load, which would be obtained if all fixings were present and functioning. Note that the design load of the fixings is higher than the characteristic load, because it is increased by the partial safety factor.

The deformation of the support framework under this design situation should be considered and may lead to increased load on the remaining fixings, for example due to sagging or prying.

Where the statistical strength distribution of the fixing is known, there may be advantage in taking a probabilistic approach assuming the weakest fixing in the series fails first, with load being shed to a fixing with mean strength. However, given the overall factors of safety involved, the additional complexity of this approach may not be warranted.

12.6.3 Secondary restraint

Secondary restraint is a method of improving redundancy. Secondary restraint can prevent the fixture from falling if the primary fixing fails. It does not necessarily address the point of failure of a primary fixing, but it can mitigate the consequence of a failure.

The factors listed in **Table 12.5** should be considered in the design of the secondary restraint.

Table 12.5 Design considerations for secondary restraint

Topic	Detail
Space for installation	Check the space available for installation of the restraint system. Where fixings are used for the secondary restraint, check the edge distances and spacings for the new fixings.
Angle of restraint	Where the restraint is inclined, then the inclination will increase the tension force in the restraint and can result in tension and shear within the support arrangement depending on the orientation of the connection detail.
Dynamic action	Where the fixture falls for a distance (for example, if movement is necessary to mobilise the restraint or if there is some slack in the restraint), then the restraint should be designed for the dynamic load required to arrest the movement of the fixture, in addition to the relevant self-weight. Where the secondary restraint is supported by fixings, then the fixings should be suitable to carry impact loading.
Type of fixing	Where the secondary restraint is supported by fixings, then it can be desirable and/or necessary to use a different type of fixing compared to the primary fixings. Where the same type of fixing is used then there can be potential for the same risk factors to apply to the secondary restraint system as to the primary fixings. Where the same risk factors apply there can be a risk of 'unzipping' failure and of the secondary restraint also failing when load is transferred to it from the primary fixings. The actions on the restraint fixings can be different to the actions on the primary fixing, depending on the respective number of fixings, inclination of restraint and dynamic effects.
Primary structure	Resistance of the primary structure to support the restraint loads, particularly where restraint is retrofitted and was not envisaged in the original design

Figure 12.4 Secondary restraint chains for tunnel jet fan

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12.6.4 Provide excess capacity

The codified design methods for fixings are intended to provide an adequate factor of safety, assuming that the fixing is installed correctly and that the design method is appropriate for the actual installed conditions including environment and applied actions. Codified design methods include the EADs (see **Appendix A3**) and BS EN 1992-4.

There is no guidance available on providing excess capacity (ie increasing the factor of safety). Even where excess capacity is provided then systematic errors can still result in common-cause failures occurring (see **Section 12.6.7**).

An arbitrary amount of excess capacity should not be relied upon to provide robustness. Instead, the risk that assumptions of the codified design methods are not fulfilled should be mitigated by undertaking assurance of both design and construction.

12.6.5 Segmentation

The purpose of segmentation is to limit the progression of a failure through a structural system by dividing it into discrete elements.

Load distribution should not occur between the discrete elements. It can still be possible to improve redundancy through alternative load paths within a discrete element, however each discrete element should include several fixings or fixing groups and a suitable system of load distribution.

A segmentation scheme and associated structural joints should be compatible with the function of the fixture. For example, segmentation of a ventilation duct can introduce the need for seals between discrete structural units.

12.6.6 Reduce exposure of fixing

A fixing can be exposed to accidental damage due to its location, or degradation due to the local environmental conditions. For example, a fixing on the inside face of a structure can be exposed to damage during maintenance work, by vandalism or by traffic impact.

Potential sources of damage or degradation of the fixing should be identified during design.

Where a risk of damage is identified, it can be possible to reduce the exposure by changing the location of the fixing. This can require an iteration of review of the structural system concept design.

Where the location of the fixing cannot be changed, it can be possible to protect the fixing, for example, by including sacrificial concrete around the fixing. See the example in **Section 8.3.4**.

12.6.7 Common-cause failures

Many case studies illustrate the potential for a particular failure mode with a common cause to apply systematically to a large number of fixings. In some of these, a large number of fixings have failed due to the same cause or event, and the global factor of safety has been considerably lower than anticipated. See **Table 12.6**.

Where a systematic error can occur, a high global factor of safety or a high degree of redundancy are not necessarily sufficient measures to prevent overall failure.

Common-cause failures can occur due to systematic errors in construction or due to errors in design particularly where the same design element is repeated many times. The primary mitigations against common-cause failures are assurance of design and of construction.

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Possible design strategies that can limit the consequence of common-cause failures are:

- **Segmentation:** dividing the structure into discrete and structurally-separate elements, so that failure will be limited to a discrete unit. Although part of the structure can still fail, it will not progress to the remainder of the structure.
- **Ductility:** initial failure causing deformation, which can be detected by inspection and acted upon before full collapse occurs.

Table 12.6 Case studies involving common-cause failures

Failure	Description
Balcombe tunnel (RAIB, 2014)	Resin used for all fixings was incompatible with damp conditions in the tunnel. Numerous fixings became loose and fell out.
Sasago Tunnel, Central Expressway (MLITT, 2013)	Transverse ventilation load consistently neglected in design so all fixings were under-designed. Resin and concrete were subject to long-term degradation.
Redbridge flyover (Simpkins, 2016)	Consistent installation error on certain structures (two out of four similar structures) thought to have led to poor bond for resin anchors throughout the structure. A complete series of anchors apparently loose and ineffective.
Oxgangs primary school (Cole, 2017)	Consistent installation error led to inadequate embedment of large numbers of wall ties, leading to failure of a large section of cladding.

Case study 12.2 Sasago tunnel ceiling collapse on the Chuo Expressway, Japan

Anchor bolts holding suspended ceiling panels pulled out over a length of 140 m in the Sasago Tunnel.

Several factors contributed to the failure. In particular, the design had neglected the bending effects caused by differential pressures, which increased the loads in the fixings by 60 per cent compared with the assumed design loads. There appeared to be installation quality issues with incomplete spreading of the resin along the anchor bolts. There appeared to be strength loss over time due to cracking and voids in the concrete, possibly made worse by cyclic loads from switching of the ventilation system.

The same factors were relevant at many fixings, and resulted in a reduction in the actual factor of safety compared with the design intent.

Figure 12.5 Progressive collapse of a 140 m length of ceiling panels in Sasago Tunnel

An initial failure at one fixing location resulted in the load being shed to adjacent fixings via the framing system. However, the actual factor of safety at the fixings (also reduced due to the common causes previously noted) was insufficient to accommodate the increase in load from the failed fixing. This led to a progressive 'unzipping' failure of the ceiling panels.

A segmentation approach (division of the ceiling into discrete sections) would not have prevented the initial failure, but could have reduced the extent of the collapse.

Case study 12.3 Vehicle impact on concrete bridge parapet

Figure 12.6 Parapet unit moved during vehicle impact

A parapet unit was displaced after it was hit by a car. The parapet unit was attached to the bridge deck by a series of 11 vertically-acting fixings that had been installed during refurbishment work some 10 years previously. The movement of the parapet indicated simultaneous failure of the fixings in the unit.

The primary cause of failure was that the resin anchors were ineffective. Further investigations found that contributory causes included that the socket diameter was small and, although compliant with the manufacturer's design specification, led to a thin resin annulus despite the socket depth. This imparted difficulty in cleansing and achieving consistent grouting, and the retrofitting during refurbishment work precluded testing of the system to assure quality of installation.

Figure 12.7 Loose resin anchors laid alongside parapet unit (courtesy Southampton City Council)

12.7 SELECTION OF FIXINGS

Recommendation 18. New safety-critical fixings should be selected from those with an ETA, unless there is no applicable ETA that covers the particular application.

After the concept design of the fixing system has been undertaken, including the determination of the type of fixing, then the specific fixing should be selected and specified.

Selection and specification of the fixing should be undertaken in accordance with Sections 5.4 and 5.5 of BS 8539.

Where possible, safety-critical fixings should be selected from anchors that are qualified to a EAD, including ETAGs used as EADs. A description of the ETA process is provided in **Appendix A3**. The terms shown in **Table 12.7** are used.

Table 12.7 Terms used in the ETA

Construction Products Regulation 305/2011 (after July 2013)		Construction Products Directive 89/106/EEC (before July 2013)
EAD	A harmonised technical specification for a construction product, relevant where there is no harmonised European product standard, such as for fixings.	ETAG
ETA	Confirms the performance of a product against the criteria given in the EAD.	European Technical Approval (ETA – note this has a different meaning, but the same acronym).

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Construction Products Regulation 305/2011 (after July 2013)		Construction Products Directive 89/106/EEC (before July 2013)
DoP	Confirms the performance of the construction product. The DoP should confirm which options, levels, classes and categories apply for the product. It entitles the manufacturer to apply a CE mark to the product.	Attestation of conformity, which may include either a certificate or a declaration.
Assessment and verification of constancy of performance	The manufacturer must adopt a system that assures the performance of the product. The system needs to be indicated in the DoP.	Systems of conformity attestation.

Key

EAD = European Assessment Document

ETA = European Technical Assessment

ETAG = European Technical Approval Guideline

Where an anchor is qualified to an EAD, it can require the use of a specific design method. For example, the EAD for mechanical fasteners for use in concrete (EOTA, 2016) specifies design in accordance with pr EN 1992-4:2013. The manufacturer can often undertake this aspect of design as part of the qualification to an EAD. As noted in Section A.4 of BS 8539, when selecting anchors qualified to an EAD, the values are ideally taken directly from the approval document or by using the manufacturer's design software.

Where specific types of action are not covered by an EAD, then reference should be made to other design and test standards. This can include, for example, fatigue tests and accidental actions. Specialist advice should be sought from fixing manufacturers.

The other design methods given in Annex A of BS 8539 can also be relevant.

As noted in Figure 2 of BS 8539, where the design process does not produce a result (ie no suitable fixing is identified), then the application parameters should be revised or the concept design of the fixing should be revisited.

Where possible, all fixings in the same installation should be of the same type, to reduce the possibility of installing the wrong one. Where it is unavoidable to use different types of fixing, then they should be readily distinguishable by the part that will remain visible after installation. This will help to identify errors following installation.

Safety-critical fixings in transport applications can often be exposed to harsh environments, which in Table 1 of BS 8539 are termed 'special applications'. Harsh environments can include exposure to de-icing salts (for example, vehicle restraint barriers) and exhausts in road and rail tunnels. Fixings for special applications should be specified with special alloys of stainless steel, in accordance with Table 1 of BS 8539, ie high corrosion-resistant stainless steels of the duplex type and austenitic steels with higher alloy content than A4 (sometimes referred to as grade C or HCR). Suitable alloys for high corrosion-resistant stainless steels include 1.452 9 and 1.456 5.

The specification for the fixing should include specification of the proof tests required to demonstrate satisfactory installation and, if required, the tests to determine allowable resistance to demonstrate suitability of the fixing for the proposed application. The specification should provide information to the tester as listed in Section 6.6 of BS 8539.

12.8 DESIGN RECORDS

Recommendation 19. Full design records should be provided and retained for new safety-critical fixings.

Design records for fixings are fundamental in enabling their future management. Complete and comprehensive design records can help to reduce the effort required to demonstrate that fixings present a tolerably low level of risk.

Design records should be stored in an asset information system (see **Chapter 10**). Guidance on the content to be included in the asset information system, including design records for safety-critical fixings, is provided in **Appendix A6**, which incorporates the data listed in Section 6 of BS 8539. The following information has particular relevance for the management of safety-critical fixings:

- full description, including make, type, EAD, ETA and DoP (where applicable), size, designation, manufacturer's reference number
- design actions and their nature
- performance data, including characteristic resistance, design resistance and recommended resistance
- material details for fixing and resin where used (eg grade, corrosion resistance)
- assumed substrate strength
- embedment depth
- minimum spacings, edge distances, base material thicknesses
- certificate of design and check (where required by asset owner technical assurance processes).

12.9 TECHNICAL ASSURANCE

12.9.1 General

Recommendation 20. New safety-critical fixings should be included in technical assurance processes, for example AIP, design certification and design checks.

In general, the purpose of technical assurance is to provide confidence in the technical integrity of a product, process or system. It includes technical governance that shows technical risk is effectively controlled and managed in a transparent way. Technical assurance can help asset owners to meet their obligations towards public safety and long-term value for money.

Different asset owners can operate different technical assurance procedures, so the guidance in this section should be interpreted and adapted as required according to the particular need and systems of an asset owner.

Guidance is provided for the following aspects, which are assumed as common features of many technical assurance systems operated by asset owners in the transport infrastructure sector:

- AIP of concept (statement of design intent)
- certification of design
- design check (including selection of anchor).

By adopting the guidance provided in this section, asset owners may need to update relevant procedures and information.

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12.9.2 Approval in Principle of concept

The intent to use safety-critical fixings should be recorded and agreed in the AIP document or other statement of design intent. They should also be identified during the design process (see **Section 12.3**).

The benefits of including the intent to use safety-critical fixings in the AIP document are:

- affording the technical approval authority the opportunity to apply a degree of review commensurate with the potential effect that the safety-critical fixing will have on future management
- defining the future maintenance responsibility for the fixing
- triggering inclusion of the fixing within the asset records.

The discipline or group responsible for future management of the safety-critical fixing should be identified. The responsible party should review and agree to the use of the fixing by sign-off of the AIP.

The need for safety-critical fixings can arise at different stages during the overall design process. The following hierarchy may be adopted by asset owners:

1. Where the need is identified during concept design of the structure, include the fixing in the structure AIP document.
2. Where the need arises from an M&E or other installation which is covered by its own AIP document, include the fixing in the AIP for the new installation.
3. Where there is no other AIP, which could cover the fixing, produce a short addendum to the main structure AIP to describe the fixing.

It is suggested that safety-critical fixings are included as a standalone subheading within the AIP document, for example under 'proposed structure' or equivalent.

As a minimum, the AIP document should identify the fixture and the proposed location on the structure of the fixings (ie the output from **Section 12.3**) and the envisaged concept for the fixing system (ie the output from **Section 12.4**).

Where there are specific conditions or applied actions that may lead to the use of a fixing that is not qualified by a EAD or may need supplementary specification or testing, then this should be highlighted in the AIP document.

The review of the AIP document for safety-critical fixings may include the following, at the discretion of the technical approval authority:

- correct identification of the need for safety-critical fixings, including foreseeable interfaces for the structure
- confirm safety-critical fixings are a suitable solution for the application, or their elimination if not
- maintenance responsibility defined
- robustness of the fixing concept
- fixing concept has been designed to assist future management
- proposed fixing type appears suitable for the applied actions and surrounding environment.

12.9.3 Certification of design

The fixing selected for each location (ie the output from **Section 12.5**) should be recorded in the information produced for construction, for example, on a design drawing or in BIM format.

Satisfactory completion of the design should be recorded, for example, by sign-off of a design certificate. The relevant design documentation which describes the safety-critical fixing should be referenced by the design certificate. The purpose of the design certificate is to certify that a design has been undertaken with reasonable professional skill and care, in accordance with the agreed AIP, and that a named principal of the design organisation has taken responsibility for the preparation of the design.

12.9.4 Design check

The fixing selection should be checked. The degree of independence of the check may be in accordance with other independent checking procedures operated by the asset owner.

The check should include all relevant factors and, as a minimum:

- fixing selected has sufficient resistance for the applied actions
- substrate has sufficient resistance for the actions applied by the fixing
- detailing is correct, for example, edge and centre spacings and embedment depth
- material grade is suitable for the environment
- where the fixing is qualified by an EAD, confirmation that the EAD and ETA adequately covers the specific application of the fixing
- where the fixing is not qualified by an EAD or requires supplementary specification or testing, confirmation that the full specification is adequate for the intended use.

Satisfactory completion of the check should be recorded, for example, by sign-off of a check certificate.

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13 Achieving confidence in installation

Summary

Correct installation of fixings is essential for providing the performance that is expected by the design. Confidence in the installation will be achieved by following the manufacturer's instructions, having competent installers and by supervision. Full records of installation, supervision and testing should be provided and retained.

13.1 GENERAL

CFA (1996) contains a salutary introduction, which is worth repeating here:

> *"Of the millions of fixings used every year the very few which fail generally do so because of poor installation.*
>
> *In any application, whether safety critical or not, the full performance expected by the specifier can only be realised if correct installation procedures are followed. In extreme cases poor installation may reduce the safety margin such that the fixing fails either during installation or while in service.*
>
> *Correct installation will be achieved by following the manufacturer's instructions. Management should ensure that installers are trained in the method for the fixing concerned and supervised on the job. The current equipment must be used."*

13.2 INSTALLATION

Recommendation 14. New safety-critical fixings should be designed, specified, installed and tested in accordance with BS 8539.

Recommendation 21. Installation of new safety-critical fixings should be carried out and supervised by competent persons.

Recommendation 22. Installation of new safety-critical fixings should be in accordance with the fixing manufacturer's instructions and the design specification.

Installation of fixings should be undertaken in accordance with BS 8539 (in particular Section 7), which includes recommendations and guidance on the competence of installers, installation procedures and aspects of the installation.

The installer should be provided with the relevant basic details about the fixing and its installation in a single document, for example, similar to the sample specification formats produced by the CFA. The CFA observes that putting the relevant basic information into the specification can improve the chances of the installer achieving the following objectives:

- obtain the correct fixing
- drill the hole to the right dimensions
- install the fixing with the right equipment (including getting the hole clean)
- tighten the fixing to the correct torque.

Fixings should not be substituted for a different type by the installer, unless this has been approved through the change management procedure (see **Section 13.3.5**).

