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Bridge Inspections to Manage Risks and Hidden Defects

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LoGEG London - 11 October 2019

Bridge Inspections to Manage Risks

- **Background**
- **Highways Act**
  - **S41 Duty to Maintain Highways Maintainable at Public Expense**
  - **S91 Bridge Maintainable at Public Expense**
  - **S92 Reconstruction of Bridge Maintainable at Public Expense**

- **BD63 - Bridge Inspections – for many years traditionally**
  - **General Inspections – 2 yearly**
  - **Principal Inspections – 6 yearly – now risk assessed intervals 2-18 years**
  - **Special Inspections**
  - **BD79 – Management of Sub-Standard Structures**

(following structural assessment to BD21)

Monitoring, Interim Measures

Bridge Inspections to Manage Risks

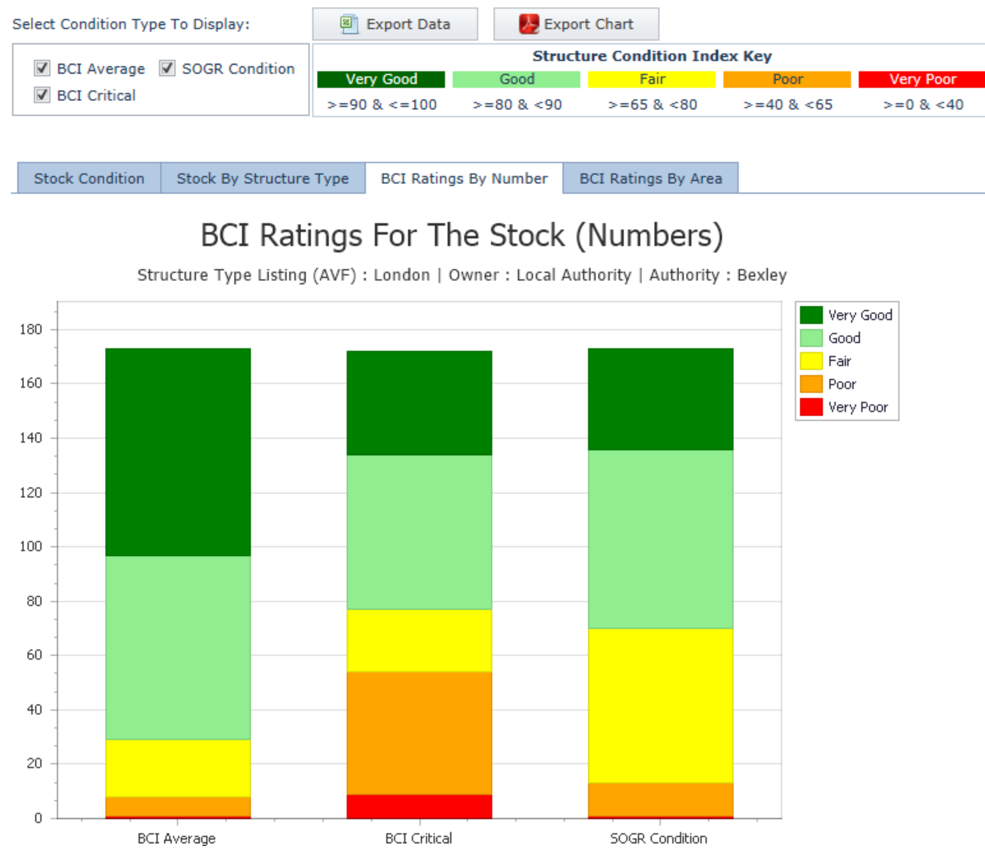
- BD63 now updated to include risk based as uniform inspection interval did not consider
  - New bridges with little existing damage
  - Environments or condition where deterioration is unlikely
  - Bridges & Bridge Types with long histories of good performance
  - Damage that has little effect on safety or serviceability

- The Challenge:

- Reduction in Revenue
& TfL/LoBEG funding

Bridge Inspections to Manage Risks

- Review Bridge Stock
- Condition, type/material, spans, obstacle crossed, consequence of failure/closure (safety, TM, political, commercial), age
- Inspectability – hidden elements?
- Desktop Study & BridgeStation
- Fill gaps
- Prioritise Risks & spend



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Bridge Inspections to Manage Risks

- How to manage highway structures risks with reduced budgets
- Tools available – BD 63/17, Guides & BridgeStation

Structure Name: **Structure Key:**

NOTE : PI Interval to remain at 6 years for the following structures (so this risk assessment process is not appropriate) :
a) Structures with severe (marine environment) exposure; b) Structures which are scour susceptible (risk rating 1-4 to BD 97); c) Structures adjacent to or over a waterway where there is a medium or high risk of damage due to flooding; d) Structures subject to BD79 measures; e) Structures which would affect an operational railway if they collapsed; f) Structures which have a current inspectors rating as 'Poor', or 'Av' or 'Ccrit' scores of 0-40 .

