Bersche-Rolt.

Masonry Reinforcement for Arch Bridges

Crack

Tensile forces induce cracking in masonry which can be resisted using rebar

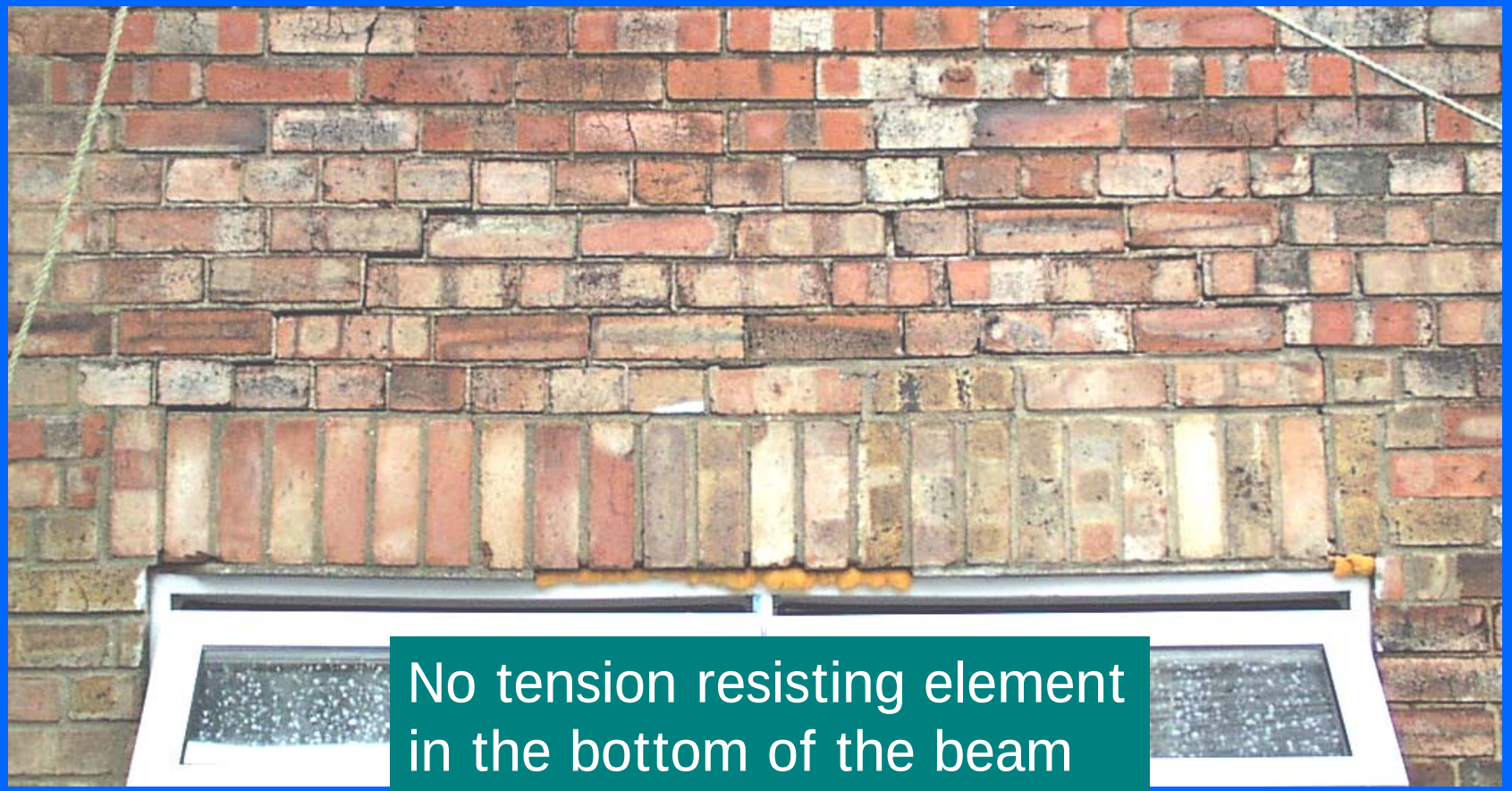
Thermal cracking

Tension induced by thermal effects

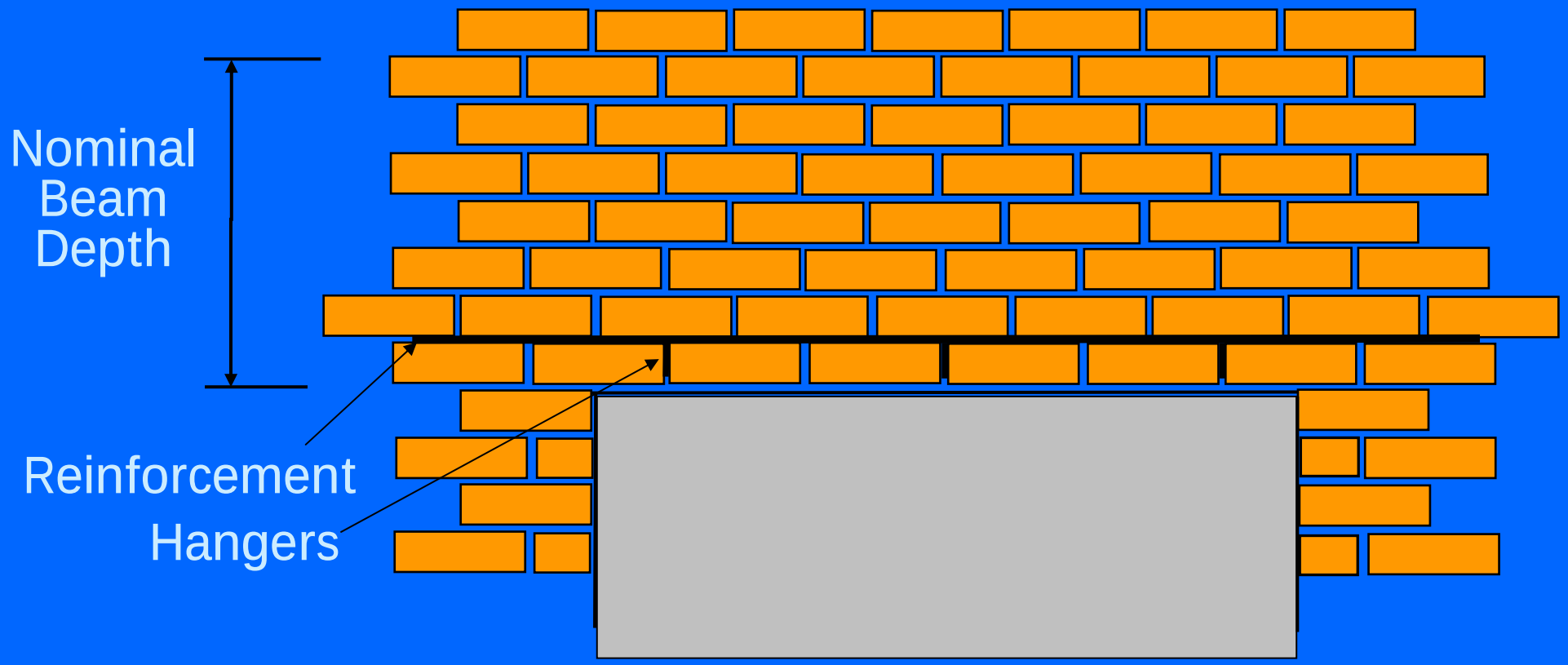
Moisture cracking

Tension induced by moisture effects

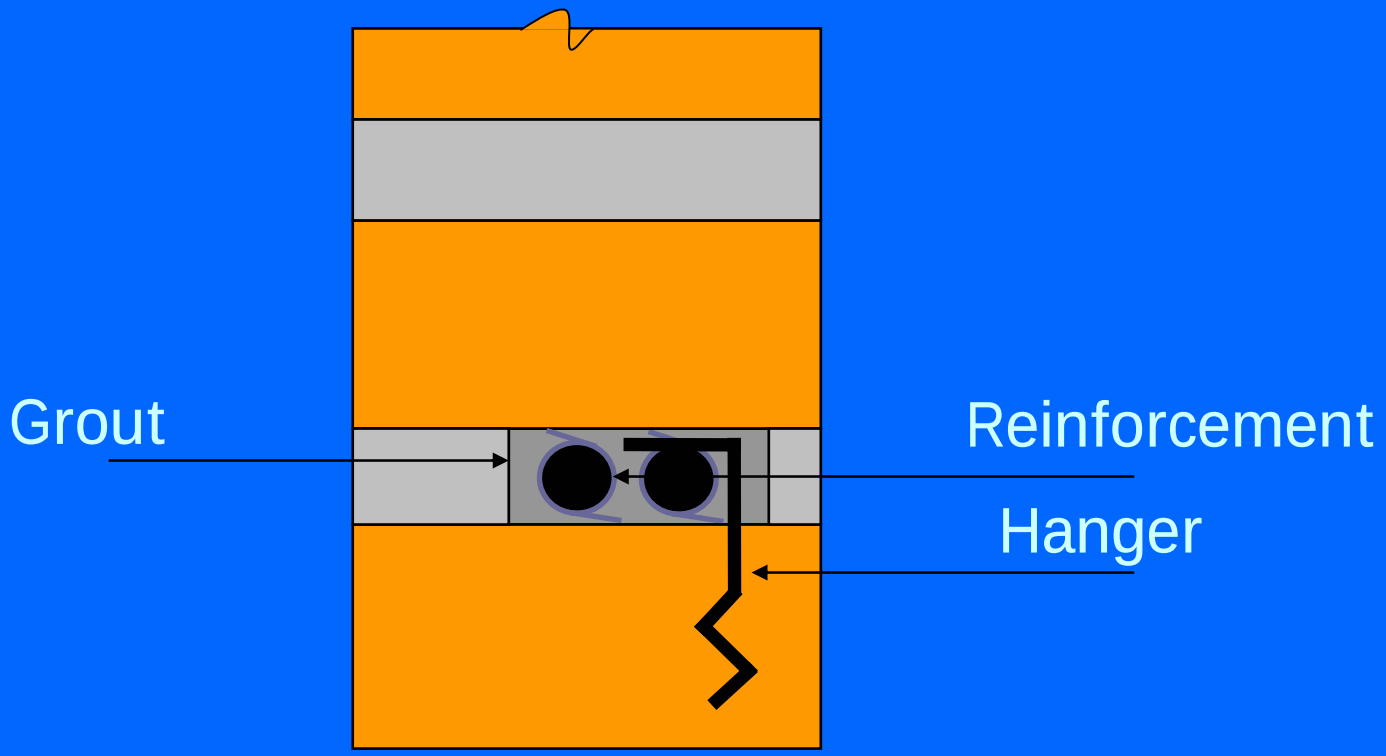
Failed beam



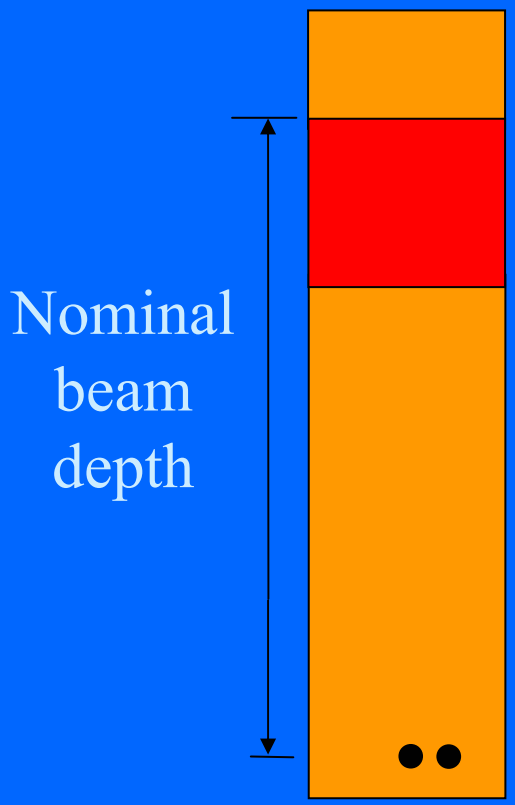
Reinforced Masonry Beam



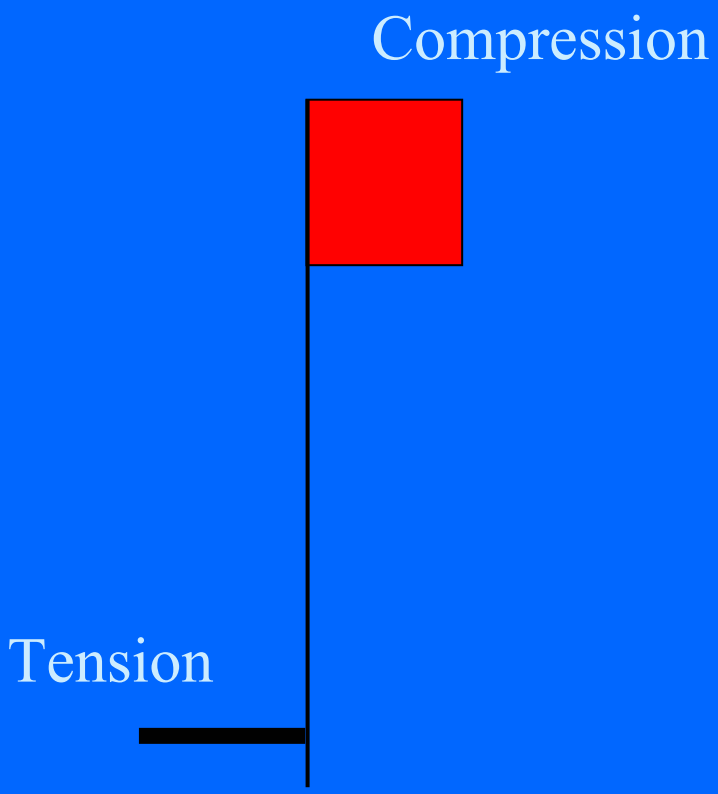
Section through beam



Masonry Beam Model



Cross Section



Stress Distribution

Design of masonry beams

Design standard BS 5628 Part 2

Formula for singly reinforced rectangular members

$Md = As \times fy \times Z/\gamma ms$

(maximum of $0.4 \times fk \times b \times d^2/ \gamma mm$)

Material partial safety factors can be adjusted to suit the condition of the structure

Materials

Reinforcement :

Stainless steel deformed bar and spacers

Grade 304 or 316

Characteristic strength 460 Mpa

Mortar:

Cementitious, shrinkage compensated, thixotropic

Characteristic strength 50MPa

Mortar strength can be varied but the key property of bond strength has to be retained to ensure composite action