Poor quality of installation can be a risk factor in the future management of fixings. Installation quality issues can include the aspects listed here (see also **Appendix A4**):

- edge distance too small or fixing spacing too small
- hole errors (not drilled to correct depth or diameter)
- hole preparation errors (not adequately cleaned or wrong surface roughness)
- wrong diameter of fixing bolt

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- resin not properly coating fixing throughout its length (insufficient resin, air entrainment, overhead installation etc)
- resin preparation errors (wrong mix proportions, outside acceptable temperature range, not pumped to waste, anchor rods not properly inserted into capsule systems etc)
- anchor rods not properly inserted into capsule systems
- anchor rods cut short when rebar is struck
- fixings loaded, tightened or tested before the manufacturer's curing time has elapsed
- fixings over-tightened.

13.3 ASSURANCE OF INSTALLATION

13.3.1 General

The assurance of the installation aims to provide confidence that what was designed is installed, and that a high-quality installation will achieve the resistance and durability intended by the design.

The processes set out in BS 8539 should be followed to achieve assurance of the installation. These include:

- supervision
- certification of installation
- testing of fixings
- change management – alternative fixings.

Also, asset owners may choose to operate independent audit roles, possibly as part of a more general verification of construction quality.

Assurance of installation through all of these methods is important for safety-critical fixings because:

- once installation is complete, it is difficult to verify critical parameters such as embedment depth
- fixings that have a superficially similar appearance can have considerably different performance characteristics
- there are a large range of fixing applications, with similar fixings used for non-safety critical and safety-critical applications
- the performance of a fixing is dependent on the quality of an individual's workmanship
- there is a low barrier to entry for individuals and companies to become a fixing installer
- there is currently no recognised industry-wide quality assurance scheme for fixings installers.

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Case study 13.1 Collapse of a wall at Oxgangs School, Edinburgh

An independent inquiry into the Oxgangs school wall collapse identified the primary cause of the collapse was poor quality construction and, specifically, failure to achieve the required minimum embedment of 50 mm for the wall ties.

The poor quality was related to the construction, supervision and quality assurance.

The inquiry report states that the only time the defects could and should have been found was during construction through a process of proper supervision and inspection. There were no externally visible signs of distress that could have allowed a maintenance inspection regime to identify defective construction.

Figure 13.1 One of a series of wall ties with inadequate (zero) embedment (from Cole, 2017)

Figure 13.2 Collapse of part of the outer skin of a cavity wall at a school during high winds, with nine tonnes of masonry falling into the playground (from Cole, 2017)

13.3.2 Supervision and certification of installation

The installation of the fixings should be overseen by a supervisor, in accordance with Section 8 of BS 8539.

The supervisor should issue a certificate to certify that the fixings have been correctly installed in accordance with the specification and are in a condition to be loaded (Section 8.3 of BS 8539).

13.3.3 Testing of fixings

Recommendation 23. New safety-critical fixings should be proof-tested to verify quality of installation.

The design should include details of the testing on the fixing to be carried out (see **Section 12.7**). Tests for quality of installation (proof tests) should be undertaken on a specified proportion of fixings for all safety-critical applications. Where specified by the design, then tests to determine the allowable resistance should be undertaken before the main installation.

Tests should be undertaken in accordance with relevant industry guidance including BS 8539 and CFA (2012).

Asset owners should ensure that testing is carried out by suitably experienced and competent persons. Competency requirements for testers are listed in Section 9 of BS 8539. An independent accreditation scheme for testers is available through the CFA.

13.3.4 Change management – alternative fixings

Where an alternative fixing is proposed, for whatever reason, then the change management procedures in Section 10 of BS 8539 should be applied. The validity of the proposed amendment should be confirmed. The revised specification should be included in the design records (see **Section 12.8**).

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13.4 INSTALLATION AND TESTING RECORDS

> **Recommendation 24.** Installation and test records should be provided and retained for new safety-critical fixings.

Similar to design records, installation and testing records for fixings are fundamental in enabling the future management of fixings. Complete and comprehensive records can help reduce the effort required to demonstrate that fixings present a tolerably low level of risk.

Installation and testing records should be stored in an asset information system. Guidance on managing information is provided in **Chapter 10**, and **Appendix A6** provides details on the content to be included (eg installation and testing records).

The following should be recorded for installation (BS 8539 does not include specific requirements):

- date of installation
- conditions (eg weather, temperature)
- name and company of installer
- name and company of supervisor
- evidence of competence of installer (eg relevant certification/training records)
- as-drilled hole diameter and depth
- observations during installation (eg hitting reinforcement, cracking, damage)
- strength of substrate at installation (or an estimate of the age of the substrate at installation)
- changes/substitutions of parts/materials compared with design intent
- certificate of installation.

Testing records should include the data listed in Section 6 of BS 8539. The following information has particular relevance for the management of safety-critical fixings:

- type of test
- date of test
- number of fixings tested
- required test load
- achieved test loads
- allowable resistance derived from tests
- observations during test.

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A1 Applications of safety-critical fixings

Table A1.1 provides a list of potential applications for safety-critical fixings on UK transport infrastructure.

Table A1.1 Summary of potential applications for safety-critical fixings

General application	**Examples**
Structural elements	▪ structural attachments ▪ connections using post-installed bars ▪ tunnel ceilings ▪ gantries.
Secondary elements	▪ vehicle restraint systems (where using post-installed fixings) ▪ pedestrian safety barriers ▪ collision protection beams ▪ canopies ▪ tunnel linings ▪ false ceilings ▪ access walkways/steps ▪ craneage (eg maintenance cranes, permanent inspection equipment).
Cladding	▪ cladding systems ▪ fascia units (eg to bridge deck edges).
Access	▪ covers to access hatches (eg into bridge decks) ▪ covers to conceal services.
Ventilation	▪ ventilation fans ▪ mechanical equipment ▪ ducting.
Electronic equipment	▪ visual display units ▪ public address ▪ CCTV cameras ▪ monitoring systems.
Lighting	▪ lighting columns ▪ suspended lighting ▪ navigation lights (eg over rivers).
Services	▪ cable trays ▪ cabling ▪ suspended utility pipes ▪ ducting ▪ drainage pipework hangers (eg inside hollow bridge decks).
Static information	▪ signage (eg suspended traffic signs) ▪ notices ▪ advertising displays.

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A2 Overview of fixing types

A2.1 INTRODUCTION

This appendix introduces the main types of fixings and their characteristics. A summary is also available in Annex C of BS 8539. It summarises the applicable European documents (EADs, ETAGs, ETAs) for each type of fixing, current at the date of publication. These documents are likely to change over time as new versions are published. See the EOTA website or other sources for the latest documents.

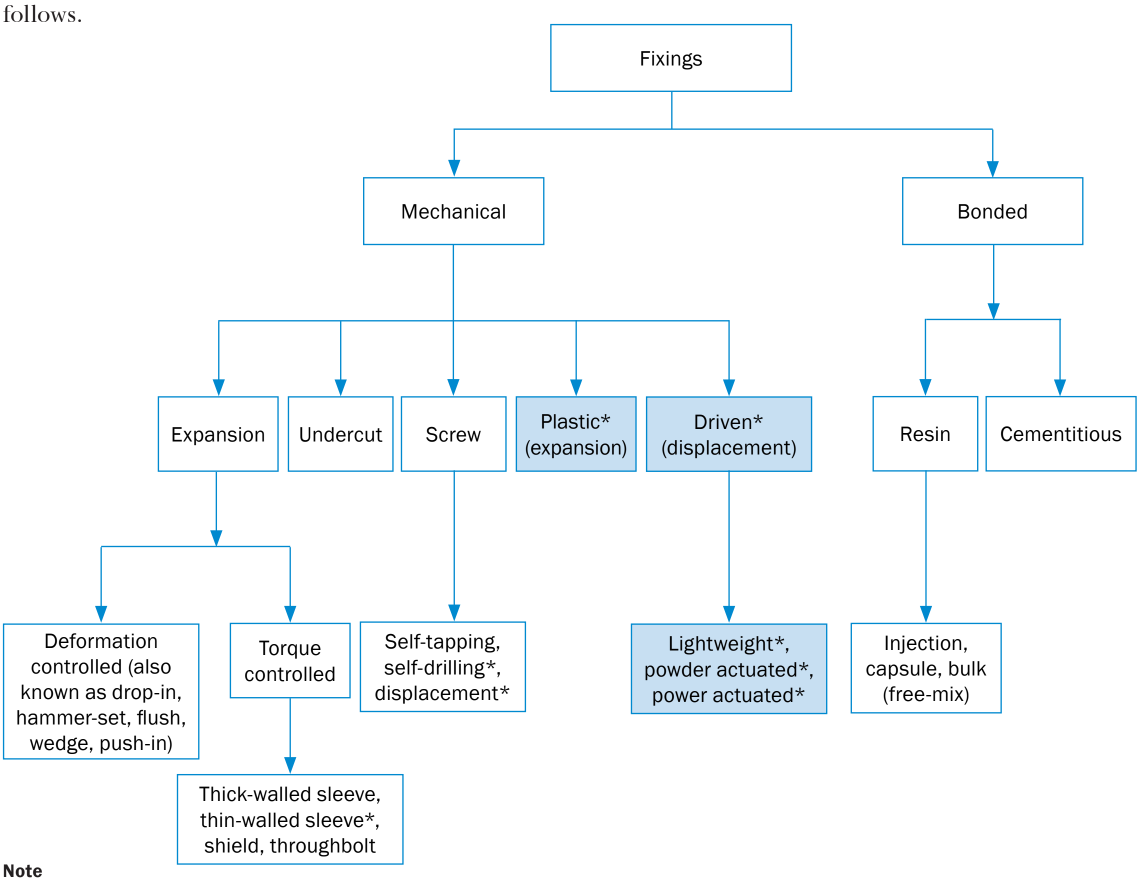
This appendix provides references to the guidance available from the CFA for different fixing types. Considerable further information is available from this source. In particular, CFA (1995) provides a description of the different types of fixings.

A2.2 TYPES OF FIXINGS

The categorisation of the different types of fixing is shown in **Figure A2.1**. Key approvals and guidance documents for each type of fixing are shown in **Figure A2.2**.

Different manufacturers have historically adopted different terms for the same type of fixing. Further detail of alternative terms is provided in CFA (2013).

There are two main categories of post-installed fixings, mechanical and bonded, which are discussed as follows.



Note

* Fixing type unlikely to be used in safety-critical application

Figure A2.1 Categorisation of fixing types

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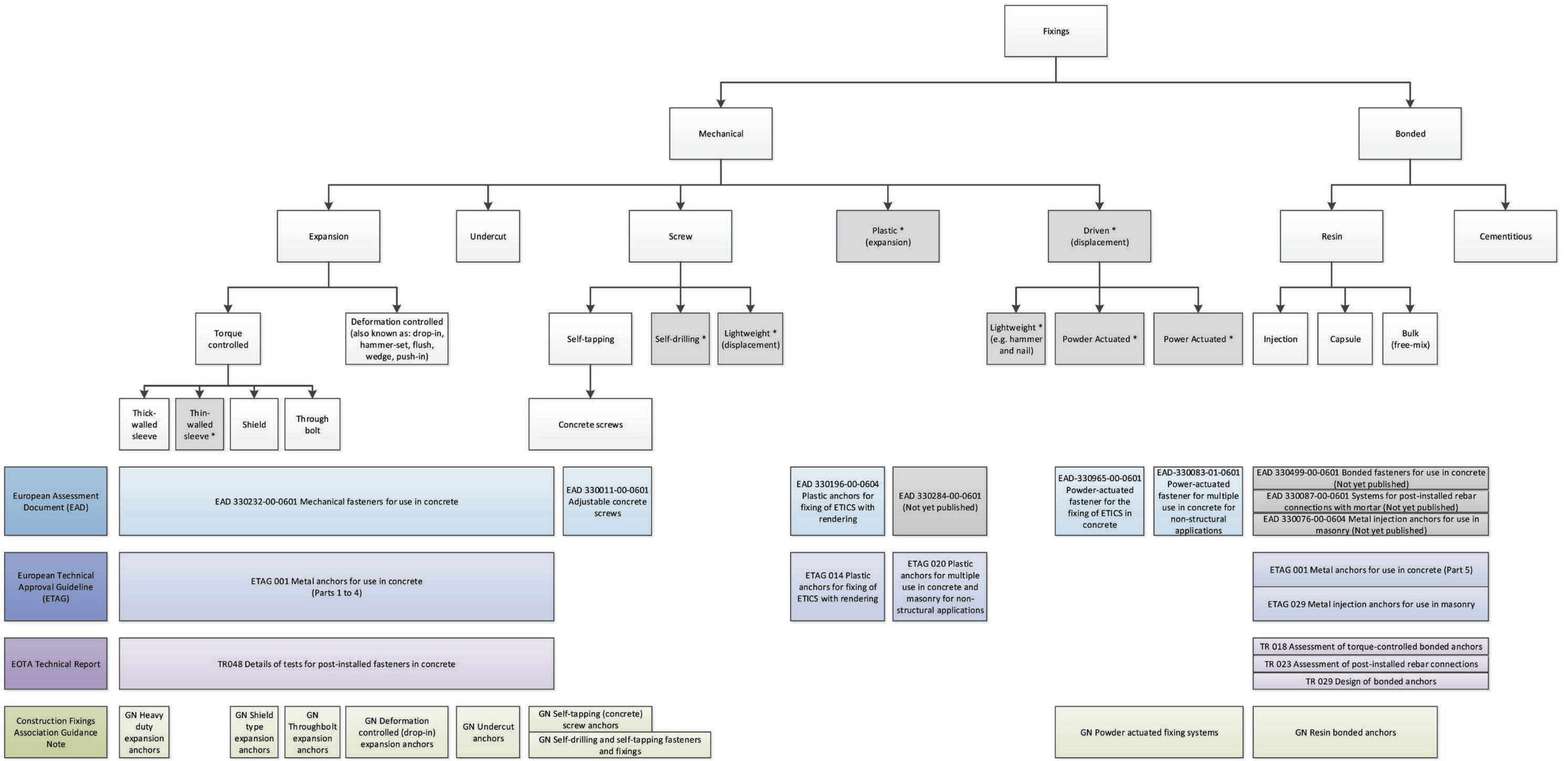

Note

* Fixing type unlikely to be used in safety critical application

Figure A2.2 Relationship between fixing types, EADs and CFA guidance

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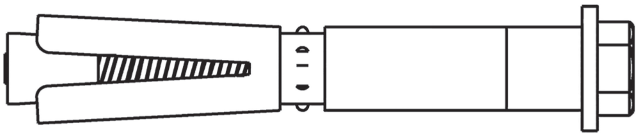
A2.2.1 Mechanical anchors

Mechanical anchors rely on friction or mechanical interlock in order to achieve the anchorage (see Section A2.3). They include the following types:

- expansion:
  - torque controlled (thick-walled sleeve, thin-walled sleeve, shield and throughbolt)
  - deformation controlled (also known asas drop-in, hammer-set, flush, wedge, push-in)
- undercut
- screw
- plastic (typically rely on expansion, but categorised separately because they usually have a lower capacity than metal expansion anchors)
- driven, including power and powder actuated.

A2.2.1.1 Torque controlled expansion anchors

Table A2.1 Torque controlled expansion anchors

Anchor type	This table includes generic information that applies to all types of torque-controlled expansion anchors (Tables A2.1 to A2.5): ■ thick-walled sleeve (Table A2.2). ■ thin-walled sleeve (Table A2.3). ■ shield (Table A2.4). ■ throughbolt (Table A2.5).
Diagram/image	
Relevant guidance	For specific types, see Tables A2.2 to A2.5.
Relevant EAD/ETAG	EOTA (2016a), ETAG (2013a and b)
Operating principal	Tightening the nut or bolt draws the expander cone into the sleeve causing it to expand. The sleeve segments are forced against the concrete causing the concrete to be deformed. Resistance to tension loads is through a combination of friction and keying effect. Shear resistance is provided by the sleeve, and in bolt head types, by the solid part of the bolt shank. These anchors exhibit follow-up expansion. An increase in applied load beyond the clamping force will pull the expander cone further into the expansion sleeve. Although this may permit greater loads to be carried and use in cracked concrete, it could also lead to failure of the concrete.
Design considerations	The anchor should be set to the manufacturer's recommended installation torque. The tightening torque is related to the bolt tension, and the clamping force through the fixture. This relationship depends on the friction conditions between the bolt thread and expansion cone and between the bolt or nut head and washer. These relationships are likely to be different for fixings from different suppliers. Care is needed to check for the recommended installation torque, which is set to: ■ ensure the clamping force provides the specified capacity, including for the effect of long-term load relaxation ■ protect the bolt material from being over-stressed. Expansion anchors introduce high expansion stresses into the concrete. This places a restriction on the minimum edge distance and anchor spacing.

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For **Tables A2.2 to A2.5** see **Table A2.1** for generally-applicable information about torque controlled expansion anchors.

Table A2.2 Thick-walled sleeve

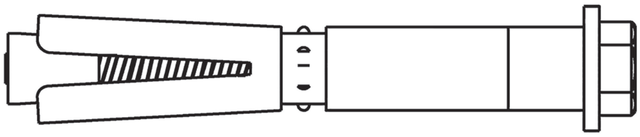
Diagram/image	
Relevant guidance	CFA (1997a), CFA (2010b)
Particular features	■ stainless steel versions likely to be available ■ some types may be installed through the fixture ■ shear resistance is provided by the thick shear sleeve and, in bolt head types, the bolt shank.
Common applications	■ may be suitable for heavy-duty applications ■ high load and safety-critical applications ■ certain types of bolts may be suitable for use in cracked concrete ■ may be capable of resisting dynamic loads and shock loads.

Table A2.3 Thin-walled sleeve

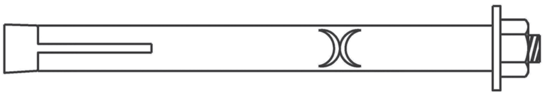
Diagram/image	
Relevant guidance	CFA (2010b)
Particular features	■ the thinner material of the sleeve leads to lower expansion forcers, which can protect the substrate from cracking or crushing, and permit use in weaker base materials ■ likely to be suitable for concrete and brickwork.
Common applications	■ likely to be suitable for light-duty applications.