A - BRIDGES & LARGE CULVERTS	Criteria Number	Criteria	Attribute	Risk Score
A1 Structure Type	A.1.1	Structural form	Framed Span - Bridges	3
	A.1.2	Constituent material	Insitu Reinforced Concrete	4
	A.1.3	Age of the structure	10-25 years	1
	A.1.4	Headroom	Greater than 'Minimum Maintained Headroom'	1
	A.1.5	Span	10m to 25m	1
A2 Environment	A.2.1	Exposure	Moderate (Routes with de-icing salts)	1
	A.2.2	Scour	No Risk (structure not near or adjacent to waterway)	4
	A.2.3	Flooding	No Risk (structure not near or adjacent to waterway)	4
A3 Inspection / Assessment	A.3.1	Level of visual accessibility during a General Inspection	An enhanced GI has been completed in the last 6 yrs and will be undertaken between PI's.	4
	A.3.2	Likelihood of latent defects going unnoticed during a Principal Inspection	Low possibility of latent defects	3
	A.3.3	Assessment	Structural review recommends assessment as low or lesser priority	2
A4 Condition	A.4.1	Condition - Inspector's opinion	Good	3
	A.4.2	Condition Performance Indicator (Average Score)	Good (80-90)	3
	A.4.3	Condition Performance Indicator (Critical Element Score)	Good (80-90)	4
	A.4.4	Signs of Concrete Deterioration including TSA, AAR, ASR and ACR	No	3
A5 Consequences	A.5.1	Applied loading	Full Highway Loading	1
	A.5.2	Route supported	Motorway	0
	A.5.3	Obstacle crossed	Motorway	0

A - BRIDGES | B - Small Span Structures | C - Retaining Walls | D- Masts | E- Gantries | F-SCOS | Lookups

Transport for London
Surface Transport

STREETS

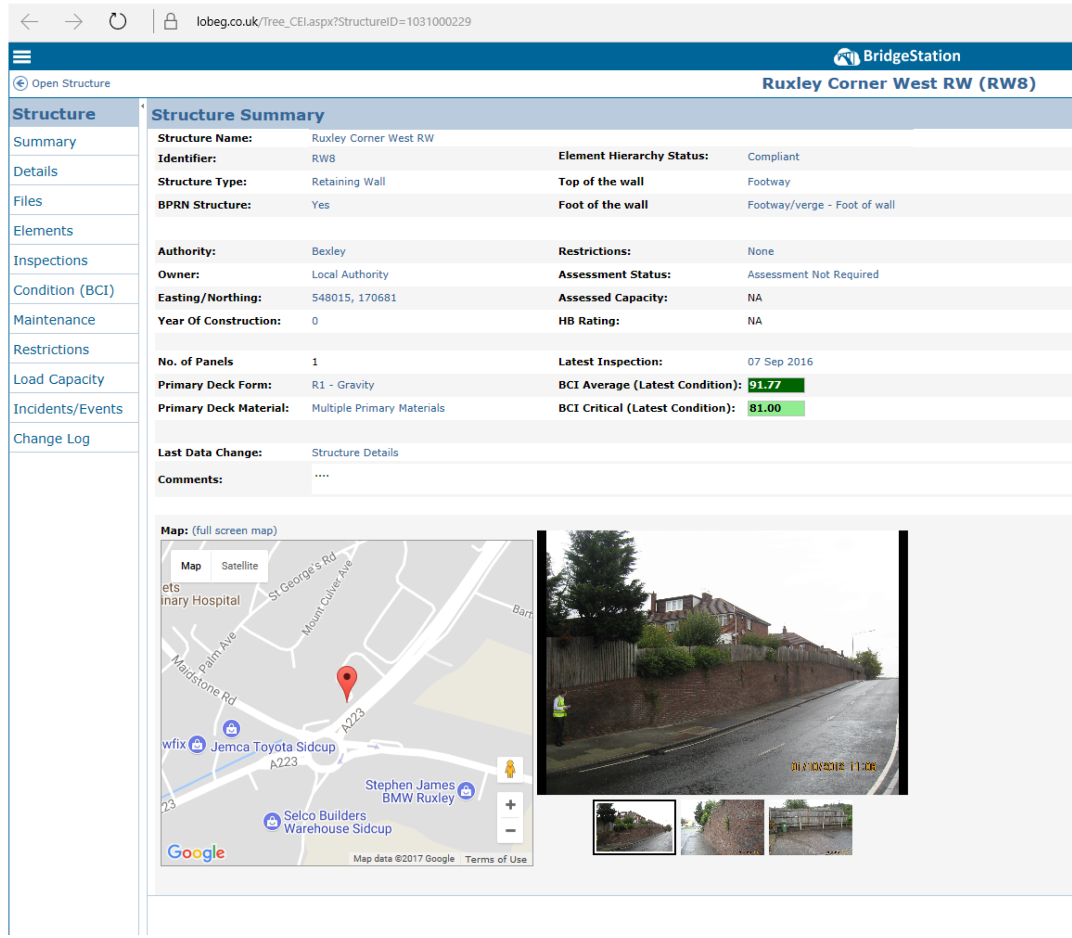
TfL Good Practice Guide

Risk Based Inspection of Highway Structures

December 2011

Engineering Judgement to Manage Risks

- Brick Wall – good condition
- High BCI_{CRIT}, high BCI_{AV}
- Generally visible (unlikely to clear vegetation to rear for PI)
- Durable low-maintenance wall
- Reduce PI 6 ⇨ 12-18 yearly
- GI 2 yearly routine maintenance & BCI update



