ASSESSMENT OF HIGHWAY MASONRY ARCH BRIDGES TO CS454 AND CIRIA C800 WITH LIMITSTATE:RING 4

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limitstate

1. INTRODUCTION

ABOUT LIMITSTATE

Our mission:

- Provide engineers with powerful analysis & design software
- Leverage state-of-the-art algorithms & optimization technology
- Provide software that is robust and well validated
- Ensure applications are fully supported and are easy to use

Our clients include:

AECOM
Amey
ARCADIS
ARUP
AtkinsRéalis
aurecon

...plus many more!

MASONRY ARCH BRIDGES

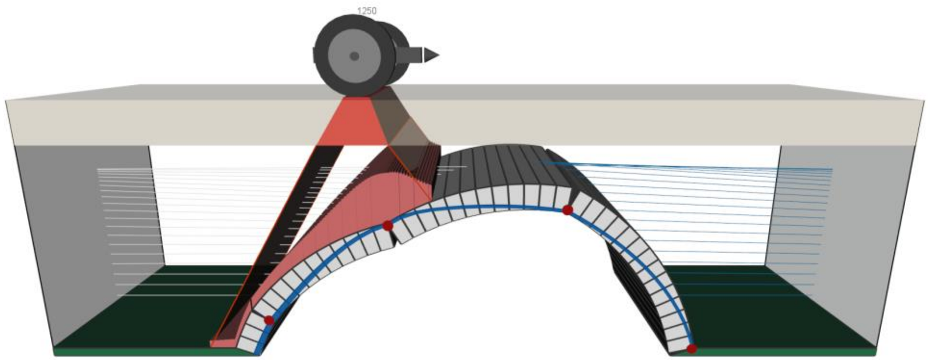
Vital infrastructure:

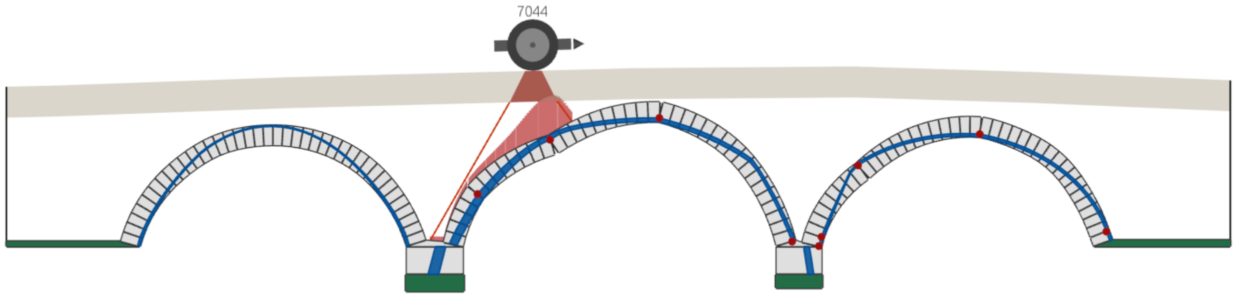
- Most >100 years old
- Many carrying heavy loads
- Many contain unique details

WHAT IS LIMITSTATE:RING?

- Interactive software tool for the analysis of masonry arch bridges

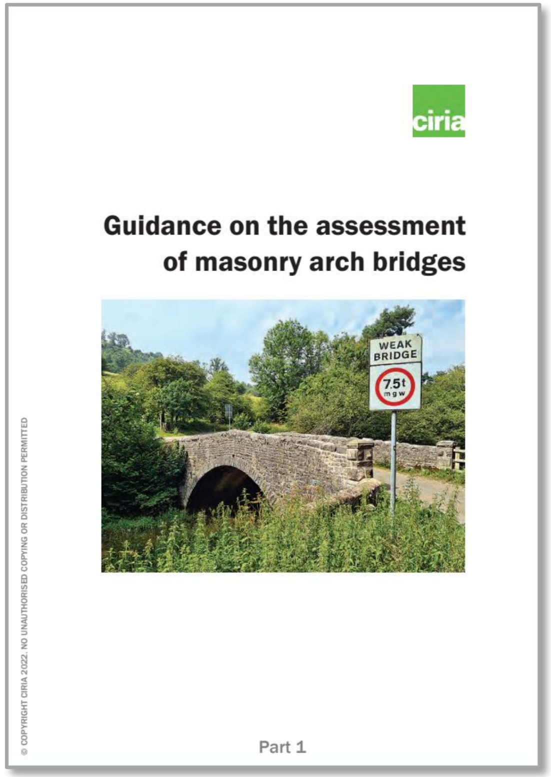
- Capable of modelling:
  - both single and multi-span bridges
  - a wide range of potential ULS failure modes
  - localised properties & defects
  - support movements