Table A2.4 Shield

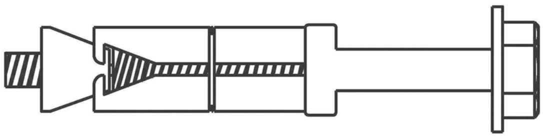
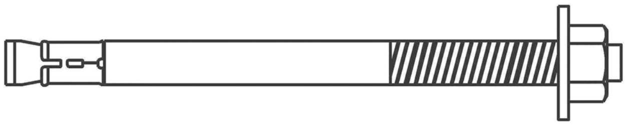
Diagram/image	
Relevant guidance	CFA (2005a) and CFA (2006a)
Particular features	■ high expansion ratio ■ may be well suited to use in brickwork and stonework where holes may be slightly oversize due to drilling process, due to high expansion ratio ■ expansion segments are independently retained, so the setting is reliable ■ cannot be fixed through the fixture and should be installed first at the correct setting-out position.
Common applications	■ likely to be suitable for medium-duty applications ■ may be used in concrete and brickwork ■ versions available for floor, wall, hook and eye fittings □ studs – brackets to wall □ eyes – suspended ceilings and signs □ hooks – safety chains and barriers.

Table A2.5 Throughbolt

Diagram/image	
Relevant guidance	CFA (2005b) CFA (2006b)
Particular features	■ intended to be installed through the fixture (note that the throughbolt is embedded in the substrate, but it does not pass through the underlying structure) ■ for use in concrete, but not brickwork ■ typically available in both carbon and stainless steel ■ wide variety of types available with ETA ■ care needed in substituting anchors because the performance can vary significantly between anchors with apparently similar dimensions.
Common applications	■ may be suitable for medium-duty applications, for example: □ racking □ structural bracketry □ hand rails □ curtain walling □ balustrades □ façade restraint systems ■ cable supports.

A2.2.1.2 Deformation controlled expansion anchors

Table A2.6 Deformation controlled expansion anchor

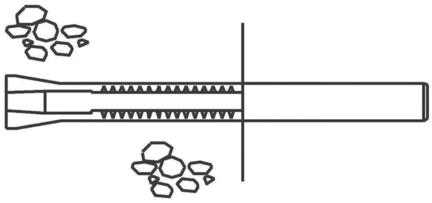
Diagram/image	
Relevant guidance	CFA (2005c) CFA (2006c)
Relevant EAD/ETAG	EOTA (2013a to d) and EOTA (2016a)
Operating principle	The anchor is inserted into a pre-drilled hole. A tapered plug is driven into the base of the anchor using a special punch. The plug expands the shell of the anchor into the concrete, deforming the concrete. The full extent of expansion is generated during setting of the anchor, so unlike the torque-controlled anchors there is no follow-up expansion should loads increase or the concrete crack. A clamping force is generated by tightening the bolt to the specified installation torque. Where the anchor is used vertically with drop-rods, this step may not be necessary. Tension forces are resisted by a combination of keying and friction. The deformation of the concrete generates compressive stresses within the substrate at the base of the anchor. The tensile strength tends to be limited by the shell, so there is little advantage in using higher strength bolts or drop rods.
Design considerations	The relatively shallow embedment depth for smaller diameters means it may be possible to set the anchor in the cover layer without disturbing reinforcement. The shock loads during setting mean that the edge distances and spacing distances should not be reduced even when the anchor is more lightly loaded. The minimum structural thickness behind the anchor is also important. Choice of bolt length is critical, in particular the correct amount of thread engagement. Drop-in anchors are not designed to be fixed through the fixture.
Common applications	■ not suitable for brickwork due to shock loads during setting ■ suspension of services from concrete deck undersides ■ drop-rods from ceilings.

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Table A2.7 Undercut anchors

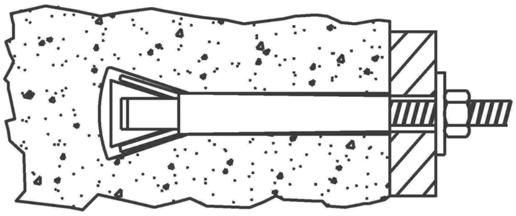
Diagram/image	
Relevant guidance	CFA (2002)
Relevant EAD/ETAG	EOTA (2013a to c) and EOTA (2016a)
Operating principal	Undercut anchors establish a positive mechanical interlock with the concrete by opening segments of the anchor shell into an undercut shape. The undercut is formed either by a separate drilling technique or by the anchor. In some applications a 'reverse undercut' can be used, typically with large embedment depths, to carry extremely high loads. This type of anchor can be suitable for use in cracked concrete. The mechanical interlock of the undercut ensures that the mode of failure is by a concrete cone failure from the base of the anchor. In some applications it may be intentionally desirable to provide a weaker bolt to ensure that bolt failure happens before concrete failure, to make reinstatement easier.
Design considerations	A critical design consideration is whether the anchor needs to be suitable for use in cracked or uncracked concrete. Anchors for use in cracked concrete are typically more expensive. The load capacity of the anchor is directly related to embedment depth, because failure is governed by the resistance of the concrete cone. Undercut anchors may be shallower than for other anchor types with similar strength. Where the anchor is set within a pre-formed undercut, then minimal stresses are generated in the substrate. This can result in closer anchor spacing and smaller edge distances than equivalent expansion anchors. Various attachment configurations may be available, including through sleeve, projecting stud and internal thread. Calculation of capacity is relatively complex, so many suppliers provide selection software.
Common applications	■ options for use in cracked and uncracked concrete ■ structural connections ■ shockproof connections in seismic zones ■ dynamic loads including holding down machinery, fans, guard rails, crash barriers, safety fences ■ lighting columns ■ cladding elements to edge beams ■ fixings services to ceiling and deck undersides.

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Table A2.8 Self tapping concrete screws

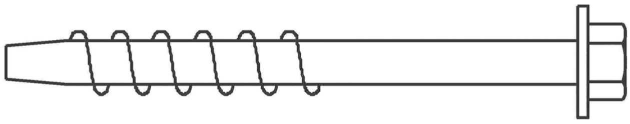
Diagram/image	
Relevant guidance	CFA (2014a and b) There is a further guidance note (CFA, 2016a), but this is less relevant to safety-critical fixings and is more concerned with lightweight fasteners.
Relevant EAD/ETAG	EOTA (2013a to c), EOTA (2015 and 2016a)
Operating principal	The thread of the screw anchor cuts an internal thread within the concrete during installation. This establishes an undercut, which provides a positive mechanical interlock with the concrete.
Design considerations	Potential for high strength steels used in manufacture to suffer from hydrogen embrittlement particularly in damp or wet conditions, which can lead to instantaneous failure. This effect is covered within the ETA process. There are minimal expansion stresses during installation, so the concrete screws can also be suitable for use in masonry. The recommended tightening torque should not be exceeded as this could result in the head twisting off. Tightening torques are generally set for concrete, and care is needed in weaker materials such as softer brick and stone. Trial installations may be required in these circumstances. Some applications may involve re-setting or adjusting the screw. This may be covered by supplementary assessments (see, for example, EOTA, 2015).
Common applications	■ likely to be suitable for medium-duty applications ■ typically dry internal conditions; stainless steel versions are available for external use ■ suitable for temporary applications because it can be removed leaving nothing in substrate.

Table A2.9 Plastic anchors

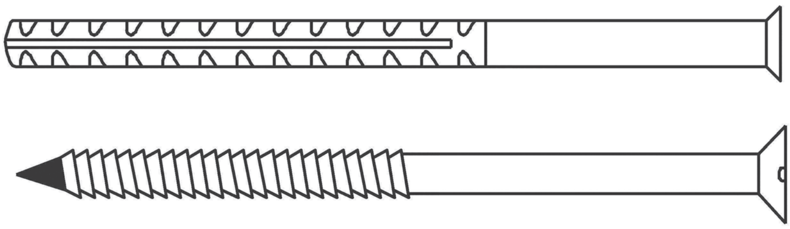
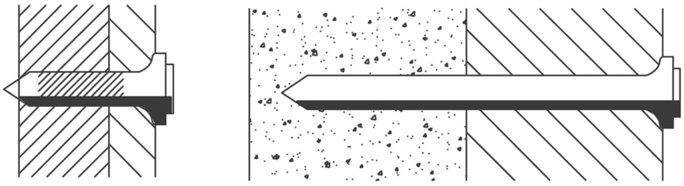
Diagram/image	
Relevant guidance	No CFA guidance notes
Relevant EAD/ETAG	EOTA (2002, 2012, 2013f)
Operating principal	Plastic anchors consist of an expansion element and a polymeric sleeve that passes through the fixture. The polymeric sleeve is expanded by hammering or screwing in the expansion element (nail or screw) that presses the sleeve against the wall of the drilled hole.
Design considerations	Plastic anchors are typically applicable to lightweight applications. The EAD/ETAGs listed above are applicable for multiple use only, ie systems with a high degree of redundancy. This type of anchor is unlikely to be used in a safety-critical application.
Common applications	This type of anchor is unlikely to be suitable for a safety-critical application. However, it may be suitable for light-duty applications such as: ■ non-structural applications ■ fixing of external thermal insulation.

Table A2.10 Driven fixings

Diagram/image	 ■ power actuated ■ powder actuated ■ nails.
Relevant guidance	CFA (2016b)
Relevant EAD/ETAG	EOTA (2016b and 2017)
Operating principal	A metal nail element is driven into concrete using a power or powder actuated fastening tool. The powder is typically a combustible propellant powder. The nail displaces material in the substrate, in contrast to other types of fixings where material is removed by drilling.
Design considerations	These driven fixings are typically applicable to lightweight applications. The EAD/ETAGs listed are applicable for multiple use only, ie systems with a high degree of redundancy.
Common applications	This type of anchor is unlikely to be suitable for a safety-critical application. Likely to be suitable for light-duty applications: ■ non-structural applications ■ fixing of external thermal insulation ■ thin metal sheets for roof decking ■ threaded studs for suspended ceilings ■ fixing battens or insulation to main structural elements.

A2.2.1.3 Bonded anchors

Tables A2.11 to A2.15 provide further details specific to each of the anchor types.

Bonded anchors consist of a metal element inserted into a pre-drilled hole, which is filled with a bonding material. Bonding agents can include the following:

- cementitious material, for example for post-installed bonded reinforcement
- resins, which may be delivered by a variety of methods including:
  - injection cartridge
  - capsules, including spin-in and hammer-in
  - pouring or bulk injection.

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Table A2.11 provides information that is generally applicable to resin-bonded anchors. **Tables A2.12 and A2.13** provide further detail on specific delivery systems including:

- capsule systems
- injection systems.

Table A2.11 Resin-bonded anchor

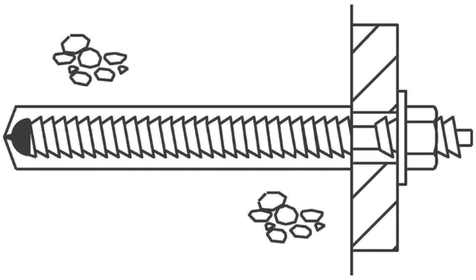
Diagram/image	
Relevant guidance	CFA (2000, 2006d, 2006e, 2006f) Burch (2000) CFA article: Understanding the different formulations used in resin bonded anchors
Relevant EAD/ETAG	EAD 330499-00-0601 (EOTA, in press), EOTA (2013a to 2013e)
Operating principal	A hole is drilled in the substrate and part-filled with resin. The metal anchor is inserted into the resin. Once the resin cures, the resin becomes hard and forms a strong bond between the anchor and the surface of the hole. It is important that the resin fully occupies the space between the anchor and the substrate. Common issues that can prevent good installation of the resin include: ■ hole diameter too large ■ hole too deep ■ voids or cracks in substrate lead to loss of resin. It is important that the resin bonds correctly with the substrate. Common issues that can prevent proper bond include: ■ hole not cleaned out correctly (typically by blowing and brushing out), leaving residue of dust from drilling ■ hole surface too smooth, for example due to using diamond drilling rather than hammer drilling. Various delivery mechanisms are available for the resin, and include: ■ capsules, including spin-in, hammer-in, torque-controlled ■ injection cartridge systems ■ free mix systems.
Design considerations	There are a wide variety of different resin formulations and specialist advice may need to be sought about an appropriate resin. Care needs to be taken that the formulation of the resin is appropriate for the application, substrate and environmental conditions. Masonry in particular may be damp and this can prevent proper curing of some resins. There are two basic families of resins: ■ catalytic curing ■ direct mix of components (epoxy resin). Particular attention needs to be paid to the creep characteristics of the resin where it is subject to sustained tensile loads. This aspect is covered by ETA for resin-bonded anchors. Resin-bonded anchors appear to be particularly sensitive to quality of installation and issues have been reported particularly for them being installed overhead.
Common applications	May include heavy-duty applications: ■ structural connections ■ safety barrier connections ■ holding down machinery and fans.

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Table A2.12 Capsule system

Diagram/image	
Operating principal	A glass or foil capsule contains the correct proportions of the resin components. This is essential for the curing process. 'Spin-in' systems require that the anchor is mechanically rotated and driven through the capsule. This ruptures the capsule and its compartments, mixing the components within the hole. 'Hammer-in' systems require that the anchor is hammered through the capsule. This pulls a catalyst through the resin components and forces them to mix. There is no spinning action, so this type of capsule is particularly sensitive to residual dust within the hole. 'Torque controlled' capsule anchors rely on a combination of bonding and expansion for load transfer. These may be particularly suitable for use in cracked concrete.
Design considerations	It is particularly important with capsule systems that the hole is drilled to the correct diameter and depth. If the hole is too wide or too long then the resin is likely to remain at the end of the hole and will not correctly bond over the full length of the anchor, leading to a reduced capacity. This system is also sensitive to imperfections in the substrate. If cracks or voids are present then the anchor may not be fully bonded due to loss of resin.

Table A2.13 Injection cartridge system

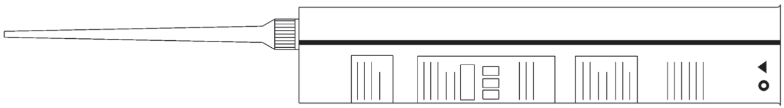
Diagram/image	
Operating principal	Resin components are carried in separate compartments of a cartridge held in a special skeleton gun. They are mixed by a series of vanes in a special nozzle as they are expelled from the cartridge. The cartridge design ensures that the correct proportions are used. The amount of resin used can be tailored to the application. This is ideal for use in materials containing voids. Waste is restricted to that contained in the nozzle and unused resin can be kept without deterioration, subject to shelf life. Special mesh sleeves may be used in weak materials, hollow blocks and perforated bricks to prevent loss of resin into voids or cracks.
Design considerations	There is reliance on the installer to ensure that sufficient resin is injected to make a full bond along the length of the anchor.

Table A2.14 Bonded reinforcement

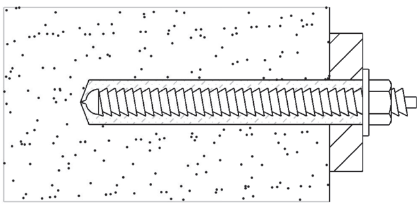
Diagram/image	
Relevant guidance	No CFA guidance note
Relevant EAD/ETAG	EAD 330087-00-0601 (EOTA, in press) EOTA (2013a to e)
Operating principal	A ribbed reinforcement bar is placed into a pre-drilled hole. The hole is usually filled with cementitious material.
Design considerations	The reinforcement connection is typically designed in accordance with the structural Eurocode for concrete, BS EN 1992-1-1:2004+A1:2014.
Common applications	Connections between concrete elements

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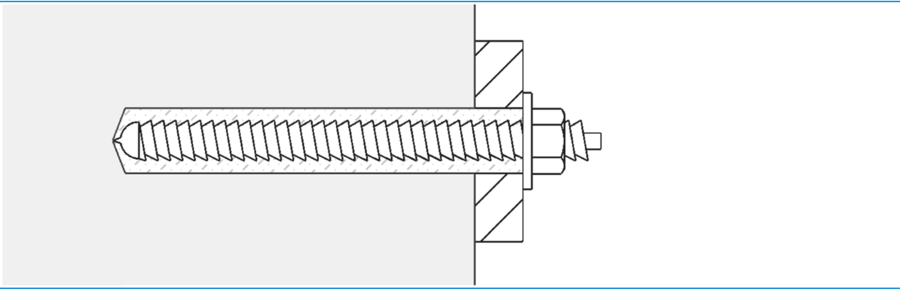
Table A2.15 Anchor stud with injected mortar

Diagram/image	
Relevant guidance	No CFA guidance note
Relevant EAD/ETAG	EAD 330076-00-0604 (EOTA, in press), EOTA (2013g)
Operating principal	A metal anchor is inserted into a hole. Mortar is injected into the hole. It may be necessary to use a mesh sleeve of metal or plastic to ensure the mortar is close to the anchor. The load transfer is achieved through mechanical interlock between the anchor, mortar and hole surface.
Design considerations	The EAD/ETAG covers static and quasi-static actions only. Note that dynamic actions are not covered.
Common applications	Connections to masonry

Note

The EAD refers to this anchor type as metal injection anchors for use in masonry. The use of the term 'injection' has potential for confusion with driven fixings. With this type of fixing, it is the mortar that is injected, not the fixing.

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A3 CE marking of fixings

A3.1 INTRODUCTION

Fixings are a construction product and subject to the Construction Products Regulation (Regulation (EU) No 305/2011) (CPR 2011), which took effect in 1 July 2013. The Regulations include provision for:

- CE marking of products
- DoP by manufacturer
- assessment and verification of constancy of performance
- ETA for products not covered by a harmonised standard, by reference to a EAD.

Before CPR 2011, fixings were subject to the Construction Products Directive 89/106/EEC. This Directive covered similar provisions, but there were differences in terminology and detail. These differences and the transition between them are explored in more detail here.

