Guidance Arising From Recent Research on Masonry Arch Bridges

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Bridge Owners' Forum
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Background & supporting research

Background

- When loading regime changes, current assessment tools sometimes not discriminating
  - e.g. sudden deterioration after pattern of loading changes
  - Expensive consequences…

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Current assessment approach

- 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

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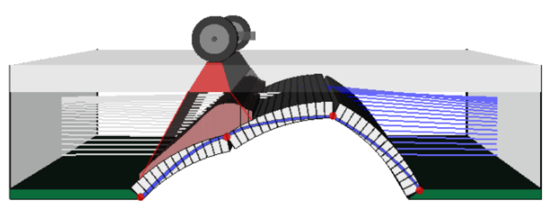
To address this:

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

1. Experiments



2. Modelling

3. Guidance

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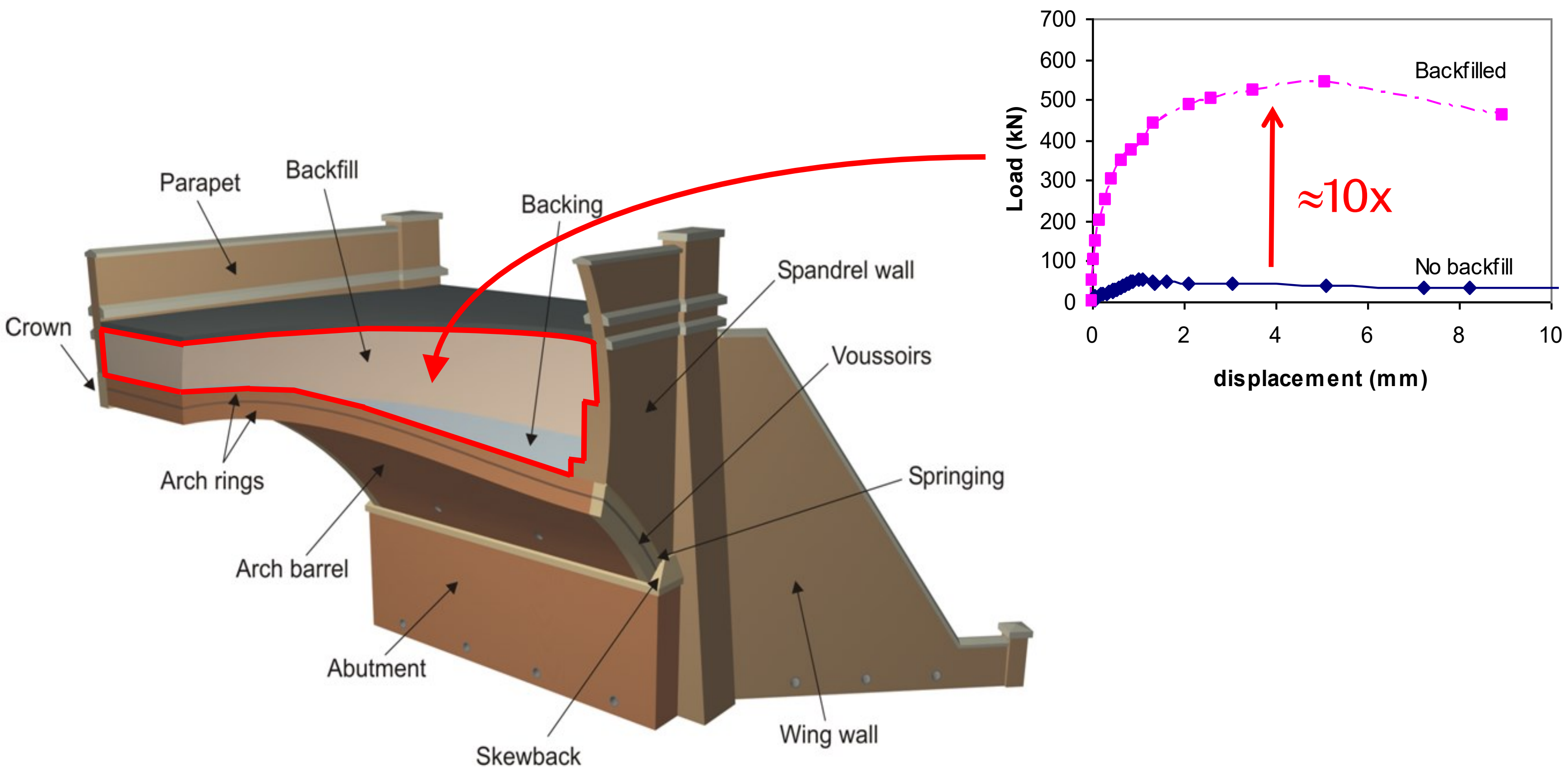
The effect of soil backfill