2. ASSESSMENT TO CS 454 AND CIRIA C800

CIRIA C800 AND CS454


Guidance on the assessment of masonry arch bridges

Part 1

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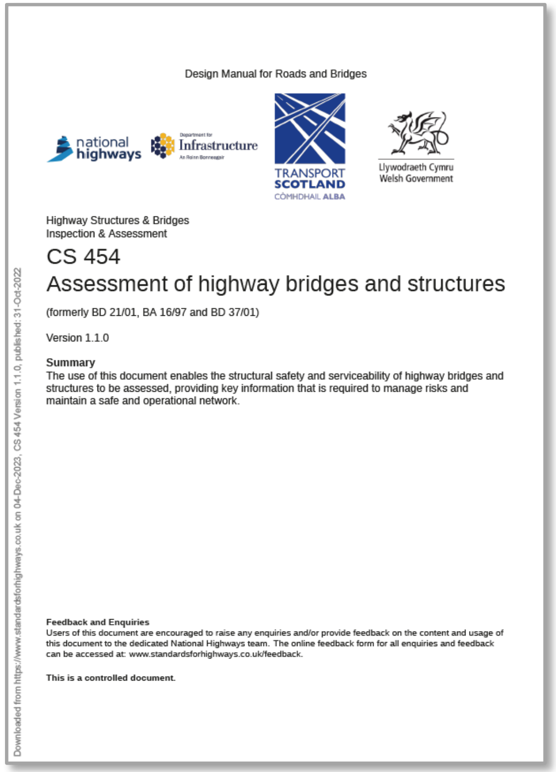
Published May 2022


Design Manual for Roads and Bridges

Highway Structures & Bridges
Inspection & Assessment

CS 454
Assessment of highway bridges and structures

(formerly BD 21/01, BA 16/97 and BD 37/01)

Version 1.1.0

Summary
The use of this document enables the structural safety and serviceability of highway bridges and structures to be assessed, providing key information that is required to manage risks and maintain a safe and operational network.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated National Highways team. The online feedback form for all enquiries and feedback can be accessed at: www.standardsforhighways.co.uk/feedback.

This is a controlled document.

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Published Oct 2022 (latest revision)

(Both free to download, from www.ciria.org and www.standardsforhighways.co.uk)

THE PERMISSIBLE LIMIT STATE (PLS)

- A key feature of the CIRIA C800 is the Permissible Limit State (PLS)
- PLS = the state beyond which long term load induced degradation occurs
- Establishing the PLS is potentially very useful for bridge management purposes

SERVICE LOAD BEHAVIOUR

- Bridge owners **rarely observe ULS** failures
- However, when a loading (traffic) regime changes, a bridge in good condition **may degrade rapidly**, then becoming unserviceable
- The **Permissible Limit State (PLS)** is designed to identify such cases - <u>before</u> damage occurs
- National Highways CS 454 code **now allows the PLS to be used when assessing UK bridges**

CIRIA C800 ASSESSMENT ASSUMPTIONS

Two separate calculations:

PLS relies on **primary resistance**:

- self-weight of elements
- endurance masonry strength
- soil pressures as if a dense fluid (K=1)