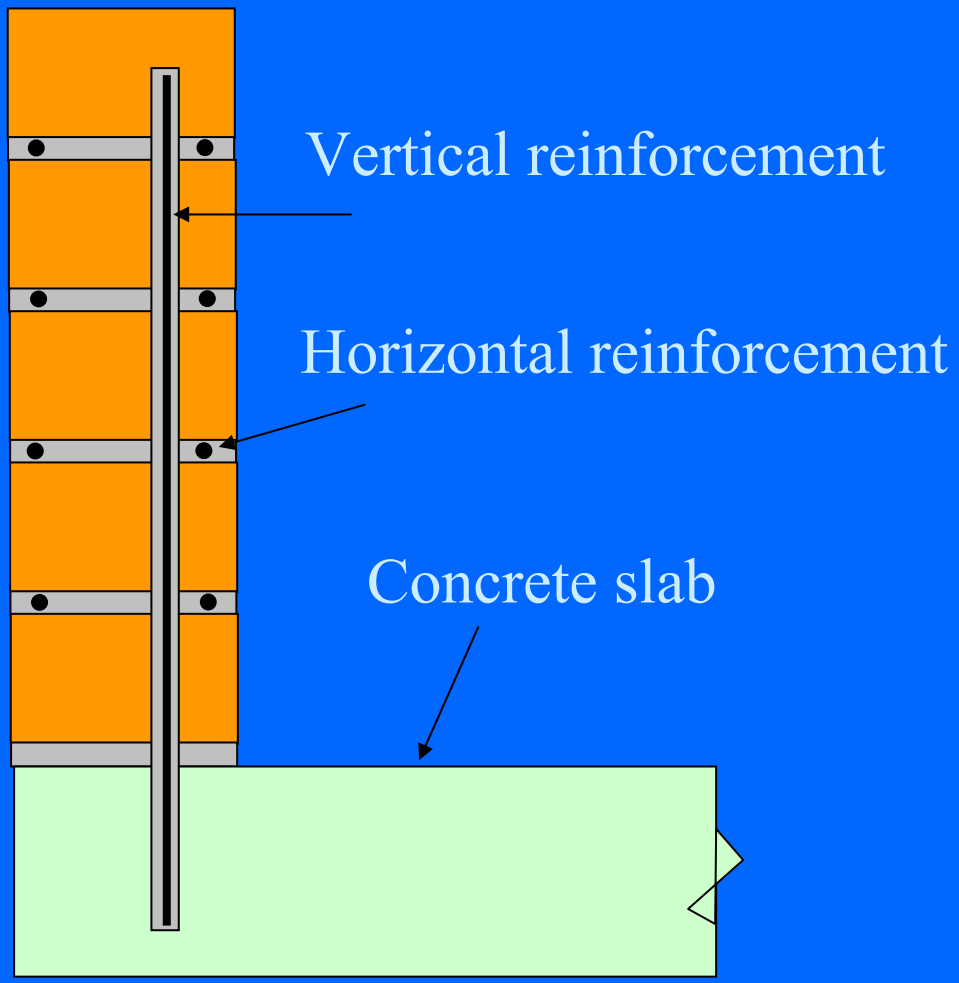
Simple beam

Beam for Temporary Works

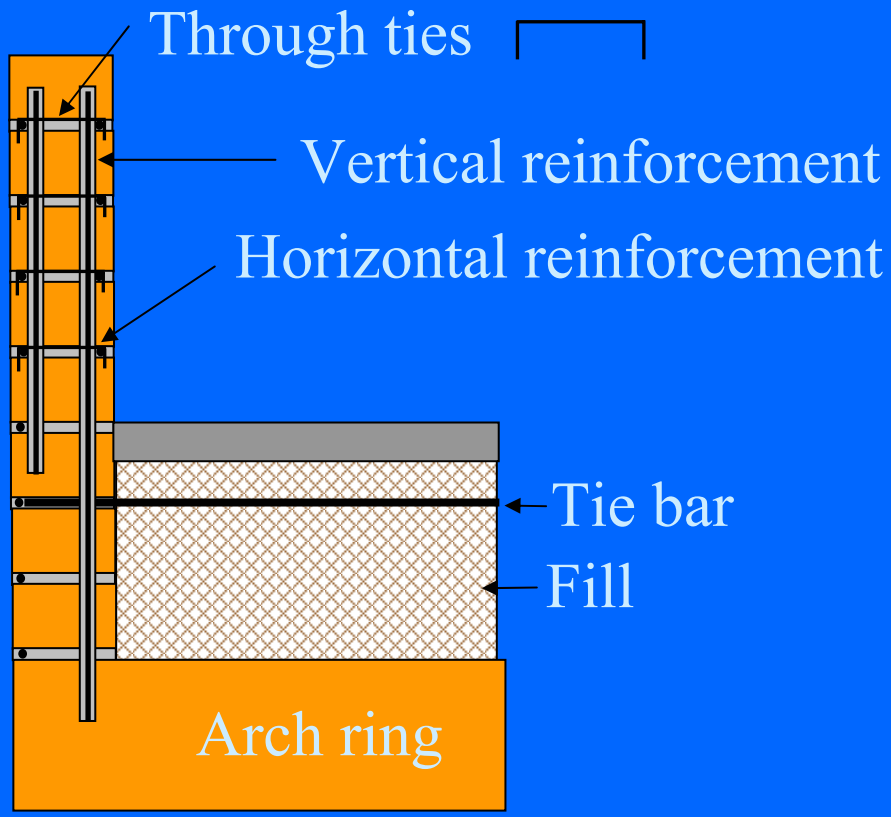
Spey Bridge

Masonry parapets failed assessment for bending capacity

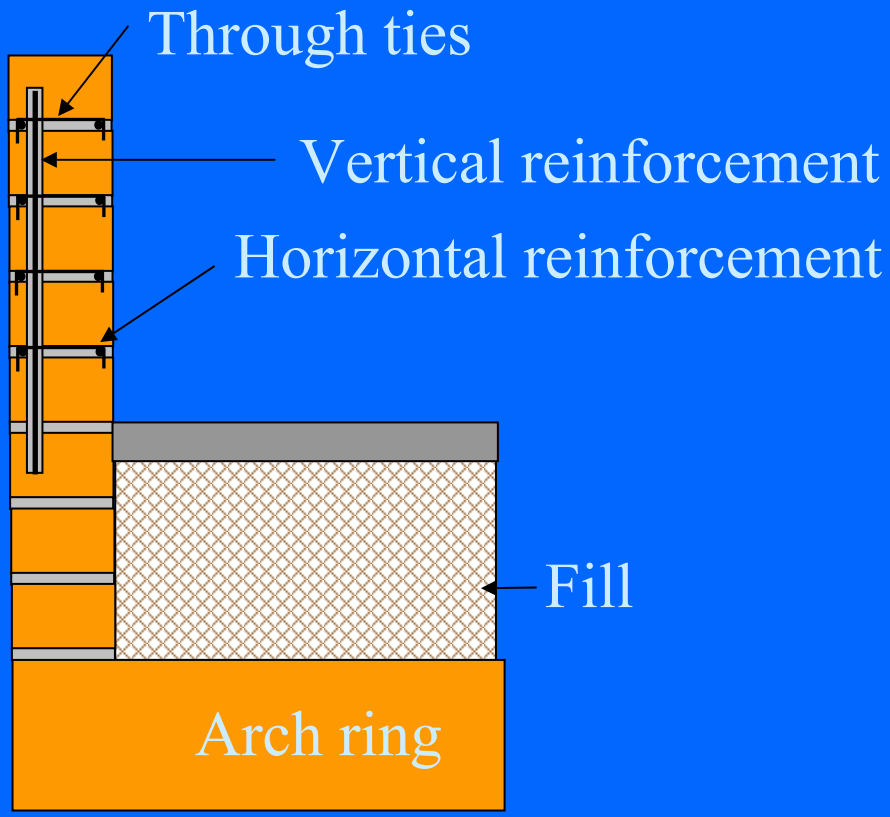
Parapet reinforcement



Parapet reinforcement



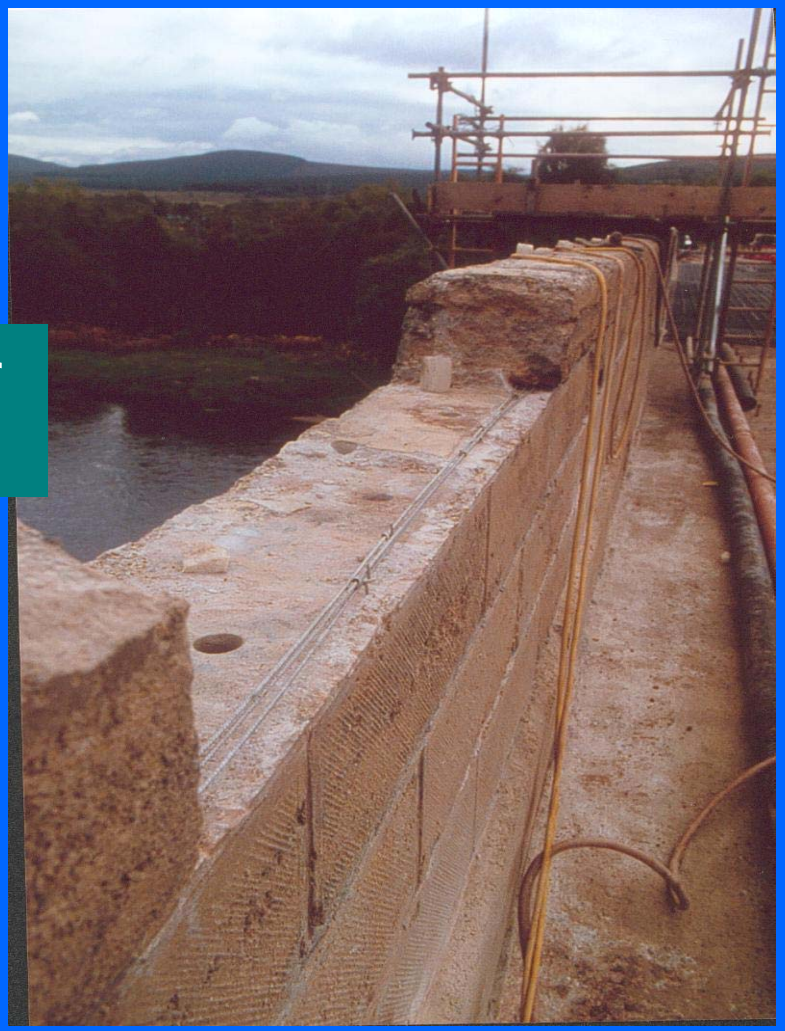
Reinforced masonry



Contained masonry

Parapet reinforcement

Core drilled holes for grouting in rebar



Drilling for vertical bars

Portable drilling rig

Completed parapet

Retaining wall

Upper courses displaced by traffic action

