Management of Substandard Structure Report – Underbarrow

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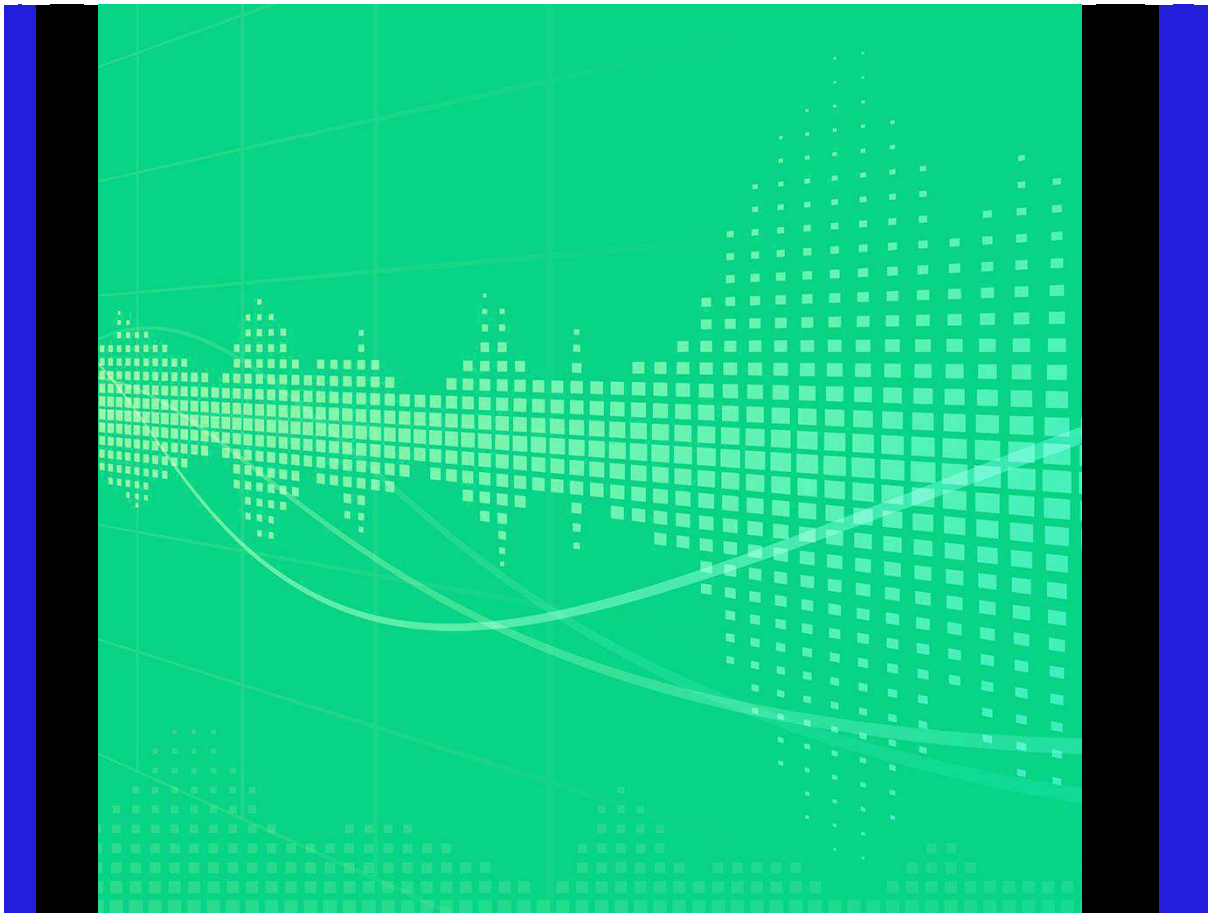
Westmorland & Furness Council
6330

Risk Assessment and Structural Assessment of Post-Tensioned and Half-Joint Bridges SL240 Brigsteer and SL221 Underbarrow
8 July 2024



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Jacobs U.K. Limited

[redacted]

Contents

Executive Summary

Jacobs UK Ltd. were commissioned by Westmorland & Furness Council to undertake a CS470 'Management of Sub-standard Highway Structures' review of Underbarrow bridge (structure number SL221).

Historically, the structure (including half-joints) had an assessed capacity of 40 tonnes GVW and full HA loading and a HB capacity of 30 units as stated on the signed assessment certification (dated 14th February 1995). However, a note on the results summary sheet states that the suspended span and the top slab of the hollow parts of the cantilever can carry 30 units HB loading, but if the HB vehicle travels within 150mm of the kerb, allowing associated HA loading, then the capacity reduces to 14 HB units, limited by the lower nib of the half-joints. SLS checks concluded that the actual crack width is greater than twice the allowable width. The cracking was attributed to poor detailing of reinforcement as opposed to overloading.

The most recent structural assessment of the half-joints (2023) has been based on the condition of the half-joints as identified by an August 2022 Special Inspection. The half-joints were found to be in a fair condition with cracks noted at the re-entrant corners of the upper and lower nibs. A condition factor of 0.9 has been used for assessment purposes, as per the accepted Approval in Principle (AIP) dated 12th January 2023. This condition factor considers the cracking noted to the upper and lower nibs of the half joint as far as could be seen at the inspection for assessment, noting the inability to determine the extent of the cracks without access on to the bearing shelf. The findings of the half-joint inspection and a review of available historical information (drawings, previous calculations, design information etc) found inconsistencies between the available design and assessment information and the actual size of the half-joints as constructed. Additionally, ferro-scanning of the half-joints determined that the reinforcement was more aligned in size to the arrangement shown within the design calculations as opposed to the bar sizes considered in the 1995 assessment. There is no justification for the bar sizes considered in the 1995 assessment and no reference is made to any investigations or specific record documents / drawings within the assessment calculations.

The original design calculations are based on smaller bar sizes than the 1995 assessment calculations. There are no records of intrusive works to verify the assumptions used throughout the 1995 assessment (only the record drawings, which conflict with dimensions measured and bar sizes scanned at the recent inspection). As a result of the inconsistencies in available information, the AIP for this assessment set out conservative assumptions, utilising the confirmed geometry of the half-joints from measurements taken during the 2022 inspection and reinforcement arrangement indicated within the design calculations and as verified as closely as possible by the 2022 ferro scanning. The conflicting information between the design calculations, assessment calculations and scanning/ measured information is shown below:

Size of Half-Joint Nibs

	Design Calculations		Record Drawings		Inspection Measurements	
	(ft / in)	(mm)	(ft / in)	(mm)	(ft / in)	(mm)
Lower nib	5 1/2" x 17 3/8"	140 x 440	12" x 1'5"	305 x 430	-	310 x 500
Upper nib (external)	9" x 20"	228 x 508	1' x 1'8"	305 x 508	-	*305 x 450
Upper nib (internal)	9" x 16"	228 x 406	1' x 1'4"	305 x 405	-	-

Table 1: Conflicting size of half-joint nibs.

Note: The parapet upstand may mask the vertical extent (450mm / 508mm) of the element.

On this basis, the upper and lower nibs have been assessed considering the sizes noted below:

Lower Nib = 310mm x 500mm (W x D).

Upper Nib (external) = 305 x 450mm (W x D)

Upper Nib (internal) = 305 x 405mm (W x D)

Reinforcement Detailing

As part of the July 2022 inspection, both upper and lower nibs were ferro-scanned to indicate the arrangement of the reinforcement and check whether it conforms with that shown within the design calculations or record drawings.

Whilst not 100% accurate, the scanning broadly conforms with the reinforcement sizes and spacings shown within the design calculations.

	Design Calculations		Record Drawings		Inspection Ferro-Scanning	
	Diameter (mm)	Spacing (mm)	Diameter (mm)	Spacing (mm)	Diameter (mm)	Spacing (mm)
Lower Nib: Shear	19.05	101.6	19.05	152	19	N/A
Lower Nib: Bending	12.7	152.4	19.05	152	11	N/A
Upper Nib: Shear	15.9	3No	19.05	152	8*	N/A
Upper Nib: Bending	19.05	3No	19.05	5No	19	N/A

**This scan is noted to be an anomaly due to the presence of surrounding reinforcement which was picked up by the scan and reduces the median size of reinforcement measured.*

Table 2: Conflicting reinforcement detailing.

The diagonal bars, shown on 'record' drawings to be present, within the upper nibs could not be found by the ferroscan due to reinforcement congestion. It is probable that they are present, but this has not been confirmed. Similarly, drawings show no diagonal bar in the lower nibs, and it has not been possible to confirm presence of diagonal bars at this location, as the drawings suggest. For assessment, the diagonal bars shown on the drawings in the upper nibs only have been assumed to be present.

On this basis, the following parameters have been adopted in the assessment:

Lower Nib =	Shear:	19.05mm bars @ 101.6mm spacing.
	Bending:	12.7mm bars @ 152.4mm spacing.
	Diagonal Reinforcement:	N/A.
Upper Nib =	Shear:	3No x 15.9mm bars (per beam).
	Bending:	3No x 19.05mm bars (per beam).
	Diagonal Reinforcement:	4No x 19.05mm bars.