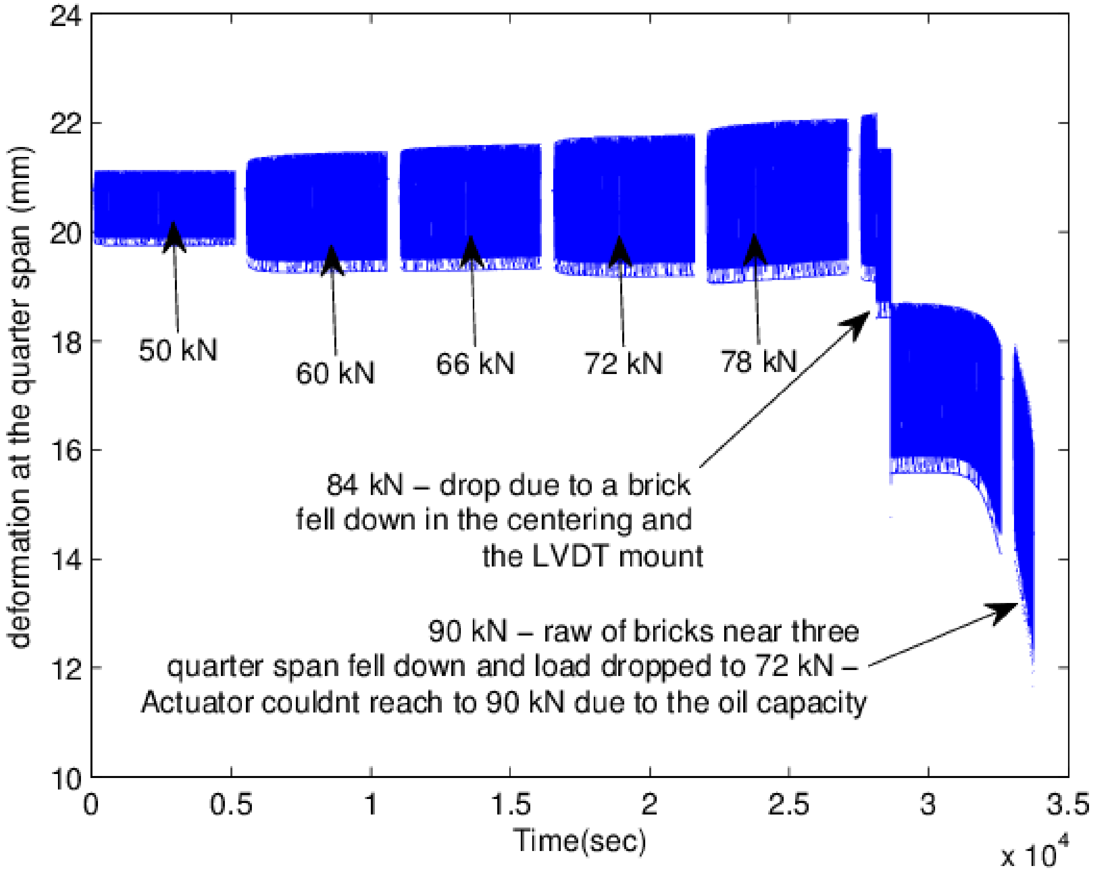
ULS also relies on **secondary resistance**:

- peak masonry strength
- passive soil pressures ($K=1/3K_p$)

EXAMPLE: 3M SPAN LABORATORY BRIDGE

Experimental behaviour under cyclic loading:

PLS load calculated to be 72kN



Extract from CS 454 (2022):

7. Assessment of masonry arches

Limit state verifications for masonry arches

7.1 At the ULS, the assessment resistance for masonry arches shall be verified to exceed the assessment load effects in accordance with the basis of assessment set out in Section 3, together with the requirements in this section regarding:

1) application of actions;
2) material partial factor and condition factor;
3) structural analysis.

ULS

7.2 The assessment of masonry arches shall confirm that the traffic loading does not reach levels that can cause further distress and reduce the life of the arch.

7.2.1 Equation 7.2.1, or another suitable approach, should be used to demonstrate that there is a sufficient live load capacity factor to avoid the traffic loading reaching levels that can cause further distress and reduce the life of the arch.

Equation 7.2.1 Required live load capacity factor to avoid further distress

$$C \geq C_{\text{min}}$$

where:

C is the live load capacity factor, defined as the additional factor that can be applied to the assessment traffic actions (in addition to the partial factors as defined in Section 3) without causing the assessment action effects to exceed the assessment resistance at ULS.