This section introduces the key provisions of the CPR 2011, which have relevance to fixings as follows:

- New fixings. A significant role in the design and installation of new fixings, in particular through ETAs.
- Existing fixings. The DoP provides information of significant value for the management of fixings in-service.

There is currently some uncertainty about the future of European legislation in the UK. It is anticipated that existing European legislation will be converted into UK law, so the same laws and rules will continue to apply for the near future.

A3.2 OBJECTIVES OF THE CONSTRUCTION PRODUCTS REGULATIONS

The CPR 2011 aims to:

- support the design and execution of construction works so as not to endanger the safety of people, domestic animals or property, or cause damage to the environment
- ensure the removal of technical barriers to the trade of construction products in the European market.

These objectives are achieved through a set of harmonised rules (ie agreed across Europe). These cover how to express the performance of construction products in relation to their characteristics, and how to declare conformity of the product using CE marking.

A3.3 CE MARKING

A CE mark on a product means that the manufacturer takes responsibility that the performance of the product is the same as that declared, in accordance with a particular European technical specification.

Where a product is CE marked, public authorities cannot require any additional marking, certificates or testing of the product.

This can include aspects of self-assurance by the manufacturer and aspects of third-party assurance, depending on the system of assessment and verification of constancy of performance (see **Section A3.4**).

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The CPR 2011 requires that CE marking is applied for products covered by a European technical specification, which include harmonised European product standards and ETAs.

There is currently no harmonised European product standard for fixings. Manufacturers may pursue the ETA route for fixings. Although, there is no obligation to obtain a ETA, it is a prerequisite when applying CE marking to fixings.

A3.4 DECLARATION OF PERFORMANCE

The manufacturer must prepare a DoP for all products that are CE marked.

The DoP confirms the performance of the construction product and the system by which this performance is assured (the assessment and verification of constancy of performance, see **Section A3.7**).

The performance is expressed in relation to the main characteristics of the product, which are defined by the ETA. The ETA can include options, levels, classes and categories of performance. As an example, the characteristic resistance to tension load is an important characteristic for a fixing.

The DoP should confirm the options, levels, classes and categories that apply for the product. For fixings, this could include, for example, use in cracked or uncracked concrete, or environmental exposure conditions.

The manufacturer can choose the main characteristics that are stated. As a minimum, the performance of at least one of these must be declared.

The effect of this is that the DoP may be silent on the performance of some main characteristics. This may be shown by the statement 'no performance declared (NPD)', or simply by omission of a particular characteristic.

All users of construction products remain liable to check and make an appropriate choice that the products made available on the market are fitting the whole set of conditions and requirements for the construction works.

It is important to confirm that the fixing is suitable for the intended application by close examination of the DoP. In particular, this requires review of:

- options, levels, classes and categories that are applicable for the fixing
- values of main characteristics, which may be detailed by reference to the ETA
- whether there are other important characteristics that are critical to the performance of the fixing, but are not covered by the DoP, such as fatigue performance.

A3.5 EUROPEAN TECHNICAL ASSESSMENT

A ETA is a route for a manufacturer to apply CE marking, where there is no harmonised European product standard. Currently this route applies for fixings, but it is not compulsory.

A ETA needs to be available for a manufacturer to issue a DoP, and also to apply a CE mark to a product.

ETAs are made based on a EAD (see **Section A3.6**). In particular, the ETA confirms the performance of the product in relation to the main characteristics, which are defined in the EAD.

The ETA is an independent confirmation of the performance. It is issued by a technical approval body (TAB), upon request by a manufacturer. The TABs are appointed on a national basis, but any TAB throughout Europe may be used with equal validity.

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A3.6 EUROPEAN ASSESSMENT DOCUMENT

A EAD is a harmonised technical specification for a construction product. It is relevant where there is no harmonised European product standard, as is the case for fixings.

A ETA confirms the performance of a product against the criteria given in the EAD. The EAD contains:

- a general description of the construction product
- the list of main characteristics applicable to the product
- the methods and criteria for assessing the performance of the product in relation to these main characteristics
- principles for factory production control to be applied.

The main characteristics relate to the basic requirements for construction works, which are defined in Annex I of the CPR 2011 as follows.

> *"Construction works as a whole and in their separate parts must be fit for their intended use, taking into account in particular the health and safety of persons involved throughout the life cycle of the works. Subject to normal maintenance, construction works must satisfy these basic requirements for construction works for an economically reasonable working life. The basic requirements are:*
>
> *1 Mechanical resistance and stability.*
>
> *2 Safety in case of fire.*
>
> *3 Hygiene, health and the environment.*
>
> *4 Safety and accessibility in use.*
>
> *5 Protection against noise.*
>
> *6 Energy economy and heat retention.*
>
> *7 Sustainable use of natural resources."*

EADs are developed by the EOTA. This body organises the co-ordination of TABs, co-ordinates requests for new EADs and makes them publicly available.

A3.7 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

The manufacturer must adopt a system that assures the performance of the product. The system is referred to as the assessment and verification of constancy of performance.

The CPR 2011 defines five types of system. These range from extensive third party assurance to self-declaration and monitoring by the manufacturer. The systems are summarised in **Table A3.1**.

Some systems require that a third party notified body performs some of the tasks. There is an official registry of notified bodies, which have been notified by the European countries.

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Table A3.1 Systems for assessment and verification of constancy of performance

	System				
Task	***1+***	***1***	***2+***	***3***	***4***
Factory production control	1M	1M	1M	1M	1M
Further testing of samples taken by manufacturer	1M	1M	1M		
Assessment of the performance	3NB	3NB	1M	3NB	1M
Initial inspector (plant and factory production control)	3NB	3NB	3NB		
Continuous surveillance, assessment and evaluation of factory production control	3NB	3NB	3NB		
Audit – testing of samples taken by the notified body	3NB				

Key:

1M	Manufacturer responsible
3NB	tasks performed by third party notified body

A3.8 TRANSITION FROM CPD TO CPR

CPR 2011 introduces some differences in terminology compared with CPD. The full transition between the two systems is expected to take a number of years and so a mixture of the terms is likely to be in use.

The main differences are:

- EAD – replaces the European Technical Approval Guideline
- European Technical Assessment – replaces the European Technical Approval (unfortunately both have the same abbreviation, ETA)
- DoP – replaces both the declaration of conformity and the option for a certificate of conformity.

The transition and validity of documents produced according to the Directive is defined in the CPR 2011 and is summarised in **Table A3.2**.

Table A3.2 Transition to CPR 2011 from CPD

Construction Products Regulation 305/2011 (after July 2013)	Construction Products Directive 89/10/EEC (before July 2013)	Transition
		Construction products that have been placed on the market in accordance with the Directive before 1 July 2013 are deemed to comply with the CPR 2011.
EAD	ETAG	After 1 July 2013 there remains an option to issue a European Technical Assessment (ie ETAG used as EAD).
ETA	ETA Note this has a different meaning but the same acronym. European Technical Approvals were based on ETAGs or issued upon agreement of the approval bodies.	European Technical Approvals may be used as European Technical Assessments so long as the approval remains valid. European Technical Approvals, which were issued up to 30 June 2013 remain valid until the end of their validity period. They can be used by manufacturers as European Technical Assessments. European Technical Approvals will disappear from the market throughout 2018. A European Technical Assessment that has been issued after 1 July 2013 is valid of indeterminate duration.

Construction Products Regulation 305/2011 (after July 2013)	Construction Products Directive 89/10/EEC (before July 2013)	Transition
DoP CE mark means the manufacturer has drawn up a DoP for the product	Attestation of conformity may include either a certificate of conformity or a declaration of conformity. Entitles the manufacturer to use the CE mark on the product.	The DoP may be drawn up based on a certificate of conformity or declaration of conformity issued before 1 July 2013 in accordance with CPD.
Assessment and verification of constancy of performance System needs to be indicated in the DoP	Systems of conformity attestation	

A3.9 ETA APPLICABILITY TO FIXINGS

Information on ETA relevant to fixings can be found on the EOTA website, including EADs (after July 2013), ETAGs (produced before July 2013 under the Construction Products Directive) and technical reports. **Table A3.3** provides a list of EADs and ETAGs relevant to fixings.

The technical reports are supporting reference documents and contain, for example, design, assessment and test methods. Technical reports are frequently referenced by the EADs. A list of technical reports relevant to fixings is provided in the further reading section at the end of this guide.

Table A3.3 is current at the date of publication of this guide. The applicable documents are likely to change over time as new ones are published. See the EOTA website or other sources for the latest documents.

Table A3.3 EADs and ETAGs relevant to fixings

EAD (under the CPR, after July 2013)	ETAG (under the CPR, before July 2013)	Relevance to safety-critical fixings
EAD 330232-00-0601 (EOTA, 2016a)	EOTA (2013a to 2013d)	High
EAD 330499-00-0601 (EOTA, in press)	EOTA (2013e)	High
EAD 330087-00-0601 (EOTA, in press)	EOTA (2006)	Medium
EAD 330747-00-0601 (EOTA, in press)	EOTA (2011)	Low
EAD 330196-00-0604 (EOTA, 2016c)	EOTA (2002)	Low
EAD 330076-00-0604 (EOTA, in press)	EOTA (2013g)	Low
EAD 330011-00-0601 (EOTA, 2015)	EOTA (2013g)	Low
EAD-330083-01-0601 (EOTA, 2016b)		Low
EAD-330965-00-0601 (EOTA, 2017)		Low

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A3.10 APPROVAL DOCUMENT EXTRACTS

A3.10.1 DECLARATION OF PERFORMANCE, DoP No. ABC-AA 100-A + ABC-Z 789

1 Unique identification code of the product-type:

Injection System ABC-AA 100-A + ABC-Z

2 Type, batch or serial number as required pursuant to Article 11(4):

See ETA-12/0006 (15.03.2013), annex 1.

Batch number: see packaging of the product.

Confirmation of options for use

3 Intended use or uses of the construction product, in accordance with the applicable harmonised technical specification:

Generic type	**Bonded anchor, injection system**
For use in	Concrete (C20/25 to C50/60) ■ cracked : M8 - M20 ■ non-cracked : M8 - M20
Option/category	Option 1 ■ Seismic: Performance category C1 (M8–M20) ■ Seismic: Performance category C2 (M12, M16)
Loading	Static, quasi-static, seismic
Material	***Zinc coated steel*** For dry internal use only ■ ABC-AA 100-A + ABC-Z (with anchor rod): M8, M10, M12, M16, M20 ***Stainless steel A4*** For internal and external use with no particular aggressive conditions ■ ABC-AA 100-A + ABC-Z (with anchor rod): ■ M8, M10, M12, M16, M20
Temperature range (if applicable)	Range I: -40° to +40° (short term), +24°(long term) Range II: -40° to +80° (short term), +50° (long term) Range III: -40° to +120° (short term), +72° (long term)

4 Name, registered trade name or registered trade mark and contact address as required pursuant to Article 11(5):

Name of manufacturer and address

5 Where applicable, name and contact address of the authorised representative whose mandate covers the tasks specified in Article 12(2):

N/A

6 System or systems of assessment and verification of constancy of performance of the construction product as set out in Annex V:

System 1

The ETAG specifies system 1, which means:

Manufacturer:

- factory production control
- further testing of samples in accordance with prescribed test plan

Notified body:

- initial type testing
- initial inspection of factory and production control
- continuous surveillance, assessment and approval of factory production control

7 In case of the declaration of performance concerning a construction product covered by a harmonised standard:

N/A

8 In case of the declaration of performance concerning a construction product for which a European Technical Assessment has been issued:

Deutsches Institut für Bautechnik (DIBt) issued European Technical Approval ETA-12/0006 (15.03.2013) on the basis of ETAG 001 Part 1, 5 annex E, the notified body 0756-CPD performed third party tasks as set out in Annex V under System 1 and issued certificate of conformity 0756-CPD-0454.

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See example provided overleaf

9 Declared performance:

Essential characteristics	Design method	Performance	Harmonised technical specification
Characteristic resistance for tension	EOTA TR 029, method A	ETA-12/0006 annex 8	ETAG 001 Part 1, 5 Annex E
	EOTA TR 045 (seismic design)	ETA-12/0006 annex 11, 13	
Characteristic resistance for shear	EOTA TR 029, method A	ETA-12/0006 annex 10	
	EOTA TR 045 (seismic design)	ETA-12/0006 annex 12, 14	
Minimum spacing and minimum edge distance	EOTA TR 029, method A	ETA-12/0006 annex 3	
Displacement for serviceability limit state	EOTA TR 029, method A	ETA-12/0006 annex 9, 10	
	EOTA TR 045 (seismic design)	ETA-12/0006 annex 11–14	

10 The performance of the product identified in points 1 and 2 is in conformity with the declared performance in point 6. This declaration of performance is issued under the sole responsibility of the manufacturer identified in point 4.

Signed for and on behalf of the manufacturer by:

XXX

Design methods are in accordance with EOTA technical reports

The ETAG (now EAD) defines:

- the essential characteristics
- methods and criteria for assessing the performance of the product
- the system of assessment.

Performance is listed in the European Technical Assessment, which includes a series of annexes to cover the respective essential characteristics

A3.10.2 Extracts from European Technical Assessment ETA-12/0006 of 18 August 2016

Table A3.4 Characteristic resistance under tension load for static and quasi static loading

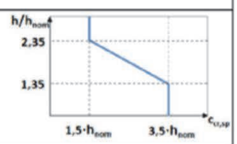
Extracts from
European Technical Assessment
ETA-12/0006 of 18 August 2016

Annex 8: Characteristic resistance under tension load for static and quasi static loading

			M8	M10	M12	M16	M20
Installation safety factor	$\gamma_2 = \gamma_{inst}$	[-]	1,0				
Steel failure							
Characteristic resistance HIT-Z, HIT-Z-F	$N_{Rk,s}$	[kN]	24	38	55	96	146
Characteristic resistance HIT-Z-R	$N_{Rk,s}$	[kN]	24	38	55	96	146
Combined pull-out and concrete cone failure							
Effective anchorage depth for calculation of $N^0_{Rk,p}$ (TR 029, 5.2.2.3 respectively CEN/TS 1992-4:2009 part 5, 6.2.2)	$h_{ef} = l_{Helix}$	[mm]	50	60	60	96	100
Characteristic bond resistance in non-cracked concrete C20/25							
Temperature range I: 40 °C / 24 °C	$\tau_{Rk,ucr}$	[N/mm²]	24				
Temperature range II: 80 °C / 50 °C	$\tau_{Rk,ucr}$	[N/mm²]	22				
Temperature range III: 120 °C / 72 °C	$\tau_{Rk,ucr}$	[N/mm²]	20				
Factor acc. to section 6.2.2.3 of CEN/TS 1992-4:2009 part 5	k_8	[-]	10,1				
Characteristic bond resistance in cracked concrete C20/25							
Temperature range I: 40 °C / 24 °C	$\tau_{Rk,cr}$	[N/mm²]	22				
Temperature range II: 80 °C / 50 °C	$\tau_{Rk,cr}$	[N/mm²]	20				
Temperature range III: 120 °C / 72 °C	$\tau_{Rk,cr}$	[N/mm²]	18				
Factor acc. to section 6.2.2.3 of CEN/TS 1992-4:2009 part 5	k_8	[-]	7,2				
Increasing factor for τ_{Rk} in concrete	Ψ_c	C30/37	1,0				
		C40/50	1,0				
		C50/60	1,0				

Parameters provided to allow for calculation in accordance with the design method, i.e. TR 029 Clause 5.2.2.3 and prEN 1992-4 Clause 6.2.2:
i.e. calculation still required for the specific case

Concrete cone failure			
Effective embedment depth for calculation of $N_{Rk,c}$ (TR 029, 5.2.2.4 or CEN/TS 1992-4:2009 part 5, 6.2.3)	h_{ef}	[mm]	h_{nom}
Factor according to section 6.2.3. of CEN/TS 1992-4:2009 part 5	k_{cr}	[-]	7,2
Factor according to section 6.2.3. of CEN/TS 1992-4:2009 part 5	k_{ucr}	[-]	10,1
Edge distance	$c_{cr,N}$	[mm]	$1,5 \cdot h_{ef}$
Spacing	$s_{cr,N}$	[mm]	$3,0 \cdot h_{ef}$

Splitting failure				
Effective embedment depth for calculation of $N_{Rk,sp}$ (TR 029, 5.2.2.6 or CEN/TS 1992-4:2009 part 5, 6.2.4)	h_{ef}	[mm]	h_{nom}	
Factor according to section 6.2.3. of CEN/TS 1992-4:2009 part 5	k_{cr}	[-]	7,2	
Factor according to section 6.2.3. of CEN/TS 1992-4:2009 part 5	k_{ucr}	[-]	10,1	
Edge distance $c_{cr,sp}$ [mm] for	$h / h_{nom} \geq 2,35$		$1,5 \cdot h_{nom}$	
	$2,35 > h / h_{nom} > 1,35$		$6,2 \cdot h_{nom} - 2,0 \cdot h$	
	$h / h_{nom} \leq 1,35$		$3,5 \cdot h_{nom}$	
Spacing	$s_{cr,sp}$	[mm]	$2 \cdot c_{cr,sp}$	

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A4 Risk factors

Evidence from known fixing failures has suggested a series of risk factors that affect the probability of necessary intervention (see Table A4.1). The risk factors are indicators based on past performance evidence that has been found to influence the likelihood of failure either adversely or beneficially.

This appendix provides further details about the risk factors to assist with understanding:

- whether a risk factor applies, when undertaking a risk assessment for an existing fixing in accordance with Section 5.4
- the risk factors that could apply in new design and installation, and either taking the opportunity to design-out those risks or, if this is not possible, to mitigate against the risk factor.