The 2023 assessment of the half-joints only, found them to be inadequate for permanent loads at Ultimate Limit State (ULS) and Serviceability Limit State (SLS). It recommended that investigative works are carried out to ascertain the true construction details and material strengths, with consideration being given to undertaking a PTSI Site Investigation to establish the details and condition of the post-tensioning.

In accordance with CS470, the structure is considered to be an 'immediate risk' sub-standard structure as a result of the 2023 half-joint assessment findings. Given the assessment rating of 0 tonnes and the fact the structure is, in theory unable to supports its own permanent loading, it is recommended that the structure is closed to all users and monitored under its permanent loads until it can be decommissioned or until investigations are complete and further (Level 3) assessment improves its load rating. Refer to CS454 Table 2.20.1 for clarification on levels of assessment.

In advance of any intrusive investigations to confirm construction details and material properties, sensitivity analysis based on 'best case' assessment parameters and material information could be undertaken to understand

what load carrying capacity the half-joints may be capable of, if it is proven through intrusive works that a greater size and strength of reinforcement exists within the half-joints.

CS470, Management of Substandard Highway Structures, (clause 3.2.1 section 1a and b) prescribes that any structure that is unable to sustain nominal loading, 40T assessment live loading, with safety and material factors reduced to 1.0 (i.e., decreased load and increased resistance) under any plastic upper-bound method of analysis, shall be considered to be 'immediate risk'. Although upper bound analysis could be carried out under the CS470 process to inform the management process. The construction arrangement and material strengths remain unconfirmed and upper bound analysis would not be recommended because of this. Upper bound analysis has not been carried out by the 2023 half-joint assessment or the CS470 process.

Lower bound sensitivity analysis has been carried out by reducing all partial load factors and material factors to unity (similarly to clause 3.2.1 section 1a and b); this has resulted in an improved Reserve Factor when compared to the Reserve Factors obtained from the assessment but the half-joints have still been found to be rated as 0 tonnes and unable to support permanent loads using the original design information and information gathered from site in 2022.

CS470 (clause 3.2.1 section 2) prescribes that the assessment load may be distributed evenly across each element, however this is only attributable to structures that have some level of capacity for live loads i.e., 3T or above. If a structure has no capacity for live load, as is the case for Underbarrow, then the structure is to be considered an 'immediate risk'. Although upper bound method of analysis would be expected to increase local resistances, it would not be expected to provide an increase in capacity rating. The conclusion of clause 3.2.1 section 2 in the absence of upper bound analysis determines the structure to be immediate risk.

Although the structure is to be considered an 'immediate risk' in accordance with CS470, Underbarrow satisfies all the criteria listed in clause 6.9 of CS470 and is not considered an immediate risk to public safety under its own permanent loading. As a result, Underbarrow is considered to be monitoring appropriate when closed to all users over the structure with reference made to sections of CS470 as described below.

In assessing the immediate risk to public safety, consideration has been given to CS470, clause 3.2 and its accompanying note. The clause gives several factors to consider but key considerations have been given to the following: *(numbering of the below is specific to clause 3.2 of CS470)*

1. The consequence of failure – The consequence of failure is extreme; the structure carries a two-lane local road over the A591 Kendal Bypass dual carriageway.

2. Nature of the structural weakness – refer to A4.2.6 and A4.2.7 and point 3 below.

3. Any corresponding signs of distress – Although there are cracks to the re-entrant corners, they are historical and are not indicative of a structure that is overloaded to the extent that the 2023 half-joint assessment determines (unknown level of live loading experienced but assessed as inadequate for permanent load).

4. The possibility of hidden distress – There is a high possibility of signs of hidden distress, the internal areas of the half joint are largely inaccessible, even with a borescope, due to debris and formwork that remains from construction.

5. Condition data – Only the half-joints have been subject to inspection under the 2023 assessment. The post-tensioning is a hidden critical element and has not been inspected. However, no defects were observed that raised concerns over the stability and adequacy of the structure. Other notable defects related to the expansion joints and surfacing but these are matters of typical maintenance and do not directly affect capacity. The structure is not sensitive to these defects and in the event that the expansion joints and surfacing were to be considered in perfect condition, the overall capacity of the structure would not change.

6. The sensitivity of the structure to the applied loading – The structure is not 'sensitive' to the applied loading. The structure is not adequate for self-weight.

7. The recent load history of the structure – The structure has been rated as having a capacity of 40T GVW and full HA loading since the 1995 assessment. As such, the structure has been subject to significantly more load than this assessment allows for a period in excess of 50 years, although the actual level of live loading experienced by the bridge is unknown. Given this exposure to live loading over such a period of

time, it would be expected that there would be severe defects visible, if there had not already been partial collapse / propping / strengthening work carried out.

8. The level of assessment completed – The level of assessment for both 1995 and 2023 assessments is Level 1, CS454 Table 2.20.1, i.e., simple structural analysis methods and conservative assumptions for material properties. Clear discrepancies have been identified between the design information, assessment information and as-constructed records. Intrusive works have been recommended to the Client to ensure than an accurate Level 3 assessment can be carried out in accordance with CS454 Table 2.20.1

Note: The past performance of the structure under unrestricted loading can inform the assessment of whether an immediate risk is posed – the bridge has performed satisfactorily under live loading for a prolonged period (although the level of live loading experienced is unknown) albeit with evidence of historical cracking to the re-entrant corners of the half-joint nibs.

As a result of the assessed inadequacies, it would be expected that significant progressive cracking would be evident to the re-entrant corners of the half-joints or bearing shelf prior to yielding of the steel within the half-joints which act as corbels.

Considering the above points, the structure cannot be categorised as anything other than immediate risk and so the structure must be closed to all live loads. However, under clause 6.9 of CS470 the structure can also be considered monitoring appropriate. With the removal of live loads on Underbarrow, the likelihood of collapse under permanent loading only is low given the above discussion of points under clause 3.2 of CS470, as a result there are currently no recommended restrictions to the A591 below unless evidence of distress or further deterioration of the half-joints is observed. Furthermore, no additional interim measures (i.e., propping or removal of the suspended span) are considered necessary at this time; this being on the basis that the structure has been in use since construction in 1970.

The results from this proposed monitoring regime will inform future decisions to implement (or retract) further actions (via 'interim measures') that would be taken if there is evidence of distress, or if further deterioration of the half-joints is observed. Future decisions may also be informed by Level 3 assessment, once the findings of intrusive investigations have been obtained.

In summary, considering the various aspects of CS470, other than closure of the structure to all live loading no additional interim measures (i.e. propping or removal of the suspended span) are considered necessary at this time; this being on the basis that a monitoring regime is implemented whilst the Level 3 assessment and necessary intrusive works are carried out to determine a more certain load carrying capacity which is (as far as is possible) free of ambiguity and assumptions.

To facilitate an effective monitoring regime, it will be necessary to inspect more of the internal surfaces of the half-joints than has currently been possible. The condition of each half-joint remains unknown along up to 90% of their length due to the presence of polystyrene filler material, expansion joints and surfacing. Works to expose the half-joints, hindered by the presence of these materials, is recommended.