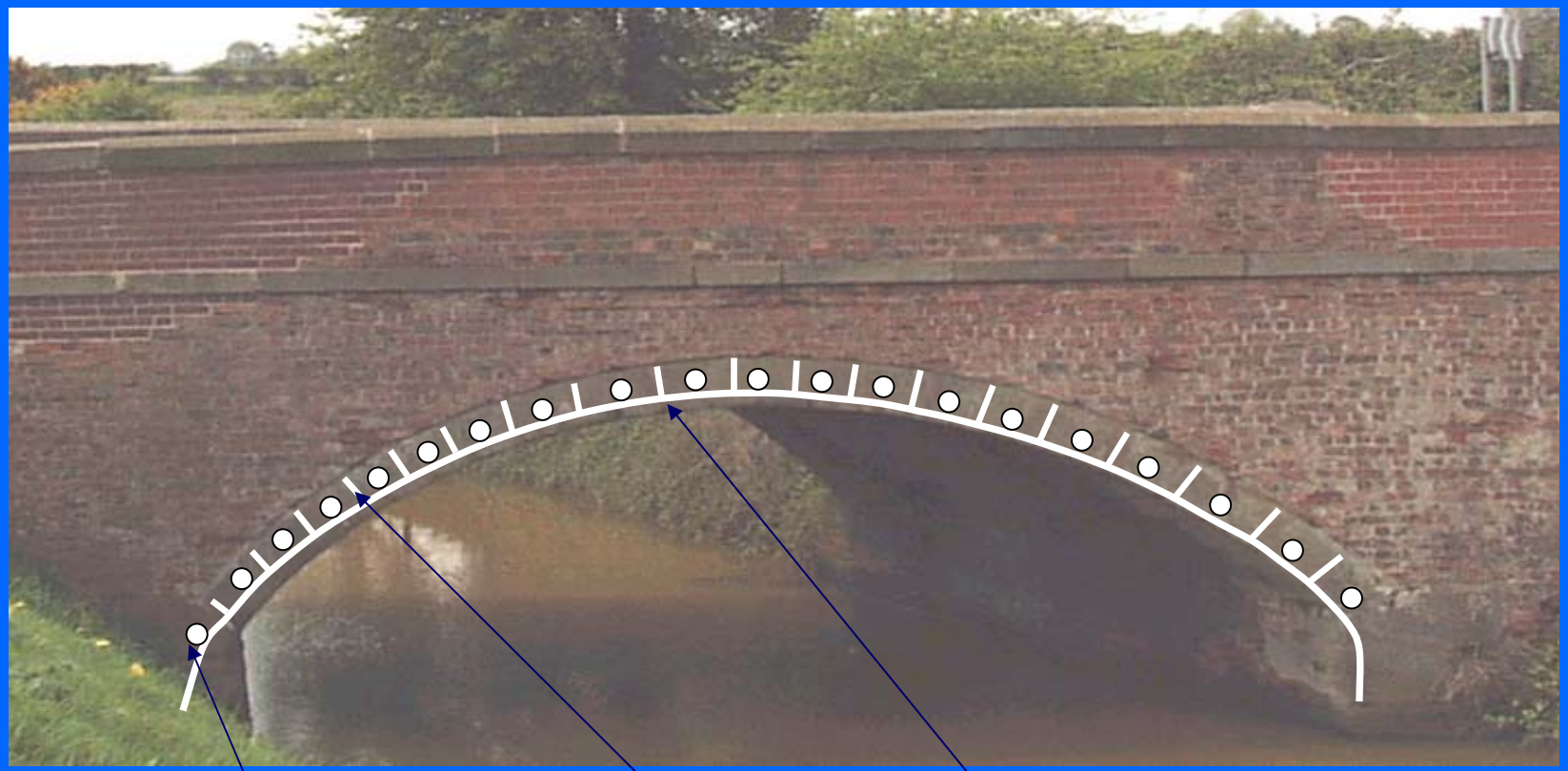
Retaining wall

Vertical and horizontal rebar installed to unify wall then repointed in hydraulic lime

Requirements for Arch Strengthening

- Increase load carrying capacity of structure
- Avoid changing beneficial characteristics of masonry arch form by over-stiffening locally
- Avoid significant increase in self-weight
- Minimum disruption for users and buried services
- Maintain arch profile
- Use materials that are tolerant of real site conditions particularly water penetration
- Be cost effective

