Management of safety critical structural fixings

16th January 2018

Bridge Owners Forum

Santosh Sansoa and Neil Loudon

Management of safety critical fixings

Background

- Bridges Board/Bridge Owners Forum task – ‘grand challenges’
- Agreed that this was an area where there was evidence of fixing failures in service and apparently very little guidance available, and few indications of how bridge owners were managing these assets and their risks
- New Civil Engineer survey of fixings

INDUSTRY FEARS OVER FIXINGS

A recent NCE survey revealed 21% of respondents have expressed doubts that chemical fixings are being properly installed on site. **Ben Cronin** reports.

An alarming number of engineers and contractors have a lack of confidence that chemical anchors are being properly installed on construction projects.

Over 7% of the 1,309 engineers, contractors and sub-contractors who completed a survey in *NCE* said they were 'not at all' confident while a further 14% said they were "slightly confident" that chemical fixings are being correctly installed on site.

The purpose of the *NCE* survey, posted in June, was to establish the levels of knowledge about the selection and installation of fixings.

Correct chemical anchor installation is particularly pertinent in light of recent anchor failures which have resulted in fatalities, including lining failures in the Boston Big Dig Tunnel (2006) and Japan's Sasago Tunnel in 2012.

Eighty two per cent of those who responded to the survey described themselves as either a contractor, subcontractor, consultant or designer. In total, 86% described themselves as influencing the design and selection of fixings to varying degrees.

Alastair Soane, director of Structural Safety, an organisation which collects confidential data on the concerns of structural and civil engineers, welcomed the survey as an important step in recognising the safety critical aspects of chemical anchor systems. He said it gave the impression that fixture failures have been experienced by those who responded to the survey.

"Most respondents very often or often consider fixings to be safety critical [84%] but most are not confident that they are properly installed on site [55%]," he said.

Levels of awareness about BS 8539:2012, the code of practice for the selection and installation of post-installed anchors in concrete and masonry, were also surprisingly low. This seemed to be the case across the data set. 38% of those surveyed said they had not heard of the standard while 28% said they were "not sure" if they were aware of the standard.

Soane said that best practice is to work to BS 8539 and select fixings with a European Technical Approval (ETA).

"The British Standard is becoming increasingly well-known and its influence is valuable in helping to reduce failures," he said. He added that another vital aspect was to follow manufacturers' recommendations for installation.

There was more agreement when it came to a question about the most critical step in the installation of chemical fixings. 80% of those surveyed said that properly cleaning the hole before attaching the fixing was paramount.

This was corroborated by a selection of comments provided by those surveyed.

Capita structural engineer Carl Bebbington said: "I think it would be a very good idea to educate engineers on how critical the installation is [by] showing the difference in capacity if say the hole was not adequately cleaned prior to chemical anchor installation."

"The biggest cause of failure I have experienced with chemical anchors has been due to insufficient depth of drilling and poor hole cleanliness," said Costain square works manager Andy Parkin.

Laing O'Rourke temporary works manager Robert Garford-Tull suggested: "New technology to address issues with cleaning holes. Hollow drill bits and tapered anchors help".

Other engineers said there was a danger that main contractors were not taking chemical fixing installation seriously enough. "[It is] critical to ensure that 'as designed' fixings are installed, as often contractors will utilise cheaper alternatives without necessarily requesting designer approval," said Ramboll senior structural engineer James Drew.

Kier site manager Ed Dwight explained that anchor design, selection and installation "is often an interface item that becomes [the] subcontractor's designed portion."

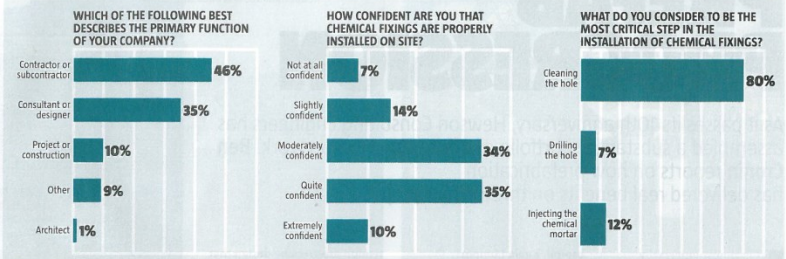
He argued that principal contractors "have to ensure it is designed and managed correctly".

■ **Download complete survey results at http://bit.ly/1Uwxqj8**

Fixings: Hole cleanliness is paramount for successful installation

"We need new technology to address issues with cleaning holes. Hollow drill bits and tapered anchors help""
Robert Galliford-Tull, Laing O'Rourke

INDUSTRY REACTION



THE INDUSTRY SPEAKS

"The confidence in the selection, design and installation as a designer is influenced by the confidence in the contractor to carry out the manufacturer's instructions correctly"

Rob Paul associate, WSP Parsons Brinckerhoff

"When using subcontractors to perform the works it is essential that they are supervised correctly by a competent individual"

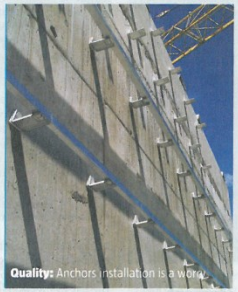
Paul Hutton section engineer, Costain

"It is critical to ensure that 'as designed' fixings are installed, as often contractors will utilise cheaper alternatives without necessarily requesting designer approval"

James Drew senior structural engineer, Ramboll

"Contractors often wish to use other fixings than those specified which may be inferior for the planned use although they consider them 'similar'. Often without designer knowledge, installation quality is a concern"

Ross Hampton project engineer, Skanska



Quality: Anchors installation is a worry

"Not all subcontractors have sufficient design experience capability in preparing calculations and preparing relevant shop drawings to consulting engineers or building control authorities for approval"

Paul Perry associate director, Sir William Halcrow and Partners

"Interim advice notes and specification appendices need to be written to better suit site construction"

Gordon Wright senior principal engineer, Jacobs

"My general experience is that main contractors, subcontractors and their operatives do not fully appreciate the safety critical function of the fixings and the importance of strictly adhering to the manufacturer's instructions"

Barry McAuliffe senior engineer, Consibee

"Most of my projects the contractors self-certify, so I have no control over site works. I know that if not applied correctly or if the design is changed onsite they are likely to fail and this has been a concern to me"

Neil Gwynne principal engineer, Jacobs

Safety critical structural fixings

- Design issues – some guidance available
- Installation issues – some guidance available
- In-service issues – very little guidance available

Boston Tunnel - 2006

On 10 July 2006 precast concrete ceiling panels fixed with resin anchors collapsed, one person killed

Investigation by US National Transportation Safety Board concluded that the cause of the failure was excessive creep in the epoxy adhesive under sustained tensile loading

Boston Tunnel - 2006

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Safety critical structural fixings

- **SCOSS Headlines**
- ‘Failure of epoxy fixings due to high temperature’
- ‘Collapse of recently installed suspended ceiling’
- ‘Glass panel fixings failure’
- ‘Ceiling failure’
- Etc.