A3. Sub-standard Structure Summary

Structure Name:		**Underbarrow**		
Structure Ref. No.:		**SL221**		
Assessment/ Review	**Stage:**	Level 1 Assessment incl. half-joints	Level 1 Assessment of half-joints only	CS470 Interim Measures Appraisal
	Date:	14th February 1995	4th July 2024	29th September 2023
	Report reference:	E06511 - Underbarrow and Brigsteer – Assessment	BCU00015-JAC-SBR-6330-RP-SL221-CB-009, Half-Joint Assessment Report - Underbarrow	This document, ref. BCU00015-JAC-SBR-6330-RP-SL221-CB-010
	Assessed capacity:	**ULS** 40T ALL 22.5HB (14HB*) Units **SLS** Inadequate for permanent loads	**ULS** Half Joints: Inadequate for permanent loads. **SLS** Half Joints: Inadequate for permanent loads (lower nib). *Note: Assessment of half-joints only.*	**ULS** Half Joints: Inadequate for permanent loads. **SLS** Half Joints: Inadequate for permanent loads (lower nib).
	Sub-standard status:	Sub-standard	Half Joints: Sub-standard. See 'Additional Notes'.	Half Joints: Sub-standard.
Interim Measures Feasibility Assessment	**Date:**	N/A	N/A	29th September 2023
	Is the structure an Immediate Risk structure or a low risk provisionally sub-standard structure?	N/A	Low Risk, provisionally sub-standard.	Immediate Risk Structure.
	Is the structure monitoring appropriate?	N/A	N/A	No.
Interim Measures Proposal	**Date:**	N/A	N/A	29th September 2023
	Recommendations:	N/A	N/A	Close the bridge to all users and consider decommissioning/ replacement of the bridge. Alongside the closure, monitor the bridge's performance under its permanent loads until its decommissioning, for evidence of distress which would warrant closing the route passing under the bridge, or until investigations and further (Level 3) assessment improves its load rating.
Interim Measures Approval	**Date:**	N/A	N/A	TBC
	Approval/Rejection:	N/A	N/A	TBC
Actions	**Implementation date:**	N/A	N/A	TBC
	Details/ref:	N/A	N/A	TBC
	Provisional finish date for monitoring:	N/A	N/A	TBC
	Removal date:	N/A	N/A	TBC
Documentation	**Form used:**	N/A	N/A	CS470 Appendix A6.
	Date:	N/A	N/A	29th September 2023
Additional Notes		The assessment is considered as Level 1 because there are no records to verify the assumptions used throughout the assessment. Many of the assumptions used throughout the 1995 assessment conflict with site findings and the design calculation records. * If the HB vehicle travels within 150mm of the kerb, allowing associated HA loading, then the assessed capacity reduces to 14 HB units, limited by the lower nib of the half-joints	Based on the results of the 2023 assessment, the half-joints have been found to be inadequate for permanent loads at ULS and SLS. The assessment report recommends that investigative works are carried out to ascertain the true construction details and material strengths. In the interim, the structure is considered to be sub-standard because of the 2023 assessment.	Sensitivity analysis has been carried out using lower bound (strut and tie) analysis with partial factors set to 1.0 and the bridge is still found to be inadequate for permanent loads. Upper bound analysis has not been carried out.

A4 Interim Measures Feasibility Assessment for Bridges

A4.1 GENERAL DETAILS

A4.1.1 Structure Name and Assessment Reference:

SL221 Underbarrow, BCU00015-JAC-SBR-6330-RP-SL221-CB-009, Half-Joint Assessment Report – Underbarrow.

A4.1.2 Location, Route, and County/Area:

Underbarrow carries the C5048 single carriageway Underbarrow Road east and west over the A591, Kendal Bypass County Road, west of Kendal.

A4.1.3 Assessing Organisation:

Assessed by: Jacobs UK Ltd

Checked by: [redacted](CAT3 Check to CG300).

Assessment date: 4th July 2024 (date signed by TAA). - assessment of the half-joints only.

Other deck elements were assessed by Cumbria County Council in 1995, with the assessment certification dated 14th February 1995.

A4.1.4 Structure Type, Form, Span, Skew:

Single span superstructure comprising in-situ concrete cantilevers, integral with large abutments, and a precast concrete beam suspended span supported on half-joints. The cantilevers are longitudinally post-tensioned and integral with the abutments; both cantilevers and abutment are voided. The suspended span comprises 17 No. prestressed pre-tensioned concrete beams and an in-situ reinforced concrete deck slab that is considered as acting compositely. The inner beams are inverted T-beams and are transversely post-tensioned. The edge beams are box beams, connected to the rest of the deck by reinforcement protruding from the inner side of each beam. The suspended span is supported by half-joints at the ends of the cantilevers.

The west cantilever and integral abutment contain 26 No. post-tensioned cables which are typically at 457.2mm centres. The cables are located within the upper areas of the voided construction, to resist tension due to hogging bending moments, and taper down at either end of the element. The cables which are situated directly above the vertical walls of the voided construction terminate within the walls and do not extend to the half-joints. All the anchorages appear to be recessed into the concrete; although no details are given regarding any capping, it is expected that the recesses were capped following tensioning. At the half-joint the tendons are anchored in the upper area of the deck and do not provide any strength to the lower nib of the half-joint. The strength of the lower nib therefore comes predominantly from the reinforced concrete detailing only and acts in a similar manner to a corbel.

The east cantilever and integral abutment contain 26 No. post-tensioned cables which are typically at 457.2mm centres. The cables are located within the upper areas of the voided construction and taper down at either end of the element. The cables which are situated directly above the vertical walls of the voided construction terminate within the walls and do not extend to the half-joints. All the anchorages appear to be recessed into the concrete; although no details are given regarding any capping, it is expected that the recesses were capped following tensioning. At the half-joint the tendons are anchored in the upper area of the deck and do not provide any strength to the lower nib of the half-joint. The strength of the lower nib therefore comes from the reinforced concrete detailing only and acts in a similar manner to a corbel.

A4.1.5 Obstacle Crossed and Facility Carried:

Underbarrow carries the C5048 single carriageway Underbarrow Road east – west over the A591, Kendal Bypass County Road.

A4.1.6 Estimated Cost of Permanent Strengthening/Replacement Works:

Permanent strengthening / replacement has not been considered at this stage.

A4.2 ASSESSMENT PROGRESS

A4.2.1 Level of Assessment Reached:

Level 1 (CS454 Table 2.20.1 - Simple structural analysis methods and conservative assumptions for material properties) by the 2023 assessment for the half-joints only. The other elements of the deck were assessed at Level 1 by the 1995 assessment and found to be adequate. The 2023 assessment of the half-joints is discussed below.

Analysis

The suspended span deck was analysed using a 2-D computer grillage model, assuming original design deck articulation, to obtain bearing reactions at the half-joints. The internal beams were modelled with torsion-less properties. The edge beams (box beams) retained their properties relevant to torsion.

The upper and lower nibs were assessed using the most onerous load effects. Idealised "strut and tie models" as recommended in CS466 were used for assessment of half-joints at ULS taking account of the proposed condition factor (0.9). The SLS assessment of crack widths was carried out in accordance with the methodology outlined in Appendix D of CS466.

Material Properties

The material properties were assumed in accordance with the values shown on the record drawings.

Concrete Strength

Abutments/ Cantilevers: fcu = 41.4 N/mm2

Precast Beams: fcu = 51.7 N/mm2

Deck Slab: fcu = 41.4 N/mm2

Mild Steel Strength

All Elements: fy = 250 N/mm2 (BS4449:1969)

Refer to section 3.10.1 of the Approval in Principle for further information.

Condition / Inspection

Previous inspection reports have raised concerns regarding the cracking to the re-entrant corners of the lower nib. By further inspection (half-joint inspection 24th August 2022), it was concluded that the existing cracks do not appear to have grown noticeably. However, the internal surfaces of the half-joints could not be fully inspected due to the presence of polystyrene filler material. It is recommended that this is removed to allow thorough inspection of the half-joints.

One of the objectives of the half-joint inspection was to confirm that dimensions on site match those shown on record drawings and hence confidence could be taken that the record drawings are a true representation of the structure as constructed. However, the upper and lower nibs of the half-joints appear to have different depths (larger lower nib and smaller upper nib) to those shown on the record drawings (see Table 1 in Executive Summary), and so it was concluded that the record drawings aren't wholly reliable.

For assessment purposes, the sizes of the upper and lower nib were taken as measured during the 2022 inspection.

As there has been no confirmation of the reinforcement detail by breakout and inspection, the reinforcement layout (arrangement of bars) as shown on record drawings was used for assessment and was found relatively consistent with that indicated by scanning techniques on site. The size of reinforcement has been considered as scanned, which differs to that (in that it offers less resistance) in the 1995 assessment (refer to Table 2 in Executive Summary).

The recommended condition factor for assessment was = 0.9.

A4.2.2 Assessed Capacity:

The 2023 assessment was limited to the assessment of the half-joints only.

The assessment concluded that the half-joints are inadequate for permanent loads. At ULS, the ties within each of the applicable strut and tie models are noted to be the critical elements.

At SLS, the lower nib's crack width failed by a significant margin. This is due to the poor detailing of the lower nibs which do not appear to contain any inclined reinforcement. At SLS, the upper nib's cracking is controlled by the inclined reinforcement shown on record drawings. The 2022 inspection found cracking to the lower nib re-entrant corner on the north elevation and within the half-joint which would be indicative of cracking induced by poor detailing. However, 2No. cracks were also observed to the upper nib within the half-joint.

The 1995 assessment found the structure to be adequate for 40T GVW and 30 units of HB loading. However, the assessment report noted*: if the HB vehicle travels within 150mm of the kerb, allowing associated HA loading, then the assessed capacity reduces to 14 HB units, limited by the lower nib of the half-joints.*

A4.2.3 Date of Assessment:

Assessment date: 4th July 2024 (date signed by TAA). - assessment of the half-joints only.

The other deck elements were assessed by Cumbria County Council in 1995, with the assessment certification dated 14th February 1995.

A4.2.4 Assessment Report Reference:

BCU00015-JAC-SBR-6330-RP-SL221-CB-009, Half-Joint Assessment Report – Underbarrow, 2023.

BD 21/93 Load assessment report (no reference), 20th February 1995.

A4.2.5 Provisionally Sub-standard or Sub-standard?

Sub-standard.