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:
  - No clear link between the ULS and the PLS
  - Hence need to establish the PLS directly

Experimental

- New '<u>medium scale</u>' rig
- Automated filling and testing
- Benefits: rapid turnaround and high quality data

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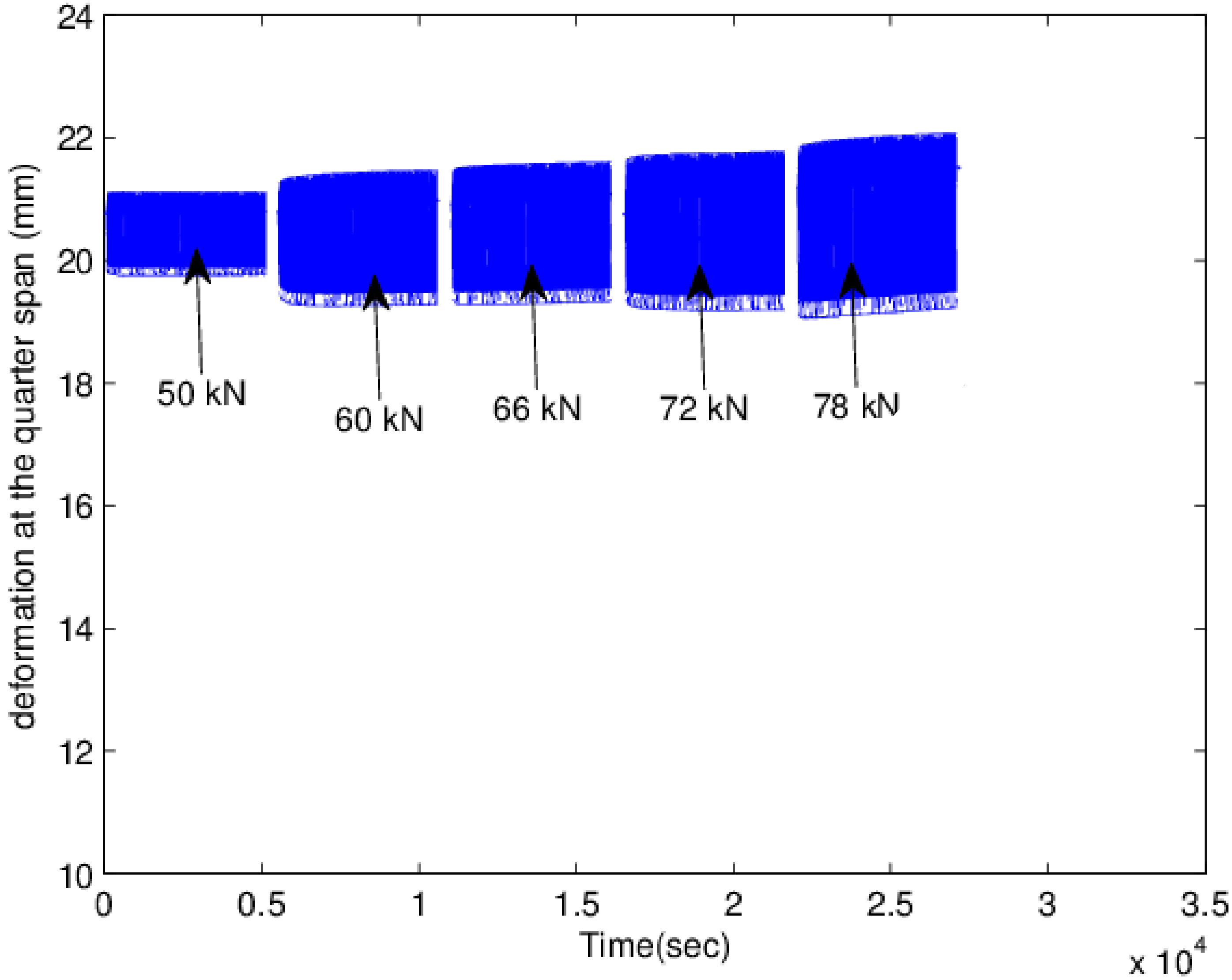
Experimental [2]

- 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



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
deformation at the quarter span (mm)
50 kN
60 kN
66 kN
72 kN
78 kN

Key project findings

- Below a certain load level repeated cyclic loads can be applied with seemingly no limit
- At higher levels of load repeated cyclic loads will cause damage and potentially 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