C_{min} is the value of live load capacity factor that corresponds to the loads frequently reaching levels that could result in further distress and reduce the life of the arch, taken as $C_{\text{min}} = 1.2$ for normal and restricted traffic or $C_{\text{min}} = 1.8$ for abnormal traffic.

NOTE 1 *The values for C_{min} have been derived based on the formulation $C_{\text{min}} = \frac{\psi \gamma_{fL,SLS}}{K \gamma_{f3} \gamma_{fL,ULS}}$ where K is the proportion of the ULS resistance where further distress could occur, assumed here to be $K = 0.5$, and ψ is the proportion of the SLS traffic load that would be frequently experienced, taken as $\psi = 0.75$ for normal or restricted traffic. For abnormal traffic, ψ is taken as $\psi = 1.0$ to align with previous practice. The values of $\gamma_{fL,SLS}$ and $\gamma_{fL,ULS}$ are the partial factors for traffic loading given in Appendix A, and γ_{f3} is the value for masonry arches given in Section 3.*

NOTE 2 *In previous versions of this document C_{min} was included within the ULS partial factor for traffic on arches.*

NOTE 3 *CIRIA C800 [Ref 14.I], Guidance on the assessment of masonry arch bridges, describes an alternative approach to satisfy this clause.*

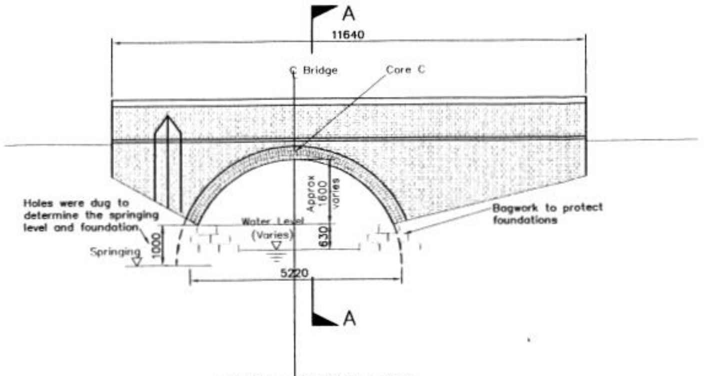
'PLS'

DEMO TWIN-SPAN BRIDGE EXAMPLE

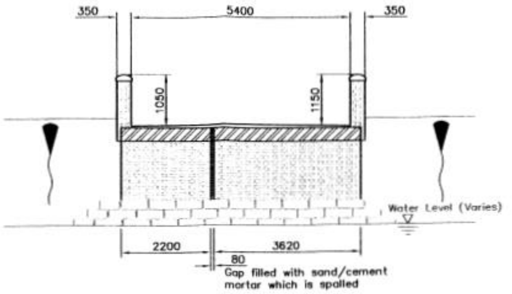
	Limit State	Axle load factor	Load effects factor	Calculated adequacy factor
CIRIA C800	PLS	1.0	1.0	1.108
	ULS	1.5	1.1	1.012
CS 454 (without using CIRIA C800)	PLS*	1.8	1.0	**0.928**
	ULS	1.5	1.0	1.114