Table A4.1 Summary of risk factors for fixings

	Risk factor	Likelihood (D/I)	Type of fixing
Design	Formal technical approval (eg ETA)	D	All
Installation	Poor quality of installation	I	All/resin anchor
	Overhead installation	I	Resin anchor
	Substitution	I	All
	Certification of installation	D	All
Actions	Shear rather than tension	D	All
	Sustained tension	I	Resin anchor
	Cyclic loading	I	All
	Vibrations	I	All/mechanical anchor
	Accidental/shock load	I	All
	Change in fixture/change in use	I	All
Environment	Wet/damp	I	All/polyester resin
	Corrosive environment	I	All
	Chlorides/marine environment	I	All
	High/low temperature	I	Resin anchor
	Masonry substrate	I	Resin anchor
Robustness	High degree of redundancy	D	All
	Secondary restraint	D	All
Degradation	Not recently inspected/hidden	I	All
	Missing/failing fixings	I	All
	Distortion/movement	I	All
	Substrate degradation	I	All
	Fixing/fixture corrosion	I	All

Note
See also Table 5.4.

Key
I = Increase
D = Decrease

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A4.1 DESIGN

A4.1.1 Formal technical approval

The availability of a formal technical approval for the fixing can be a beneficial factor, if the technical approval is appropriate for the actual application of the fixing.

Fixings installed in accordance with ETAs can generally be considered as lower risk, as noted in SCOSS (2008).

Fixings that were installed before the introduction of formal technical approvals such as European Technical Approvals (ETA) can have been subject to less stringent design, inspection and testing regimes during construction.

Where clients have issued particular guidelines, then installation before a particular cut-off date may be a method to categorise the risk level. For example, the Highways Agency issued an interim advice note (IAN) in 2007 to define the requirements for post-installed anchors and reinforcing bars in concrete (George, 2015). Fixings installed in in 2007 or later may be considered as lower risk.

The use of an ETA does not necessarily guarantee performance, because the ETAs can be complex to interpret and there is potential to use a fixing in an application that is not covered by it.

A4.2 INSTALLATION

A4.2.1 Poor quality of installation

Quality of installation is of paramount importance to the performance of post-installed fixings. Poor quality of installation should be considered as a potential risk factor unless evidence is available that gives confidence in the installation.

Resin-bonded anchors are sensitive to a larger number of parameters than mechanical anchors, as detailed in **Table A4.2**. Mechanical anchors can be sensitive to the errors listed in **Table A4.3**.

Installation in masonry can increase the risk of installation errors (see **Section A4.5.5 and Table A4.7**).

It is generally not possible to determine whether an existing fixing has been correctly installed by visual observation alone. A check of applied torque on a fixing can provide assurance for some types of fixing.

Installation records can assist in providing confidence in the quality of installation, and can include installer records and certification, supervision records and third-party inspection and audit records.

Records of proof testing can provide confidence in the installation. Proof testing demonstrates that the fixing can achieve a test load, which is likely to be considerably lower than the design resistance. Where the proof test was carried out some time previously, it is possible that the resistance of the fixing has degraded since it was undertaken.

Intrusive investigation can provide direct confirmation of quality of installation, for example, of the achieved bond or embedment depth. They can be destructive so the information may only be useful where there are several similar fixings.

Where direct records are not available, it may be possible to use indirect indicators to gauge the overall level of confidence in quality of installation, such as date of installation and frequency of other types of construction defect.

Knowledge of construction practices at the time of installation can provide an indication of likely levels of supervision and independent checking. Construction practices that could indicate a higher level of supervision include, for example, the presence of a resident engineer, or installation following the introduction of BS 8539:2012.

The frequency of other types of construction defect on the asset can be an indicator of the overall level of quality assurance applied during construction. Where a statistically higher number of defects are present on the asset overall, then it is possible that a lower level of checking and supervision was applied during installation of fixings if these were installed at the same time.

Table A4.2 Possible installation errors for resin-bonded anchors

Possible installation error	Effect of error
Edge distance too small or anchor spacing too small	Anchor resistance is reduced, with increased likelihood of pull-out failure of the concrete
Hole not drilled to correct depth	Resin can collect in a plug at the end of the anchor if the hole is too long. This was noted as an issue in the Balcombe tunnel failure and Sasago tunnel failure (see Appendix A4.3 and A4.4). If cartridge or capsule systems are used then there can be inadequate coverage of the anchor. If the hole is too short then inadequate embedment length can lead to reduced resistance.
Hole not drilled to correct diameter	The resin layer may be too thick if the hole diameter is too large. If cartridge or capsule systems are used then there can be inadequate coverage of the anchor. Holes drilled in masonry can become oversized as the drill bit encounters non-homogeneity in the masonry.
Hole not adequately cleaned	Residual drilling dust left in hole can reduce effectiveness of the bond.
Hole not drilled using the correct equipment	The surface roughness of the hole participates in the bond. A hole that is too smooth, for example from diamond drilling rather than hammer drilling, can reduce effectiveness of the bond.
Wrong diameter of anchor bolt	Resistance will be lower for a smaller diameter
Insufficient resin injected into the hole	The space between the anchor and the substrate needs to be fully filled with resin. The following application methods may result in insufficient resin being applied: ▪ an injection system if care is not taken that the hole is completely filled ▪ a capsule system if the hole is too large or too long. ▪ There may be voids or lack of full coverage, leading to a reduction in bond.
Air being inadvertently entrained in the injected resin	Voids in the resin will reduce effectiveness of the bond.
Injection resin not being pumped to waste to ensure even mixing before insertion	The early resin may not be mixed in the correct proportions and so may not achieve the required strength.
Resin used outside its recommended installation temperature range	The full bond strength may not be developed. Caution is also needed when storing the resin before installation, for example avoid leaving it in direct sunlight. There are many different resin formulations that can have significantly different characteristics and temperature limits.
Incorrect accessories used (eg for hollow or perforated masonry)	Resin may escape into cracks or voids within the substrate. Insufficient resin may remain in contact with the anchor and substrate.
Anchor rods not properly inserted into capsule systems	Resin may not be mixed properly or coat the full surface of the anchor. Effectiveness of the bond may be reduced.
Anchor rods cut short when rebar is struck	Effective embedment depth will be less and this will reduce the resistance of the anchor.
Anchors loaded, tightened or tested before the manufacturer's curing time has elapsed	The bond between resin and substrate may be damaged if the anchor is loaded, tightened or tested before the resin has strengthened sufficiently.
Anchors over-tightened	The bond between resin and substrate may be damaged if too much torque is applied.

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Table A4.3 Possible installation errors for mechanical anchors

Possible installation error	Effect of error
Edge distance or anchor spacing too small	Anchor resistance is reduced, with increased likelihood of pull-out failure of the concrete.
Hole not drilled to correct diameter	The mechanical anchor may not interface correctly with the substrate.
Incorrect accessories used (eg setting tools)	Anchor may not be set correctly, for example without full expansion against the substrate.
Anchor cut short or shorter version substituted when rebar is struck	Effective embedment depth will be less and this will reduce the resistance of the anchor.
Anchor not tightened to recommended torque	Under-tightening may mean the correct clamping force is not applied. Over-tightening may damage the substrate.
Grit/dirt prevents expansion anchor operating correctly	May occur if anchor is not stored correctly. Anchor may not expand against substrate correctly.

A4.2.2 Overhead installation (resin anchors)

Correctly installed resin anchors will perform satisfactorily. Overhead installation is considered a risk factor because it can increase the difficulty of correct installation. SCOSS (2014) discusses the difficulty of overhead installation of resin anchors.

For existing fixings, overhead installation is an indicator that there is greater likelihood of poor quality installation.

For new fixings, the risk of poor quality installation in overhead applications can be mitigated by careful consideration of the installation method, provision of suitable equipment or temporary works and by adequate supervision.

Where resin anchors are installed overhead, the resin needs to be forced upwards into the hole against the force of gravity. Overhead installation can make correct application of the resin more difficult than when the hole is horizontal or angled downwards. In particular, overhead installation may increase the likelihood of:

- incomplete resin application – resin not reaching the full length of the anchor or not filling the gap between the anchor and the substrate over the full length
- voids forming within the resin, either at the end of the anchor or along its length.

Working overhead can also increase the difficulty of drilling the hole. Records may not be available that document the installation method used. For larger applications it is possible that a drilling rig was used and this would reduce the likelihood of incorrect drilling. On smaller applications it is possible that manual overhead drilling was undertaken, which could increase the likelihood of error in hole size and length.

A4.2.3 Substitution

Suppliers and installers can propose to substitute a fixing with a different type, from the wide range that is available.

Where there is evidence that different types of fixing have been used in the same installation, then it can indicate that substitution has occurred.

The appropriateness of the substitution should be given the same level of scrutiny as the choice of the original fixing (see **Section 13.3**). This can be problematic if it occurs in a reactive or time-limited situation, such as a technical query during construction, so evidence of substitution should be treated as increasing the risk level, unless design records are available.

Section 10 of BS 8539:2012 notes that it is not sufficient to compare headline figures such as static strength or key dimensions. The fixing needs to satisfy all of the requirements of the original fixing. These may include static and dynamic actions, corrosion resistance properties, long-term effects, edge distances etc.

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A4.2.4 Certification of installation

A certificate of installation may be taken as an indicator that quality control processes have been applied during installation, and that there may be a lower likelihood of failure due to installation issues. BS 8539:2012 states that *"the installer and/or supervisor should issue a certificate to certify that the anchors have been correctly installed in accordance with the specification and are in a condition to be loaded."*

Asset owners may wish to verify that installation certificates can be relied upon. Processes may include independent audit and third-party construction inspections. See **Section 13.3**.

An installation certificate does not preclude errors occurring during installation. Asset owners should consider whether the other installation risk factors could apply.

Fixings are a commodity item and there is a low barrier to entry for suppliers. Currently there is no industry-wide competence, certification or quality scheme applicable to fixings. Fixings installation may be subcontracted through the supply chain with the installation ultimately performed by a small subcontractor. Care is needed that the quality procedures specified in BS 8539:2012 are understood and applied on site.

A4.3 ACTIONS

A4.3.1 Shear rather than tension

A fixing acting in shear rather than tension is a beneficial factor.

SCOSS (2008) have noted that fixings working in shear usually have a greater robustness against certain short-comings compared to fixings working in pure tension.

Section 5.3.4.2 of BS 8539:2012 notes that tensile anchor performance is dependent on a variety of factors including anchor type, anchor rod material, base material strength and quality of installation. However, shear performance is dependent broadly on anchor rod material and base material strength (if sufficient edge distance is present) and is little affected by installation quality.

Likewise, Section 9.4 of BS 8539:2012 notes that the shear performance of anchors in concrete is dependent primarily on the strength of the anchor rod and base material, and is determined in concrete by calculation. Tests to define allowable shear actions are not normally needed in concrete.

Care is needed that the fixing is installed hard up against the substrate. Where a gap is unintentionally introduced, for example due to a rough surface finish, then the fixing can be subject to a bending moment that may not have been considered in the design.

A4.3.2 Sustained tension

Sustained tension is a risk factor particularly for existing fixings installed before knowledge became more widespread about the problems of creep of anchors. Incidents of failures involving sustained tension on fixings include the ceiling collapse on the Interstate 90 Tunnel in Boston (NTSB, 2006), the canopy failure on 17th Street Bridge (Baxter, 2012) and a failure in concrete reported by CROSS (2014).

New resin fixings that are qualified appropriately to an EAD will perform satisfactorily under sustained tension. The test regime in the EAD includes tests for creep performance. During selection of the fixing, verification should be made that the EAD, ETA and DoP provide the desired long-term performance and that the fixing has adequate creep resistance.

For existing resin fixings subject to sustained tension, it can be possible to detect creep problems in existing fixings through periodic inspections.

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A4.3.3 Cyclic loading

Examples of failures involving cyclic loadings are given in **Table A4.4**.

The application of reversing loads can cause issues with mechanical anchors, where mechanical elements may come loose if they are not subject to pre-tensioning. Manufacturers may be able to provide test data to justify the use of particular fixings in these conditions.

The application of cyclic loads can cause issues with bonded anchors, and can lead to deterioration of the bond or the substrate over time. This was noted as a potential contributory factor in the Sasago tunnel failure.

Cyclic actions can arise from:

- Buffeting action, eg pressure changes caused by passing traffic that can cause load reversal or uplift. This was a factor in the Balcombe tunnel failure (**Box A4.1**). The effect can be significant on lightweight structures that have a low permanent load.
- Pressure variations, eg due to switching on/off of ventilation fans. The failure to consider transverse bending effects due to different pressures in side-by-side ventilation chambers was a factor in the Sasago tunnel failure.
- Traffic, eg repeated passage of wheel loads.
- Wind.

Load data published by manufacturers generally refers to the static load case, which can include permanent and variable actions.

Care is needed with cyclic actions. Current EADs and design methods do not necessarily provide standard design and test methods for cyclic actions. Where an EAD does not cover cyclic actions then additional specification should be included, such as supplementary standards, and may require specialist testing or access to manufacturer's test results.

Fixings subject to cyclic or reversing loads should be checked for fatigue. Fatigue checks can be outside the scope of an EAD.

Table A4.4 Failures involving cyclic loadings

Failure	Description
Balcombe tunnel (RAIB, 2014)	Aerodynamic forces greater than self-weight appear to have generated oscillations in the fixings, which led to the fixings working loose (see **Box A4.1**).
Sasago tunnel (MLITT, 2013)	Cyclic loading due to switching on/off of the ventilation system and due to wind pressure from passing vehicles was thought to contribute to deterioration of pull-out strength of the fixings. This was caused by load and material deterioration over a long time caused by the development of cracks and voids in the substrate.

Box A4.1 Inadequte bond between resin and brickwork at Balcombe tunnel

A Balcombe tunnel investigation report identified that some holes exhibited signs of wear and had deformed, indicating that the stud had oscillated upwards and downwards rather than simply rotating out of the hole (**Figure A4.1**). Post-incident analysis showed that the aerodynamic forces generated by passing trains were greater than the self-weight of the catchment tray structure. After the main pressure wave had passed, further oscillating pressure waves lasted for about one minute.

Figure A4.1 Deformed hole due to oscillation of stud under aerodynamic forces

A4.3.4 Vibrations

Vibrations of fixings have not been noted in the literature as a potential cause of failure. However, an analogy to connection design for buildings and bridges indicates that there can be potential for fixings to work loose when subject to repeated vibrations. Ordinary 'black bolts' are permitted in building connections, but are not permitted for bridge connections, where friction grip connections are required due to issues with traffic vibration.

Sources of vibration can include:

- machinery, eg the operation of fans can cause high frequency vibration
- traffic, eg repeated passage of wheel loads.

The tests required under most EADs are static tests with no vibration requirement, so there is a risk that the behaviour under vibrations is not considered.

Vibrations can increase if there are other defects on the structure, for example, hammer of vehicles passing over an expansion joint or rail joint. Vibrations can also be transmitted to a fixing through the structure even if the fixing is not directly loaded by traffic.

A4.3.5 Accidental/shock load

Fixings that are designed for accidental or shock loads can have only a small proportion of the design load present in the normal situation. The full design load may only be applied in the accidental situation, for example, upon impact on a safety barrier. So, there may be no warning that a fixing may be unable to sustain the design load. This was demonstrated on the Southampton bridge parapet failure (see **Box A4.2** and also **Section A4.5**).

Similar to cyclic actions, the standard EAD may not cover shock or impact. Supplementary specification, design methods and testing may be required.

Box A4.2 Parapet failure due to impact

A vehicle restraint system suffered an impact. The post-installed fixings pulled out of the concrete base (Figure A4.2). This is incorrect behaviour, because the design intent for a vehicle restraint system is for the post to fail before the connection fails.

The fixings were subject to very low loads under normal circumstances, so there was no indication that the fixing would not perform adequately.

Figure A4.2 Vehicle restraint system showing post-installed fixings that had pulled out of the base

A4.3.6 Change in fixture/use

It can be evident from inspection of a fixing (or from access to the original design records) that the actions are different to how they were envisaged in the design, for example:

- change in fixture
- change in use
- components of action that were not envisaged in the design, such as:
  - transverse loading in addition to a primary vertical load (this was an issue in the Sasago tunnel failure, see MLITT, 2013)
  - bending effects leading to additional push-pull loading on a group of fixings.

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A4.4 ENVIRONMENT

A4.4.1 Wet/damp

Certain resins are not suitable for use in damp conditions, such as may be found in tunnels. In particular, polyester resins are unsuitable for use in damp or wet conditions. Failures involving damp or wet conditions include the partial failure at Balcombe tunnel (RAIB, 2014 and LU, 2013).

Damp conditions may be present in:

- historic masonry tunnels, which may be subject to water seepage
- concrete-lined tunnels, which may be subject to condensation.

Damp conditions can also lead to atmospheric corrosion of fixings.

A4.4.2 Corrosive environment

Transport infrastructure can present a particularly harsh environment leading to heightened corrosion. Table 1 of BS 8539:2012 cites these as 'special applications' that require special alloys of stainless steel. This is due to:

- presence of de-icing salts
- vehicle emissions, particularly in tunnels.

Care is needed over the selection of materials for fixings. In particular, some grades of stainless steel are not suitable for harsh environments.

Further guidance is provided in Annex F of BS 8539:2012 and HILTI (2010).

A4.4.3 Chlorides/marine environment

Stainless steels can be subject to stress corrosion cracking where the steel is subject to chlorides because of a marine environment or de-icing salts. Failure of a component is sudden and without warning.

There have been well-reported failures of swimming pool roofs due to this effect, for example in Uster, Switzerland, in 1985 (SCOSS, 2015).

Stainless steel elements in the marine environment may be at risk from this failure mode. **Box A4.3** provides an example of where 12 of 90 stainless steel tie bars failed due to stress corrosion cracking.

Case study A4.3 Failure of tie bars, Shaldon Bridge, Devon

Shaldon Bridge in Devon was widened in 2002 with cantilevered footways stressed to the main bridge deck using stainless steel tie bars.

A principal inspection of the bridge in 2015 found that 12 of 90 tie bars had failed. Remedial works were undertaken, and the inspection regime was successful in detecting the failure before a serious structural failure occurred.

The probable cause was identified as stress corrosion cracking, due to:

- exposure to chlorides from sea water spray and the marine atmosphere
- failure to specify a suitable grade of stainless steel for this application
- the element was sheltered from rain water so chlorides were not naturally cleaned away.