Guidance

May 2018 draft

- ‘Straw man’ for comment
- Feedback / comments welcome on e.g:
  - Format
  - Coverage (i.e. key gaps etc.)
  - Detailed content
  - Potential role of the document
  - Pilot application
  - Possible distribution channels

Key recommendations

1. MEXE is not to be used, as it has very limited predictive capability

2. Separate ULS and PLS checks should be carried out

ULS check

- BD21 uses a factor of 3.4 on the critical axle, based on serviceability concerns
- If this is dealt with separately, the factor can be reduced to 2.5*

*though proposed 'model factor' of 1.0 to 1.2 may effectively increase this, up to 3.0

PLS criteria

I. System level: excessive 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 continual opening & closing of joints

II. Material level: fatigue damage

- Repeated application of large stress ranges reduces mechanical performance of masonry

Simplified PLS check

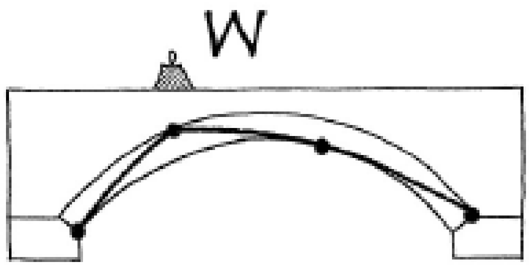
- Seeks to combine PLS-I and PLS-II criteria into a single calculation, in which:
  - Passive restraint is neglected (as is the influence of other ‘flexible’ elements)
  - Reduced masonry strength is used (to take some account of fatigue damage effects)
- Most appropriate for short span bridges, where PLS-I likely to dominate (otherwise may need separate PLS-II check)

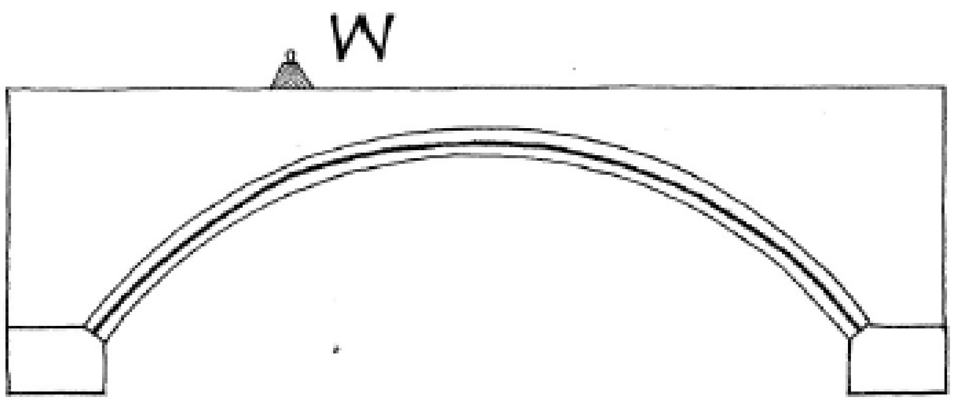
Sample results (lab. bridges)

	Unfactored (kN/m)		Factored (kN/m)		
	ULS	PLS	ULS (factor = 2.5)	PLS (factor = 1.7)	BD21 ULS (factor = 3.4)
Salford bridge 1	122	71	49	**42**	**36**
Salford bridge 2	96	79	**38**	46	**28**
Salford bridge 5	274	71	110	**42**	**81**

Also in the draft guidance

- Simple sketches to illustrate behaviour





Request for feedback

- Feedback / comments welcome on e.g:
  - Format
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  - Detailed content
  - Potential role of the document
  - Pilot application
  - Possible distribution channels
- And next steps?

Acknowledgements

Colin Smith, Clive Melbourne & Graham Cole

(plus funders EPSRC & Network Rail, and all project steering committee members)

Assessment calculations: loads

Table 17 – Actions: partial load factor (γ_F) values

Description	ULS Value	PLS Value
Permanent unfavourable action, γ_G	1.35	1.0
Variable unfavourable action (critical axle), γ_Q	2.5	1.7
Variable unfavourable action (other axle), γ_Q	1.7	1.0
Permanent favourable action, γ_G	1.0	1.0

Assessment calculations: resistance

Table 18 – Resistance: partial factor values and modelling assumptions (assessment Levels 1 and 2)

Description	ULS Value / Assumption	PLS Value / Assumption
Model factor (γ_{Rd})	1.2 (Level 1) 1.1 (Level 2)	1.0
Partial factor on masonry strength (γ_m)	1.0	2.0 (if no information available) Varies (if test or model data available)
Peak lateral earth pressure coefficient (K)	Mobilised (e.g. 0.33K_p)	1.0
Assumed load spreading due to presence of near-surface elements (e.g. rail)	Modelled	Not modelled (unless test or model data available)