*Calculated by applying a factor of 1.2 to the ULS capacity

FIELD BRIDGE EXAMPLE

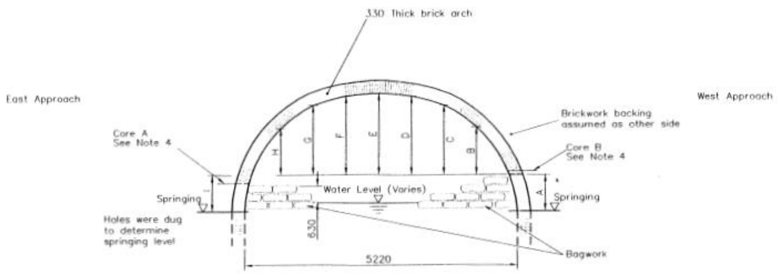


NORTH ELEVATION

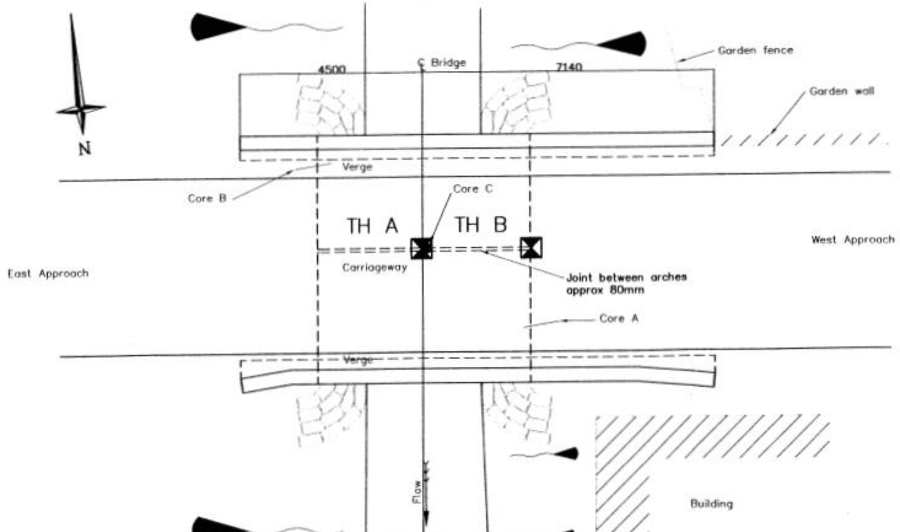


SECTION A – A
LOOKING WEST

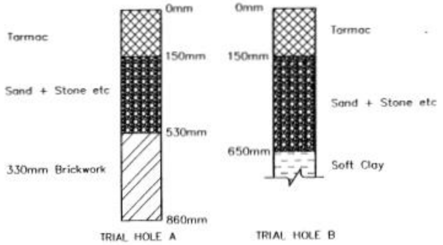
NB
Arch has been built in two sections with approx 80mm gap