A4.2.6 Description of anticipated mode of failure, including its progressions from local overstress to global collapse mechanism:

The 1995 Assessment Report states:

'The suspended span and the free ends of the cantilevers are over-reinforced: - the concrete will fail in compression before the tendons have started to yield. This was done deliberately, but it means that, should the bridge be overloaded, it will fail suddenly without any warning, cracking, or yielding.'

The above statement refers only to the post-tensioning within the reinforced concrete cantilevers, from which the lower nibs are supported. The post-tensioning provides no strength to the half joint elements as it terminates at the end of the cantilever above the lower nib. No assessment has been carried out (since 1995) with respect to the prestressed, pre-tensioned or post-tensioned elements, furthermore there is conflicting information between the historical records (including 1995 assessment), design records and site observations. A review of further historical information 07/03/2024 found correspondence between the Client and Contractor during the

construction period relating to the alteration of anchorage details at the rear face of the cantilevers (abutments) with no indication of alterations to the locations of tendons etc that would alter the accuracy of the above statement.

The 2023 assessment of the half-joints indicates that the reinforcement is overstressed at ULS and insufficient at SLS. As a result of the inadequacies, it would be expected that significant progressive cracking would be evident to the re-entrant corners of the half joints or bearing shelf prior to yielding of the steel within the half-joints which act as corbels.

A4.2.7 Description of Distress (if present):

There is some historical cracking of the re-entrant corner of the half-joints on the elevations of the deck and within the half-joint, but this was predicted by the 1995 assessment, which found that the SLS crack widths were more than twice the allowable width.

The 2023 assessment of the half-joints found them to be inadequate for permanent loads at SLS, but also at ULS, however the half-joint elements are not currently regarded to be in poor condition. The cracks emanating from the re-entrant corners on the elevations do not appear to have increased in width since the 2018 inspection. However, the internal surfaces of the half-joints could not be fully inspected due to the presence of polystyrene filler material and the condition of the half joint along up to 90% of its length remains unknown. By inspection of the few areas accessible via borescope, there was evidence of cracking within the half-joints on both the upper and lower nibs. Minor cracking identified within the half joint has only been identified at the 2023 inspection, presumably due to the lack of access equipment at previous inspections. It is therefore unknown whether this cracking is historical or recent.

A4.3 CONSIDERATION OF RISK POSED BY STRUCTURE IN CURRENT STATE

A4.3.1 Discussion

As the assessment finds the half-joints inadequate for permanent loads, the structure shall be considered as sub-standard in accordance with CS470. Section 3 of CS470 details the approach for assessment and classification of structures as immediate risk.

CS470, Management of Substandard Highway Structures, (clause 3.2.1 section 1a and b) prescribes that any structure that is unable to sustain nominal loading, 40T assessment live loading, with safety and material factors reduced to 1.0 (i.e., decreased load and increased resistance) under any plastic upper-bound method of analysis, shall be considered to be immediate risk. Although upper bound analysis could be carried out under the CS470 process to inform the management process, the construction arrangement and material strengths remain unconfirmed and upper bound analysis would not be recommended because of this. Upper bound analysis has not been carried out by the 2023 half-joint assessment or the CS470 process.

Lower bound sensitivity analysis has been carried out by reducing all partial load factors and material factors to unity (similarly to clause 3.2.1 section 1a and b); this has resulted in an improved Reserve Factor when compared to the Reserve Factors obtained from the assessment but the half-joints have still been found to be rated as 0 tonnes and unable to support permanent loads using the original design information and information gathered from site in 2022. Refer to the tables below for the results of the lower bound sensitivity analysis:

	Figure (App. E, CS466)	Member (Strut / Tie)	Assessment Load Effects				Assessment Resistance			Adequacy			
			Dead + Superimposed Dead + HA Loads	Dead + Superimposed Dead Loads	Type HA Vehicle Loading (40T)	SV Vehicles	Resistance	Condition Factor	Assessment Resistance	Reserve Factor (DL + SIDL)	Critical Element	Reserve Factor (DL + SIDL + HA)	Critical Element
			S^*_A	S^*_D	S^*_{HA}	S^*_{SV}			R^*_A	R^*_A / S^*_D		R^*_A / S^*_A	
Lower Nib	E.16	Strut(s)	N/A Structure inadequate for permanent Loads	5.21	N/A Structure inadequate for permanent Loads	N/A Structure inadequate for permanent Loads	17.62	0.9	15.86	3.05	Fs1	N/A Structure inadequate for permanent Loads	N/A Structure inadequate for permanent Loads
		Ties(s)		370.9			250		225	0.61	Ft4		
		Node(s)		5.21			24.96		22.46	4.31	Node A/B		
	E.3	Strut(s)		6.21			17.62		15.86	2.55	Fs1		
		Ties(s)		404.7			250		225	0.5	Ft5		
		Node(s)		6.21			24.96		22.46	3.62	Node A		
	E.9	Strut(s)		6.32			17.62		15.86	2.51	Fs1		
		Ties(s)		228.9			250		225	0.98	Ft1		
		Node(s)		6.32			24.96		22.46	3.55	Node A/B		

	Figure (App. E, CS466)	Member (Strut / Tie)	Assessment Load Effects				Assessment Resistance			Adequacy			
			Dead + Superimposed Dead + HA Loads	Dead + Superimposed Dead Loads	Type HA Vehicle Loading (40T)	SV Vehicles	Resistance	Condition Factor	Assessment Resistance	Reserve Factor (DL + SIDL)	Critical Element	Reserve Factor (DL + SIDL + HA)	Critical Element
			S^*_A	S^*_D	S^*_{HA}	S^*_{SV}			R^*_A	R^*_A / S^*_D		R^*_A / S^*_A	
Upper Nib	E.16	Strut(s)	N/A Structure inadequate for permanent Loads	3.57	N/A Structure inadequate for permanent Loads	N/A Structure inadequate for permanent Loads	20.91	0.9	18.8	5.27	Fs2	N/A Structure inadequate for permanent Loads	N/A Structure inadequate for permanent Loads
		Ties(s)		238.4			250		225	0.95	Ft2/3		
		Node(s)		3.57			26.67		23.5	6.58	Node B		
	E.3	Strut(s)		4.81			20.91		18.8	3.9	Fs2		
		Ties(s)		488.1			250		225	0.46	Ft5		
		Node(s)		4.81			29.6		26.7	5.55	Node A/D		
	E.15	Strut(s)		2.91			20.91		18.8	6.46	Fs1		
		Ties(s)		153			250		225	1.47	Ft2		
		Node(s)		2.91			29.6		26.7	9.18	Node A		
	E.9	Strut(s)		6.8			20.91		18.8	2.77	Fs1		
		Ties(s)		383.37			250		225	0.59	Ft1		
		Node(s)		6.79			26.67		23.5	3.46	Node A/B		

To the requirements of CS470 clause 3.2.1, part 1(b), the structure would have to be subjected to upper bound analysis with partial factors reduced to 1.0 to be classified as an Immediate Risk. Upper bound analysis has not been completed however lower bound sensitivity analysis has been carried out with partial factors reduced to 1.0. Given that the Level 1 assessment, and sensitivity analysis, has shown that the bridge is inadequate for its own permanent loads, the structure has been determined as Immediate Risk and advise that it be closed to all users until it can be decommissioned or until investigations and further (Level 3) assessment improves its load rating.

CS470 (clause 3.2.1 section 2) prescribes that the assessment load may be distributed evenly across each element, however this only attributable to structures that have some level of capacity for live loads i.e., 3T or above. In the event that a structure has no capacity for live load, as is the case for Underbarrow, then the structure is to be considered an Immediate Risk.

The likelihood of an improved load rating through investigations is considered relatively low, considering the margin of failure found by the assessment and following a review of all available historical information, where no evidence was found of any significant alterations having been carried out during construction, which would have increased the capacity (load rating) of the half-joints.

Given the above, in advance of any intrusive investigations to confirm construction details and material properties, it is considered sensible to carry out sensitivity analysis based on 'best case' assessment parameters and material information. This could be undertaken to understand what load carrying capacity the structure's half-joints may be capable of if it is proven through intrusive works that a greater size and strength of reinforcement exists within the half-joints.

A4.4 APPROPRIATENESS OF MONITORING

A4.4.1 Discussion

The purpose of monitoring would be to identify signs of predicted overstress, to react prior to elements leading to a deteriorated state where emergency intervention is required. As stated in A4.2.7 there are currently no signs of what is considered to be overstress of the reinforcement.

The structure is considered to satisfy all the criteria listed in clause 6.9 of CS470 as discussed in sections A4.2.6, A4.2.7 and A4.3.1, and therefore the structure can be considered as monitoring appropriate:

Distress – There is some cracking of the re-entrant corner of the half-joints on the elevations of the deck, but this is historical and does not appear to have worsened since the 2018 inspection.