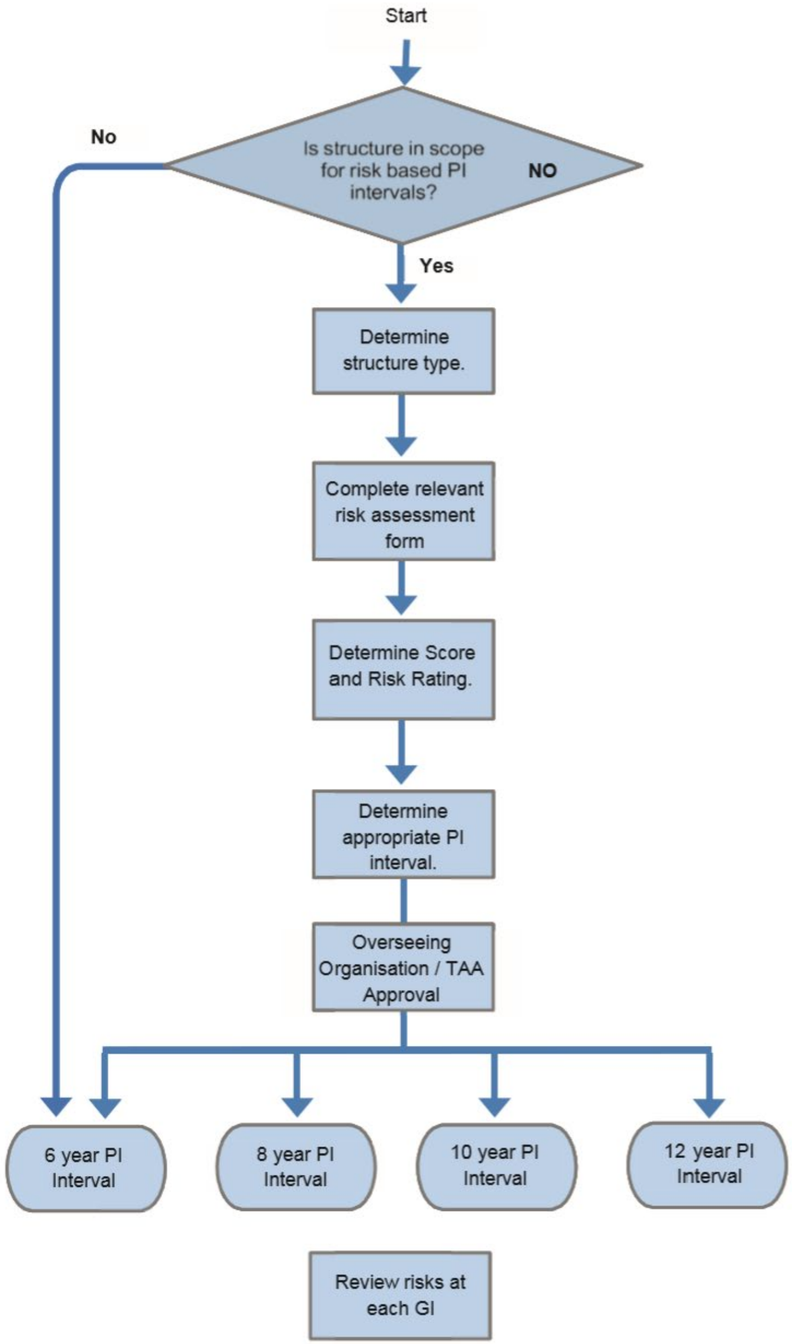


Figure 8. 6 – Flow chart to show Risk Assessment Methodology

Table 1 – Risk Assessment Criteria

ASSESSMENT CRITERIA	COMMENTARY	SOURCE OF INFORMATION
Structure Type		
Form	Different structural forms can be expected to experience varying degrees of deterioration and have each been rated accordingly to consider this.	(a) Inventory (b) Structure File
Material	The primary constituent material will have an impact on the likelihood of deterioration. Historical performance has been evaluated for different construction materials and is reflected in the scoring.	(a) Inventory (b) Structure File
Age	The age of a structure will usually affect the likelihood and rate of deterioration. In general, it would be expected that an older structure approaching the end of its design life will encounter more maintenance issues and hence be more prone to deterioration. Newer structures may encounter initial teething problems before they are considered to be performing optimally.	(a) Inventory (b) Structure File
Span / Height / Headroom / Length	Although every structure has different design requirements, probabilistic analysis shows that bridges with longer spans and retaining walls with greater retained heights, tend to be at a higher risk of failure. Not only is the likelihood increased but also the associated consequence of failure.	(a) Inventory (b) Structure File
Environment		
Scour	Scour susceptible structures are not suitable for reduced inspection intervals.	(a) Inventory (b) Structure File (c) Scour Assessment in accordance with BA 74/06 or BD 97/12
Flooding	Structures in areas susceptible to flooding should be assessed as having increased risk.	(a) Qualitative assessment of the available information that would inform the likelihood of flooding (b) Environment Agency records
Inspection / Assessment		
Visual Access	Limited visual accessibility to critical elements will reduce the reliability of the General Inspections undertaken between Principal Inspections.	(a) Qualitative assessment of the available information on visual accessibility.
Latent defects	Some structure types are more susceptible to containing defects that are not evident during a Principal Inspection for example, post-tensioned concrete bridges with internal grouted tendons.	(a) Inventory (b) Structure File

Table 1 – Risk Assessment Criteria

ASSESSMENT CRITERIA	COMMENTARY	SOURCE OF INFORMATION
Assessments	Where an assessment has been carried out on a structure, a greater degree of confidence can be achieved with regard to the structure's ability to carry load. The findings of the assessment report should give a clear indication of any current load restrictions and any recommended condition factors. Any current load restrictions in place indicate that the current condition of the bridge is below design standard, resulting in a higher potential risk of deterioration.	(a) Load Management Records (b) Assessment reports (c) Interim Measures Records
Condition		
Inspector's Condition Rating	Condition is to be assessed using two criteria. The first is the Inspector's subjective condition rating of the structure (ie. Good, Fair or Poor), which should give a good overview of the condition of the structure.	(a) inspection records
Condition Performance Indicators	Secondly, Condition Performance Indicators, where available, are to be taken into account. These are an objective measure of the physical condition of the highway structures stock, calculated using the Highways Agency's Severity/Extent condition rating system[5]. They are reported for each structure on a scale of 0 to 100, where 0 represents the worst possible condition and 100 represents the best possible condition. There are two scores to consider: 1. Average Condition PI Score, PI_{Av} (based on all elements) 2. Critical Condition PI Score, PI_{Crit} (based on the most critical elements only)	(a) Condition Performance Indicator Reports
Concrete Deterioration	Any deterioration of concrete including that due to Thaumasite Sulphate Attack, Alkali Aggregate Reaction, Alkali Silica Reaction and Alkali Carbonate Reaction should be scored	(a) Inventory (b) Structure File (c) inspection records
Consequences		
Load Type	Load type may not have an impact on the likelihood of deterioration or failure. However, it will have a bearing on the overall consequence of any potential collapse.	(a) Load Management Records (b) Assessment reports (c) Interim Measures Records
Route supported and obstacle crossed	These attributes are intended to reflect the importance of the structure within the overall road network in the event of a structural collapse.	Inventory
Failure Mode	Brittle failure modes can result in collapse without warning and high consequences whereas ductile modes typically give warning of structural distress.	(a) Inventory (b) Assessment reports