Arch reinforcement



Delph Bridge

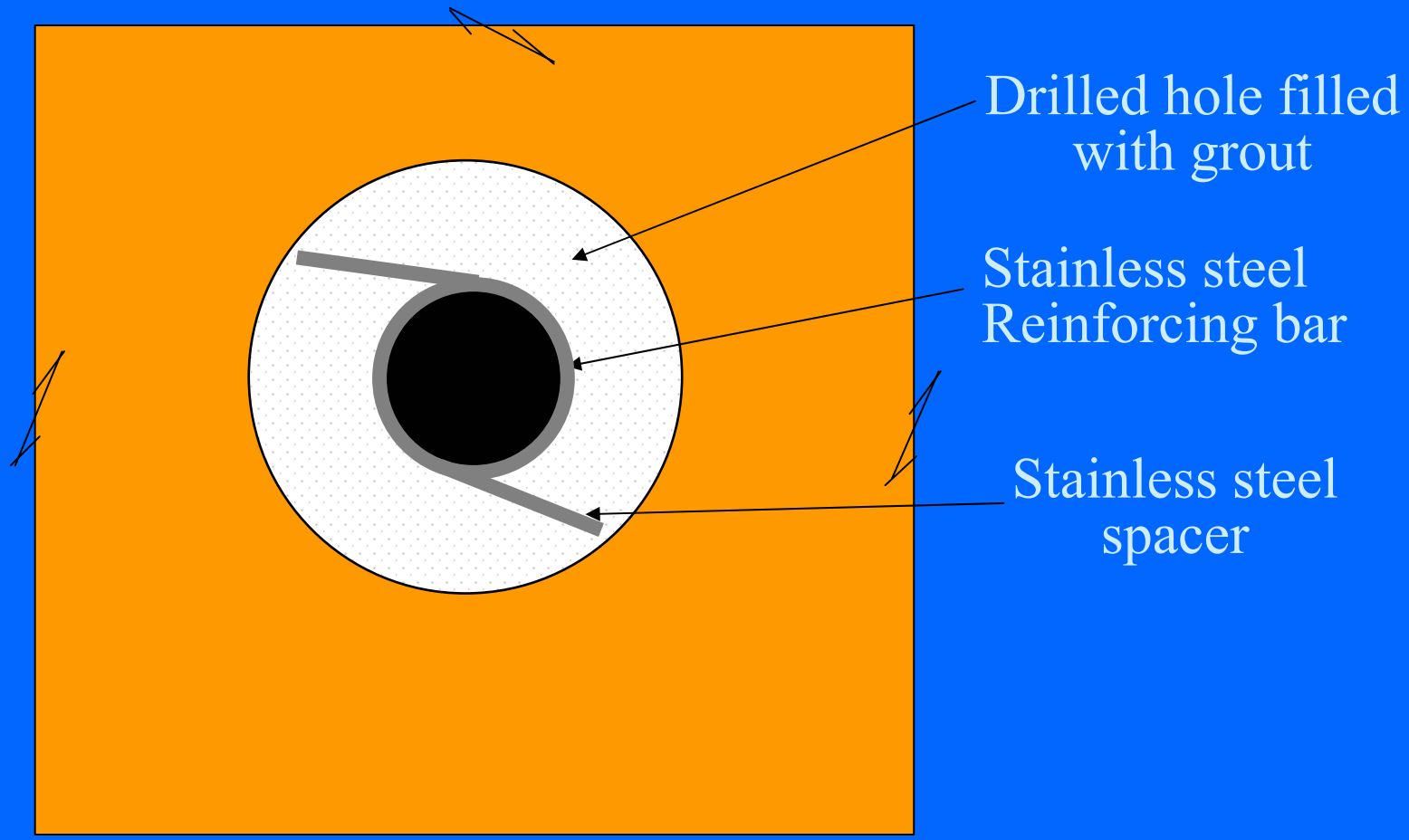
Arch discontinuity

Transverse drilled bars form dowels across step in arch

Hambleden Bridge

Transverse bars cross cracks allowing a higher condition factor to be used in the assessment