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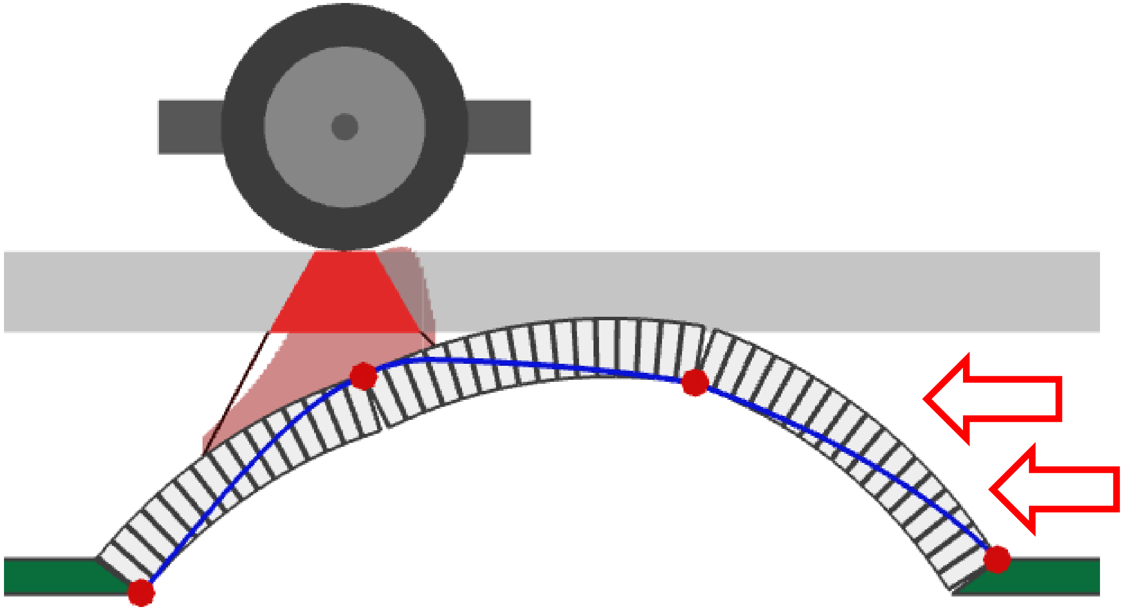
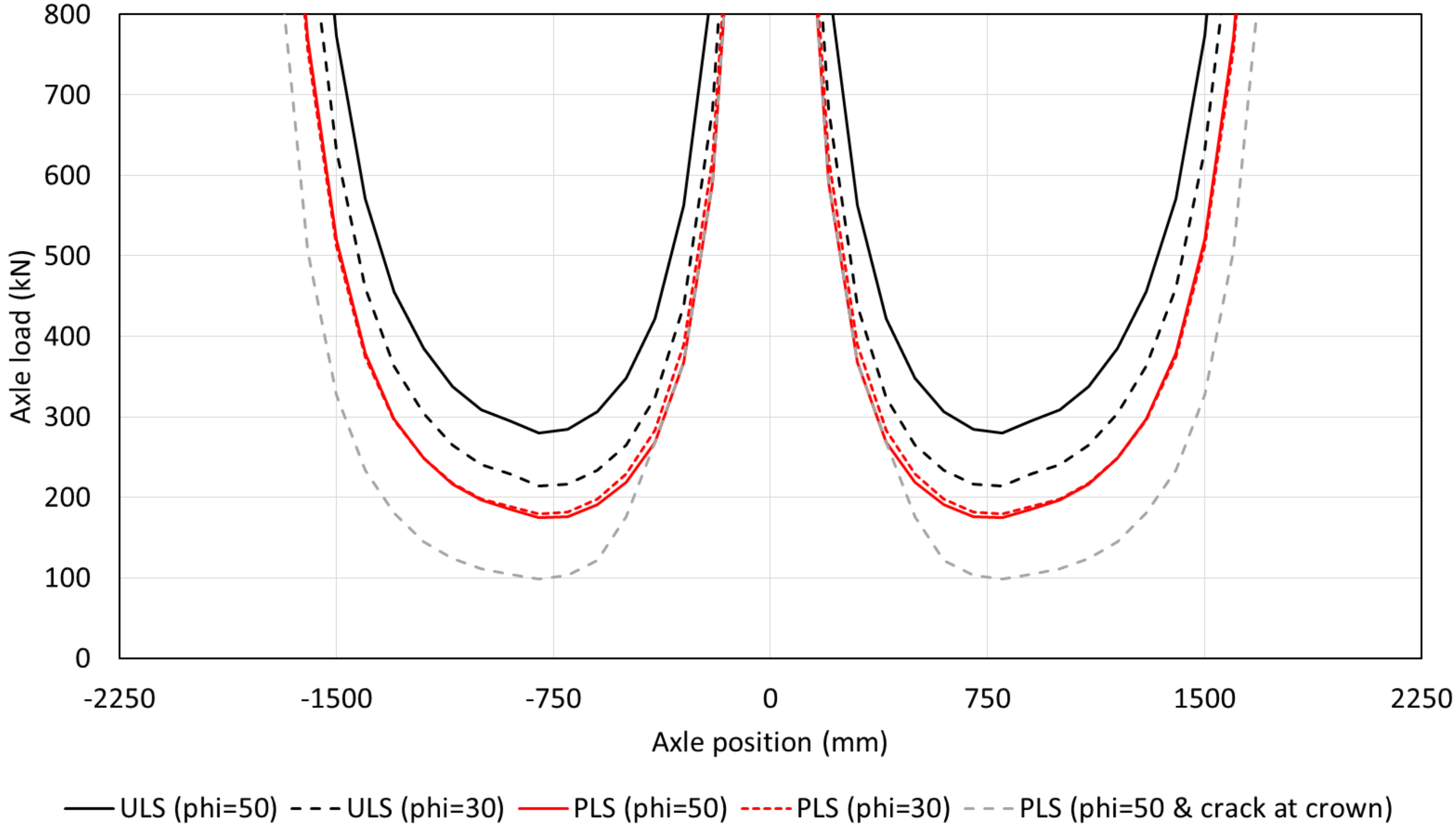
PLS-I: analysis