BD63/17 Risk Rating & PI Intervals

A3.1.3 Separate risk assessment forms have been developed for each of the following structure types.

- Bridges and Large Culverts
- Small Span Structures
- Retaining Walls
- Masts and Mast Schemes
- Sign/Signal Gantries
- Service Crossings and Other Structures

A3.1.4 For multi-span bridges a single risk assessment may be carried out using a combination of the worst criteria across all spans. This, however, is likely to result in a conservative score. Alternatively, each individual span may be assessed separately, with the lowest scoring span (most conservative) being used to determine the most appropriate Principal Inspection interval for the structure.

A3.1.5 Tables Showing Risk Rating and the Correlation with Recommended Principal Inspection Interval

Total Risk Score	Risk Rating	Recommended Principal Inspection Time Interval
$0 \leq x < 65$	High	6 years
$65 \leq x < 75$	Medium	8 years
$75 \leq x < 85$	Low	10 years
$85 \leq x \leq 100$	Very Low	12 years

Table A3.1.1 – Risk Ratings and Recommended Principal Inspection Intervals for Bridges and Large Culverts

Total Risk Score	Risk Rating	Recommended Principal Inspection Time Interval
$0 \leq x < 50$	High	6 years
$50 \leq x < 60$	Medium	8 years
$60 \leq x < 70$	Low	10 years
$70 \leq x \leq 100$	Very Low	12 years

Table A3.1.2 – Risk Ratings and Recommended Principal Inspection Intervals for Small Span Structures

BD63/17 Risk Based Spreadsheet

Structure Name: **Structure Key:**

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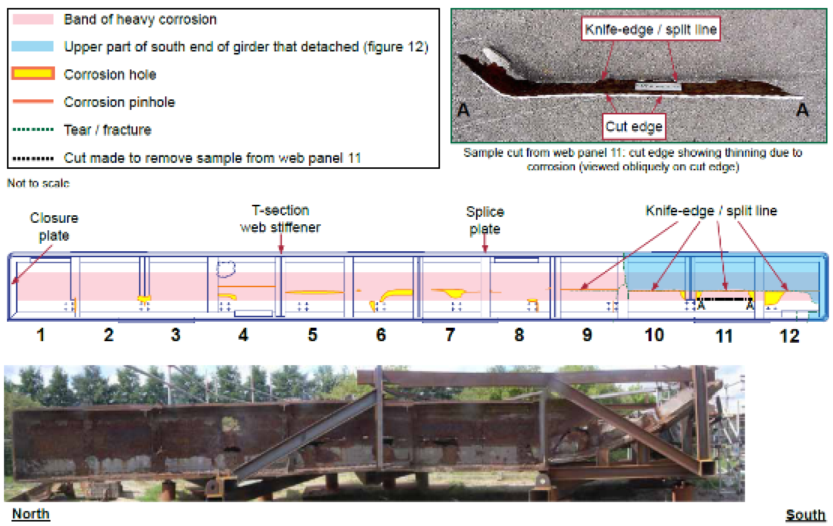
Hidden Defects

- Further Guides and Case Studies – CIRIA Hidden Defects - known problems & best practice guidance.
- TfL method assigns an ‘inspectability’ factor recognising potential risks within hidden elements.



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What do we mean by ‘hidden’?

Rail, 2014). In a bridge, a hidden component is **an element that would not usually be visually inspected as part of a principal inspection** i.e. to within touching distance using normal inspection techniques such as:

- Visual inspection from within touching distance.
- Hammer tapping.