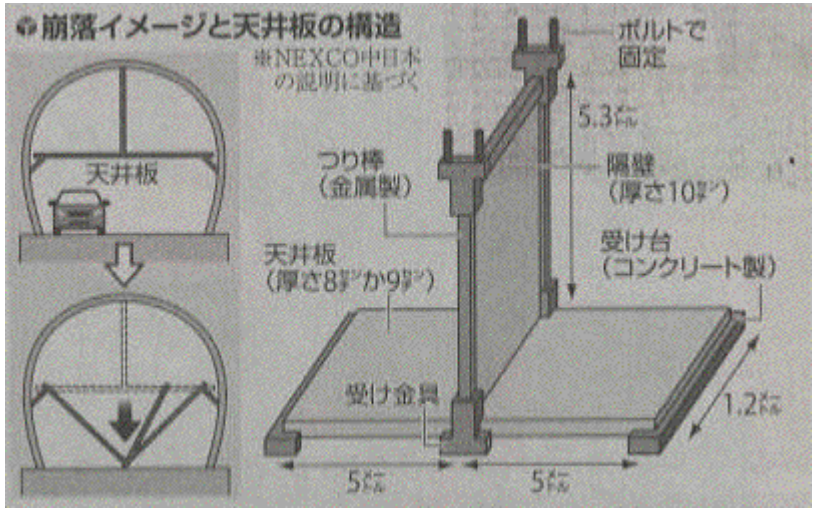
Safety critical structural fixings

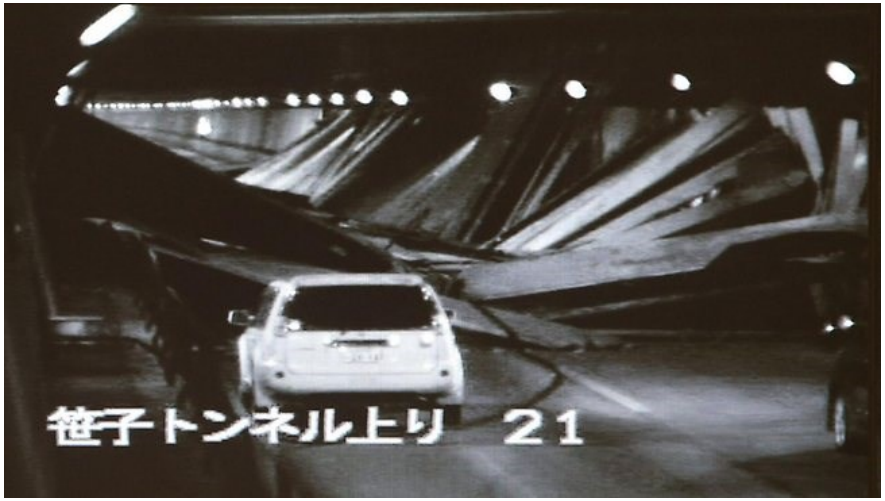
Japanese tunnel collapse – 2nd December 2012

- On 2nd December 2012 Japan's Sasago Tunnel experienced a catastrophic collapse of its ventilation 'false' concrete panel ceiling over a length of 110m on Sunday, killing nine motorists.
- The Executive Officer of the tunnel operator company said that it appeared some 'anchor bolts' used to secure the concrete slabs to the tunnel roof were missing.
- There were parts of concrete where bolts had fallen off. The aging of the bolts or the concrete slabs could be a potential cause.

Safety critical structural fixings

Sasago Tunnel Collapse 2012





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Safety critical structural fixings

Balcombe Railway Tunnel UK - 2011

- On the 23rd September 2011 part of a large steel structure mounted in the roof of the Balcombe Rail Tunnel, spanning over both railway tracks, was sagging down on one side of the structure, three supports had become detached from the tunnel lining leaving a 12 metre length partially supported.
- The structure, one of six within the tunnel, was intended to catch water dripping from the tunnel roof.
- It was supported by anchor studs fixed with resin into holes drilled in the tunnel's brick lining.
- The Rail Accident Investigation Branch (RAIB) found the resin appeared to have degraded over time; there was insufficient resin around some fixings on installation.

Safety critical structural fixings

Balcombe Railway Bridge - 2011

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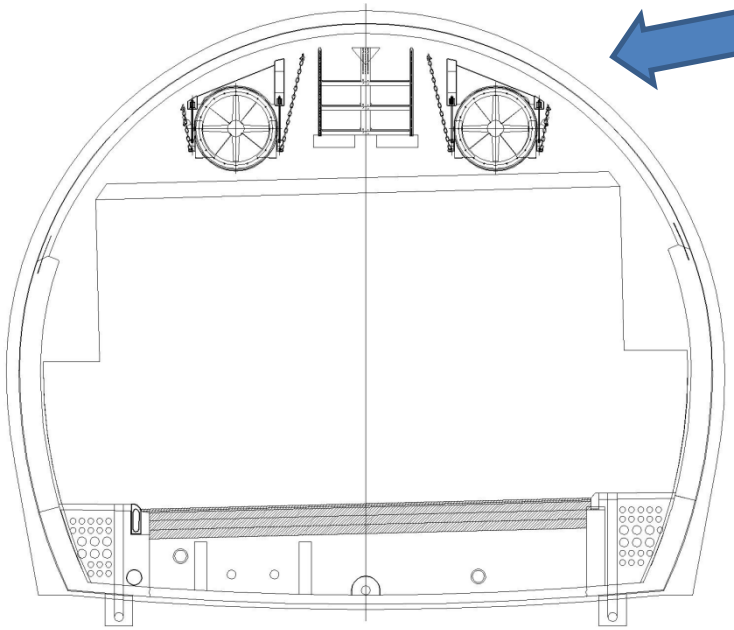
Safety critical structural fixings



Safety critical structural fixings

Less critical structural fixings

Issues

Departure granted – compliance with conditions in departure?
Extant ETA?
Installed correctly?
Designed for cyclic and buffeting loads?
Tested for cyclic and buffeting loads?