Lessons learnt

- It is important that the correct grade of stainless steel is used for marine environments.
- Stainless steel may still corrode in certain environmental conditions. Further protection measures may be required against stress corrosion cracking and other failure modes.
- It is difficult to identify stress corrosion cracking from *in situ* visual inspection.
- Sudden failures can occur in tensioned elements.
- The surface finish and regular washing of stainless steel components has a major effect on their durability and can be critical to their successful application in a marine environment.

See CROSS (2015a).

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A4.4.4 High/low temperature including fire

Resin anchors should be installed within the manufacturers' specified temperature range. Installation outside of the temperature range has led to reported failure of fixings of mobile phone masts, due to leaving the resin exposed to direct sunlight during installation. See CROSS (2015b).

A further failure has been reported due to low temperatures, leading to failure of resin anchors during lifting. See CROSS (2014).

Where the structure could be subject to fire (for example, vehicle fire in a tunnel), then there can be potential for significantly elevated heat and concrete spalling. Guidance is provided in CFA (1998).

A4.4.5 Masonry substrate

A masonry substrate increases the chance of issues during installation. **Table A4.5** indicates possible installation errors in masonry.

Requirements and guidance for masonry are provided in Section 5.3.3.3 of BS 8539:2012 and CFA (1997b).

Table A4.5 Possible installation errors in masonry

Possible installation error	Effect of error
Variability/lack of knowledge of masonry strength	Masonry strength can vary from about 2 N/mm^2 for aerated blocks to 90 N/mm^2 for engineering bricks (Section 5.3.3.3, BS 8539:2012).
Non-homogeneity of substrate	Masonry units can be solid or have perforations. There can be voids or cracking either in the masonry units or in the mortar. Measures such as mesh sleeves should be used to limit the spread of resin away from the fixing into voids. Where resin capsule systems are used, there is a risk that insufficient resin is applied if the resin enters voids.
Weak mortar	Mortar can be weak or non-existent in parts of the joints. The strength of the fixing system can be governed by pull-out of a block around the mortar joint. Fixings should be installed into the centre of masonry units. Where fixings have been installed directly into the mortar there is a risk that the strength of the fixing will be lower than assumed.
Enlarged holes during drilling	Strength variations within a masonry unit can cause a drill bit to 'wander' during drilling and result in an enlarged hole. Powerful hammer and percussion drilling machines can produce oversized holes in soft materials such as old bricks and can break out the back face of the brick. Enlarged holes can reduce the effectiveness both of mechanical and bonded anchors.
Potential for incompatibility of resin with brickwork	The Balcombe tunnel failure investigation report noted incompatibility of the resin with the brickwork (RAIB, 2014). Incompatibility may be found where the brickwork has low porosity leading to lack of adherence of the resin to the brickwork, or where percolating water leads to softening of the resin.
Use of expansion fixings	Potential for mechanical expansion anchors to split the masonry units.
Overtightening fixings	'Tighter' is not 'better'. Overtightening of mechanical anchors can cause splitting of the masonry units. Overtightening of bonded anchors can cause failure of the bond.
Limitations of ETAs	ETAs for anchors can be restricted to certain categories of masonry or can require tests to determine the allowable resistance.

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A4.5 ROBUSTNESS

A4.5.1 High degree of redundancy

Redundancy can be beneficial. Examples of redundancy in fixing systems leading to robustness include:

- where there is a support framework that can distribute loads between fixings
- where it is clear that failure of one fixing will not lead to failure of the system as a whole.

Redundancy alone does not necessarily guarantee satisfactory performance. Several failures have displayed common issues, where the same mode of failure has applied to a large number of fixings.

Further guidance on design for robustness and on common failures is provided in **Section 12.6**.

A4.5.2 Secondary restraint

The presence of a secondary restraint system can be beneficial. Examples of secondary restraint include:

- lanyard
- safety chains
- corbel or other structural device to 'catch' the fixture
- crash deck.

Secondary restraint does not reduce the likelihood of failure of the main fixing, but it mitigates the consequence of failure. Care is needed in the design of the secondary restraint. This is because restraint and any associated fixing can be subject to shock loading including a dynamic element. A fixing for secondary restraint is unlikely to be subject to significant load unless the secondary restraint is required, so there will be no indication of whether the fixing will perform satisfactorily.

A fixing that is providing secondary restraint may need to be a different type to the main fixing. There is advantage in using a different type of fixing to mitigate against common failures.

Guidance on design for secondary restraint is provided in **Section 12.6.3**.

A4.6 DEGRADATION

A4.6.1 Not recently inspected/hidden

Inspections offer the opportunity to detect warning signs of approaching failure. Where inspections are not carried out then these warning signs can be missed. Examples of failures where lack of inspection contributed are provided in **Table A4.6**.

Lack of routine observation is a risk factor and may be due to:

- hidden or concealed fixing, eg behind suspended ceiling (see **Sections 7.3.6 and 12.5.2**)
- limited time or difficult access for inspections, eg due to arranged closure to road or rail traffic
- lack of appreciation of significance of fixing (perception that it is a structural detail of minor importance).

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Table A4.6 References of failures where inadequate inspection was a contributory factor

Failure	Role of inspection in the failure
Balcombe tunnel (RAIB, 2014)	The accident investigation report states: *"Staff found that Balcombe tunnel was a particularly difficult location to gain sufficient access for examination work. The long possessions required for tunnel examination were seldom available because of an intensive daily train service, an overnight gap in services of less than three hours, and the lack of a diversionary route… Inadequate access meant that tunnel examinations were not undertaken in accordance with Network Rail standards."*
Sasago tunnel (MLITT, 2013)	A report into the failure states: *"There was no close visual inspection or hammer testing of the ceiling bolts in the L cross section for 12 years, because of a change of inspection plan without first clarifying the condition of the ceiling adhesive bolts."*

A4.6.2 Missing fixings

Missing fixings can be detected by inspection or by third-party reports. Missing fixings require urgent attention. The cause of the missing fixing should be investigated. A similar cause can apply to other fixings on the same and on other structures. The extent of the problem should be determined. **Table A4.7** indicates failures where fixings were noted as missing.

See also **Section 7.3 and Appendix A7** for guidance on inspections.

Table A4.7 References of failures where fixings were missing

Failure	Missing fixings
Balcombe tunnel (RAIB, 2014)	At least 10 studs fell to the ground in the seven months before the failure, but were not acted upon. See Section 7.3.5.
Sasago tunnel (MLITT, 2013)	A press briefing about the failure noted that it appeared some anchor bolts used to secure the concrete slabs to the tunnel roof were missing.

A4.6.3 Distortion/movement

Similar to missing fixings, distortion or movement of the fixing can be detected by inspection or by third-party reports. Distortion or movement of the fixing can also be detected by observation of movement of the fixture. Distortion or movement of fixings requires urgent attention.

Similar to missing fixings, the cause of the distortion or movement should be investigated. A similar cause can apply to other fixings on the same and on other structures. The extent of the problem should be determined.

Distortion or movement can be indicated by:

- obvious movement of the fixing or fixture
- gap or lack of fit between the baseplate and substrate.

See **Section 7.3 and Appendix A7** for guidance on inspections.

A4.6.4 Substrate degradation

Substrate degradation such as cracking of concrete can indicate that the substrate strength is lower than assumed in design. There is potential that the fixing has lower capacity than assumed.

A4.6.5 Fixing/fixture corrosion

Corrosion of the fixing or the substrate can be indicated by rusting or staining. Over time, it can reduce the effective section of the fixing and can lead to failure. In addition, corrosion of reinforcement within the substrate can reduce the strength of the substrate and the fixing system.

A5 Examples of screening

Section 5.2 defines a set of screening criteria to determine whether a fixing is safety critical or non-safety critical. This appendix gives examples of the application of the initial screening exercise on a number of fixtures located on UK transport infrastructure, as follows.

A5.1 SUSPENDED HIGHWAY SIGN

Photo	
Geographic location	London
Fixture	Sign (junction exit)
Fixture location in relation to people/traffic	Suspended from overbridge, and over carriageway
Fixing details	Not known
Screening questions	People killed or seriously injured? Yes Severe damage to vehicles/vessels? Yes Structural failure? No Progressive failure? No Closure of route? Yes, strategic link on network Disrupt operation? Yes (sign is functionally important for safe operation, also likely that traffic management would be needed for a lengthy duration to replace the sign)
Screening decision	Safety critical (at least one answer is 'Yes')

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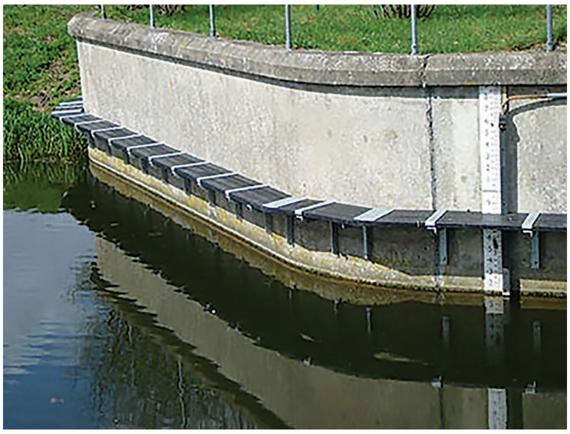
A5.2 OTTER WALKWAY

Photo	
Geographic location	Sluice gates, Norfolk
Fixture	Otter walkway
Fixture location in relation to people/traffic	Cantilevered from abutment and wing wall, next to river, below underbridge
Fixing details	Not known
Screening questions	People killed or seriously injured? No Severe damage to vehicles/vessels? No Structural failure? No Progressive failure? No Closure of route? No Disrupt operation? No
Screening decision	Not safety critical (all answers are 'No')

A5.3 LIGHTING COLUMN ON BRIDGE PARAPET

Photo	 
Geographic location	9627 A30 km 330.1, A30/A388 overbridge, Devon
Fixture	Lighting column
Fixture location in relation to people/traffic	Fixed to stringcourse of bridge deck, above A30
Fixing details	4No. post-installed fixings, type not known
Screening questions	People killed or seriously injured? Yes Severe damage to vehicles/vessels? Yes (if light column fell and struck a vehicle) Structural failure? No Progressive failure? No Closure of route? Yes, trunk road Disrupt operation? No
Screening decision	Safety critical (at least one answer is 'Yes')

A5.4 SMALL SUSPENDED SIGN

Photo	
Geographic location	5420 A1 km 244.8, A1/A634 underbridge, Blyth, Nottinghamshire
Fixture	Height restriction sign
Fixture location in relation to people/traffic	Fixed to stringcourse of bridge, above A634
Fixing details	Not known
Screening questions	People killed or seriously injured? No (sign is lightweight so could cause injury, but unlikely to cause serious injury) Severe damage to vehicles/vessels? No (sign is lightweight and could dent a vehicle, but unlikely to cause severe damage) Structural failure? No Progressive failure? No Closure of route? No (unlikely even to cause closure of the A road) Disrupt operation? No
Screening decision	Not safety critical (all answers are 'No')

A5.5 BRIDGE FASCIA PANELS

Photo	
Geographic location	3952 M56 km 44.7, M56/Weaver Lane overbridge, Cheshire
Fixture	Bridge fascia panels
Fixture location in relation to people/traffic	Fixed to outside face of bridge edge beam, above M56
Fixing details	Not known, hidden fixings
Screening questions	People killed or seriously injured? Yes (size and weight of panels could cause series injury if striking a moving vehicle) Severe damage to vehicles/vessels? Yes (as above, due to normal speed of traffic of 70 mph) Structural failure? No Progressive failure? No Closure of route? Yes Disrupt operation? No
Screening decision	Safety critical (at least one answer is 'Yes')

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A5.6 CABLE TRAYS

Photo	
Geographic location	Surbiton station
Fixture	Cable trays, lights, signage
Fixture location in relation to people/traffic	Suspended from station canopy over platform. Not directly over rails
Fixing details	Multiple post-installed fixings, type not known
Screening questions	People killed or seriously injured? No (individual elements are lightweight) Severe damage to vehicles/vessels? No (suspended elements are not above rail track) Structural failure? No Progressive failure? No Closure of route? No Disrupt operation? No
Screening decision	Not safety critical (all answers are 'No')

A5.7 COLLISION PROTECTION BEAM

Photo	 
Geographic location	Stockbridge Road Bridge, RTJ2 80 m 72 ch
Fixture	Collision protection beam
Fixture location in relation to people/traffic	Fixed to face of abutment, protection beam over road and footway
Fixing details	Several horizontal and inclined anchors, details not known
Screening questions	People killed or seriously injured? Yes (due to weight of beam in event of failure) Severe damage to vehicles/vessels? Yes (due to beam above road) Structural failure? No Progressive failure? No Closure of route? No Disrupt operation? No
Screening decision	Safety critical (at least one answer is 'Yes')

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A5.8 CLADDING PANELS

Photo	 
Geographic location	Piccadilly Underpass, Westminster, London
Fixture	Cladding panels
Fixture location in relation to people/traffic	Fixed to wall of underpass alongside traffic lane
Fixing details	Hidden fixings used to attached steel channels with secondary fixings to attach cladding to channels
Screening questions	People killed or seriously injured? Yes (in the event of the panel falling onto a vehicle or causing a road traffic accident) Severe damage to vehicles/vessels? Yes (due to the large element size above and near to traffic lanes) Structural failure? No Progressive failure? No Closure of route? Yes Disrupt operation? Yes
Screening decision	Safety critical (at least one answer is ‘Yes’)

A5.9 NOISE BARRIER

Photo		
Geographic location	3706 M25 km 78, near Bourne River	
Fixture	Noise barriers	
Fixture location in relation to people/traffic	Fixed to ground beam and bridge stringcourse over river	
Fixing details	4 no. post-installed fixings per upright, type not known	
Screening questions	People killed or seriously injured? No (but this would change to yes if there was public access along the river) Severe damage to vehicles/vessels? No (barriers are set back from the traffic lane and vehicle restraint barriers would prevent the noise barrier falling onto the carriageway) Structural failure? No Progressive failure? No Closure of route? No (due to the presence of vehicle restraint barriers) Disrupt operation? No	
Screening decision	Not safety critical (all answers are 'No')	

A5.10 POST-INSTALLED VEHICLE RESTRAINT SYSTEM

Photo	
Geographic location	M62
Fixture	Vehicle restraint system
Fixture location in relation to people/traffic	Fixed to bridge parapet over interchange
Fixing details	4No post-installed fixings per upright, type not known
Screening questions	People killed or seriously injured? Yes Severe damage to vehicles/vessels? Yes Structural failure? No Progressive failure? No Closure of route? Yes (interchange below) Disrupt operation? Yes
Screening decision	Safety critical (at least one answer is 'Yes')

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A6 Content of asset information systems

Table A6.1 provides a list of suggested content for asset information systems to enable the management of safety-critical fixings.

The asset owner should establish the most appropriate system and format to store this data, which may be as part of a new or existing asset information system or as a set of records specific to safety-critical fixings. The suggested content structure provided in the table may be adapted depending on the features of the asset information system.

Table A6.1 Suggested content of asset information systems

Asset	Suggested content of asset information system
Safety-critical fixings in general	Knowledge generally applicable to safety-critical fixings, including: ▪ policies ▪ processes ▪ works programmes ▪ summaries ▪ failure reports (including from external sources).
Primary asset	The asset that the fixture is attached to. Ideally referenced using an index to the relevant primary asset record in the asset information system, to avoid duplication of content. ▪ asset unique reference number ▪ name ▪ location (may be by reference to the network or geographical area) ▪ type of asset (eg bridge, tunnel, retaining wall) ▪ [other information as required to manage the primary asset] ▪ links to other fixings attached to this asset ▪ links to inspection records for the primary asset.
Fixture	May be referenced using an index to a record for the fixture within the asset information system. ▪ asset unique reference number ▪ type of fixture (eg sign, CCTV) ▪ date of installation ▪ anticipated year of replacement ▪ [other information as required to manage the fixture] ▪ weight of fixture ▪ dimensions of fixture (eg from a drawing) ▪ support arrangement (eg drawing) ▪ asset owner (fixture) ▪ links to other fixings supporting the fixture ▪ links to inspection records for the fixture.

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Asset	Suggested content of asset information system
Fixing	***Inventory of fixings*** ■ record applicable to single fixing/family of fixings ■ fixing unique reference number ■ fixing location ■ visible/hidden ■ type of fixing (where known) ■ type of substrate ■ hole orientation (vertical/horizontal/inclined) ■ asset owner (fixing).

	Screening decisions
	■ date of screening
	■ safety critical/non safety critical/not screened
	■ information to support screening decision (see Section 5.2):
	  □ harm to people
	  □ damage to vehicles
	  □ failure of structural members
	  □ progressive failure
	  □ closure of key routes/services
	  □ time to restore operations.

	Inspections recorded The information about fixings can form part of an overall structures inspection report. It may be beneficial to extract the following records to assist in the management of safety-critical fixings: ■ date of inspection ■ inspection type ■ changes since last inspection ■ summary of condition including defects ■ environment surrounding fixing (eg dampness) ■ photographs ■ defects or changes requiring urgent attention.
	Risk factors (see **Section 5.4**). It may be beneficial to set up the records to allow for filtering against the risk factors.
	Risk assessment details ■ date of risk assessment ■ persons carrying out risk assessment ■ information available ■ level of risk ■ justification for level of risk ■ evaluation (tolerable/not tolerable) and justification ■ recommended action ■ recommended interim measures (where required).
	Interventions undertaken (including interim measures, to mitigate the risks) ■ date of intervention ■ details of intervention ■ (for interim measures) maximum permitted duration of interim measures ■ further action required.