- Neglect passive restraint in ULS style analysis (since passive restraint requires large structural deformations to generate)

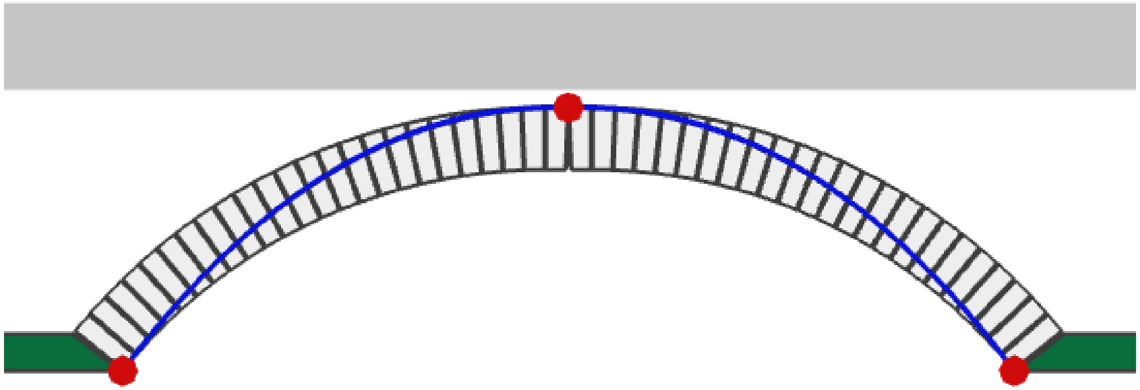


ULS & PLS-I analyses: load vs. position



PLS-II: analysis

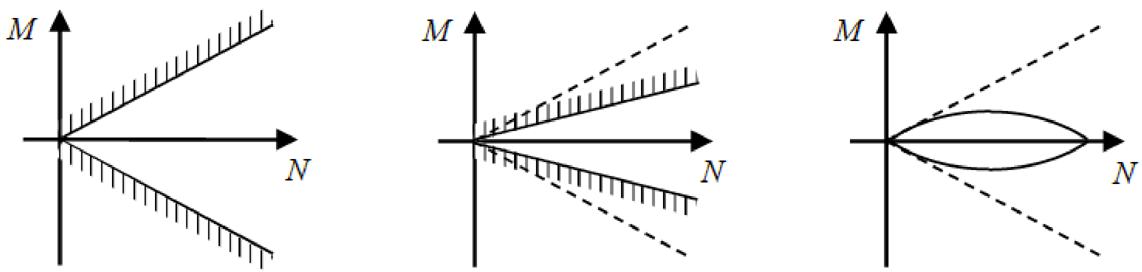
1. Start with (likely) current state, e.g:



2. Next traverse (increasing) service loads across bridge
3. Evaluate stress ranges in the masonry, and cross-reference with material fatigue characteristics

PLS-II: analysis (cont.)

- In arch analysis we often use M-N envelopes



- For PLS we can do the same: