Masonry Arch Bridge Assessment

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Bridge Owners' Forum
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- Background & supporting research
- Development of assessment guidance
- Next steps
- Conclusions

Background & supporting research

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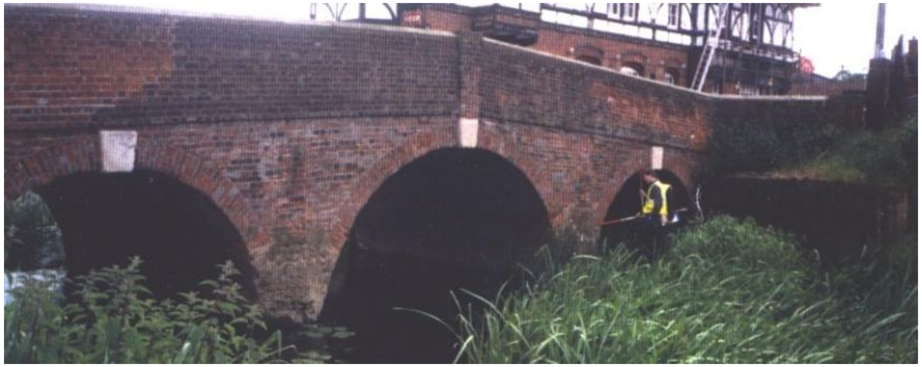
Vital infrastructure

- Approx. 70,000 spans in UK (1M worldwide)
- Almost all >100 years old
- Need regular assessment



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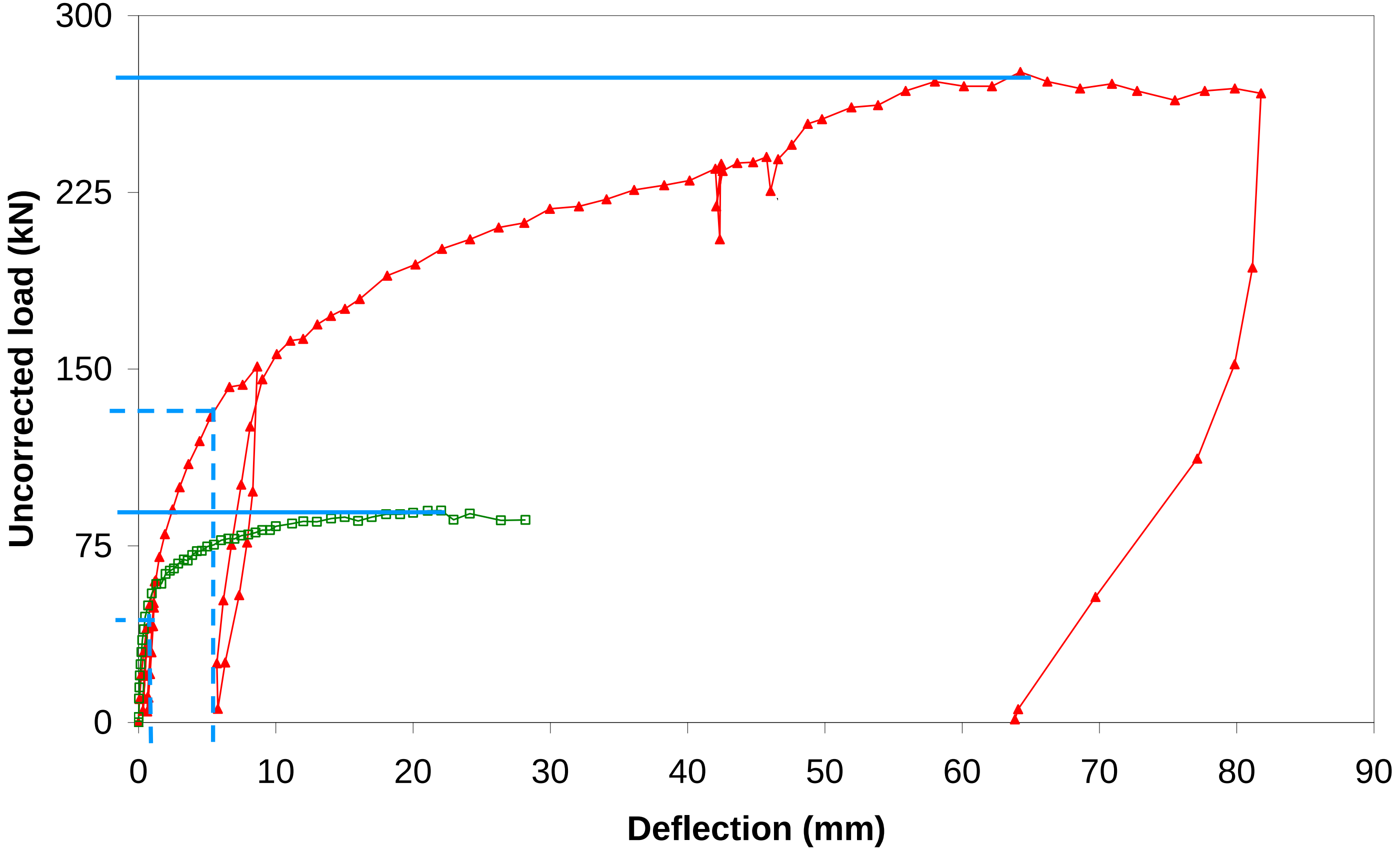
But…

- Current assessment codes (e.g. BD21) don't take account of research of last few decades
- Also, 'SLS' and 'ULS' considerations are usually combined (e.g. 'SLS' deemed satisfied if working load ≤ 0.5×'ULS' load)
  - Over-conservative for bridges where real 'SLS' load and 'ULS' load are close together
  - Under-conservative for bridges where real 'SLS' load and 'ULS' load are far apart

A tale of two bridges…



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Therefore:

- Need a better holistic understanding of arch-bridges at ultimate and working load states

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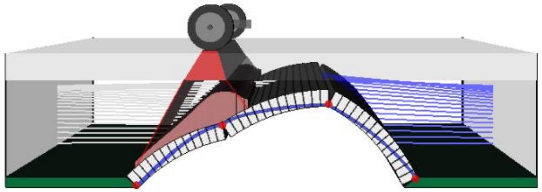
Therefore:

- Need a better holistic understanding of arch-bridges at ultimate and working load states
- To help achieve this, an EPSRC research project, has recently been undertaken:
  - Focus has been on soil-filled bridges, with 3 strands:

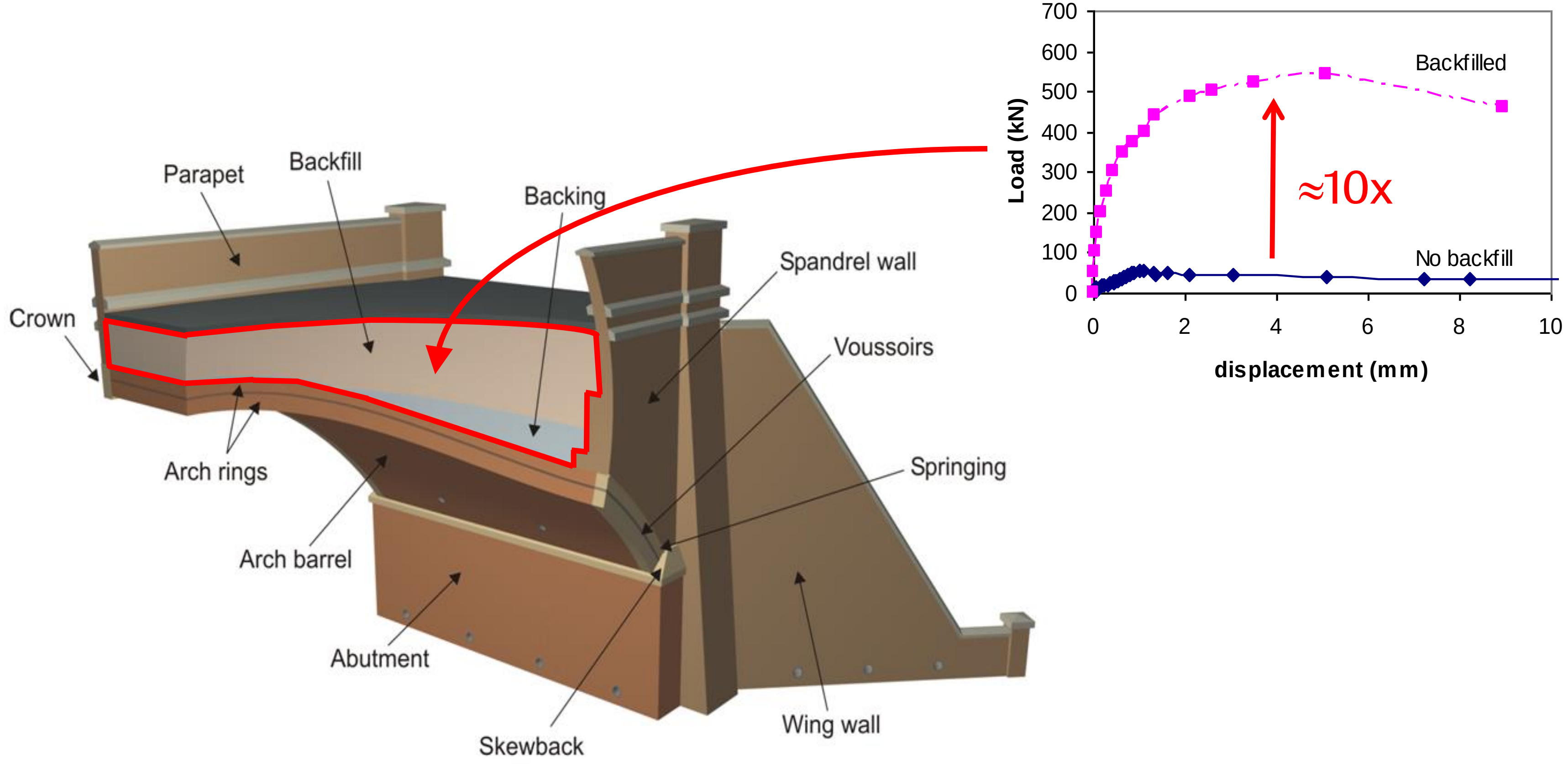
1. Experiments



2. Modelling

3. Guidance

The effect of soil backfill

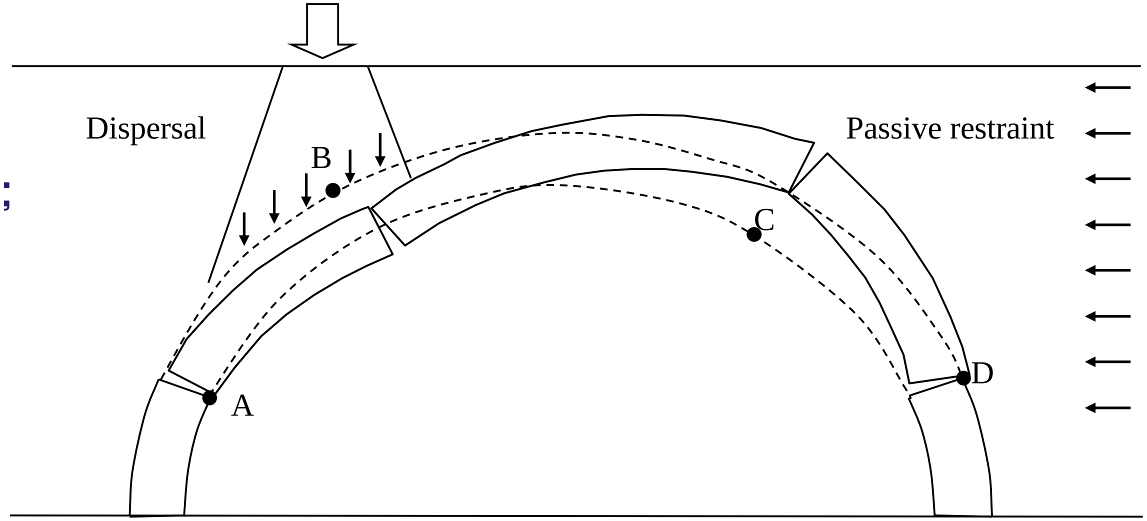


The effect of soil backfill (2)

(i) Self-weight;

(ii) Dispersal of live load;

(iii) Passive restraint.



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What about working loads?

- Repeated (cyclic) loads can lead to degradation of the bridge
- ‘Permissible limit state’ (PLS) = the state beyond which long term load induced degradation occurs

Experimental

- New ‘medium scale’ rig
- Automated filling and testing
- Benefits: rapid turnaround and high quality data

Experimental [2]

- Existing ‘large scale’ rig upgraded to allow cyclic and railway loads to be applied
- Benefits: 3m spans are representative of many bridges in the field

Sample test results

Test*	Description
ULS1	Benchmark (pseudo-static)
ULS2	Retest (pseudo-static)
ULS3	Retest (pseudo-static)
‘Cyclic ULS’	Progressively increasing cyclic loading intensity

*cyclic loading (min 100,000 cycles) applied prior to each ULS test, helping to compact fill and help restore original arch profile

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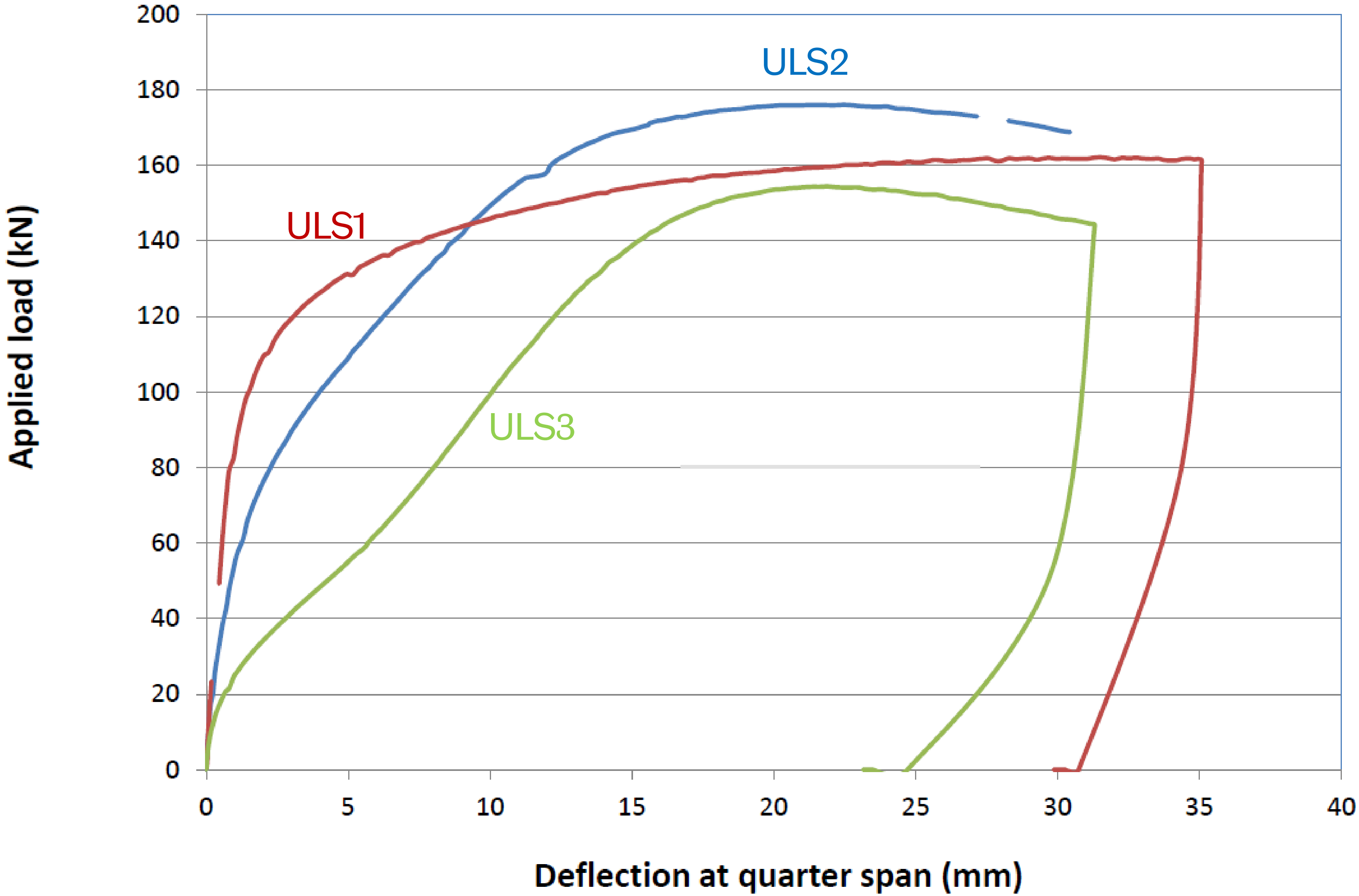

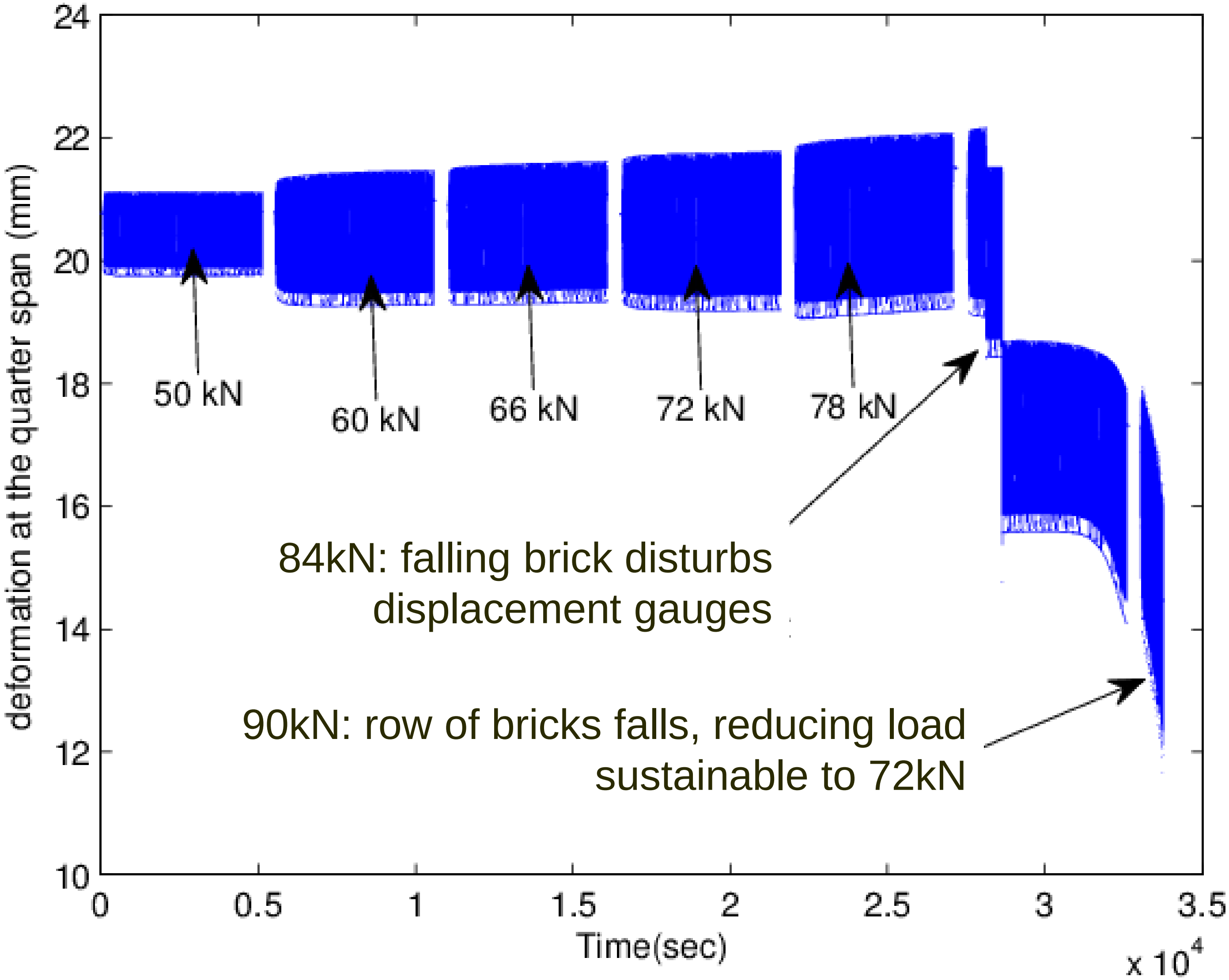

deformation at the quarter span (mm)
24
22
20
18
16
14
12
10
0
0.5
1
1.5
2
2.5
3
3.5
Time(sec)
x 10^4
50 kN
60 kN
66 kN
72 kN
78 kN
84kN: falling brick disturbs displacement gauges
90kN: row of bricks falls, reducing load sustainable to 72kN

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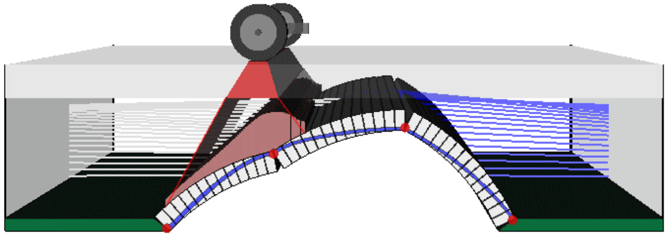
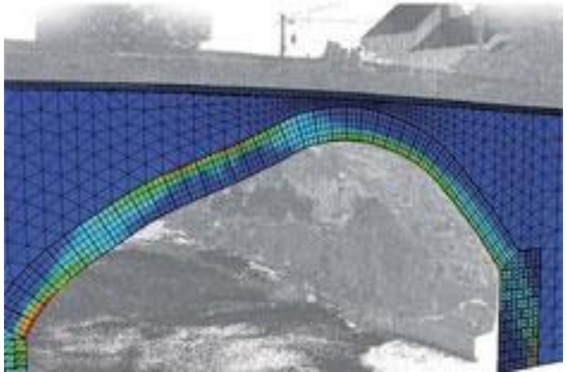
Numerical modelling

Various modelling approaches:

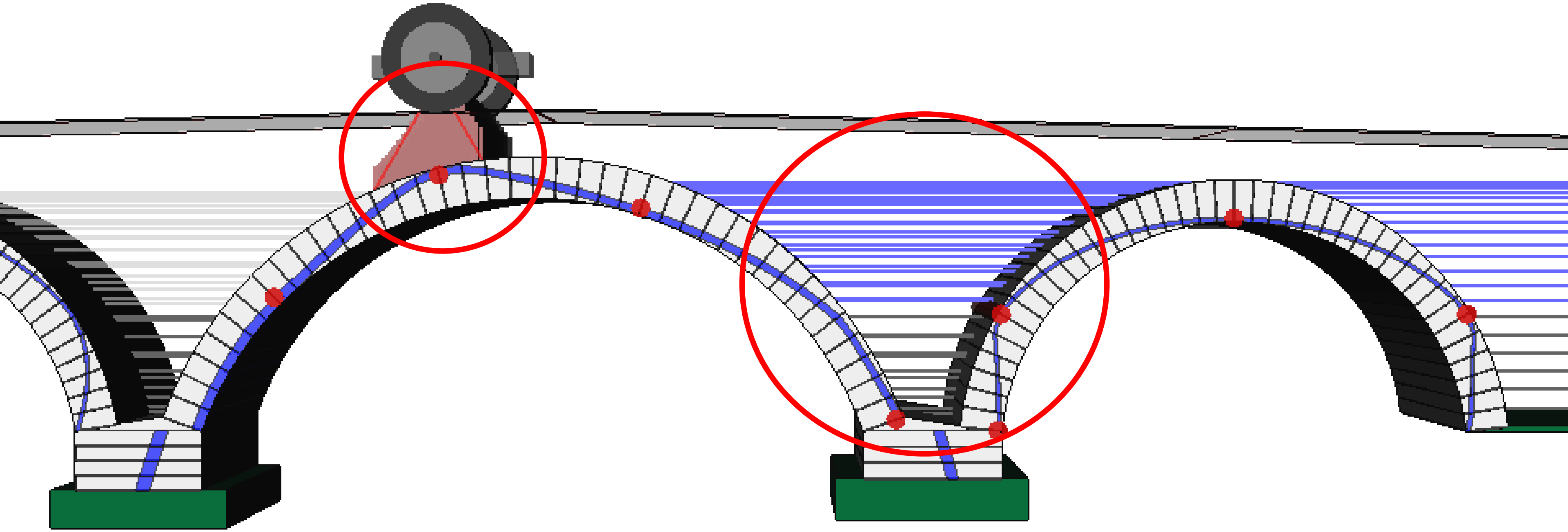
1. **'Crude'**: ignores most of the anticipated effects of soil
2. **'Simplified'**: includes the anticipated effects of soil
3. **'Midrange'**: models soil directly (basic material model)
4. **'Complex':** models soil directly (detailed material model etc)





'Simplified' example

- 'Rigid block' limit analysis method (e.g. used by LimitState:RING) models anticipated effects of soil



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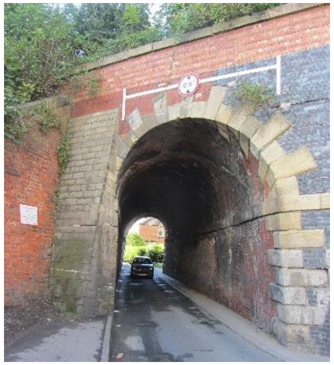
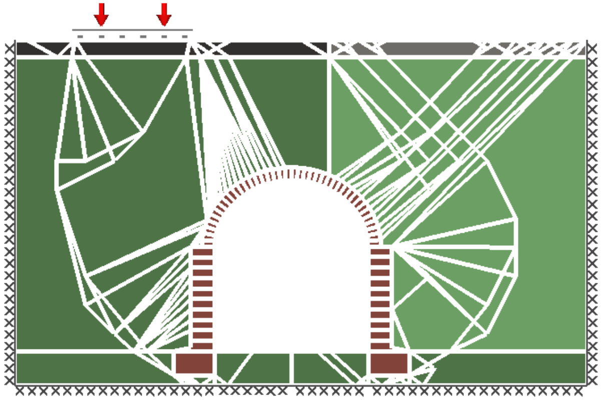
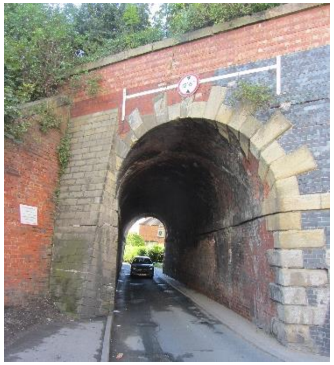
'Midrange' example

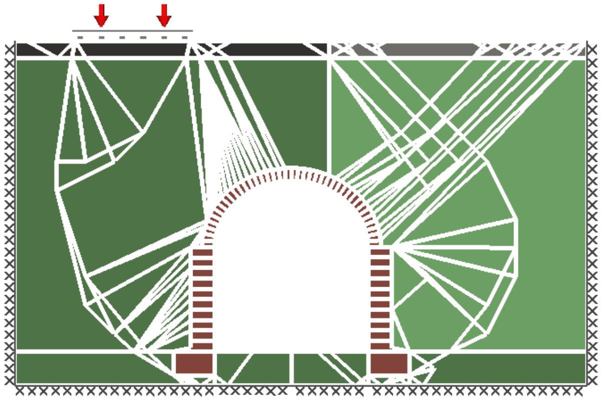
- Discontinuity Layout Optimization (DLO) extends 'rigid block' method to allow masonry and soil to be modelled
  [e.g. see Smith & Gilbert, *Proc. Roy. Soc. A*, 2007; software: www.limitstate.com/geo]





‘Midrange’ example





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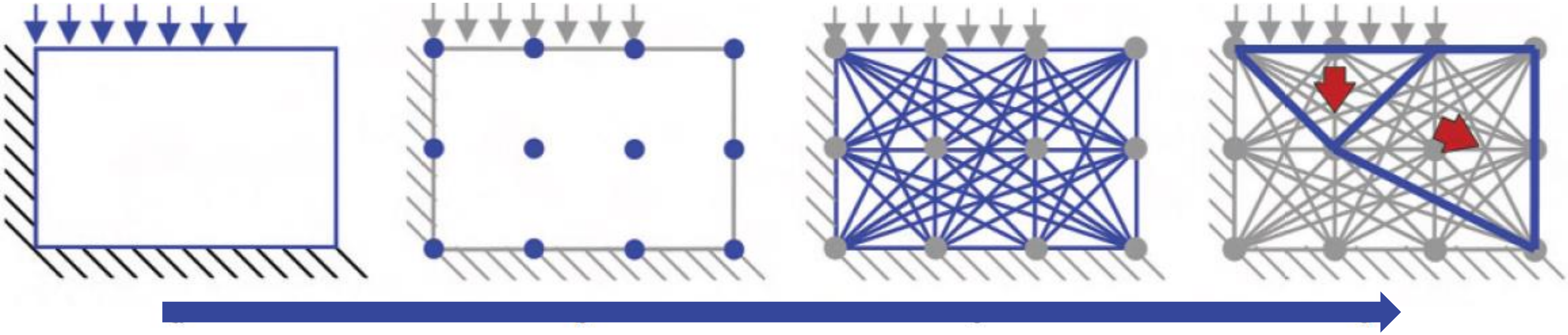
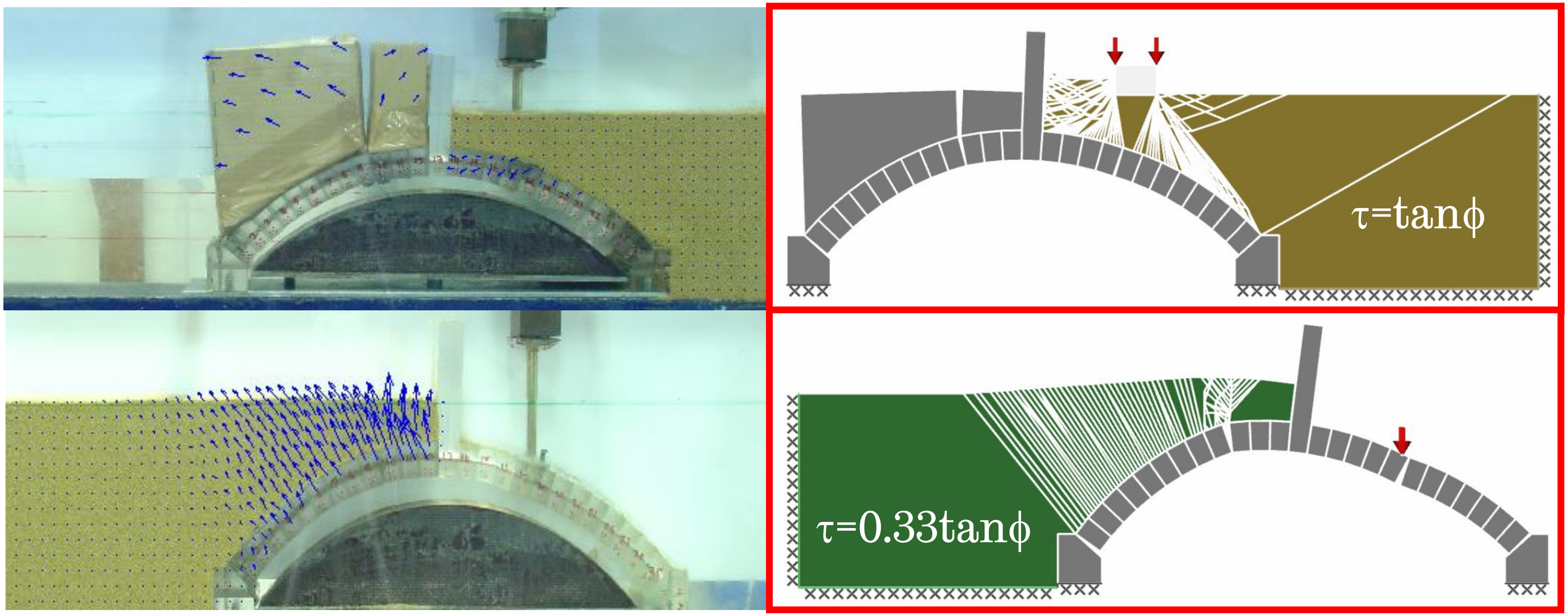
- Steps in DLO procedure:



Validation: small-scale bridges

- Good agreement (±10%) if mobilized strength used in passive region [see: Callaway, Gilbert & Smith, Proc. ICE, 2012]



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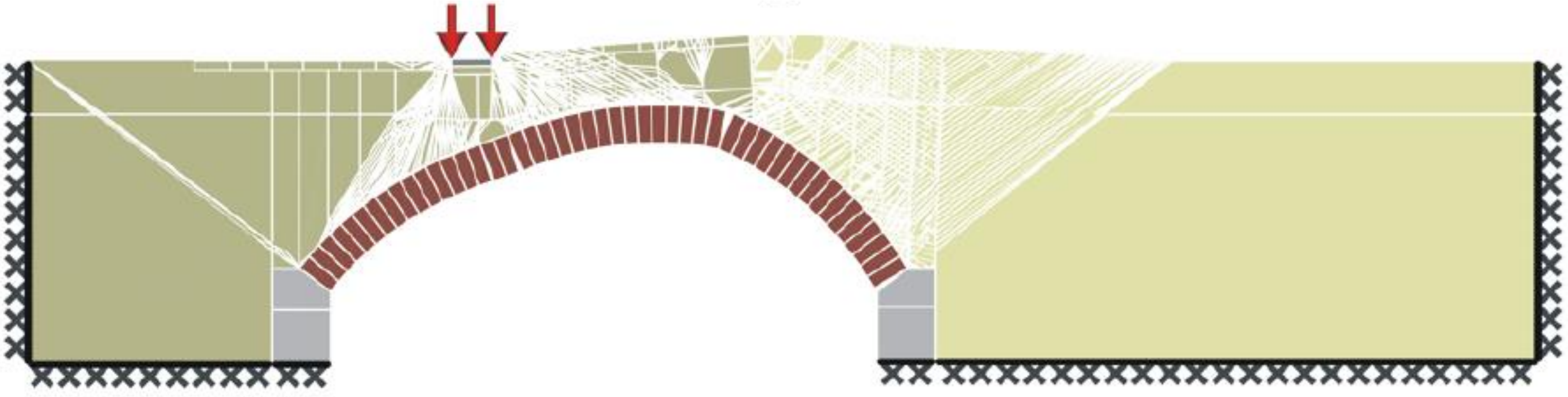
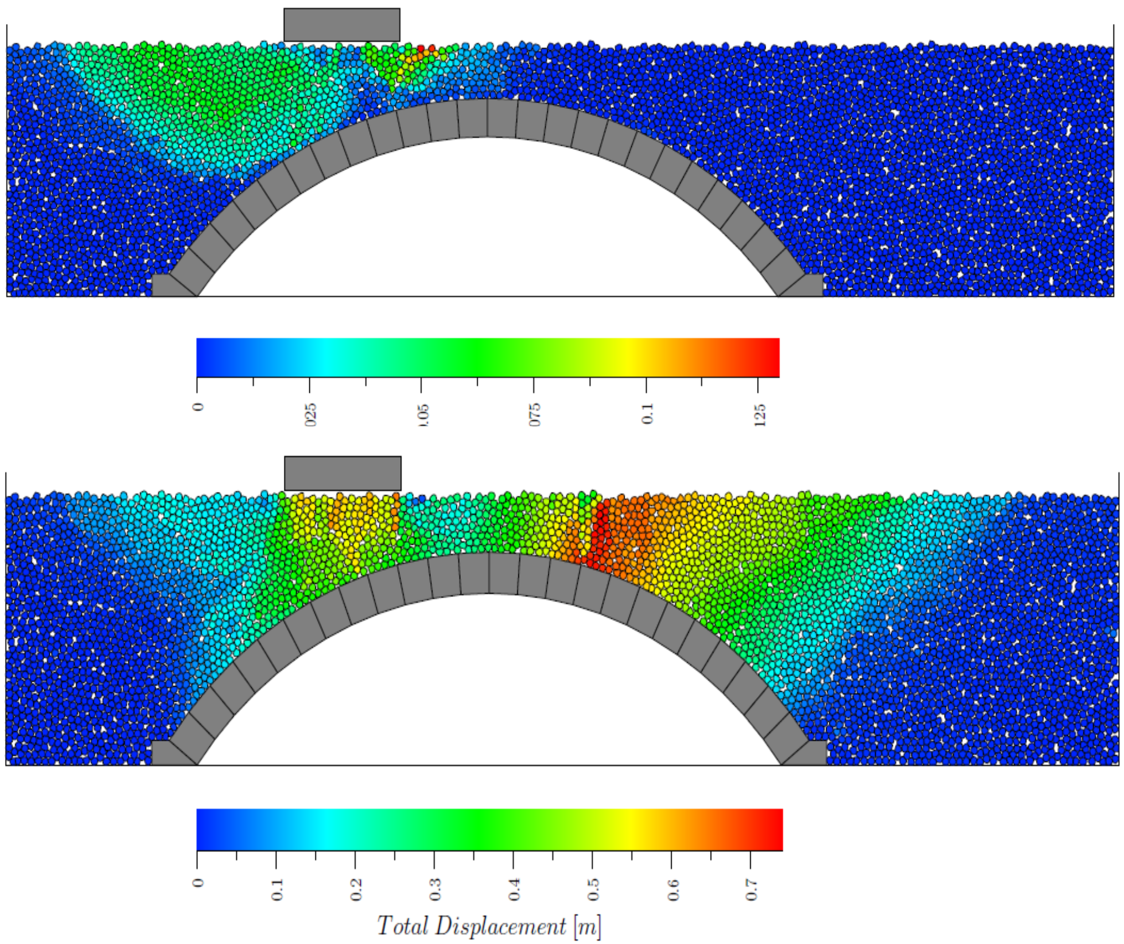
Validation: large-scale bridges



Aside: ‘physics engine’ model



Key project findings

- Below a certain load level (e.g. 50kN), repeated cyclic loads can be applied with seemingly no limit
- At higher levels of load repeated cyclic loads will curtail the life of a bridge
- The trigger point appears to be the point at which horizontal soil pressures start to need to be mobilized, to restrain the barrel

Development of assessment guidance

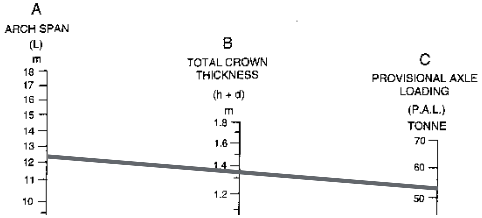
Assessment guidance

- Guidance document currently being drafted
- Sample areas covered:
  - Fundamental arch bridge behaviour
  - A critique of multi-level assessment
  - Observational & analysis-based assessment
  - Ultimate **and** Permissible Limit State analysis

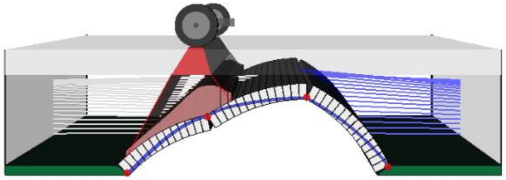
Contents list

Multi-level assessment: are current tools compatible with this?

Level 1: [e.g. MEXE]

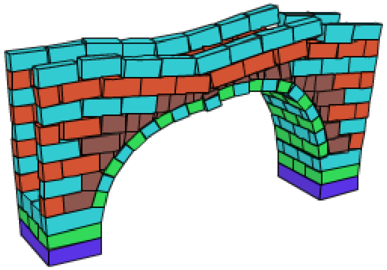


Level 2: [e.g. rigid block analysis]



Level 3: [e.g. finite, discrete element]

- more complex
- more input parameters
- more expertise required
- should be more accurate (<u>and less conservative</u>)



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Aside: the MEXE method

- Semi-empirical method dating from the 1940s, and still in use
- The method was reviewed a few years ago:
  - Pippard's simplified equations (on which MEXE is based) are **non-conservative** when short span bridges are involved

  [See: Wang & Melbourne, Proc. ICE, 2010]
- Other issues:
  - 'Black box' method (engineer left unenlightened...)
  - Difficult to improve in the light of research

Example contents (Table 9)

Observation	Note
1. The pattern of loading in relation to the shape of a masonry gravity structure governs stability.	This means that it is important to measure the shape of the arch barrel, piers etc. when undertaking an assessment, and to use loadings which are representative of those that will be applied in practice.
2. Masonry gravity structures resist applied actions through their inherent self-weight and thickness.	Since self-weight is normally beneficial it should be factored down (as well as up) for the purposes of assessment. Also the thickness of masonry elements should be carefully measured prior to an assessment.
3. The load carrying capacity of a masonry arch bridge reduces during a flood event.	If the bridge is flooded up to traffic surface level then buoyant self-weights should be used in any assessment calculations. As buoyant self-weight is much lower than dry self-weight then the load carrying capacity is reduced (see 2. above).
4. A masonry arch is a statically indeterminate structure.	This means that in an uncracked arch there are many possible load paths, so that it is not possible to be certain which areas are highly stressed and which are not.
5. Stresses scale linearly with bridge size	This means that in a long span bridge stresses will often be high

Overarching methodology

- Move away from BD21/BA16 approach (& factors); instead use Eurocode factors where possible
- For assessment based on analysis, recommend both ULS and service load checks are carried out

Permissible limit state (PLS)

- PLS = *the state beyond which long term load induced degradation occurs*
- Very useful for bridge management purposes, but:
  - No clear link between the ULS and the PLS
  - Hence need to establish the PLS directly

Key PLS trigger

Excessive system level deformation

- Largely rigid body masonry movements due to 'lack of fit' and/or reliance on passive soil restraint
- Leads to ratcheting (distortion of profile) and/or degradation of masonry due to opening & closing of joints

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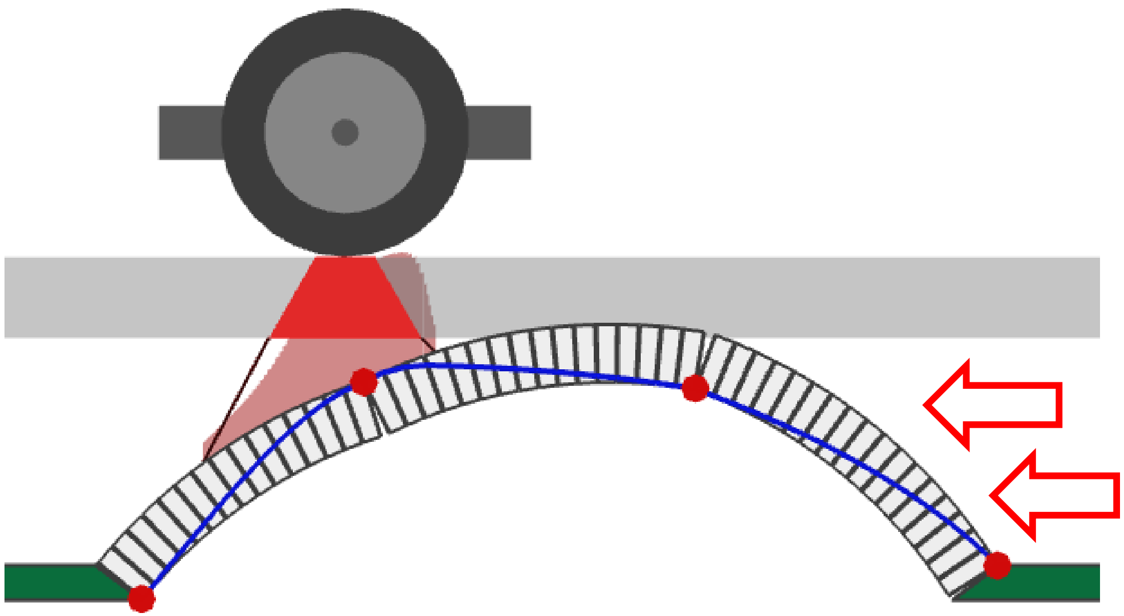
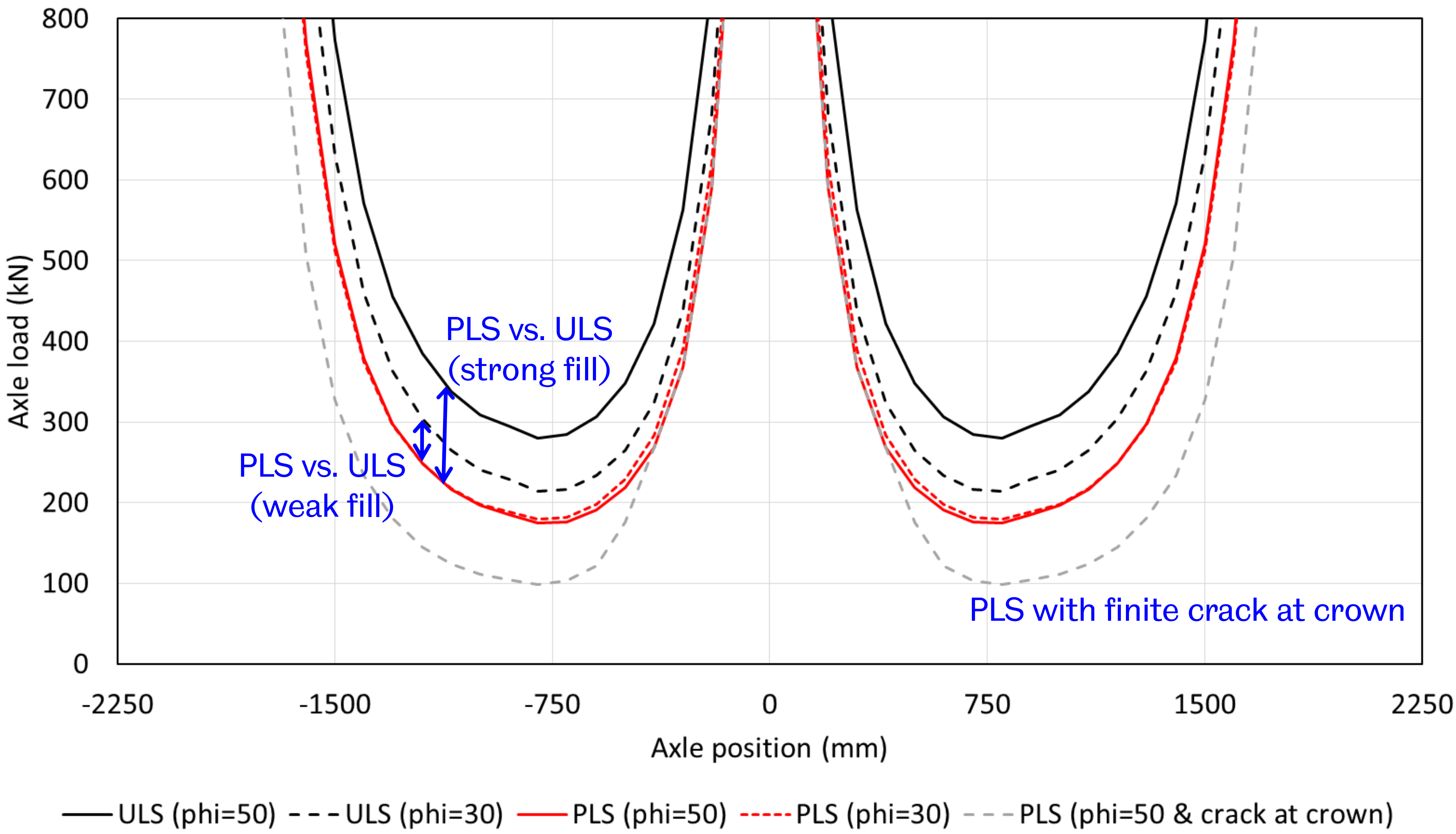
PLS analysis - example

- Neglect passive restraint in PLS analysis (as requires large structural deformations to generate)
- Also use 'degraded' masonry mechanical properties





800
700
600
500
400
300
200
100
0
Axle load (kN)
-2250
-1500
-750
0
750
1500
2250
Axle position (mm)
PLS vs. ULS
(strong fill)
PLS vs. ULS
(weak fill)
PLS with finite crack at crown
ULS (phi=50)
ULS (phi=30)
PLS (phi=50)
PLS (phi=30)
PLS (phi=50 & crack at crown)

Next steps

Next steps

- Working hard to complete a full draft of guidance document (for comment)

- Planned future research:
  - Investigate behaviour of cracked arches under cyclic loads, and apparent ‘self-healing’ behaviour
  - Develop better understanding of 3D behaviour
  - More robust multi-level assessment methodology

Conclusions

Conclusions

- EPSRC funded research project has provided valuable new data
- Assessment guidance arising from the project is currently being drafted
- However, despite considerable research over the last few decades, still unanswered questions

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Acknowledgements

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