Transverse Reinforcement Detail



Transverse bar

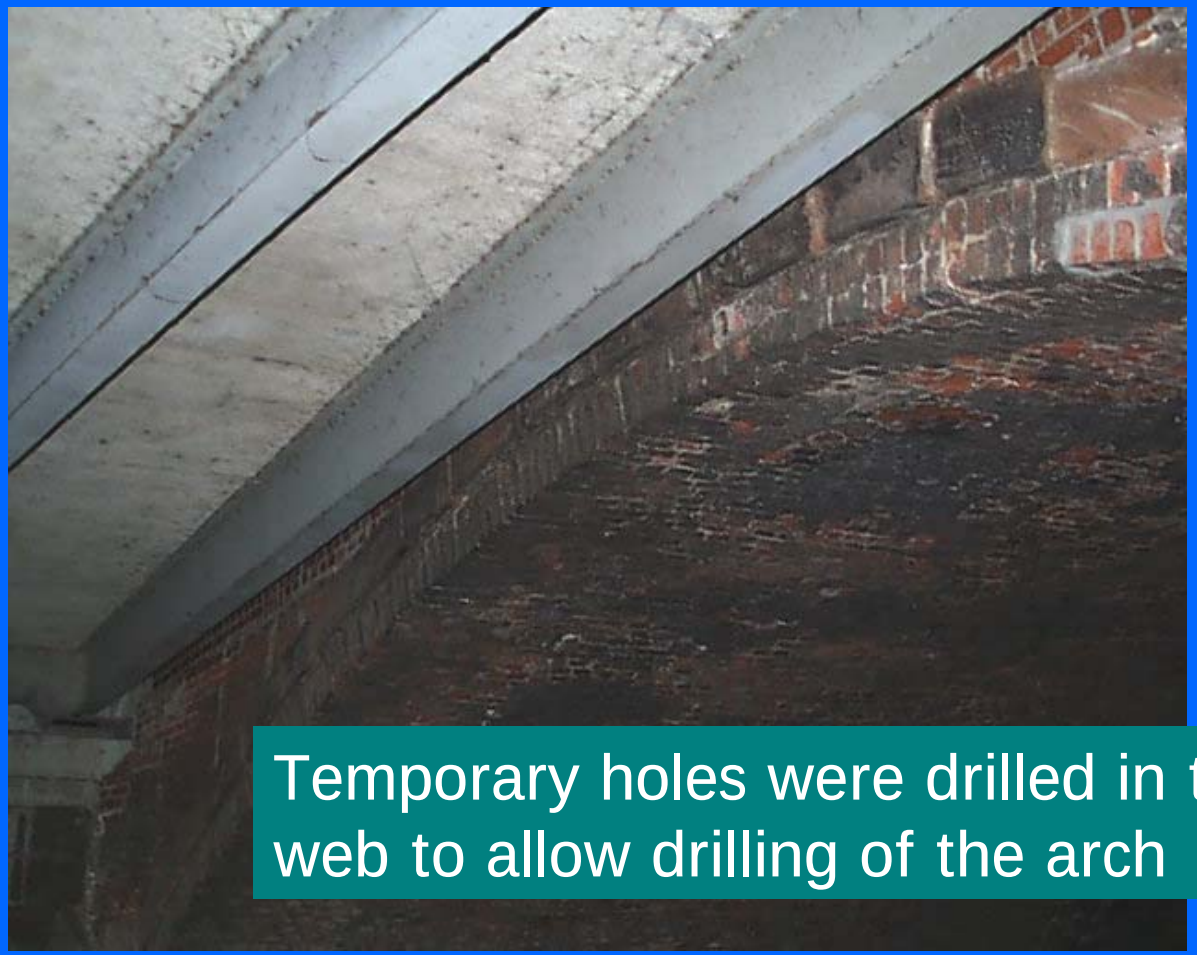
Drilling transverse holes

Drilling transverse holes

Drilling water is collected and solids settled out before disposal

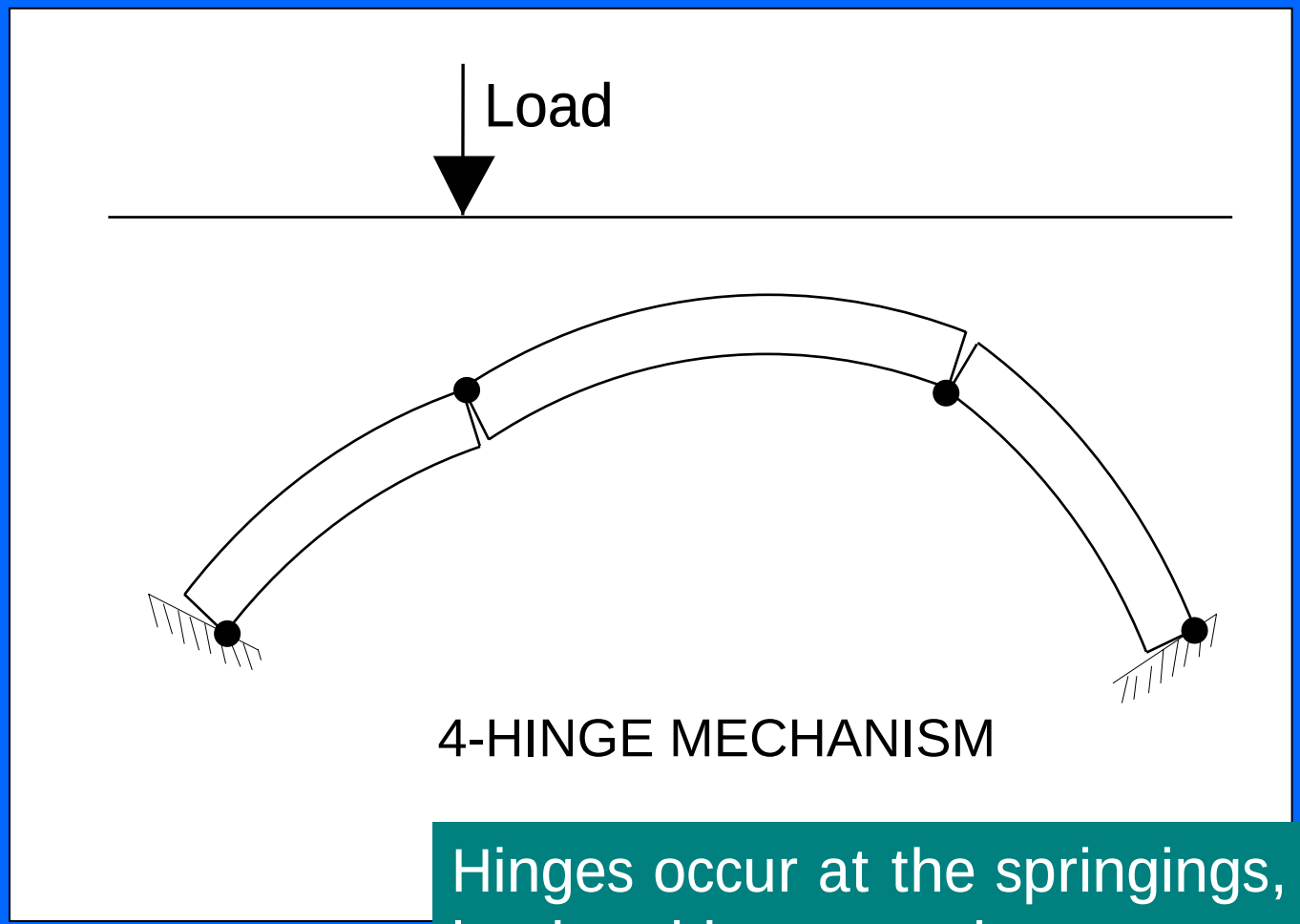
Drill cores