LONGITUDINAL SECTION THROUGH BRIDGE
Scale 1:100



PLAN

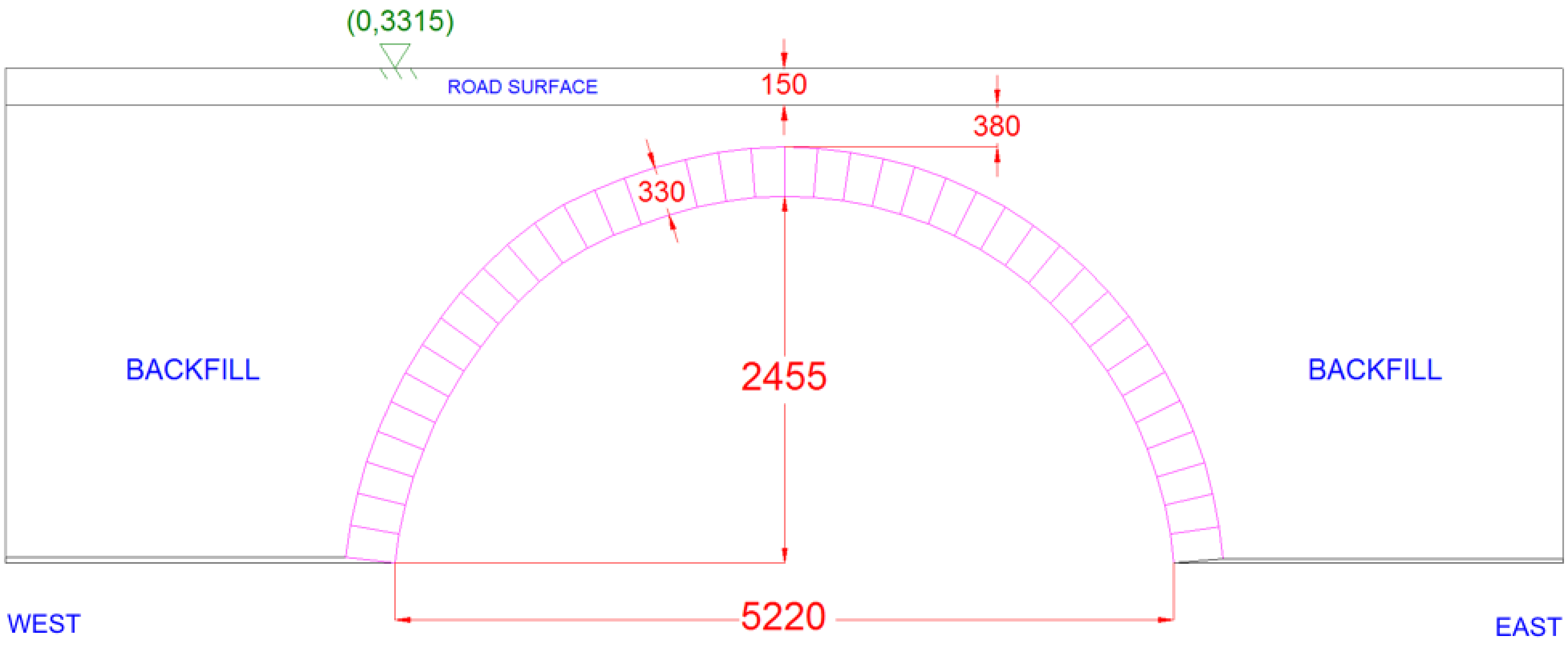


TRIAL HOLES
Not to Scale

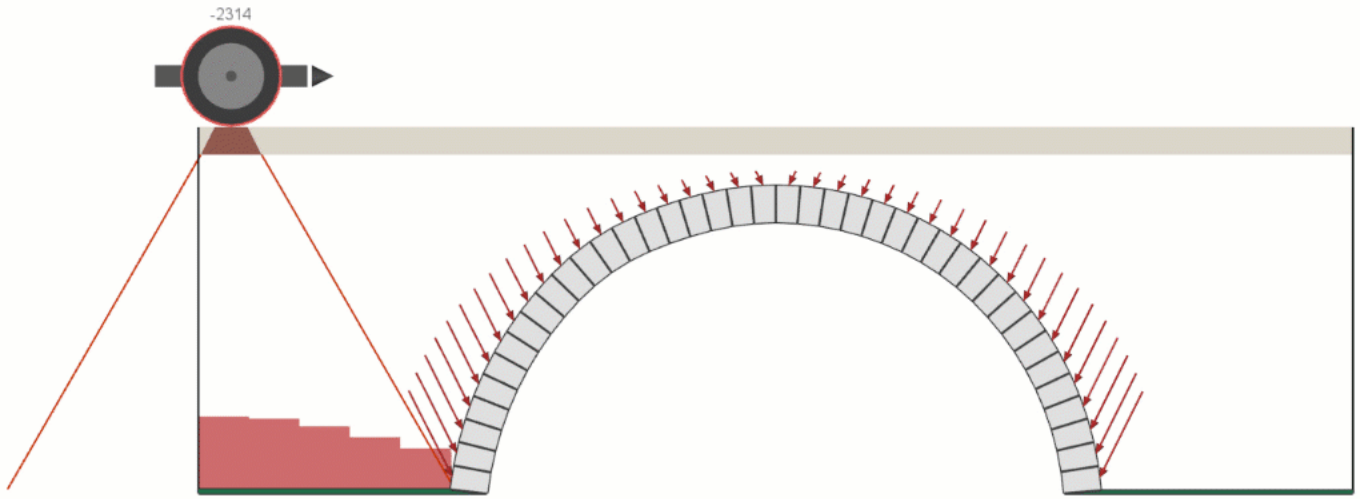
		TABLE OF ARCH HEIGHTS (mm)								
		Dim. A	Dim. B	Dim. C	Dim. D	Dim. E	Dim. F	Dim. G	Dim. H	Dim. I
North section of the arch	Grid 1 – 1	1000	820	1290	1500	1550	1460	1240	880	1000
	Grid 2 – 2	1000	840	1275	1460	1530	1460	1275	840	1000
	Grid 3 – 3	1000	840	1280	1460	1525	1460	1270	890	1000
Extended arch on the south side	Grid 4 – 4	1000	800	1190	1385	1455	1390	1185	790	1000
	Dimension locations at 1/8th points across the span.									