The 2023 assessment of the half-joints found them to be inadequate for permanent loads at SLS, but also at ULS, however the half-joint elements are not currently regarded to be in poor condition. The cracks emanating from the re-entrant corners do not appear to have increased in width since the 2018 inspection. The internal surfaces of the half-joints could not be fully inspected due to the presence of polystyrene filler material, and the condition of the half joint along up to 90% of its length remains unknown. By inspection of the few areas accessible via borescope, there was evidence of minor cracking within the half-joints on both the upper and lower nibs. Minor cracking identified within the half joint has only been identified at the 2023 inspection, presumably due to the lack of access equipment at previous inspections. It is therefore unknown whether this cracking is historical or recent.

Redundancy, ductility, predictability – The half-joints have been assessed as inadequate for permanent loads but have for a period in excess of 50 years carried some unknown level of live load. Over time, signs of distress would be expected to have progressed from local distress (minor cracking) to major distress indicative of imminent collapse. Numerical assessment indicated inadequacies in the half-joints' capacity, which would carry significant consequences as the suspended span could collapse on to the A591. The structure should be closed to all live loads, which provides the opportunity to effectively inspect and monitor the internal faces of the half-joint. Monitoring will allow any signs of local distress (minor or severe) to be identified and monitored.

Risk (likelihood and consequence) – The likelihood of local collapse is considered relatively low given that the structure has been in service without any known load restrictions for the loads it has been assessed to since construction and that there are no significant defects that are attributable to distress (the defects identified are not considered to be indicative of moderate or severe distress). The risk has been assessed considering the following points in accordance with clause 3.2 of CS470:

1. The consequence of failure – The consequence of failure is extreme; the structure carries a two-lane local road over the A591 Kendal Bypass dual carriageway.

2. Nature of the structural weakness – refer to A4.2.6 and A4.2.7 and point 3 below.

3. Any corresponding signs of distress – Although there are cracks to the re-entrant corners, they are historical and are not indicative of a structure that is overloaded to the extent that the 2023 half-joint assessment determines (unknown level of live loading experienced but assessed as inadequate for permanent load).

4. The possibility of hidden distress – There is a high possibility of signs of hidden distress, the internal areas of the half joint are largely inaccessible, even with a borescope, due to debris and formwork that remains from construction.

5. Condition data – Only the half-joints have been subject to inspection under the 2023 assessment. The post-tensioning is a hidden critical element and has not been inspected. However, no defects were observed that raised concerns over the stability and adequacy of the structure. Other notable defects related to the expansion joints and surfacing but these are matters of typical maintenance and do not directly affect capacity. The structure is not sensitive to these defects and in the event that the expansion joints and surfacing were to be considered in perfect condition, the overall capacity of the structure would not change.

6. The sensitivity of the structure to the applied loading – The structure is not 'sensitive' to the applied loading. The structure is not adequate for self-weight.

7. The recent load history of the structure – The structure has been rated as having a capacity of 40T GVW and full HA loading since the 1995 assessment. As such, the structure has been subject to significantly more load than this assessment allows for a period in excess of 50 years, although the actual level of live loading experienced by the bridge is unknown. Given this exposure to live loading over such a period of time, it would be expected that there would be severe defects visible, if there had not already been partial collapse / propping / strengthening work carried out.

8. The level of assessment completed – The level of assessment for both 1995 and 2023 assessments is Level 1, CS454 Table 2.20.1, i.e., simple structural analysis methods and conservative assumptions for material properties. Clear discrepancies have been identified between the design information, assessment information and as-constructed records. Intrusive works have been recommended to the Client to ensure than an accurate Level 3 assessment can be carried out in accordance with CS454 Table 2.20.1

Note: The past performance of the structure under unrestricted loading can inform the assessment of whether an immediate risk is posed – the bridge has performed satisfactorily under live loading for a prolonged period (although the level of live loading experienced is unknown) albeit with evidence of historical cracking to the re-entrant corners of the half-joint nibs.

As a result of the assessed inadequacies, it would be expected that significant progressive cracking would be evident to the re-entrant corners of the half-joints or bearing shelf prior to yielding of the steel within the half-joints which act as corbels.

Effectiveness and meaningfulness of monitoring – Monitoring the structure through visual inspection, by taking measurements, and by using non-destructive testing techniques is considered an effective means of monitoring, as significant distress would be observed on the surface of the elements.

A4.4.2 Is the Structure Monitoring-Appropriate?

As the bridge is considered to be an Immediate Risk structure, strictly it should not be considered monitoring-appropriate in accordance with CS470. However, for the reasons given in A4.4.1 which is backed up by statements contained within CS470, the structure is deemed both immediate risk and monitoring appropriate under its permanent loading while closed to all users.

Underbarrow has been found inadequate for its own permanent load and will remain in place until such time as it can be decommissioned, or until intrusive investigations and further (Level 3) assessment can improve its load rating, it should be monitored under permanent loading for evidence of distress which, if it was found to occur in the future, would warrant consideration of a decision to close the route passing under the bridge.

As discussed in A4.2.6, it would be expected that significant progressive cracking would be evident to the re-entrant corners of the half joints or bearing shelf prior to yielding of the steel.

It should be noted that any regular monitoring regime will require access to the dual carriageway below. To ensure safe access can be provided, it is expected that as a minimum, phased lane closures would be required in each direction of travel with an impact protection vehicle utilised. Due to the busyness of the route and the only suitable diversion route being through Kendal town centre, the most appropriate window of inspection would be overnight.

The provision and cost of access (Mobile Elevated Work Platform) should also be considered.

A4.5 OPTIONS FOR LOAD MITIGATION INTERIM MEASURES

CS 470, Clause 6.1.1, states that load mitigation interim measures should comprise one or more of the following actions:

1. vehicle weight restrictions, calculated in accordance with CS454.
2. lane restrictions, calculated in accordance with CS454.
3. propping of the structure.
4. use of a temporary structure.
5. closure of the structure to all users or classes of vehicles.

Of the actions noted above, it is considered that only 'closure of the structure to all users' is appropriate on the following basis:

- The assessment has found the structure to be overstressed at permanent loads and therefore weight restrictions and lane restrictions are not sufficient – the structure needs to be closed to all users.
- The half-joints are positioned directly above the carriageway of the A591 below and it is therefore not feasible to install props in combination with long-term traffic management that would be required.
- The site does not allow for the opportunity to utilise a temporary structure without significant cost.

A4.5.1 Option 1: Closure of the structure to all users

Description

In this instance, the structure would be closed to all users (vehicular and pedestrian traffic) due to being found to be overstressed for permanent loads at ULS and SLS. It would remain closed until it can be decommissioned or investigations and further (Level 3) assessment improves its load rating.

Operational and cost implications

Operational costs are considered to be very high. It should be noted that SL221 Underbarrow and 'sister' bridge SL240 Brigsteer have both had their half-joints assessed and found to be overstressed for permanent loads. Any closure of SL221 Underbarrow because of it being found sub-standard by recent assessment would also need to be applied so SL240 Brigsteer. The diversion route for both structures is via Kendal town centre, but this may not be considered suitable for the diversion of the volumes of traffic that would be generated by the closure of one or both structures.

There are not considered to be any particular cost implications, other than the installation and maintenance of equipment used to enforce the closure of the structure.

Other implications

Reputational damage would be likely.

A4.6 OPTIONS FOR MONITORING INTERIM MEASURES

A4.6.1 Option 1: Monitoring from Ground Level and Deck Level

Description

Underbarrow is considered under CS470 to be an immediate risk structure and strictly it should not be considered monitoring-appropriate (because it is immediate risk). However, for the reasons given in A4.4.1 considering various clauses of CS470, the structure is also deemed monitoring appropriate under its permanent loading only, in the scenario that Underbarrow is closed to all users.

Underbarrow should be monitored under its own permanent loading for any evidence of distress or deterioration which, if it was found to occur at some time in the future would warrant consideration of a decision to close the route passing under the bridge.

Monitoring should remain in place until such time as the bridge can be decommissioned, or until intrusive investigations and further (Level 3) assessment can improve its load rating.

Implement monitoring of the deck from ground level using binoculars and from deck level above. This monitoring should include opening up of each expansion joint, initially 2No trial pits per expansion joint, 500mm in length towards the edges of the carriageway, including removal of filler material and formwork from the joint gaps to allow visual inspection of the lower nib re-entrant corner. The excavation should be covered with road plates between inspections along with appropriate measures to minimise flow of rainwater through the joint, such as sealants. Precautions should be taken so as to not load the suspended span with plant, materials, or personnel.

The frequency of monitoring inspections in the short term should be every month for the first 3 months. The frequency of monitoring inspections should be reviewed following each inspection, and if necessary, frequency increased depending on the on the findings. Any change to the frequency should be reviewed, recorded and approved as part of a CS470 report update. Monitoring should continue until either:

- Investigations and further (Level 3) assessment improves the load rating, at which point the CS470 will be revised/withdrawn as appropriate,

  or,

- Proposals for the continued management of the substandard structure are agreed and implemented, or a permanent solution (replacement etc.) is commissioned.