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Safety critical structural fixings

Issues and questions

- Are our design rules robust?
- Compatibility with Europe?
- Do we know where we have used fixings?
- Do we have materials and test records?
- Extra functionality in asset information systems?
- Do we inspect or test safety critical fixings in-service?
- Particular problems – tunnel panels and equipment, cladding, signage?
- Do we need a National Structures Programmes for safety critical fixings?
- Code of Practice/Guidance/Standards

Collaborative BOF task

- Project management – Santosh Sansoa and Neil Loudon
- Brief – drafted by HE, circulated to bridge owners, changes incorporated
- Procurement – by HE on behalf of BOF
- Let to WSP/PB
- Overseen by Steering Group
- Start date – mid November 2015
- Industry workshop held at start of task
- Completion of report end of 2017 (last Steering Group held December for sign-off)
- Liaison with CIRIA – similar related work of less critical fixings in buildings and other facilities
- CIRIA publication route – Summer 2018 launch and publication

BOF
Bridge Owners' Forum

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Collaborative funding

- DfT
- Transport Infrastructure Ireland
- Transport Scotland
- Welsh Government
- Transport Northern Ireland
- Network Rail
- Highways England

- Collaborative approach for all bridge owners in Ireland and the UK

Safety critical structural fixings

Records, planning, competence!!

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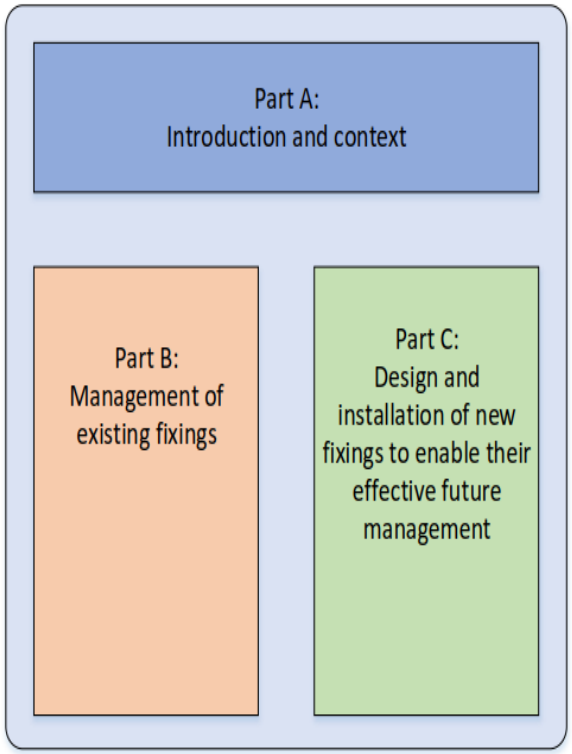
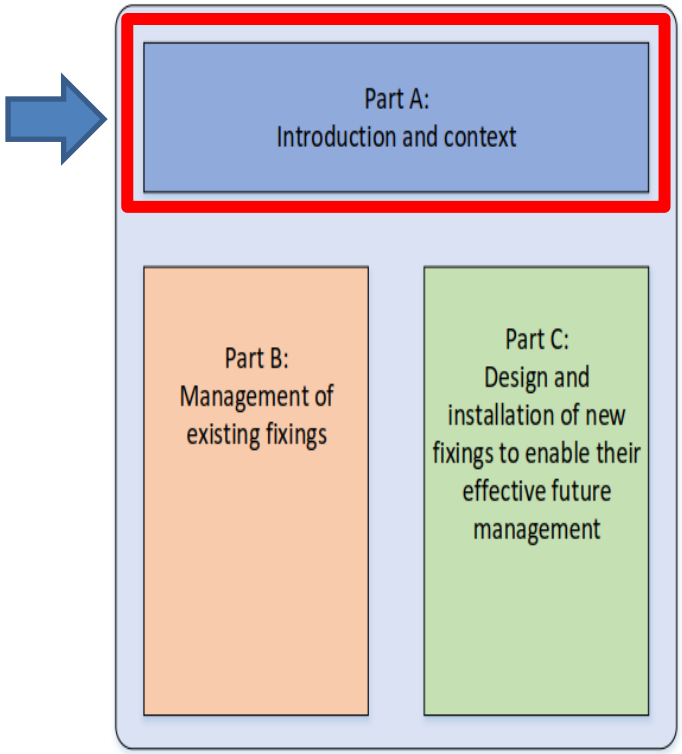
Structure of the report

3 parts:



Part A - introduction



Safety critical application

Application in which the failure of a fixing can:

a. result in collapse or partial collapse of the structure; and/or
b. cause risk to human life; and/or
c. lead to significant economic loss (including disproportionate loss of function or availability of elements of the transport network)

Aims of the guidance

- to provide nationally applicable guidance
- cover the management of safety-critical fixings
- how activities at other lifecycle stages, including the design of fixings, influence these management activities
- aimed at competent practitioners responsible for the management of assets

Scope

- Primarily intended for transport infrastructure (but can be applied to other asset types)
- Safety critical applications
  - These include vehicle restraint systems and temporary applications
- Post-installed anchors using resin or cement based grouted systems and mechanical fixing systems, installed into concrete and masonry substrates

- Not covered:
  - Rock bolts;
  - Cast-in fixings;
  - Fall-arrest systems;
  - Structural connections, such as bolts and welds.