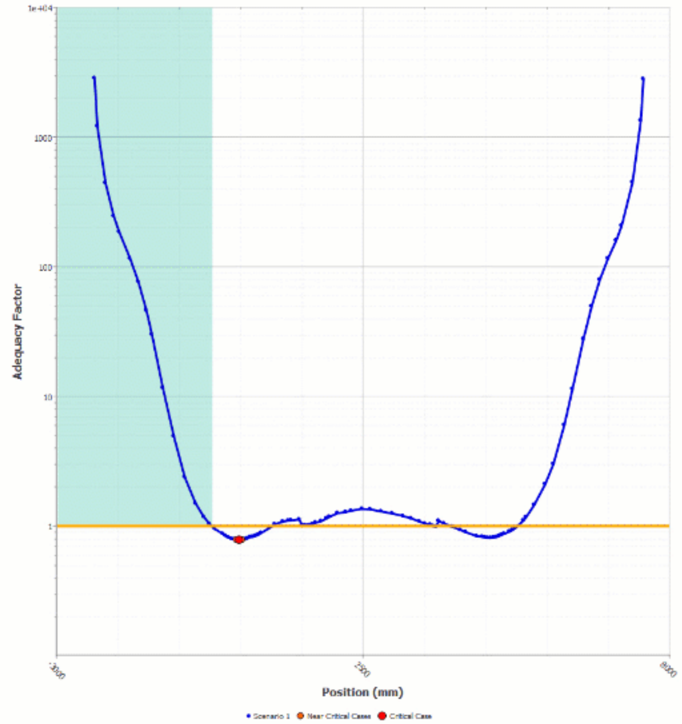
GENERAL NOTES:

1. All dimensions are in millimetres unless otherwise stated.
2. All levels are in metres above local datum unless otherwise stated.
3. The survey and intrusive investigation were undertaken in October 2002.


(0,3315)
ROAD SURFACE
150
380
330
BACKFILL
2455
BACKFILL
WEST
5220
EAST

FIELD BRIDGE EXAMPLE: PLS ANALYSIS RESULTS





LIMITSTATE RING 4 FEATURE: BATCH FILES

- E.g. allow results to be obtained for a population of bridges on a route

The syntax for running LimitState:RING via the command-line takes the following form:

```
>_<APPLICATION>[OPTIONS] <INPUT FILE>
```

Where:

<**APPLICATION**> is the path to, and name of, the LimitState:RING executable file.

[**OPTIONS**] are optional parameters that influence the nature and output of the analysis.

[**INPUT_FILE**] is the name of the LimitState:RING input file.

A typical command-line call might read:

```
ring64.exe -execute -vehicle_override:"CU Tripl
"C:\User Data\UserName\Documents\LimitState RIN
```

example_batch_file.txt

File Edit View

```
ring64.exe -execute -r -vehicle_override:"[18t+ GVW] 11.5t Single Axle (CS454)" ".\025_Robinfield.ring"
ring64.exe -execute -r -vehicle_override:"[18t+ GVW] 11.5t Single Axle (CS454)" ".\108_Anotherspan.ring"
ring64.exe -execute -r -vehicle_override:"[18t+ GVW] 11.5t Single Axle (CS454)" ".\126_Richards_Cross.ring"
ring64.exe -execute -r -vehicle_override:"[18t+ GVW] 11.5t Single Axle (CS454)" ".\243_Jacobs_Farm.ring"
ring64.exe -execute -r -vehicle_override:"[18t+ GVW] 11.5t Single Axle (CS454)" ".\327_Station_Road.ring"
ring64.exe -execute -r -vehicle_override:"[18t+ GVW] 11.5t Single Axle (CS454)" ".\459_Sycamore_Park.ring"
```

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3. CONCLUSIONS

CONCLUSIONS

- CIRIA C800 introduces the Permissible Limit State (PLS), the state beyond which long-term load induced degradation occurs

- CS 454 allows the CIRIA PLS calculation approach to be used (as an alternative to simply factoring the calculated ULS capacity)

- LimitState:RING 4 has been designed to simplify the process of assessing bridges to CS 454 and CIRIA C800:
  - New PLS analysis mode
  - Bridge template functionality, including e.g. code-specific partial factors
  - Batch mode to allow rapid assessment of a population of bridges
  - Large database of built-in loading vehicles

Q&A

Thank you for attending!