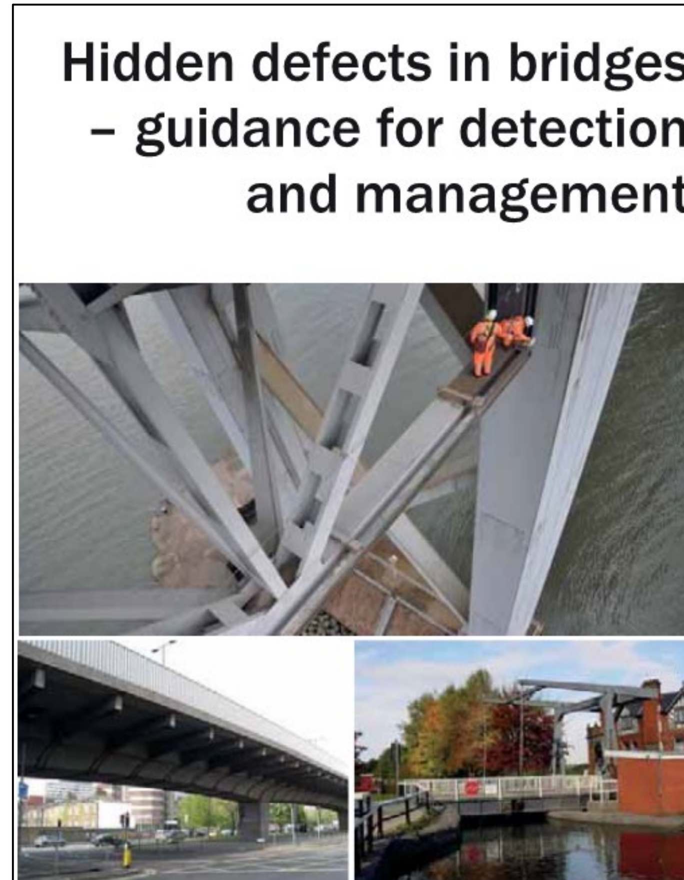
CIRIA Hidden Defects in Bridges Guide

Owners and managers

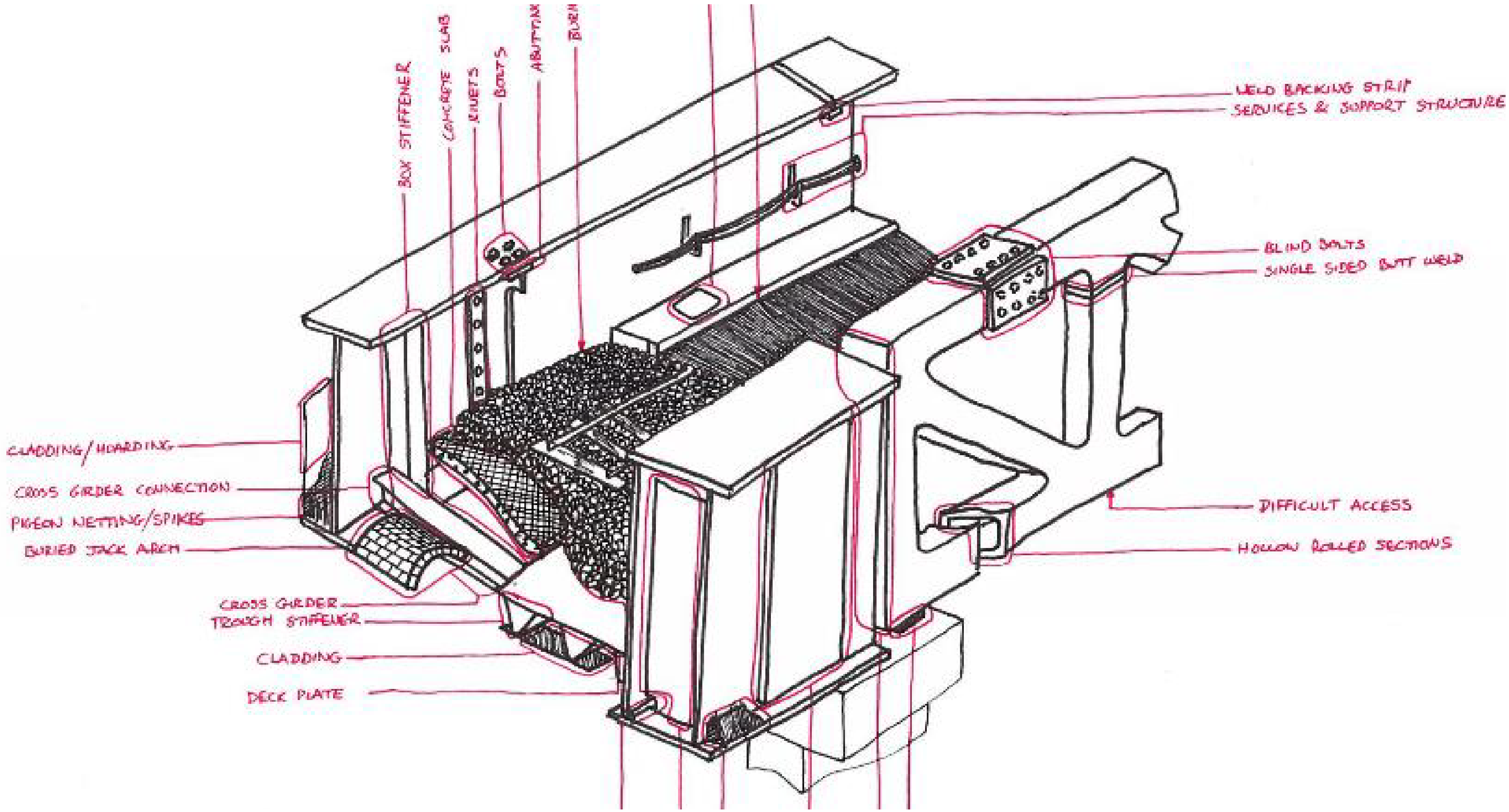
Inspectors, maintainers, designers

All

All



Hidden defects – Steel Bridges Example



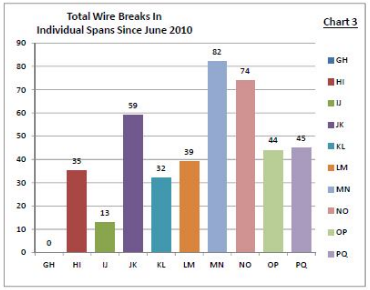
From AECOM Arup CIRIA Report on Hidden Defects – after sketch by John Collins of Arup