Obstructions to drilling



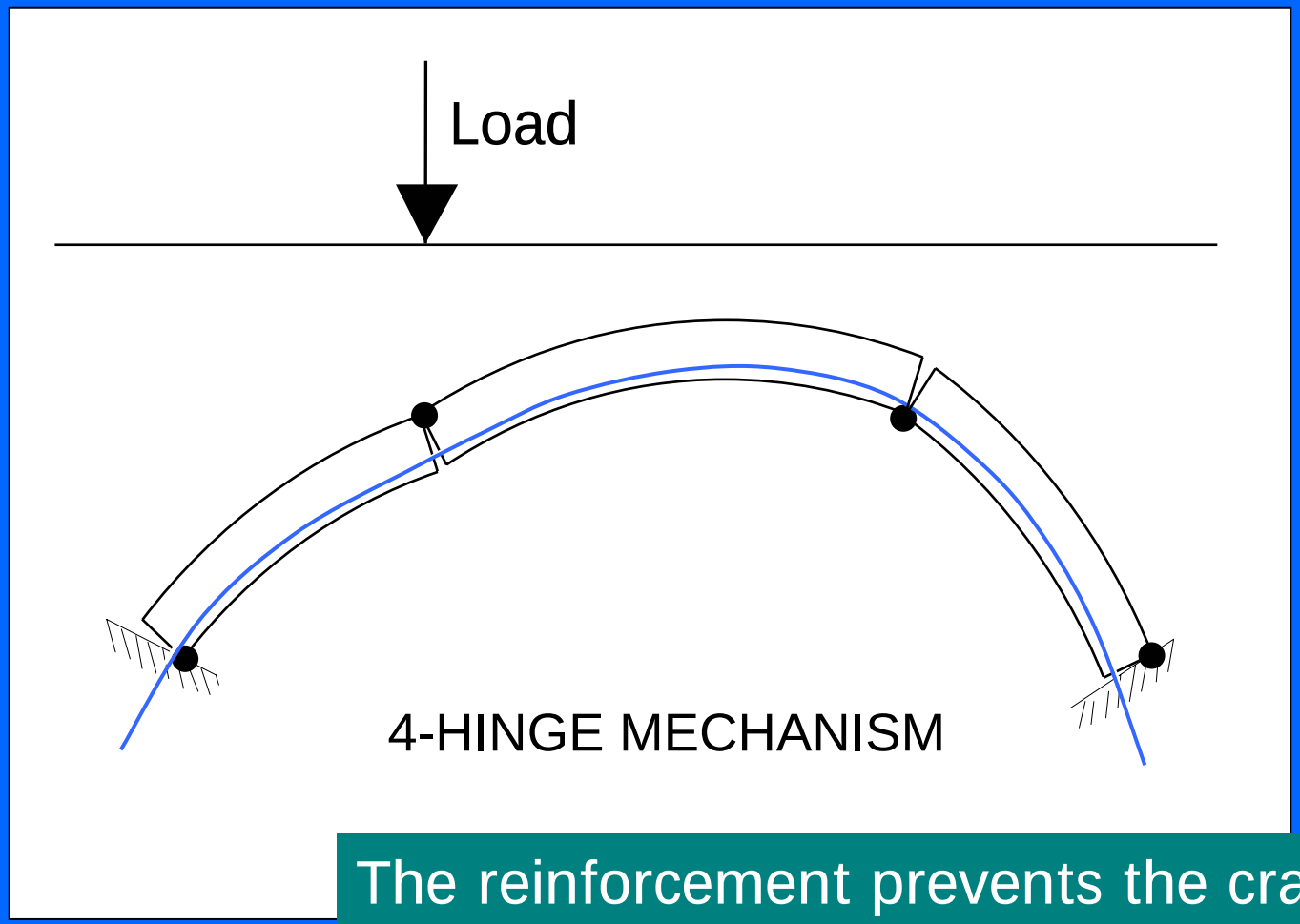
Temporary holes were drilled in the web to allow drilling of the arch

Hinge mechanism



Hinges occur at the springings, under the load and between the crown and springing

Reinforced hinge