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<table>
<tr><th>Asset</th><th>Suggested content of asset information system</th></tr>
<tr><td rowspan="4">Fixing</td><td>Design details
All the data listed in BS 8539:2012 Section 6 should be recorded. The following information has particular relevance:
■ full description, including make, type, ETA (where applicable), size, designation, manufacturer's reference number
■ design actions and their nature
■ performance data, including characteristic resistance, design resistance and recommended resistance
■ material details for fixing and resin where used (eg grade, corrosion resistance)
■ assumed substrate strength
■ embedment depth
■ minimum spacings, edge distances, base material thicknesses
■ certificate of design and check (where required by asset owner technical assurance processes).</td></tr>
<tr><td>Installation and supervision details
BS 8539:2012 does not include specific requirements for information to be recorded about the installation. The following information has particular relevance:
■ date of installation
■ conditions (eg weather, temperature)
■ name and company of installer
■ name and company of supervisor
■ evidence of competence of installer (eg relevant certification/training records)
■ as-installed hole diameter and depth
■ observations during installation (eg hitting reinforcement, cracking, damage)
■ strength of substrate at installation (or, where not known, estimate of age of substrate at installation)
■ changes/substitutions of parts/materials compared with design intent
■ certificate of installation.</td></tr>
<tr><td>Testing details
All the data listed in the test report from BS 8539:2012 (Annex B, Section B.4) should be recorded. Where the test report is provided as a consolidated document, it may be beneficial to extract the following records:
■ type of test
■ date of test
■ number of fixings tested
■ required test load
■ achieved test loads
■ allowable resistance derived from tests
■ observations during test.</td></tr>
<tr><td>Decommission
■ date of decommissioning</td></tr>
</table>

A7 Inspections

Table A7.1 provides guidance on the aspects relevant to fixings that should be identified during inspections.

The table provides an indication of the type of inspection that may be necessary to provide information on each aspect, either visual inspection or touching distance inspection. Where a fixing is readily accessible then it may be possible to gather more information from a visual inspection or by using visual magnification (eg binoculars).

Where hidden fixings are present, then work may be needed to expose the fixing before or as part of the inspection.

Table A7.1 relates the aspects covered by the inspection to the risk factors listed in Section 5.4. Where information on these aspects is obtained, then a decision on the applicability of the risk factor can be taken, updated or refined. It may not be possible to obtain full information on all risk factors by inspection alone. For example, inspection may not confirm that the fixing was correctly installed with a high quality of construction.

The table has been divided into groups based on the type of inspection and the potential levels of information that may be available during the transition period. During the transition period it may be appropriate to follow a strategy of targeted inspections that gather only a basic level of information on certain fixings, to understand the highest risk areas and make the most efficient use of constrained resources. Where touching distance inspections are carried out, either as part of the transition period or during steady state, then data on all the aspects given in the table should be gathered.

Geometric information on fixings, such as edge distance and spacing, is not included. This type of geometric information is relevant to the calculation of resistance of a fixing, but needs to be supplemented by further information such as embedment depth, which is not typically available by inspection alone.

Table A7.1 Aspects relevant to fixings that should be identified during inspections

Visual	Touching	Inspection details	Risk topic	Risk factor
Inventory				
✓	✓	Presence of fixings: ▪ primary asset that supports the fixing ▪ number of fixings.	N/A	
✓	✓	Presence of hidden elements (may require special inspection to identify hidden fixings)	N/A	
Screening				
✓	✓	Fixture location in relation to people/traffic	N/A	
✓	✓	Consequence of failure: ▪ harm to people ▪ damage to vehicles ▪ failure of structural members ▪ progressive ▪ closure of key routes/services ▪ time to restore operations.	N/A	
Readily observable detail				
✓	✓	Purpose of fixture and fixing	Actions	Accidental/shock load
✓	✓	Substrate type	Environment	Masonry substrate

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Visual	Touching	Inspection details	Risk topic	Risk factor
✓	✓	Hole location and orientation	Installation	Overhead installation
			Actions	Shear rather than tension
✓	✓	Applied permanent action ■ likely proportion of permanent to variable actions ■ direction of permanent action.	Actions	Sustained tension
Observation				
✓	✓	Change in fixture/use: ■ compare previous inspection records ■ compare design records ■ take and compare photographs.	Actions	Change in fixture/use
✓	✓	Observe actions in service: ■ wind, aerodynamics, traffic load ■ check for observable back-and-forth movement of fixture ■ traffic actions that may be transmitted to fixing ■ overall vibration of structure.	Actions Actions	Cyclic loading Vibrations
✓	✓	Surrounding environmental conditions: ■ corrosive atmosphere, eg exhaust fumes/industrial pollution ■ chlorides, eg de-icing, marine conditions ■ extremes of temperature, eg due to altitude or exposure.	Environment Environment Environment	Corrosive environment Chlorides High/low temperature
Fixing				
	✓	Fixing type (mechanical/resin): ■ inconsistency in fixing types.	Installation Installation	Poor quality of installation Substitution
	✓	Fixing condition: ■ missing fixings ■ fixing loose in substrate ■ evidence of degradation of resin.	Degradation	Missing/failing fixings
		■ damaged fixing ■ movement ■ gap between fixing/fixture and substrate ■ tightness of bolts.	Degradation	Distortion/movement
		■ corrosion of fixing, including bimetallic.	Degradation	Fixing/fixture corrosion
	✓	Quality of installation ■ inconsistency, eg different projecting lengths ■ out-of-true ■ abandoned holes.	Installation	Poor quality of installation
Substrate				
?	✓	Substrate environment: ■ water present (wet/damp).	Environment	Wet/damp
		■ subject to cyclic wetting/drying ■ subject to freeze/thaw.	Degradation	Substrate degradation

Visual	Touching	Inspection details	Risk topic	Risk factor
?	✓	Substrate condition: ■ cracking ■ voids ■ staining ■ signs of water damage ■ rusting ■ evidence of reinforcement corrosion (concrete) ■ delamination (concrete) ■ alkali-silica reaction (concrete) ■ crumbling/loss of strength (masonry) ■ mortar loss (masonry).	Degradation	Substrate degradation
Fixture				
	✓	Fixture condition: ■ corrosion ■ section loss ■ rusting ■ staining ■ chemical damage.	Degradation	Fixing/fixture corrosion Distortion/movement
?	✓	Physical damage to fixture: ■ accident ■ impact ■ vandalism ■ fire.	Actions Degradation	Accidental/shock load Fixing/fixture corrosion Distortion/movement
Attachment/connection				
?	✓	***Degree of redundancy in attachment***	***Robustness***	***High degree of redundancy***
?	✓	***Presence of secondary restraint***	***Robustness***	***Secondary restraint***
	✓	Attachment condition: ■ loose or missing nuts ■ failure of bolt or nuts	Degradation	Missing/failing fixings
		■ corrosion of connection	Degradation	Fixing/fixture corrosion
		■ damage of connection.	Degradation	Distortion/movement

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A8 Sample model for assessment of risk

A8.1 GENERAL

This appendix provides a sample model to assess the risk related to an individual fixing or family of fixings, in accordance with **Section 5.4**.

Asset owners may adapt or simplify this model as they see fit based on their specific network needs using the theory outlined in this guide.

A8.1.1 Risk assessment score

The general model of risk described in **Section 5.4** is adopted, where risk is defined as the product of likelihood and consequence. The consequence and likelihood scores are calculated and then combined to create a risk assessment score for each fixing or family of fixings.

$$\textit{Risk assessment score} = \textit{consequence score x likelihood score}$$

A8.1.2 Consequence score

Consequence scores are calculated for three categories based on typical network objectives. These are:

- safety (ie effects on human life)
- functionality (ie the ability to continue to operate a transport network unrestricted)
- environment (ie environmental issues resulting from the failure of a fixing).

The consequence score shall be determined by adding up the safety scores, the functionality scores and the environment scores given in **Tables A8.2 to A8.4**, as follows:

$$\textit{Consequence score} = \sum \textit{safety scores} + \sum \textit{functionality scores} + \sum \textit{environmental scores}$$

The safety scores shall be determined using **Table A8.2**. For each row in the table a score of 10, 3, 1 or 0 shall be determined. The description that best fits the fixing or family of fixing is used to determine the appropriate score. The scores for each row are added together to determine the sum of the safety score. The total sum of the safety scores can be a maximum of 60 in the situation where each row is determined as critical.

The functionality scores are calculated in a similar manner using **Table A8.3** with a maximum sum of the functionality scores of 60.

The environment scores use table **Table A8.4** with a maximum sum of 10.

Table A8.6 gives an example of how to use the consequence tables.

A8.1.3 Likelihood score

Table 5.4 sets out risk factors that can increase and decrease the likelihood of failure of a fixing. These risk factors have been used to create the likelihood risk factors used in this model. These are described in **Table A8.5**.

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The output from **Table A8.4** should then be converted to the likelihood score using **Table A8.1**, and multiplied by the consequence score to obtain the risk score.

Table A8.1 Likelihood score

Total likelihood risk factor score	Likelihood score
49 to 59	10
38 to 48	7
23 to 37	5
8 to 22	3
0 to 7	1

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Table A8.2 ***Consequence: safety score***

		Critical	**High**	**Medium**	**Low**
	Score	*10*	*3*	*1*	*0*
A	Number of people killed or seriously injured	Potential for 1 or more people to be killed or seriously injured	Potential for slight injuries to five or more people	Potential for slight injuries to fewer than five people	No potential for injuries or other harm to health
B	Potential damage vehicles	Potential for severe damage to one or more: ■ road vehicles ■ trains ■ floating vessels.	Potential for minor damage to one or more: ■ road vehicles ■ trains ■ floating vessels.	Potential for minor damage to a single: ■ road vehicle ■ train ■ floating vessel.	No damage sustained
C	Potential damage to utilities and other public or private services	Any of the following: ■ potential for any disruption to 1 or more nationally and regionally important utility services ■ potential for severe disruption to 1 or more locally important utility services ■ potential for moderate disruption to more than one locally-important utility services.	Any of the following: ■ potential for severe disruption to a single locally-important utility service ■ potential for moderate disruption to one or more locally-important utility service ■ potential for severe disruption to other utility services.	Any of the following: ■ potential for moderate disruption to a single locally-important utility service ■ potential for minor disruption to one or more locally-important utility services ■ potential for moderate disruption to one or more other utility service.	Any of the following: ■ no potential for disruption to nationally and regionally or locally-important utility services ■ potential for minor disruption to one or more other utility service.
D	Location to route	Any of the following: ■ directly above any carriageway, railway line or waterway ■ directly above any high use footpath, cycle way or other public access area.	Any of the following: ■ near to any carriageway, railway line or waterway ■ directly above any medium use footpath cycle path or other public access area ■ directly above any high use maintenance access area.	Any of the following: ■ directly above any low use footpath or cycle path or other public access area ■ near to any low use footpath or cycle path or other public access area ■ near to any medium use maintenance access area.	Any of the following: ■ remote from any route ■ near to any low use maintenance access area.
E	Potential for fixing failure to lead to structural failure of more elements of a structure	Structural attachment	Secondary structural attachment	Non-structural attachment	Not used
F	Disproportionate collapse	Disproportionate collapse inevitable	Disproportionate collapse likely to occur	Disproportionate collapse unlikely to occur	No potential for disproportionate collapse to occur

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Table A8.3 ***Consequence: functionality score***

		Critical	High	Medium	Low
	Score	*10*	*3*	*1*	*0*
A	**Nature of route**	Any of the following: ▪ strategic road ▪ motorway ▪ trunk Road ▪ Network Rail route criticality band 1 or 2 ▪ mass transit urban railway ▪ commercial waterway.	Any of the following: ▪ a road/principal road ▪ city centre footpath ▪ cycle superhighway ▪ Network Rail route criticality band 3 or 4 ▪ freight only line ▪ leisure waterway.	Any of the following: ▪ B/C road ▪ urban commuter cycle path ▪ town centre footpath ▪ Network Rail route criticality band 5.	Any of the following: ▪ unclassified road ▪ accommodation road ▪ rural cycle path ▪ rural footpath/right of way/ bridleway ▪ other waterway.
B	**Diversion route**	Any of the following: ▪ no viable pedestrian or vehicular diversion route exists ▪ no alternative route exists for rail, waterway or utility ▪ rural diversion route >10 miles ▪ urban diversion route >5 miles ▪ pedestrian division route >1 mile.	Any of the following: ▪ one alternative rail, waterway or utility route exists ▪ rural diversion route >5 miles and ≤10 miles ▪ urban diversion route >2 miles and ≤5 miles ▪ pedestrian diversion route >0.5 miles and ≤1 mile.	Any of the following: ▪ multiple alternative rail, waterway or utility routes exist ▪ rural diversion route >1 miles and ≤5 miles ▪ urban diversion route >0.5 miles and ≤2 miles ▪ pedestrian diversion route >0.25 miles and ≤0.5 miles.	Any of the following: ▪ rural diversion route ≤1 mile ▪ urban diversion route ≤0.5 miles ▪ pedestrian diversion route ≤0.25 miles.
C	**Volume of traffic**	Very high traffic flow	High traffic flow	Low traffic flow	Very low traffic flow
D	**Length of time to restore normal network operation**	>1 month	>1 week and ≤1 month	>1 day and ≤1 week	≤1 day
E	**Political and reputational damage**	Very high	High	Low	Very low
F	**Financial impact**	Very high	High	Low	Very low

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Table A8.4 Consequence: environment score

		Critical	High	Medium	Low
Score		*10*	*3*	*1*	*0*
A	**Description**	Major pollution incident	Moderate pollution incident	Low pollution incident	No pollution

A8.1.4 Calculating the likelihood score

The total likelihood score is calculated by adding up the appropriate likelihood risk factor scores most appropriate to each fixing or family of fixings from each row. The total value will be a minimum of 7 and a maximum of 59.

Table A8.5 Likelihood score

Likelihood risk factor description	Likelihood risk factor score	Comments
Type approval		
Type approval certificate available (eg ETA)	-1	
No type approval certificate	5	
Inspection/observation records		
Comprehensive regular inspection records available	-1	
Inspection/observation records incomplete or infrequent	5	
Missing or distorted fixings		
All fixings present and undistorted	1	
Some fixings missing or distorted	5	
Vertically installed fixings		
None – verified	1	
Unknown or unverified	5	
Subject to tension	5	
Resin anchors		
Fixing verified as not being a resin anchor type	1	
Type of fixing not known	5	
Installed in brickwork	3	
Vertically installed overhead	3	
Low factor of safety	3	
Fixing subject to cyclic loading		
Yes	3	
No	1	
Accidental loading		
Potential	3	
No potential	1	
Design loading		
Known	1	
Unknown	5	
Subject to unanticipated loading	5	
Redundancy		
Low	3	
High	1	
Support system		
Determinate	1	
Indeterminate	3	
Environmental conditions		
Substrate dry	1	
Substrate subject to cyclic wetting and drying	3	
Substrate constantly wet or saturated	5	

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Likelihood risk factor description	Likelihood risk factor score	Comments
Remote monitoring		
Installed	-1	
Not installed	1	
Reserve capacity		
Low or unknown	3	
High	-1	
Condition of substrate		
No defects or deterioration	1	
Minor defects or deterioration	3	
Significant defects or deterioration	5	
Installer		
Recognised training/certification	1	
Untrained/not certified/unknown	3	
Total	***Maximum permissible = 59*** ***Minimum permissible = 7***	

A8.1.5 Description of safety consequence factors

The following safety consequence factors, which are discussed in the following sections, are used to determine the consequence score:

- potential for people to be killed or injured.
- potential for damage to vehicles.
- potential for damage to utilities and other public or private services.
- location of a fixing to the route.
- potential for a fixing failure to lead to structural failure of one or more elements of a structure.
- potential for disproportionate collapse.

A8.1.6 Potential for people to be killed or injured

The primary purpose of this guide is to ensure that fixings are managed to ensure the safety of the public and workforce using and maintaining the UKs transport infrastructure. It is imperative that safety is maintained at all times and that safety issues are identified and responded to as quickly as possible.

The potential to cause death or injury may come from a number of different sources, either as a direct or indirect consequence of the fixing falling. It may not always be immediately obvious what the impact of a fixing failure might be and the potential for injury may be overlooked. Examples of incidents that can lead to injury or loss of life are:

- a fixture falling or striking a person
- a fixture failing and causing damage to utility services resulting in injury to people eg burns, toxic fumes
- fixtures striking vehicles and causing injury to occupants
- drivers taking action to avoid an incident and striking pedestrians or other vehicles.

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The different degrees of consequence for personal safety are set out here:

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Potential for one or more people to be killed or seriously injured	Potential for slight injuries to five or more people	Potential for slight injuries to fewer than five people	No potential for injuries or other harm to health

Definitions (from DfT, 2013)

Killed	Human casualties who sustained injuries that caused death less than 30 days after the incident.
Serious injury	An injury for which a person is detailed in hospital as an 'in-patient', or any of the following injuries whether or not they are detained in hospital fractures, concussion, internal injuries, crushing, burns, severe cuts, severe general shock after the incident.
Slight injury	An injury of minor character such as a sprain (including neck whiplash injury), bruise or cut that is not thought to be severe or slight shock requiring roadside attention. This definition includes injuries not requiring medical treatment.

A8.1.7 The potential for damage to vehicles

In the event of an incident causing damage to vehicles the safety of its occupants and those in other vehicles near the incident may be compromised.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Potential for severe damage to one or more: ■ road vehicles ■ trains ■ floating vessels	Potential for minor damage to one or more: ■ road vehicles ■ trains ■ floating vessels	Potential for minor damage to a single ■ road vehicle ■ train ■ floating vessel	No damage sustained

Definitions

Vehicle	A road vehicle, train or floating vessel.
Road vehicle	Any motorised vehicle authorised for use on public roads.
Trains	Includes national and local rail passenger services, inter urban services, trams, freight trains, underground and metro services.
Floating vessel	Any vessel using waterways.
Waterways	A body of water and associated infrastructure that facilitates the movement of people and goods, including ports, harbours, locks, pontoons etc.
Severe damage	Damage sustained to a road vehicle, train or floating vessel that prevents it from being moved without assistance following the incident.
Minor damage	Damage sustained to a road vehicle, train or floating vessel that does not prevent it from being moved unaided from the scene of the incident.