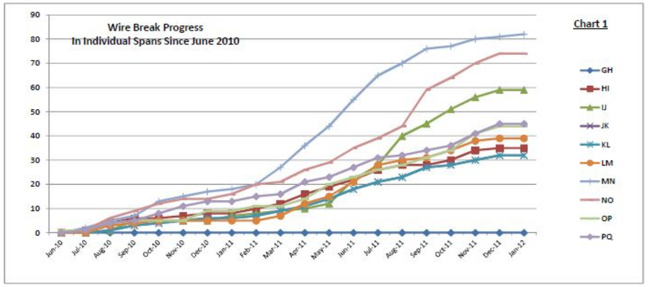
Case Study – Hammersmith Flyover

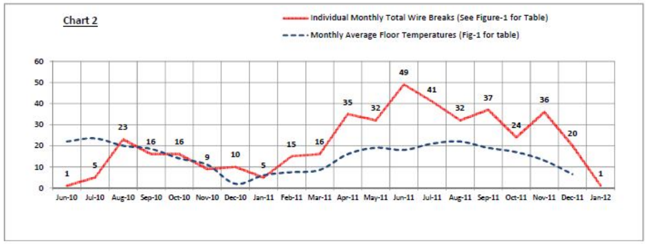
- Hidden defects in post-tensioning
- Inspection & Testing – Post-Tensioned Special Inspection
- Complex live remote monitoring – Acoustic Emissions etc.
- Analysis of AE readouts to confirm wirebreaks vs 'noise'
- Regular assessments based on wirebreaks, condition & trends
- Prediction of capacity & time to failure
- Expertise of team managing

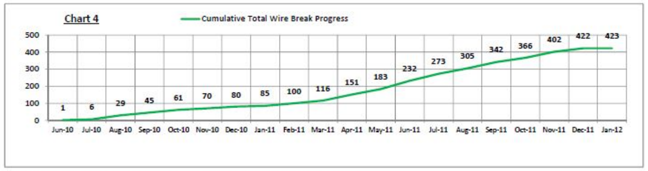
	1	2	3	4	5	6	7	8	9	10	
Month/ Span	GH	HI	IJ	JK	KL	LM	MN	NO	OP	PQ	Cumu Total
Jun-10	0	0	0	0	0	0	0	0	1	0	1
Jul-10	0	1	0	0	0	0	2	1	1	1	6
Aug-10	0	4	1	1	1	3	5	6	4	4	29
Sep-10	0	6	1	5	3	4	7	9	5	5	45
Oct-10	0	6	3	5	4	5	13	12	5	8	61
Nov-10	0	7	3	5	5	5	15	14	5	11	70
Dec-10	0	8	3	5	6	5	17	14	9	13	80
Jan-11	0	8	3	7	6	5	18	16	9	13	85
Feb-11	0	10	4	8	7	5	20	20	11	15	100
Mar-11	0	12	4	9	9	7	27	21	11	16	116
Apr-11	0	16	5	10	11	12	36	26	14	21	151
May-11	0	19	7	12	14	15	44	29	20	23	183
Jun-11	0	22	9	22	18	21	55	35	23	27	232
Jul-11	0	26	9	28	21	28	65	39	26	31	273
Aug-11	0	28	10	40	23	30	70	44	28	32	305
Sep-11	0	28	11	45	27	31	76	59	31	34	342
Oct-11	0	30	12	51	28	34	77	64	34	36	366
Nov-11	0	34	12	56	30	38	80	70	41	41	402
Dec-11	0	35	13	59	32	39	81	74	44	45	422
Jan-12	0	35	13	59	32	39	82	74	44	45	423
Span Total	0	35	13	59	32	39	82	74	44	45	

Table 2: Lists cumulative wire breaks for all the spans









Notes:
1. Refer to PAL drawing no. 024 for the temperature sensor locations.
2: The monthly average internal temperature graph in Chart-2 is based on the approximate estimates deduced by scaling the average temperature graph in 'Mistras' website.

Figure 2: Cumulative Wire Breaks - Comparison of Span Behaviour

Last Updated: 17/01/2012

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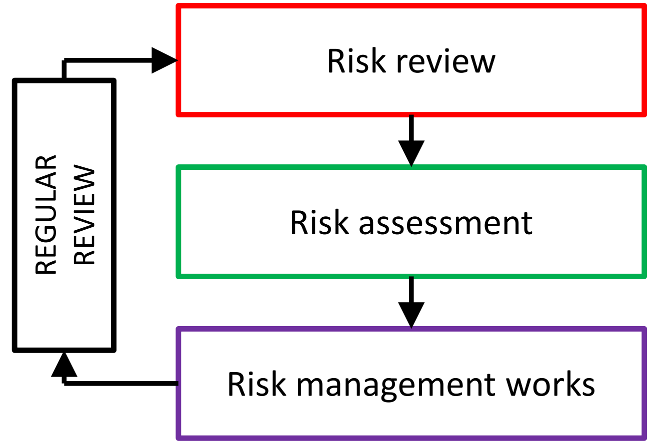
Risk review

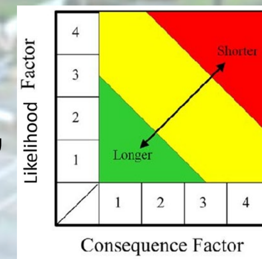
- How has risk changed?
- Gathering and reviewing information.
- What could fail?

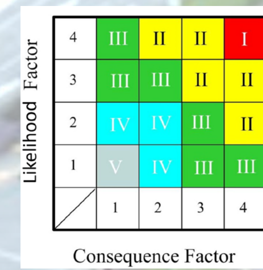


- What is the consequence?

Risk Matrix

- Plot values of likelihood and consequence
- Components in the top right are "high risk"
- High likelihood may not mean high risk, if consequence is small
- High consequence may not be high risk, if the likelihood is low





How likely is it?

- Design e.g. Concrete cover, strength, waterproofing
- Loading e.g. AADT, High HGV, AIL route
- Condition - Spalling, cracking etc.
- Durability - Leaking joints
- Experience, judgment, deterioration – HE/TfL guides

- **Prioritise** importance & develop Likelihood scoring - example

Level	Qualitative Rating	Description	Likelihood (POF)	Expressed as a percentage
1	Remote	Remote probability of occurrence, unreasonable to expect failure to occur	≤1/10,000	0.01% or less
2	Low	Low likelihood of occurrence	1/1000-1/10,000	0.1% or less
3	Medium	Moderate likelihood of occurrence	1/100-1/1,000	1% or less
4	High	High likelihood of occurrence	>1/100	> 1%

Consequence Factors

- Focus attention on the ***most critical*** damage
  - *Could this result in collapse?* ***FMEA methods*** *Use* ***HE/TfL guidance***
- Consequence scenarios
  - Low, Medium, High, Severe
  - Consequence scenarios – case studies – ***CIRIA Guide on Hidden Defects*** etc
  - Political, Strategic Route, Traffic, Commercial, Social Mobility

Forth Road Bridge

FMEA Examples – safety criticality

Table 3.2 Failure mode effect analysis examples

Failure mode	Location	Defect/event	Initial consequence	Other consequences	Failure type
1	Steel girder transverse stiffener weld to bottom flange	Fatigue crack growth from weld	Growth of crack: new load path formed	Increased brittle fracture susceptibility: sudden, catastrophic failure	Fatigue, brittle
2	Concrete deck at mid-span	Flexural overload to deck (sagging)	Local distress (excessive cracking) at soffit	Loss of durability	Ductile
3	Unreinforced joint in prestressed concrete deck	Corrosion of tendons passing through joint	Loss of prestress force	Collapse of deck	Brittle
4	Half-joint	Corrosion of tensile steel due to chloride ingress	Signs of water leakage through joint but limited outward signs of the onset of failure	Loss of capacity and failure of joint leading to partial or full collapse of supported section	Ductile (but not visible) followed by brittle collapse
5	Arch barrel	Loss of support due to undermining of support	Local distress (cracking and/or separation of arch barrel rings)	Loss of capacity due to separation of rings	Ductile
6	Deck tie down	Loss of restraint	Change in load distribution. Instability of structure	Deterioration of surfacing	Depending on form of structure: ductile or brittle

CIRIA Hidden Defects Guide

Risk-based approach to Managing Hidden Defects

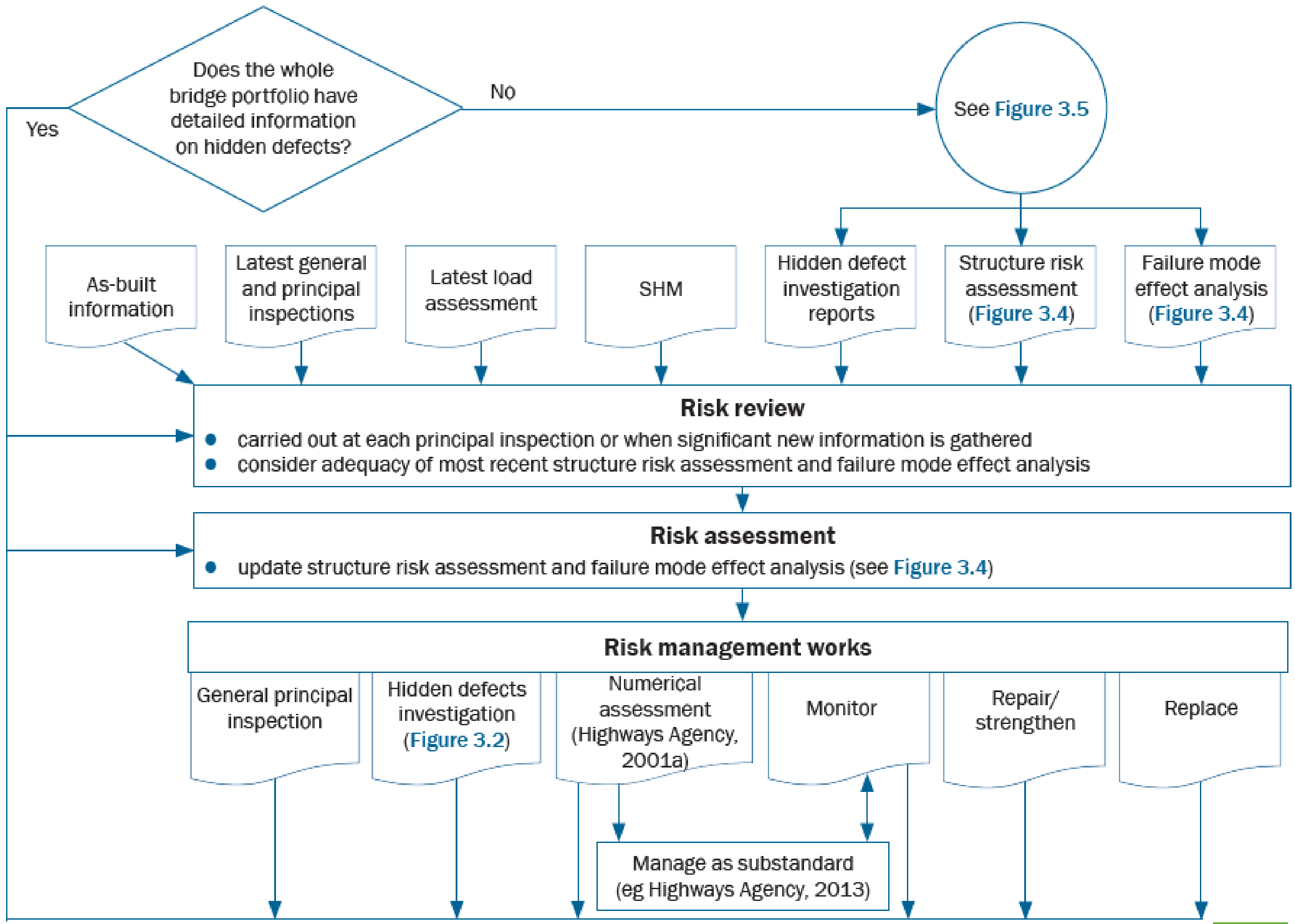


Figure 3.1 Risk-based approach to management of hidden defects in bridges (after Highways Agency, 2015)

New Civil Engineer

Initial comments from experts are pointing at lack of adequate maintenance on difficult to inspect elements – hangers and cables

LATEST

Possible cable corrosion investigated in fatal Taiwan bridge collapse

03 OCT, 2019 | BY ROB HORGAN

Smart Bridges – Structural Health Monitoring

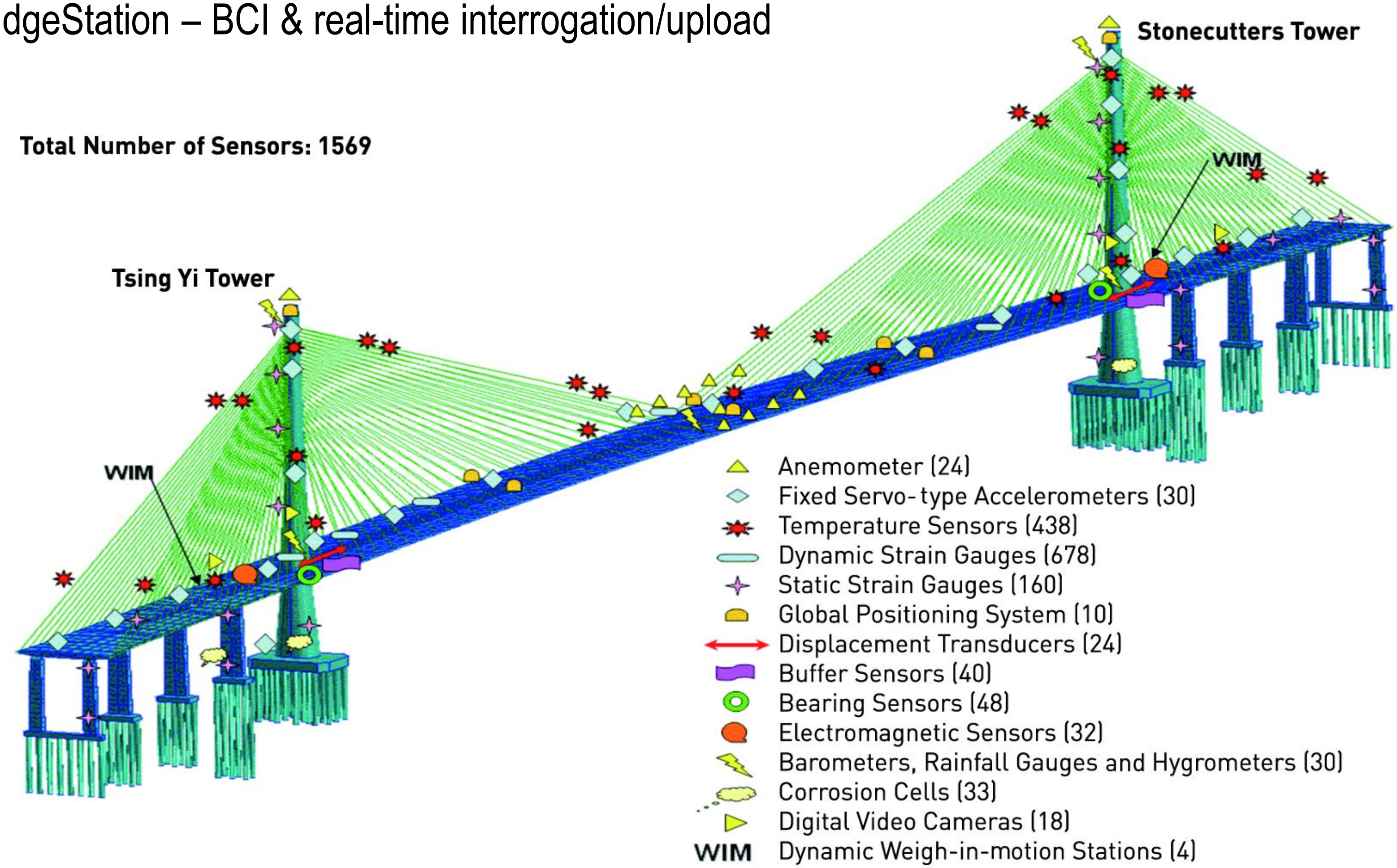
For complex and high value assets – Queensferry system monitored in real-time

Future – reduced costs wider application

BIM – As-Builts & Maintenance Records

Asset Tagging – Maintenance trends

BridgeStation – BCI & real-time interrogation/upload



Historic Structures - Investigation & Refurbishment Challenges

Bridge Inspections for Risk - Summary

- *Risk assessed PI intervals*
- *Special Inspections & Monitoring*
- *Hidden Defects*
- *Smart Monitoring is coming!*
- *Engineering Judgement*
- *BD63/17, TfL Guide, BridgeStation, FMEA*
- *Efficiency savings*

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Thank you!

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