Effectiveness of monitoring regime with reference to anticipated failure mode

Monitoring for evidence of crack elongation, rust staining and spalling to the half-joints would provide a clear indication of evidence of the predicted failure mode. These defects could be detectable from ground level with the use of binoculars. However, there is still risk of defects being missed since inspecting from ground level is not as reliable as inspecting from touching distance. It should also be noted that by monitoring from ground level, there is no access or method of viewing the internal faces of the half joints, monitoring from ground level will only allow for inspection of the half joint elevations, most notably the re-entrant corners.

For the reasons outlined above, it is recommended that Option 1 should not be undertaken as a standalone monitoring measure.

Risk of collapse

The purpose of monitoring would be to identify signs of predicted overstress, to react prior to elements leading to a deteriorated state where emergency intervention is required. As stated in section 4.2.7 there are no signs of what is considered to be overstress of the reinforcement local to the half-joints.

Risk of damage at loads lower than the collapse load

The structure has been found inadequate for permanent loads with partial and material factors set to unity. Considering the assessment rating and further sensitivity checks, any applied loads would risk damaging the structure or even collapse of the suspended span, see 4.2.7.

The structure has been found inadequate for permanent loads but has continued to successfully carry vehicular loading, therefore the risk of collapse is considered low given the observed condition of the structure. However, the recommendation is to close the bridge to all users until it can either be decommissioned or investigations and further (Level 3) assessment improves its load rating.

Operational and cost implications

Increasing the frequency of inspections will incur additional cost, however, this is justified to reduce the associated risks to sub-standard elements by informing the asset team of the current status and allowing timely intervention. Inspection from ground level will be a lot cheaper and less disruptive than implementing TM and access equipment.

Other implications

None.

A4.6.2 Option 2: Tactile Special Inspection Monitoring

Description

Inspection and monitoring of the half-joints from touching distance (i.e., MEWP access provided) and hand tools including hammer testing for spall / loose concrete is recommended at 0 months, 3 months, 6-months, and then 6-monthly intervals. The intervals could be reviewed depending on the results from the tactile inspections.

Consideration should be given to the installation of tell-tales as discussed in A2.2.2, which would increase the accuracy of crack monitoring widths.

Effectiveness of monitoring regime with reference to anticipated failure mode

Tactile visual inspection at the intervals outline above would establish any increase in the cracks emanating from the re-entrant corners of the half-joints which have been observed as not increasing in width when compared to available historical inspection reports. The intervals could be reviewed depending on the results from the tactile inspections. All filler material and sealants to the half-joints would need to be removed to facilitate inspection of the internal surfaces using a borescope (note, the effectiveness of a borescope is limited by the presence of debris and lack of light within the half joint). Removal of all filler material within the joints may be difficult and will likely require access from above and below the half-joints, however all efforts shall be made in order to allow thorough inspection of the internal surfaces of the half-joints. Removal of sealant would increase the risk of water ingress and subsequent corrosion and deterioration of the half-joints, and so re-application of sealant would be recommended following each inspection.

Risk of Collapse

The purpose of monitoring would be to identify signs of predicted overstress, to react prior to elements leading to a deteriorated state where emergency intervention is required. As stated in section 4.2.7 there are no signs of what is considered to be overstress of the reinforcement local to the half-joints.

Risk of damage at loads lower than the collapse load

The structure has been found inadequate for permanent loads with partial and material factors set to unity. Considering the assessment rating and further checks in accordance with CS470, it is considered that any applied loads would risk damaging the structure or even collapse of the suspended span, see 4.2.7.

The structure has been found inadequate for permanent loads but has continued to successfully carry vehicular loading, therefore the risk of collapse is considered low given the observed condition of the structure. However, the recommendation is to close the bridge to all users until it can either be decommissioned or investigations and further (Level 3) assessment improves its load rating.

Operational and cost implications

Increasing the frequency of inspections will incur additional cost, however, this is justified to reduce the associated risks to sub-standard elements by informing the asset team of the current status and allowing timely intervention. Yearly traffic management and access equipment implementation will increase the operational and cost implications.

Other implications

None.

A4.6.3 Option 3: Non-destructive Testing/Monitoring

Description

The following are examples of non-destructive testing, common to half-joint structures:

- Impact echo testing - non-destructive to the structures under study. It is based on a frequency analysis of the structure's vibrational response when subjected to a shock.
- Radiography - a non-destructive testing method which uses either x-rays or gamma rays to examine the internal structure of manufactured components identifying any flaws or defects.
- Acoustic emission testing - Acoustic emission testing is a non-destructive testing technique that detects and monitors the release of ultrasonic stress waves from localised sources when a material deforms under stress.
- Thermography - Infrared thermography for non-destructive testing and evaluation aims at the detection of subsurface features (i.e., subsurface defects, anomalies, etc.).

Effectiveness of monitoring regime with reference to anticipated failure mode

This method would decrease the risk of missing any defects which are present sub-surface and hence not visible at regular tactile inspections. It is suggested that any non-destructive testing should be carried out at intervals concurrent to tactile inspections.

Risk of Collapse

The purpose of monitoring would be to identify signs of predicted overstress, to react prior to elements leading to a deteriorated state where emergency intervention is required. As stated in section 4.2.7 there are no signs of what is considered to be overstress of the reinforcement local to the half-joints.

Risk of damage at loads lower than the collapse load

The structure has been found inadequate for permanent loads with partial and material factors set to unity. Considering the assessment rating and further checks in accordance with CS470, it is considered that any applied loads would risk damaging the structure or even collapse of the suspended span, see 4.2.7.

The structure has been found inadequate for permanent loads but has continued to successfully carry vehicular loading, therefore the risk of collapse is considered low given the observed condition of the structure. However,

the recommendation is to close the bridge to all users until it can either be decommissioned or investigations and further (Level 3) assessment improves its load rating.

Operational and cost implications

Increasing the frequency of inspections will incur additional cost, however, this is justified to reduce the associated risks to sub-standard elements by informing the asset team of the current status and allowing timely intervention.

Other implications

None.

A4.7 RECOMMENDED OPTIONS FOR INTERIM MEASURES

A4.7.1 Recommended Load Mitigation Interim Measures:

The structure has recently closed to all live loads, following the recommendation made in the previous revision of this report, and there are no recent defects that have been observed to suggest that the structure is in distress under the previous unrestricted loading or that the historical cracking is worsening.

The Level 1 assessment has found the bridge to be inadequate for permanent loads, even with partial factors set to unity. Considering the assessment rating and further sensitivity checks, the structure is deemed an Immediate Risk and the implementation of a closure to all users is justifiable. The closure should remain in place until the bridge can be decommissioned or investigations and further (Level 3) assessment improves its load rating.

The risk of collapse under permanent loading only is considered to be low, refer to A4.4.1, and therefore no restrictions are recommended for the A591 below.

A4.7.2 Recommended Monitoring Interim Measures:

The bridge should be closed to all users as outlined above, however, as the assessment has found the bridge to be inadequate to support its permanent loads, it is recommended that a combination of all three monitoring interim measures options is implemented alongside the closure, whilst the bridge remains in place and under permanent loading. It is recommended that the half-joints be monitored monthly for the first 3-months from ground level with binoculars, and from above the expansion joints at deck level. The Intervals between monitoring should be reviewed following the initial 3-month period A Special Inspection within touching distance is recommended at 0 months, 3 months, 6-months, and then 6-monthly intervals. The intervals could be reviewed depending on the results from the tactile inspections. A specialist testing company should also be engaged to undertake the NDT testing/monitoring to further establish the presence of any hidden defects in the half-joints.

Alongside the above recommended monitoring, it is further recommended that intrusive investigations and material testing are carried out to establish material condition and strengths to inform further (Level 3) assessment work with a view to improving the assessed capacity and reviewing the interim measures.

The likelihood of an improved load rating through investigations is considered relatively low, considering the margin of failure found by the assessment and following a review of all available historical information, no evidence was found of any significant alterations having been carried out during construction, which would have increased the capacity (load rating) of the half-joints.

Given the above, in advance of any intrusive investigations to confirm construction details and material properties, it is considered sensible to carry out sensitivity analysis based on 'best case' assessment parameters and material information. This could be undertaken to understand what load carrying capacity the structure half-joints may be capable of if it is proven through intrusive works that a greater size and strength level of reinforcement exists within the half-joints.

A6 Proposal for Interim Measures

A6.1 GENERAL DETAILS

A6.1.1 Structure Name and Assessment Reference:

SL221 Underbarrow, BCU00015-JAC-SBR-6330-RP-SL221-CB-009, Half-Joint Assessment Report – Underbarrow.

A6.1.2 Location, Route, and County/Area:

Underbarrow carries the C5048 single carriageway Underbarrow Road east and west over the A591, Kendal Bypass County Road, west of Kendal.