Examples of types of fixing

Tunnel ventilation and information systems

Gantry attached to bridge parapet

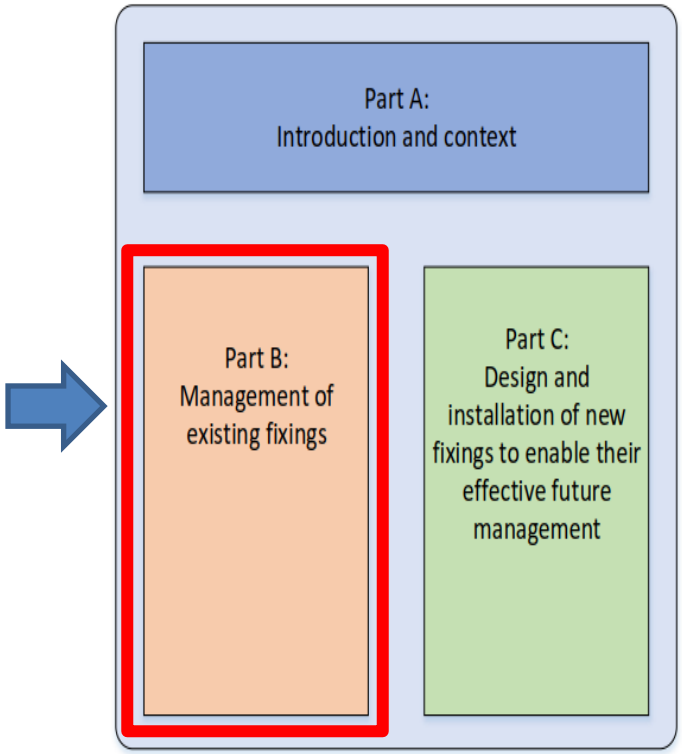
Cladding system in underpass

Utility suspended from bridge deck

Post-installed parapet fixing

Sign fixed to bridge

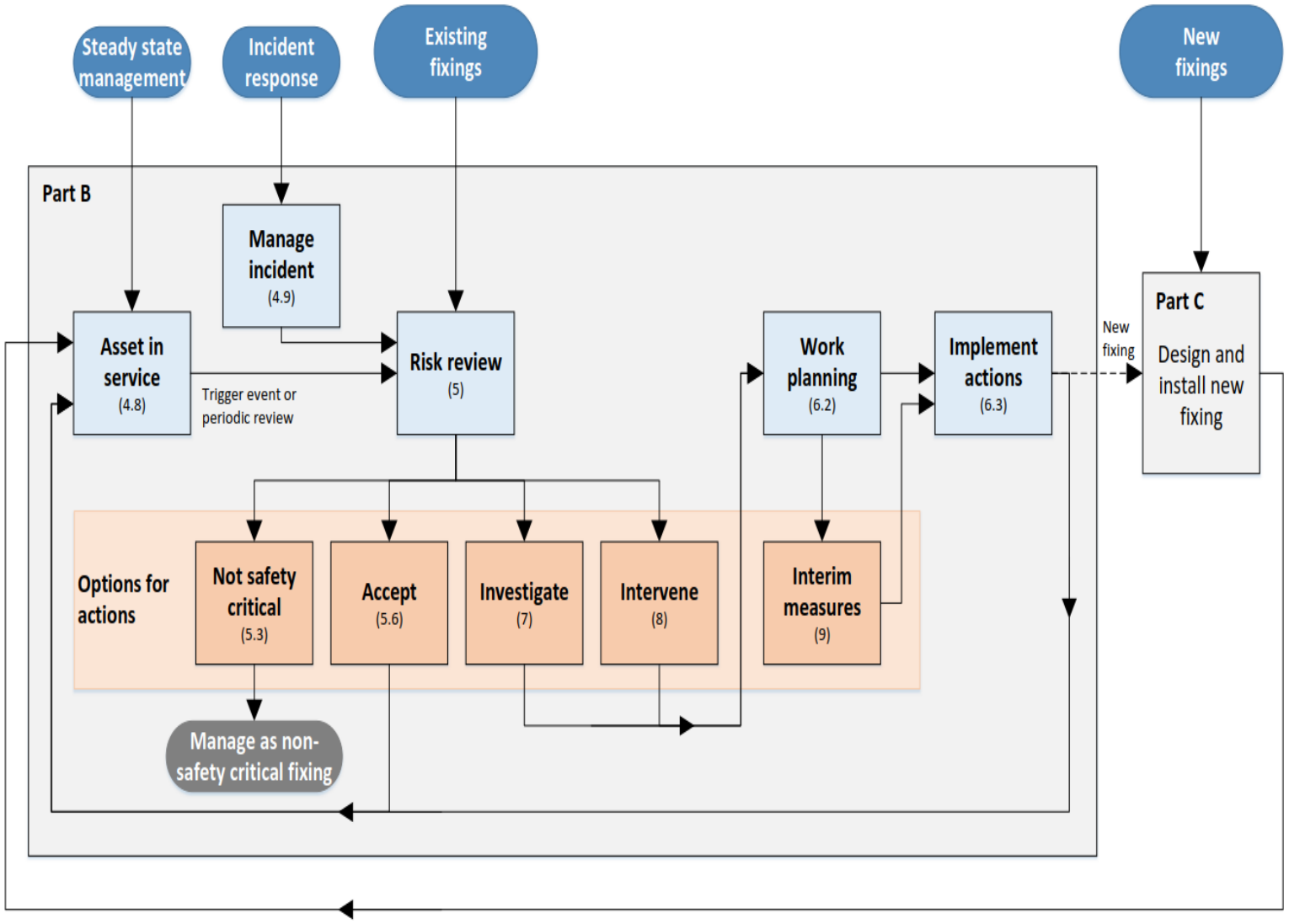
Part B – Management of existing fixings



Management of existing fixings – (selected) key concepts

5. Decision making on the adequacy of installed fixings should be **risk based**, considering the consequence and likelihood of failure.
7. Prior to 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. As a result it will sometimes 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 an acceptable level.
10. If the time required to undertake further investigation or an intervention will pose an unacceptable level of risk, **interim measures** should be implemented.

Management of existing fixings



Figures in brackets provide references to relevant sections of the text

Recommendations for implementation

	Recommendation	Refer to report sections
1.	Asset owners should produce an implementation plan including defined timescales	4.6
2.	Management responsibility for fixings should be defined	4.6, 4.6.2
3.	An initial risk assessment should be undertaken to establish the overall level of risk presented by safety critical fixings and identify priority actions	4.6, 5
4.	Basic inventory information about the number and location of fixings should be captured as a priority	4.6, 5.2
5.	Asset owner policies and processes should be updated to include requirements for managing safety critical fixings	4.6
6.	An asset information system which is capable of storing and retrieving adequate information about safety critical fixings should be established	4.6, 10.2
7.	Relevant staff and suppliers should be briefed on need for and approach to managing safety critical fixings	4.6

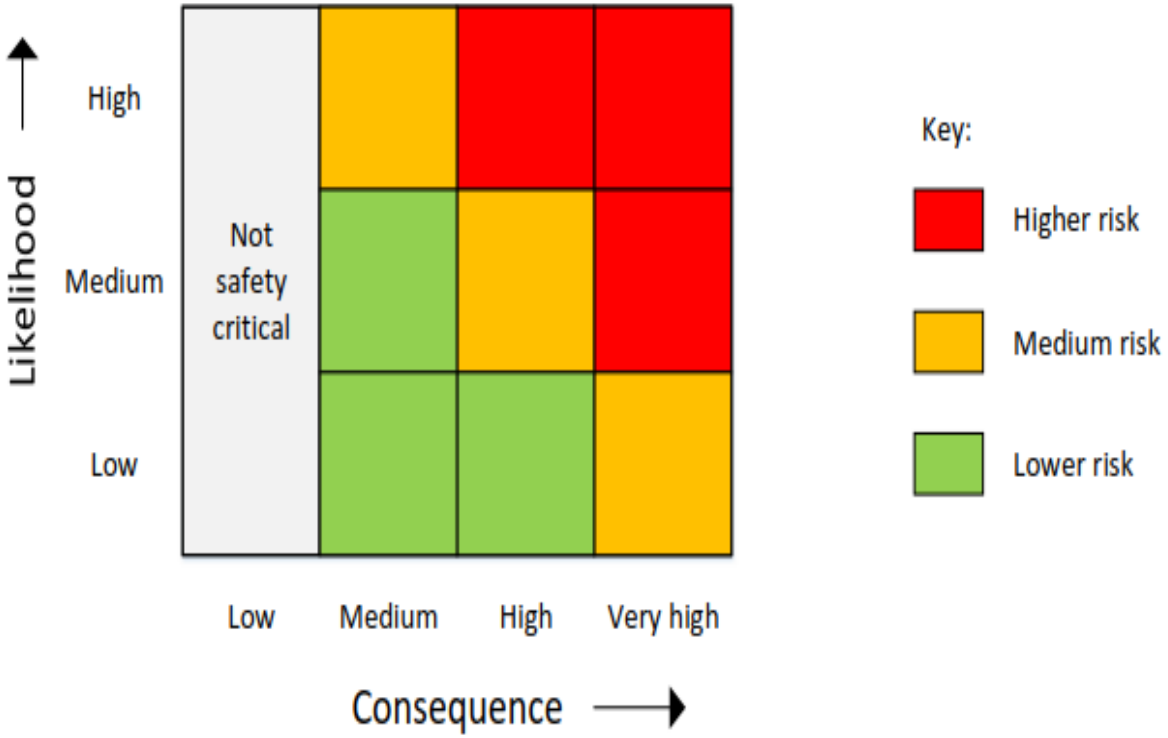
Recommendations for fixings in service

	Recommendation	Refer to report sections
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
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

Screening

	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? i. Road ii. Railway iii. Commercial waterway iv. A principal pedestrian access to a building or facility v. 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

Risk review


Likelihood
High
Medium
Low
Not safety critical
Low
Medium
High
Very high
Consequence
Key:
Higher risk
Medium risk
Lower risk

Risk factors (1)

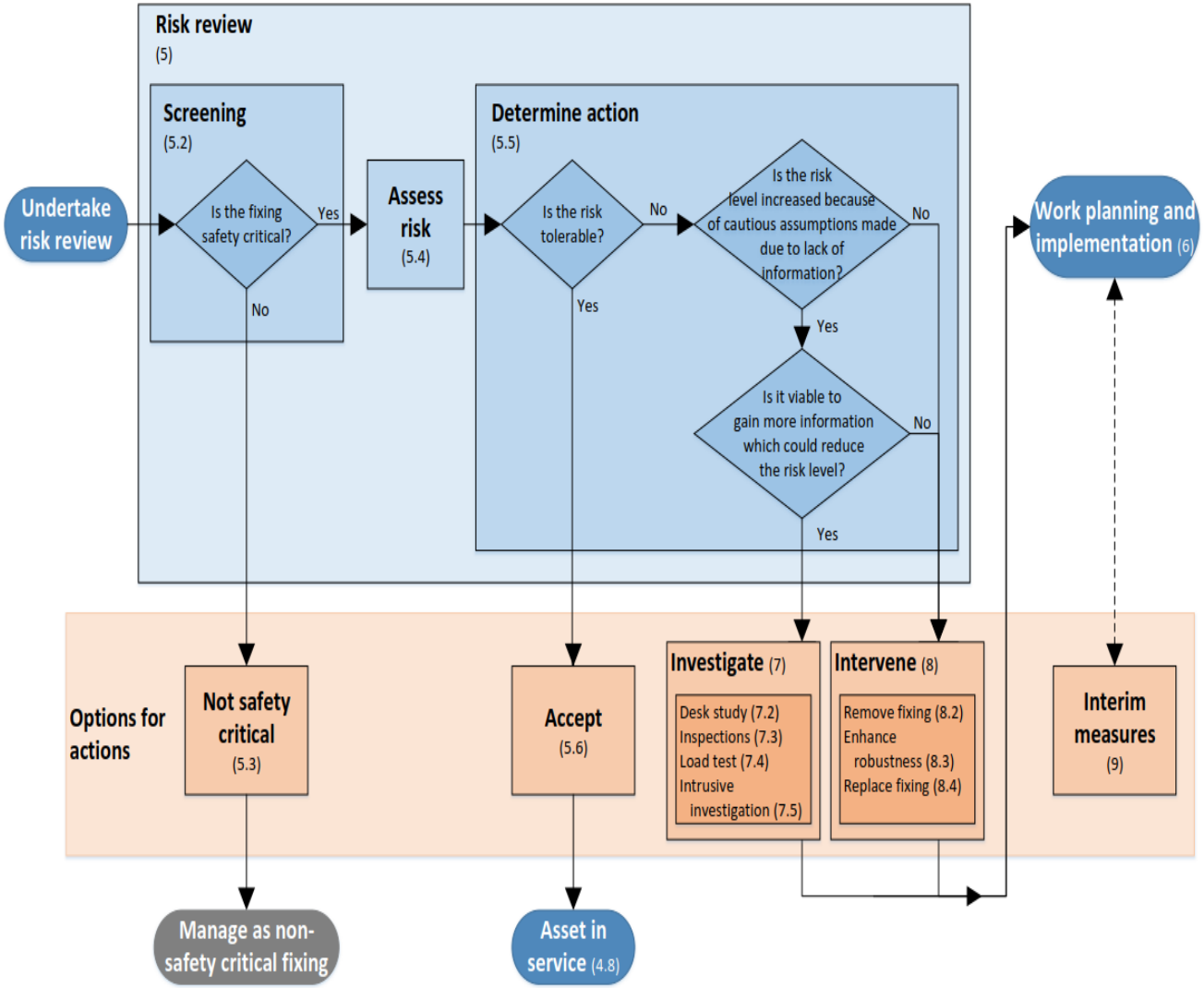
	Risk factor	Increase / decrease likelihood	Type of fixing
Design	Formal technical approval (e.g. ETA) which covers applicable actions	Decrease	All
Installation	Poor quality of installation	Increase	All / resin anchor
	Overhead installation	Increase	Resin anchor
	Substitution	Increase	All
	Certification of installation	Decrease	All
Actions	Shear rather than tension	Decrease	All
	Sustained tension	Increase	Resin anchor
	Cyclic loading	Increase	All
	Vibrations	Increase	All / mechanical anchor
	Accidental / shock load	Increase	All
	Change in fixture / change in use	Increase	All

Further guidance on all risk factors provided in Appendix E

Risk factors (2)

	Risk factor	Increase / decrease likelihood	Type of fixing
Environment	Wet / damp	Increase	All / polyester resin
	Corrosive environment	Increase	All
	Chlorides / marine environment	Increase	All
	High / low temperature including fire	Increase	All / resin anchor
	Masonry substrate	Increase	All / resin anchor
Robustness	High degree of redundancy	Decrease	All
	Secondary restraint	Decrease	All
	Exposure to sources of damage	Increase	All
Degradation	Not recently inspected / concealed	Increase	All
	Missing / failing fixings	Increase	All
	Distortion / movement	Increase	All
	Substrate degradation	Increase	All
	Fixing / fixture corrosion	Increase	All

Determine actions



Figures in brackets provide references to relevant sections of the text

Guidance on inspections

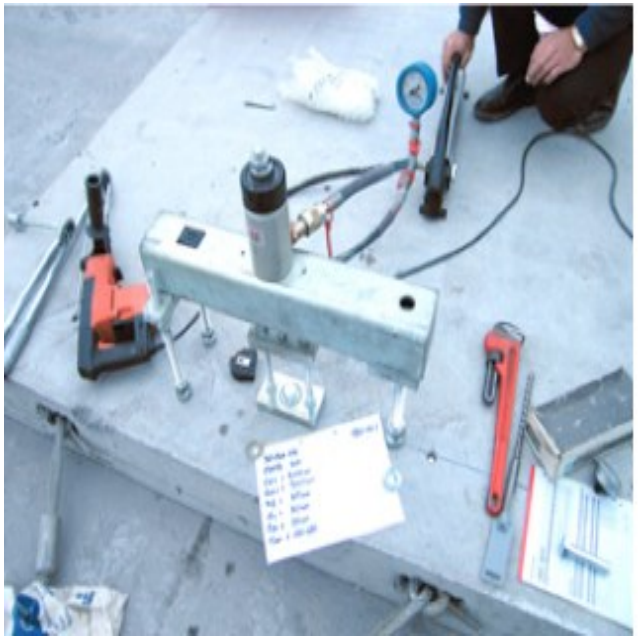
Type of change	Example of change
Change in fixture / change in use	New fixture has different centre of gravity and different weight, hence change in loads on the group of fixings supporting the fixture
Change in actions	Use of hard shoulder on a frequent basis by high vehicles means that a fixture is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

Corrosion of hidden fixings

Missing studs found at Balcombe tunnel

Inspection checklist provided in Appendix H

Investigations



Proof test of fixing

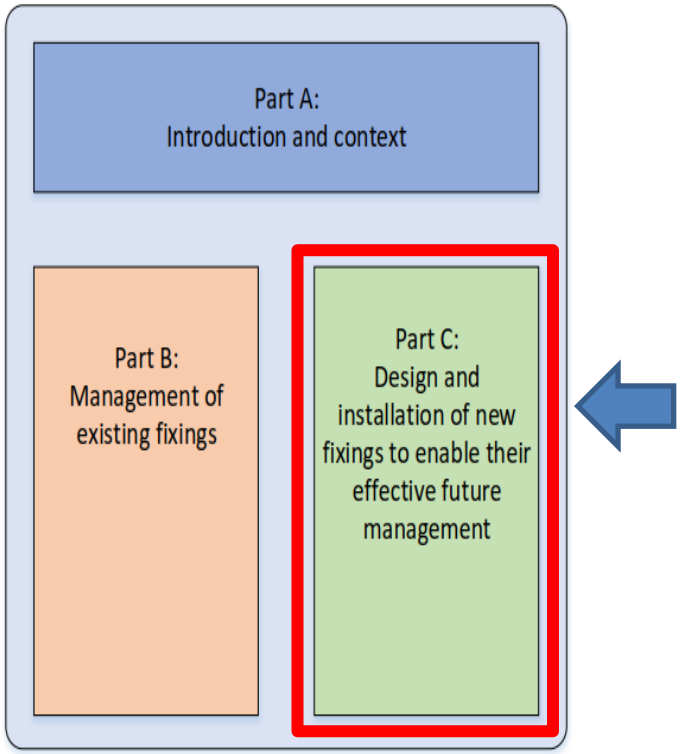
Ultrasound testing of bolt length

Information about fixings

- Extensive guidance in Appendix G
- Recommendations for sharing lessons learned from failures / near misses

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 (e.g. bridge, tunnel, retaining wall, etc.) • [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 (e.g. sign, CCTV, etc) • Date of installation • Anticipated year of replacement • [Other information as required to manage the fixture]

Part C – Design and installation of new fixings



New fixings – scope of report

- Good guidance is available elsewhere for design and installation – not intended to duplicate this
- Report provides information on how effective future management can be enabled through design and installation
- Particular topics are:
  - Design-out risk factors
  - Robustness
  - Enabling future inspection, testing, replacement
  - Technical approval
  - Assuring quality of installation

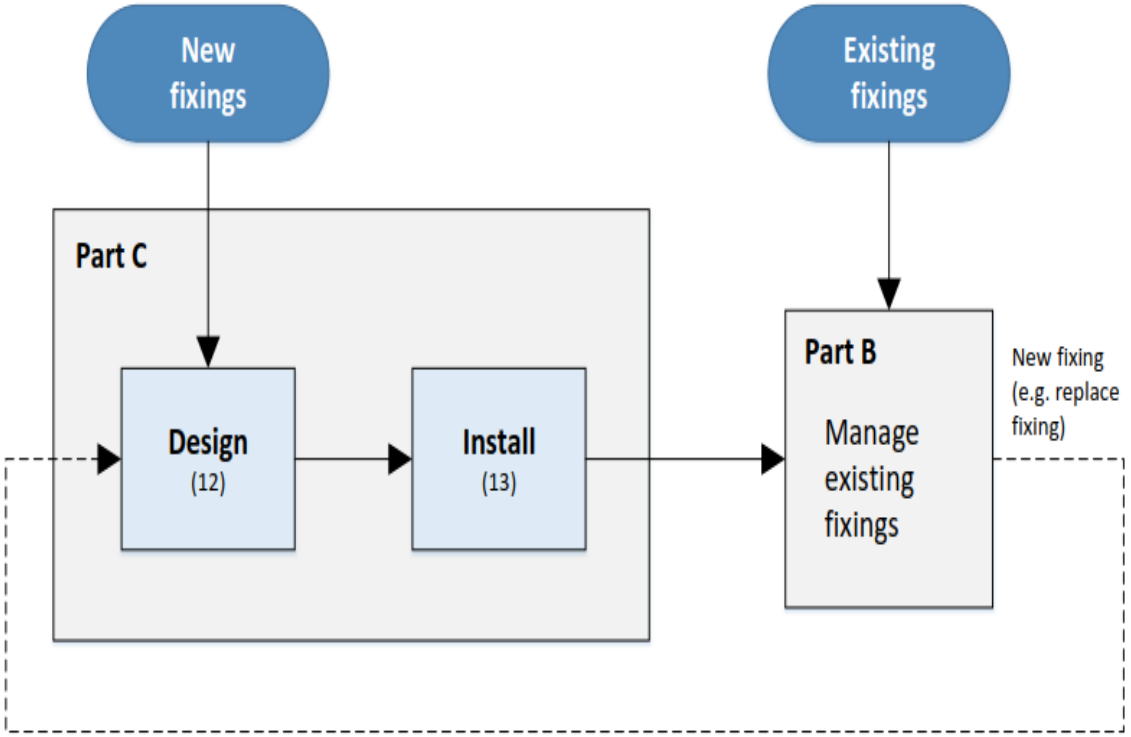
Recommendations for new fixings: design

	Recommendation	Refer to report sections
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, 12.4
16.	The design of new safety critical fixings should facilitate future management, such as inspection, future testing and replacement	12.5
17.	The design of new safety critical fixings should incorporate robustness	12.6
18.	New safety critical fixings should be selected from those with an ETA, unless there is no applicable ETA which covers the particular application	12.7
19.	Full design records should be submitted 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, design checking and independent checking	12.9

Recommendations for new fixings: installation

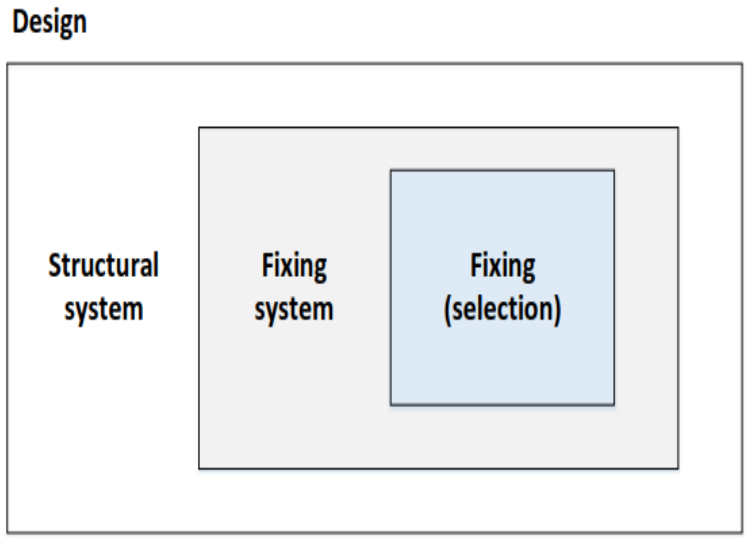
	Recommendation	Refer to report sections
21.	Installation of new safety critical fixings should be carried out and supervised by competent persons	13.2
22.	Installation of new safety critical fixings should be in accordance with the fixing manufacturer's instructions and the design specification	13.2
23.	New safety critical fixings should be proof-tested to verify quality of installation	13.3
24.	Installation and test records should be submitted and retained for new safety critical fixings	13.4

New fixings – link to management

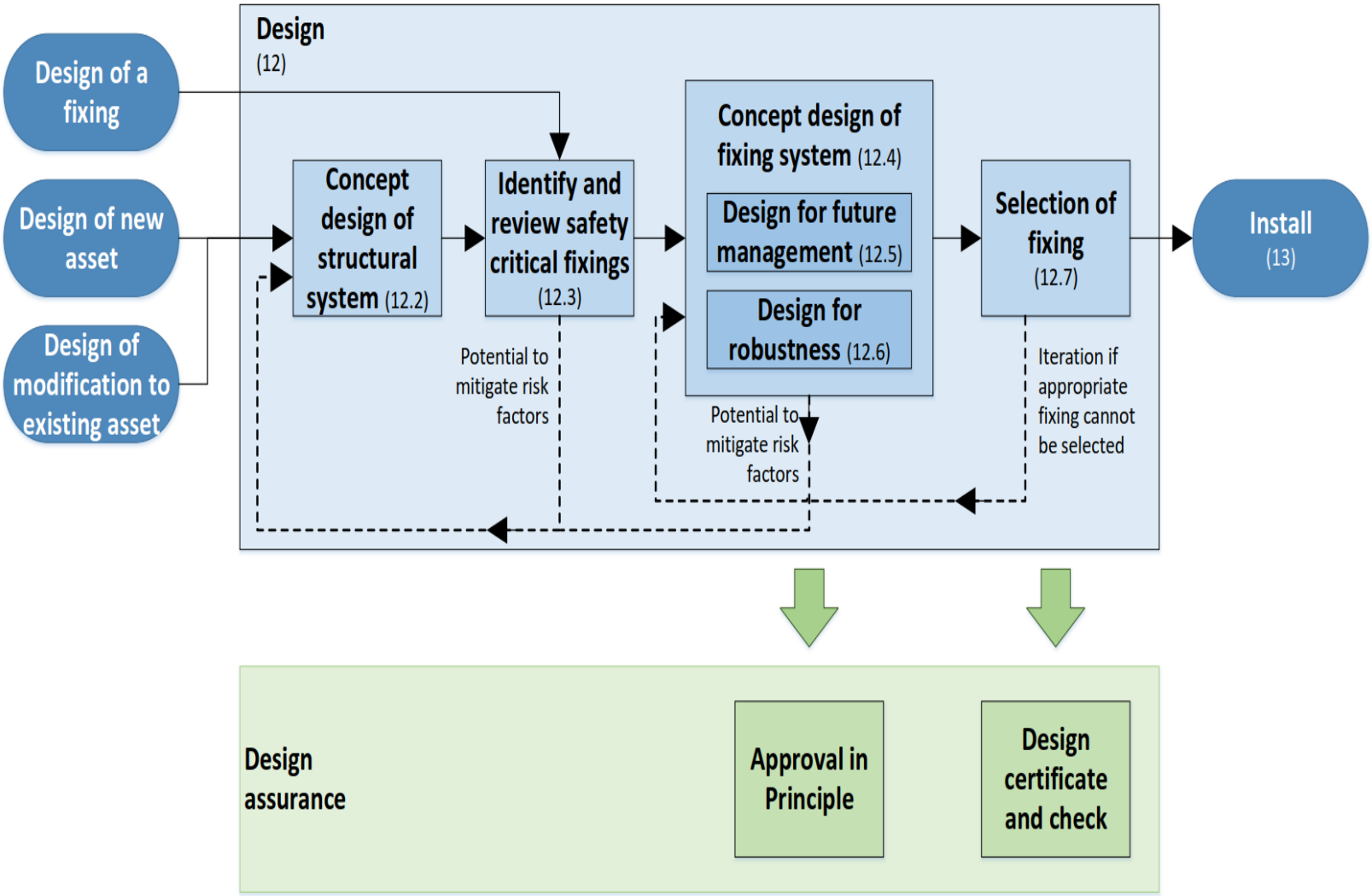


Design

- This guidance takes a wide definition of ‘design’ to include design of the structural system, fixing system and fixing itself.



Design process



Design out risk factors

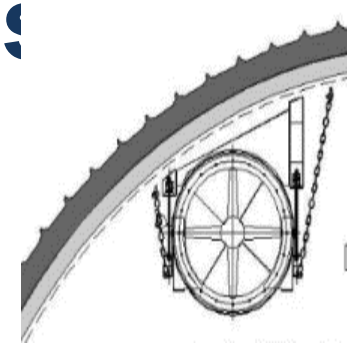
Factor	Specific aspect of factor	Implication for concept design of fixing
Base material	Reinforced concrete	Likelihood of hitting reinforcement during drilling; specification of action to take if reinforcement is hit
	Shotcrete	Interface between fixture connection and rough surface finish
	Prestressed concrete	Potential unsuitability of post-installed fixings due to risk of destroying structural prestressing strand / tendons
	Masonry	Potential variation in masonry and mortar strength; potential voids Check against pull-out of section of masonry
	Cladding	Potential for fixings to be hidden
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 which are suitable for these actions. Some of these actions are not covered by standard European Assessments (see Appendix B). Supplementary justifications and test results from fixing suppliers should be sought.
Environment	Water management (e.g. in tunnels)	Likelihood of fixing being exposed to damp conditions
	Exposure to severe chemical pollution, e.g. exhaust fumes in road tunnels, de-icing salts	Selection of fixing material type and grade (special alloys of stainless steel required in these conditions)

Design for future management

- Design for inspection of fixing
- Design to enable future testing
- Design for end-of-life of fixing

Design for robustness

- Enhance redundancy
- Provide excess capacity
- Segmentation
- Reduce exposure of fixing
- Consider common
  -cause failures



Secondary restraint chains for ventilation fan

Progressive collapse (Sasago tunnel)

Technical assurance

- Approval in principle of concept
- Certification of design
- Independent checking
- Design records
- Use of CE marked products

Installation

CFA Guidance Note on Anchor Installation:

"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."

Installation – assurance of quality

- Supervision and audit
- Certification of installation
- Testing of fixings
- Change management – alternative fixings
- Installation and test records

Appendices

APPENDIX A - EXAMPLES OF FIXINGS

APPENDIX B - OVERVIEW OF FIXING TYPES

APPENDIX C - CE MARKING OF FIXINGS

APPENDIX D - SELECTED CASE STUDIES OF FIXING FAILURES

APPENDIX E - RISK FACTORS

APPENDIX F - EXAMPLES OF SCREENING

APPENDIX G - GUIDANCE ON CONTENT OF ASSET INFORMATION SYSTEMS FOR SAFETY CRITICAL FIXINGS

APPENDIX H - GUIDANCE ON INSPECTIONS

APPENDIX I - SAMPLE MODEL FOR ASSESSMENT OF PRIORITY

APPENDIX J - REFERENCES AND ADDITIONAL INFORMATION SOURCES

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Recommendations for fixings in service

	Recommendation	Refer to report sections
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
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

Recommendations for new fixings: design

	Recommendation	Refer to report sections
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, 12.4
16.	The design of new safety critical fixings should facilitate future management, such as inspection, future testing and replacement	12.5
17.	The design of new safety critical fixings should incorporate robustness	12.6
18.	New safety critical fixings should be selected from those with an ETA, unless there is no applicable ETA which covers the particular application	12.7
19.	Full design records should be submitted 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, design checking and independent checking	12.9

Recommendations for new fixings: installation

	Recommendation	Refer to report sections
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 submitted and retained for new safety critical fixings	13.4

Next steps

- So what?
- Action Plan to be developed

- Thanks

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