A8.1.8 Potential damage to utilities and other public or private services

Public and private utilities are often attached to or suspended from transport infrastructure, particularly bridges. This usually involves a bracket that is fixed to the structure. This section is not intended to cover utilities that are buried within a structure, but does include utility services that are located and fixed within dedicated service bays, which form part of a bridge, tunnel or other structure.

It is often unclear from visual inspection alone what type of utility is present, who the owner is and the criticality of the utility service. It is also often unclear who is responsible for inspecting and maintaining the fixings holding the utility services in place and as a result have not been inspected for long periods of time. It is recommended that a utility search is undertaken and that the various utility companies are contacted and consulted as part of the risk ranking process and information gathering exercise.

The impact of a fixing failure may result in disruption to the service. The severity of the incident will be governed by the scale of the disruption and the length of time the service is disrupted for.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Potential for any of the following: ▪ disruption to one or more nationally and regionally-important utility services ▪ severe disruption to one or more locally important utility services ▪ moderate disruption to more than one locally-important utility service.	▪ severe disruption to a single locally-important utility service ▪ moderate disruption to one or more locally-important utility service ▪ severe disruption to other utility services.	▪ moderate disruption to a single locally-important utility service ▪ minor disruption to one or more locally-important utility services ▪ moderate disruption to one or more other utility services.	▪ disruption to nationally and regionally or locally-important utility services ▪ minor disruption to one or more other utility service.

Definitions

Utility service	Any pipe, cable transmission station and associated supports or other infrastructure providing or supporting the provision of fuel, water, electricity, communications, sewerage etc.
Nationally and regionally important utility service	Any utility service that if interrupted has the potential to cause disruption on a regional or national scale, eg National Grid.
Locally important utility service	Any utility service that if interrupted has the potential to cause disruption to local communities, eg small town and villages.
Other utility service	Any utility service not considered as nationally or locally important, eg connecting supplies to small communities, single supplies to premises.
Severe disruption	When the utility service is unavailable for three or more consecutive days.
Moderate disruption	When the utility service is unavailable for more than 24 hours and less than three days.
Minor disruption	When a utility service is unavailable for less than 24 hours.

A8.1.9 Location of a fixing to a route

Where a fixing and fixture are located near to a trafficked route will have a direct impact on the safety of those using the route should the fixing fail. A fixture directly above a route is likely to have a more severe consequence of failure than one located several metres away. When considering the impact of a fixing failure the assessor should examinbe the potential for a fixture to move away from its original location and fall directly on the route as the fixing fails.

The nature of the route will also have an effect on the potential consequence of failure. Busier and more frequently-used routes have a higher potential for injury to occur.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Any of the following: ▪ directly above any carriageway, railway line or waterway ▪ directly above any high use footpath, cycle way or other public access area.	Any of the following: ▪ near to any carriageway, railway line or waterway ▪ directly above any medium use footpath cycle path or other public access area ▪ directly above any high use maintenance access area.	Any of the following: ▪ directly above any low use footpath or cycle path or other public access area ▪ near to any low use footpath or cycle path or other public access area ▪ near to any medium use maintenance access area.	Any of the following: ▪ remote from any route ▪ near to any low use maintenance access area.

Definitions

Route	Any area designated as carriageway, railway line, footpath, cycle path, waterway and other public access areas or provided for maintenance access.
Carriageway	The part of a road where vehicles normally run, including hard shoulders, laybys, rest areas etc.
Railway line	The tracks, cess and 4 ft, 6 ft, tunnels and other areas that are required for the normal running of trains, trams etc.
Footpath	Any route primarily intended for the use of pedestrians and other non-motorised users except cyclists, including bridleways and tow paths.
Cycle path	Any route primarily intended for the use of cyclists.

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Other public access area	Any area that is generally open to public access, eg public squares and piazzas, sports pitches, stations.
Maintenance access	Any area provided for those undertaking inspection, repair and maintenance activities and not accessible by the public.
Directly above	Where a fixing or fixture is located directly above a carriageway, railway line, footpath or cycle path or within two metres of the edge of a carriageway, railway line, footpath or cycle path and has the potential to fall into these areas should the fixing fail.
	Near to where a fixture or fixing is located between two and five metres from the edge of a carriageway, railway line, footpath or cycleway.
Remote	Where a fixture or fixing is located more than five metres from the edge of a carriageway, railway line, footpath or cycleway etc.

A8.1.10 Potential for fixing failure to lead to failure of one or more elements of a structure

Fixings that provide fixity for structural elements of infrastructure are more likely to cause danger and disruption in the event of failure. For example, the failure of fixings attaching a main structural member of a bridge could cause collapse.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Structural attachment	Secondary structural attachment	Non-structural attachment	Not used

Definitions

Structural attachment	Provides fixity for a primary structural member.
Secondary structural	Provides fixity for a secondary structural member.
Non-structural member	Provides fixity for a non-structural member.

A8.1.11 Potential for disproportionate collapse

Disproportionate or progressive collapse occurs when additional fixings fail because of an incident affecting a single or small number of initial fixings. For example if a single fixing attaching lighting fixtures in a tunnel fails and the nearby fixings become overloaded and fail, the lighting system will progressively collapse. Often a large amount of information is required to accurately assess whether disproportionate collapse is likely. In the absence of further information, where a large fixture is held by a large number of fixings and the failure of one fixing will increase the load one of the other fixings disproportionate collapse should be considered likely.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Disproportionate collapse inevitable	Disproportionate collapse likely to occur	Disproportionate collapse unlikely to occur	No potential for disproportionate collapse to occur

Definitions

Disproportionate collapse	In the event of damage to a structure or part of a structure the resultant collapse is disproportionate to the original cause

A8.1.12 Functionality consequence factors

The functionality score reflects the impact of a fixing failure on the ability of a transport network to continue to perform as originally intended. A fixing failure may have a direct or indirect impact on the functionality of a network.

A direct impact could be where the failure of a fixing allows a fixture to fall onto the network preventing the flow of traffic. An indirect impact could be where the failure of a fixing results in a loss operation of a fixture that prevents the safe operation of a network, eg the loss of a signal or CCTV camera.

If a piece of infrastructure is restricted in use either fully (closure) or partially (eg lane closure) then it is no longer functioning as originally intended. The impact on those using the network will vary depending on whether there is an alternative route and the time it takes to rectify the defect either permanently or temporarily.

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The transport operator may incur adverse publicity because of the incident, which may affect their reputation. Financial losses may also be incurred either as a direct result of revenue, eg reduced ticket sales or compensation payments. Indirect financial impacts may be incurred because of loss of business in the local or wider community.

The following functionality consequence factors are used to determine the risk ranking score:

- importance and/or nature of the route
- traffic volume
- traffic/line speed
- availability of a diversion route
- length of time required to restore normal network operation
- political and reputational damage
- financial impact.

A8.1.13 Importance and/or nature of a route

The strategic importance of a route is an important consideration when assessing the functionality impact of a fixing failure. More strategically-important routes are often heavily trafficked so the consequence of them being unavailable for full use is greater. The nature and importance of a route takes into account the potential effect on the local, regional and national scale.

	Critical	**High**	**Medium**	**Low**
Score	*10*	*3*	*1*	*0*
Description	Any of the following: ■ strategic road ■ motorway ■ trunk road ■ Network Rail route criticality band 1 or 2 ■ mass transit urban railway ■ commercial waterway.	Any of the following: ■ a road/principal road ■ city centre footpath ■ cycle superhighway ■ Network Rail route criticality band 3 or 4 ■ freight only line ■ leisure waterway.	Any of the following: ■ B/C road ■ urban commuter cycle path ■ town centre footpath ■ Network Rail route criticality band 5.	Any of the following: ■ unclassified road ■ accommodation road ■ rural cycle path ■ rural footpath/right of way/bridleway ■ other waterway.

Definitions

Road	Strategic route network/motorway/trunk road, 'A' road/principal road, 'B' road, 'C' road, unclassified or accommodation road, footpath/public right of way.
Railway (excluding Network Rail)	Mass transit urban railway (eg London Underground, Docklands light railway, metro railways, trams), freight-only line (ie rail routes that primarily or only carry freight traffic), leisure line (eg heritage lines).
Railway (Network Rail)	Route criticality is defined as the structures route criticality band as set out in.
Footpath/public right of way	City centre footpath, town centre footpath, rural right of way/bridleway.
Cycleway/cycle path	Cycle superhighway, urban commuter cycle path, rural cycle path.
Waterway	Commercial waterway, leisure waterway, other waterway.

Traffic volume

The greater the volume of traffic, the higher the effect on the movement of people and goods, and the effect on the local, regional and national economy. In extreme cases this may also have international impacts where airports, ports or international rail is affected.

	Critical	**High**	**Medium**	**Low**
Score	*10*	*3*	*1*	*0*
Description	Very high traffic flow	High traffic flow	Low traffic flow	Very low traffic flow

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Definitions

- Very high traffic flow:
  - highway: >70,000 vehicles/day
  - Network Rail: >6 trains/hour
  - mass transit urban rail: >10 trains/hour
  - commercial waterway: >10 vessels/hour
  - leisure waterway: >20 vessels/hour
- High traffic flow:
  - highway: >20,000 and ≤70,000 vehicles/day
  - Network Rail: >3 and ≤6 trains/hour
  - mass transit urban rail: >5 and ≤10 trains/hour
  - commercial waterway: >5 and ≤10 vessels/hour
  - leisure waterway: >10 and ≤20 vessels/hour
- Low traffic flow:
  - highway: >5,000 and ≤20,000 vehicles/day
  - Network Rail: >1 and ≤3 trains/hour
  - mass transit urban rail: >2 and ≤5 trains/hour
  - commercial waterway: >2 and ≤5 vessels/hour
  - leisure waterway: >5 and ≤10 vessels/hour
- Very low traffic flow:
  - highway: ≤5,000 vehicles/day
  - Network Rail: ≤2 trains/hour
  - mass transit urban rail: ≤5 trains/hour
  - commercial waterway: ≤5 vessels/hour
  - leisure waterway: ≤10 vessels/hour

Diversion route availability

The availability of a suitable diversion route will affect the criticality of a fixing. The impact of the failure of a fixing on a route where there is no alternative diversion route is greater than where one can be provided. The length of the diversion route and the nature of the mode of transport being diverted is also an important consideration. The length of diversion route for pedestrians is often more critical than for other forms of transport. If the diversion route is too long it may encourage pedestrians to take unnecessary risks, for example crossing busy roads rather than taking a longer safer route.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Any of the following: ■ no viable pedestrian or vehicular diversion route exists ■ no alternative route exists for rail, waterway or utility ■ rural diversion route >10 miles ■ urban diversion route >5 miles ■ pedestrian division route >1 mile	Any of the following: ■ one alternative rail, waterway or utility route exists ■ rural diversion route >5 miles and ≤10 miles ■ urban diversion route >2 miles and ≤5 miles ■ pedestrian diversion route >0.5 miles and ≤1 mile	Any of the following: ■ multiple alternative rail, waterway or utility routes exist ■ rural diversion route >1 miles and ≤5 miles ■ urban diversion route >0.5 miles and ≤2 miles ■ pedestrian diversion route >0.25 miles and ≤0.5 miles	Any of the following: ■ rural diversion route ≤1 mile ■ urban diversion route ≤0.5 miles ■ pedestrian diversion route ≤0.25 miles

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Definitions

- Modes of transport to be diverted:
  - road vehicles only
  - buses/coaches
  - cyclists
  - pedestrians
- Road vehicle diversion route:
  - no viable diversion route
  - rural diversion route – does not include part of the route in a city or town:
    - >10 miles
    - >5 miles and ≤10 miles
    - >1 mile and ≤5 miles
    - ≤1 mile
  - urban diversion route – part of a route includes a city or town:
    - >5 miles
    - >2 miles and ≤5 miles
    - >0.5 miles and ≤2 miles
    - ≤0.5 miles
  - pedestrian diversion route:
    - no viable diversion route
    - >1 mile
    - >0.5 miles and ≤1 mile
    - >0.25 miles and ≤0.5 miles
    - ≤0.25 miles
  - rail and waterway diversion route:
    - alternative available
    - no alternative available
  - utility diversion route:
    - alternative available
    - no alternative available

Time required to restore normal network operation

The amount of time taken to restore a network to normal operation following an incident is a key consideration. This is not necessarily the time taken to affect a permanent repair, but is often the time taken to put in place an interim or temporary solution that allows normal operation during peak times. Permanent repairs can then be undertaken during off peak or less busy times to reduce disruption. Factors that may affect the ability to return a network to normal operation include:

- investigating an incident and make safe
- completing a temporary repair
- completing permanent repairs
- clearing a backlog on the network, eg congestion.

	Critical	**High**	**Medium**	**Low**
Score	***10***	***3***	***1***	***0***
Description	>1 month	>1 week and ≤1 month	>1 day and ≤1 week	≤1 day

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Political and reputational damage

Political and reputational damage to an organisation and individuals can occur because of an incident causing:

- death or injury
- transport network being unavailable for use or severely restricted
- pollution.

Often this results in adverse publicity and is usually directly related to the severity of the incident and the number of people affected. An incident resulting in local media coverage may be tolerated whereas an incident resulting in national media coverage may be considered unacceptable. So, the criticality of a fixing is related to the scale of any media coverage. Although for local highway authorities extensive local media coverage may be considered critical to them.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Very high	High	Low	Very low

Definitions

Very high	National media coverage
High	Regional media coverage
Low	Local media coverage
Very low	No media coverage

Financial impact

The tolerance to financial loss because of an incident involving the failure of a fixing will vary between organisations. It is recommended that each organisation sets its own financial impact limits as shown in the table. In doing so the following should be considered:

- direct financial impact on an asset owner including:
  - loss of revenue
  - compensation costs to network users
  - costs of repair
  - third-party claims
- consequential or indirect financial impacts including:
  - road user delay costs
  - financial impact on local, regional or national economy.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Very high	High	Low	Very low

Environmental consequence factors

The main environmental consideration is whether an incident results in pollution, the impact it has on the surrounding area and the extent of the pollution radiating from the incident.

	Critical	High	Medium	Low
Score	*10*	*3*	*1*	*0*
Description	Major incident	Moderate incident	Low incident	None

Definitions

Major incident:

- widespread pollution to major watercourses

- affects fisheries or other commercial activities
- results in evacuation of premises located off site
- requires removal of contaminated land and or other material
- affects neighbouring land owners/occupiers.

Moderate incident:

- high volume of contaminant contained within the boundaries of the site, eg within holding tanks
- results in evacuation of the on-site premises only
- does not affect neighbouring land owners/occupiers.

Low incident:

- localised incident that can be dealt with by a one or two man crew
- does not result in contamination of watercourses or land.

Example using the consequence score tables

A consequence score is determined for each line in the following table by determining the description that best fits the situation presented by a fixing or group of fixings. A consequence score shall only be one of the following 10, 3, 1 or 0. No other scores are permitted.

Table A8.6 ***Safety score***

		Critical	High	Medium	Low
	Score	*10*	*3*	*1*	*0*
A	Number of people killed or seriously injured	Potential for one or more people to be killed or seriously injured	Potential for slight injuries to five or more people	Potential for slight injuries to fewer than five people	No potential for injuries or other harm to health
B	Potential damage vehicles	Potential for severe damage to one or more: ■ road vehicles ■ trains ■ floating vessels.	Potential for minor damage to one or more: ■ road vehicles ■ trains ■ floating vessels.	Potential for minor damage to a single: ■ road vehicle ■ train ■ floating vessel.	No damage sustained
C	Potential damage to utilities and other public or private services	Any of the following: ■ potential for any disruption to one or more nationally and regionally-important utility service ■ potential for severe disruption to one or more locally-important utility service ■ potential for moderate disruption to more than one locally-important utility service	Any of the following: ■ potential for severe disruption to a single locally-important utility service ■ potential for moderate disruption to one or more locally important utility service ■ potential for severe disruption to other utility service	Any of the following: ■ potential for moderate disruption to a single locally-important utility service ■ potential for minor disruption to one or more locally-important utility services ■ potential for moderate disruption to one or more other utility services	Any of the following: ■ no potential for disruption to nationally and regionally or locally-important utility services ■ potential for minor disruption to one or more other utility service
D	Proximity to route	Any of the following: ■ directly above any carriageway, railway line or waterway ■ directly above any high use footpath, cycle way or other public access area	Any of the following: ■ near to any carriageway, railway line or waterway ■ directly above any medium use footpath cycle path or other public access area ■ directly above any high use maintenance access area	Any of the following: ■ directly above any low use footpath or cycle path or other public access area ■ near to any low use footpath or cycle path or other public access area ■ near to any medium use maintenance access area	Any of the following: ■ remote from any route ■ near to any low use maintenance access area

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		Critical	High	Medium	Low
	Score	*10*	*3*	*1*	*0*
E	Potential for fixing failure to lead to structural failure of more elements of a structure	Structural attachment	Secondary structural attachment	Non-structural attachment	Not used
F	Disproportionate collapse	Disproportionate collapse inevitable	Disproportionate collapse likely to occur	Disproportionate collapse unlikely to occur	No potential for disproportionate collapse to occur

In this instance the safety score will be:

Line ref	Score
A	10
B	1
C	3
D	10
E	3
F	1
Total	***28***

T the $\sum$ safety scores = 28

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Fixings are widely used in construction and include those that are safety-critical and non safety-critical. The body of case studies in this guide provides evidence that incorrect performance of safety-critical fixings can contribute to structural failures, including several high-profile fatal accidents. This guide aims to improve the management of safety-critical fixings and to highlight how good design and installation can minimise risks in-service. Recommendations are made on the management process for existing fixings including cyclical stages of risk review, work planning and work implementation, and risk factors are identified. Recommendations are also made that complement existing industry standards and guidance for new design and installation, to facilitate effective future management of new fixings. This guide is aimed at competent practitioners responsible for the management of assets and those involved in design of structures and fixings.

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