A6.1.3 Assessing Organisation:

Assessed by: Jacobs UK Ltd

Checked by: [redacted] (CAT3 Check to CG300).

Assessment date: 4th July 2024 (date signed by TAA). - assessment of the half-joints only.

Other deck elements were assessed by Cumbria County Council in 1995, with the assessment certification dated 14th February 1995.

A6.1.4 Structure Type, Form, Span, Skew:

Single span superstructure comprising in-situ concrete cantilevers, integral with large abutments, and a precast concrete beam suspended span supported on half-joints. The cantilevers are longitudinally post-tensioned and integral with the abutments; both cantilevers and abutment are voided. The suspended span comprises 17 No. prestressed pre-tensioned concrete beams and an in-situ reinforced concrete deck slab that is considered as acting compositely. The inner beams are inverted T-beams and are transversely post-tensioned. The edge beams are box beams, connected to the rest of the deck by reinforcement protruding from the inner side of each beam. The suspended span is supported by half-joints at the ends of the cantilevers.

The west cantilever and integral abutment contain 26 No. post-tensioned cables which are typically at 457.2mm centres. The cables are located within the upper areas of the voided construction, to resist tension due to hogging bending moments, and taper down at either end of the element. The cables which are situated directly above the vertical walls of the voided construction terminate within the walls and do not extend to the half-joints. All the anchorages appear to be recessed into the concrete; although no details are given regarding any capping, it is expected that the recesses were capped following tensioning. At the half-joint the tendons are anchored in the upper area of the deck and do not provide any strength to the lower nib of the half-joint. The strength of the lower nib therefore comes from the reinforced concrete detailing only and acts in a similar manner to a corbel.

The east cantilever and integral abutment contain 26 No. post-tensioned cables which are typically at 457.2mm centres. The cables are located within the upper areas of the voided construction and taper down at either end of the element. The cables which are situated directly above the vertical walls of the voided construction terminate within the walls and do not extend to the half-joints. All the anchorages appear to be recessed into the concrete; although no details are given regarding any capping, it is expected that the recesses were capped following tensioning. At the half-joint the tendons are anchored in the upper area of the deck and do not provide any strength to the lower nib of the half-joint. The strength of the lower nib therefore comes predominantly from the reinforced concrete detailing only and acts in a similar manner to a corbel.

A6.1.5 Obstacle Crossed or Facility Carried:

Underbarrow carries the C5048 single carriageway Underbarrow Road east and west over the A591, Kendal Bypass County Road.

A6.2 PROPOSED INTERIM MEASURES

A6.2.1 Summary of Assessment Progress.

Level 1 (CS454 Table 2.20.1 - Simple structural analysis methods and conservative assumptions for material properties) by the 2023 assessment for the half-joints only. The other elements of the deck were assessed at Level 1 by the 1995 assessment and found to be adequate. The 2023 assessment of the half-joints is discussed below.

Analysis

The suspended span deck was analysed using a 2-D computer grillage model, assuming original design deck articulation, to obtain bearing reactions at the half-joints. The internal beams were modelled with torsion-less properties. The edge beams (box beams) retained their properties relevant to torsion.

The upper and lower nibs were assessed using the most onerous load effects. Idealised "strut and tie models" as recommended in CS466 were used for assessment of half-joints at ULS taking account of the proposed condition factor (0.9). The SLS assessment of crack widths was carried out in accordance with the methodology outlined in Appendix D of CS466.

The 2023 assessment was limited to the assessment of the half-joints only.

The assessment concluded that the half-joints are inadequate for permanent loads. At ULS, the ties within each of the applicable strut and tie models are noted to be the critical elements.

Some subsequent sensitivity analysis has been carried out using lower bound (strut and tie) models with partial factors reduced to 1.0. The results of this sensitivity analysis are tabulated in Appendix A4.

At SLS, the lower nib's crack width failed by a significant margin. This is due to the poor detailing of the lower nibs which do not appear to contain any inclined reinforcement. At SLS, the upper nib's cracking is controlled by the inclined reinforcement shown on record drawings.

The 1995 assessment found the remaining elements of the deck to be adequate for 40t ALL and 30 units of HB loading.

A6.2.2 Summary of Feasibility of Options for Interim Measures.

Load Mitigation Interim Measures

Option 1: Closure of the structure to all users

Monitoring Interim Measures

Option 1: Monitoring from Ground Level

Option 2: Tactile Special Inspection Monitoring

Option 3: Non-destructive Testing/Monitoring

Refer to Appendix A4 for details.

A6.2.3 Summary of Recommended Load Mitigation Interim Measures Including Maximum Duration and Date for Formal Review.

The structure has recently closed to all live loads, following the recommendation made in the previous revision of this report, and there are no recent defects that have been observed to suggest that the structure is in distress under the previous unrestricted loading or that the historical cracking is worsening.

The Level 1 assessment has found the bridge to be inadequate for permanent loads with partial factors set to unity. Considering the assessment rating and further sensitivity checks, the structure is deemed an Immediate Risk and the implementation of a closure to all users is justifiable. The closure should remain in place until the bridge can be decommissioned or investigations and further (Level 3) assessment improves its load rating.

A6.2.4 Summary of Recommended Monitoring Interim Measures, if appropriate (refer to Monitoring Specification, attached as an appendix) including maximum duration and date for formal review.

The bridge has been closed to all users, however, as the assessment has found the bridge to be inadequate to support its permanent loads, it is recommended that a combination of all three monitoring interim measures options is implemented until either:

- Investigations and further (Level 3) assessment improves the load rating, at which point the CS470 will be revised/withdrawn as appropriate,

  or,

- Proposals for the continued management of the substandard structure are agreed and implemented, or a permanent solution (replacement etc.) is commissioned.

Note 1) Load mitigation interim measures and monitoring interim measures shall be reviewed following any condition inspection of the structure in accordance with CS470 clause 7.5, and measures outlined within the current CS470 should be updated accordingly and submitted to the Overseeing Organisation for approval. Reviews shall not exceed intervals of two years in accordance with CS470 clause 7.1, and so the date for the first formal review shall not exceed 2 years from the date of signature in section A6.3.3.

Note 2) Continued application of load mitigation interim measures and monitoring following the two years shall be formally agreed with the Overseeing Organisation and recorded using the form in CS470 Appendix A7, as stated in CS470 clause 7.3.

It is recommended that the half-joints be monitored monthly for the first 3-months from ground level with binoculars, and from above the expansion joints at deck level. The Intervals between monitoring should be reviewed following the initial 3-month period. A Special Inspection within touching distance is recommended at 0 months, 3 months, 6-months, and then 6-monthly intervals. The intervals could be reviewed depending on the results from the tactile inspections. A specialist testing company should also be engaged to undertake the NDT testing/monitoring to further establish the presence of any hidden defects in the half-joints. The frequency of NDT monitoring should be informed by the specialist testing company but would be expected to align with the frequency of tactile special inspections.

Alongside the above recommended monitoring, it is further recommended that intrusive investigations and material testing are carried out to establish material condition and strengths to inform further (Level 3) assessment work with a view to improving the assessed capacity and removing the interim measures.

Given the differences between the 1995 Assessment and the 2023 Assessment certifications, it is recommended that a PTSI is carried out to confirm the details of the post tensioning system. On completion of the testing, the post tensioning and cantilever abutments should be assessed.

A6.2.5 Proposal Made By:

[redacted]

Date: 8th July 2024

[redacted] Jacobs UK Ltd.

Assessment Team Leader

[redacted]

Date: 8th July 2024

[redacted] Jacobs UK Ltd.

Principal

A6.3 ACCEPTANCE OF INTERIM MEASURES

A6.3.1 Appraisal of recommended Load Mitigation Interim Measures and Monitoring Interim Measures

[redacted]

Date 8th July 2024

[redacted]
Westmorland & Furness Council

TAA and/or Overseeing Organisation

[redacted]

Date 8th July 2024

[redacted]
Westmorland & Furness Council

Team Leader

A6.3.2 Acceptance of Load Mitigation & Monitoring Interim Measures

…… Date……

…… Highway (or Roads) Authority (if different from TAA)

A6.3.3 Instruction to implement Interim Measures

Interim Measures to be implemented:

[redacted]

…… Date 8th July 2024

[redacted]

Westmorland & Furness Council

…… Overseeing Organisation and/or Structure Owner

A.2 Monitoring Specification

A.2.1 Background

A.2.1.1 Assessment Findings

The 2023 assessment was limited to the assessment of the half-joints only.

The assessment concluded that the half-joints are inadequate for permanent loads. At ULS, the ties within each of the applicable strut and tie models are noted to be the critical elements.

At SLS, the lower nib's crack width failed by a significant margin. This is due to the poor detailing of the lower nibs which do not appear to contain any inclined reinforcement. At SLS, the upper nib's cracking is controlled by the inclined reinforcement shown on record drawings.

The 1995 assessment found the remaining elements of the deck to be adequate for 40t ALL and 30 units of HB loading.

Subsequently, the half-joints have been subject to sensitivity analysis, considering all partial factors set to unity. The half-joints are still found to be inadequate for permanent loads and hence the structure is identified as an Immediate Risk.

A.2.1.2 Deterioration of Structure

There is some cracking of the re-entrant corner of the half-joints on the elevations of the deck, but this was predicted by the 1995 assessment, which found that the SLS crack widths were more than twice the allowable width. The 2023 assessment of the half-joints also found them to be inadequate for permanent loads at SLS, but also at ULS, however the half-joint elements are not regarded to be in poor condition and the cracks emanating from the re-entrant corners do not appear to have increased in width since the previous inspection.

A.2.1.3 Service Performance

No changes to the structure condition, load carrying requirements or standards since the 1995 assessment have been observed. The structure currently remains open to unrestricted traffic (although it is unknown what level of vehicle loading actually uses the bridge) without exhibiting any significant or worsening defects which would be considered attributable to overloading.

A.2.1.4 Anticipated Failure Mode(s)

The 1995 Assessment Report states:

'The suspended span and the free ends of the cantilevers are over-reinforced: - the concrete will fail in compression before the tendons have started to yield. This was done deliberately, but it means that, should the bridge be overloaded, it will fail suddenly without any warning, cracking, or yielding.'

The above statement refers only to the post-tensioning within the reinforced concrete cantilevers, from which the lower nibs are supported. The post-tensioning provides no strength to the half joint elements as it terminates at the end of the cantilever above the lower nib. No assessment has been carried out (since 1995) with respect to the prestressed, pre-tensioned or post-tensioned elements, furthermore there is conflicting information between the historical records (including 1995 assessment), design records and site observations. A review of further historical information 07/03/2024 found correspondence between the Client and Contractor during the construction period relating to the alteration of anchorage details at the rear face of the cantilevers (abutments) with no indication of alterations to the locations of tendons etc that would alter the accuracy of the above statement.

The 2023 assessment of the half-joints only indicates that the reinforcement is overstressed at ULS and insufficient at SLS. As a result of the inadequacies, it would be expected that significant progressive cracking would

be evident to the re-entrant corners of the half joints or bearing shelf prior to yielding of the steel within the half-joints which act as corbels.

A.2.2 Monitoring Plan

A.2.2.1 Visual Observations

Option 1 – Monitoring from Ground Level

Option 2 - Tactile Special Inspection Monitoring

Option 3 - Non-destructive Testing/Monitoring

The bridge has been closed to all users, however, as the assessment has found the bridge to be inadequate to support its permanent loads, it is recommended that a combination of all three options is implemented until either:

- Investigations and further (Level 3) assessment improves the load rating, at which point the CS470 will be revised/withdrawn as appropriate,

  or,

- Proposals for the continued management of the substandard structure are agreed and implemented, or a permanent solution (replacement etc.) is commissioned.

It is recommended that the half-joints be monitored monthly for the first 3-months from ground level with binoculars, and from above the expansion joints at deck level. The Intervals between monitoring should be reviewed following the initial 3-month period. A Special Inspection within touching distance is recommended at 0 months, 3 months, 6-months, and then 6-monthly intervals. The intervals could be reviewed depending on the results from the tactile inspections. A specialist testing company should also be engaged to undertake the NDT testing/monitoring to further establish the presence of any hidden defects in the half-joints.

Alongside the above recommended monitoring, it is further recommended that intrusive investigations and material testing are carried out to establish material condition and strengths to inform further assessment work with a view to improving the assessed capacity and removing the interim measures.

A.2.2.2 Measurements

Measurements of the crack widths and lengths emanating from the re-entrant corners of the half-joints should be taken on each elevation of each half-joint at the yearly Special Inspections. It may be more beneficial to install 'tell-tales' to ensure readings are taken from a consistent location at each inspection.

It is recommended that a specialist non-destructive testing contractor is consulted regarding the appropriateness of the methods discussed within the earlier sections of this document. It is recommended that the specialist contractor advises on the acceptable levels of results for each test citing the appropriate British Standards as evidence of their advice.

A.2.2.3 Photographs

Photographs of relevant details shall be taken during each monitoring survey/inspection.

A.2.2.4 Records

A summary report of each inspection including photographs should be produced.

A.2.3 Monitoring Frequency

Monitoring should be carried out until either:

- Investigations and further (Level 3) assessment improves the load rating, at which point the CS470 will be revised/withdrawn as appropriate,

  or,

- Proposals for the continued management of the substandard structure are agreed and implemented, or a permanent solution (replacement etc.) is commissioned.

The frequency of monthly inspections for the initial 3-months with a potential increase upon review at the end of this period to 3-monthly is considered appropriate given the facts discussed in section A4.3.1, with a Special Inspection at 0-months, 3-months, 6-months and at 6-monthly intervals thereafter. Should monitoring show signs of distress, such as increased crack widths at the re-entrant corners or new cracks appearing within the half joints then load mitigation interim measures such as a full closure of the route passing beneath the bridge shall be considered for immediate implementation with consultation and approval from the TAA.

A.2.4 Monitoring Trigger Levels

The purpose the frequently proposed inspections and special inspections is to identify signs of distress or progression of the existing cracks to the half-joints and to react prior to elements progressing to a damaged state where emergency intervention is required. Where the defects observed are found to be static in their rate of deterioration, the intervals should be reviewed and potentially extended to less frequent inspections.

The failure mechanism is anticipated to manifest in the form of significant progressive cracking to the re-entrant corners of the half joints or bearing shelf prior to yielding of the steel within the half-joints which act as corbels.

If monitoring identifies some distress in the half-joints such as further cracking, spalling or corrosion staining, urgent action should be taken to impose closure of the route passing beneath the bridge, to be agreed with the TAA.

A.2.5 Monitoring Trigger Actions

It is recommended that the structure is closed to all users as proposed in Appendix A6, however, the following additional progressive actions should be undertaken when trigger levels indicated in A.2.4 above are identified by Westmorland and Furness Council Bridges & Structures Asset Team:

Half-Joints

1. Immediately close the route passing beneath the bridge.
2. Increase frequency of monitoring inspections.
3. Prop the suspended span, if required.
4. Decommission the bridge.

The identification for the need for trigger actions will be made by Westmorland and Furness Council Asset Team based upon a review of inspection information provided by the inspection team.

Westmorland and Furness Council Bridges & Structures Asset Team contacts:

[redacted] Bridges & Structures, For Westmorland and Furness Council. Tel: [redacted]

[redacted] Bridges & Structures, For Westmorland and Furness Council. Tel: [redacted]

Responsibility for implementing trigger actions and the detailed design of safeguarding measures lies with Westmorland and Furness Council Bridges & Structures Asset Team.

A.2.6 Recording and Reporting

A summary report of each inspection and testing instance, including photographs, should be produced. Westmorland and Furness Council Asset Team shall review the data and confirm their recommendations to the TAA.

A.2.7 Review of Monitoring Requirements

Monitoring should be carried out until either:

- Investigations and further (Level 3) assessment improves the load rating, at which point the CS470 will be revised/withdrawn as appropriate,

  or,

- Proposals for the continued management of the substandard structure are agreed and implemented, or a permanent solution (replacement etc.) is commissioned.

Alongside the proposed monitoring regime, material testing should be undertaken to ascertain the relevant material strengths and the size and layout of reinforcement. These items of work, along with the monitoring findings, will inform a Level 3 assessment, with a view to improving the load rating.

A.2.8 Protocol for Monitoring, Reporting and the Escalation of Decision Making

Monitoring inspections shall be carried out in accordance with the intervals recommended under A.2.3 by the Westmorland and Furness Council Asset Team. A summary report of each inspection including photographs shall be produced.

Where the inspection is carried out by others on behalf of the Westmorland and Furness Council Asset Team, it Is recommended that an emergency contact, from the Westmorland and Furness Council Asset Team is contactable if the Engineer(s) undertaking the inspection identify defects at a level of severity that is considered to require immediate or emergency action.

Any identification of distress or trigger levels shall be reported immediately.

The identification for the need for trigger actions will be made by Westmorland and Furness Council Asset Team based upon a review of inspection information provided by the inspection team.

Westmorland and Furness Council Asset Team contacts:

[redacted] Bridges & Structures, For Westmorland and Furness Council. Tel: [redacted]

[redacted] Bridges & Structures, For Westmorland and Furness Council. Tel:[redacted]

Responsibility for implementing trigger actions and the detailed design of safeguarding measures lies with Westmorland and Furness Council Asset Team.

A.2.9 Emergency Response and Communication Plan

If the condition of the structure poses an immediate risk to the health and safety of the public, then police or fire and rescue should be contacted on 999. In addition, where the contacts above are not available, Westmorland and Furness Council emergency out of hours should be contacted on [redacted]

Otherwise, as per Section A.2.8.