The reinforcement prevents the crack under the load from opening

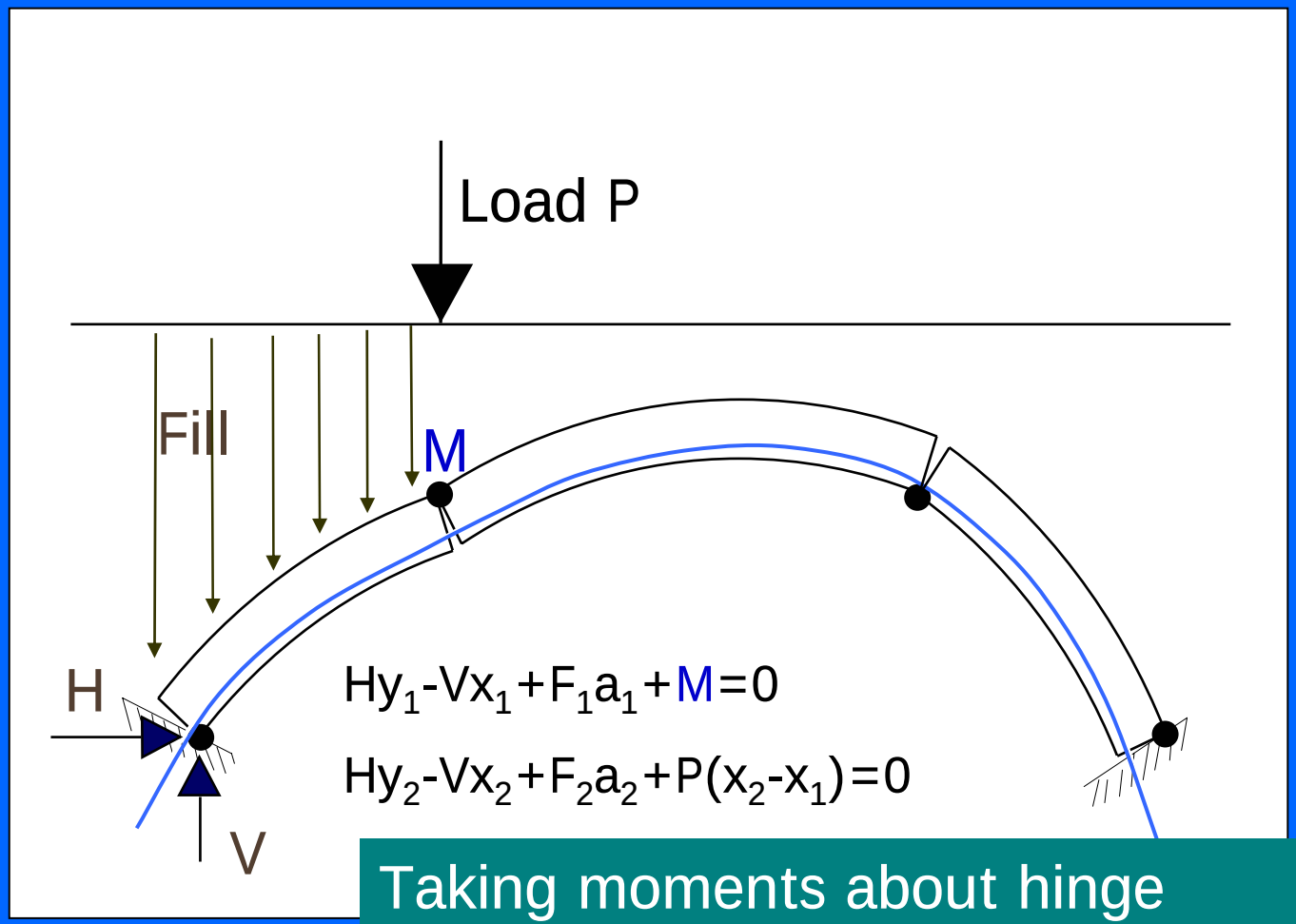
Hinge positions at failure

Note multiple small cracks under load position where reinforced compared to single large crack in extrados

Delph sandstone

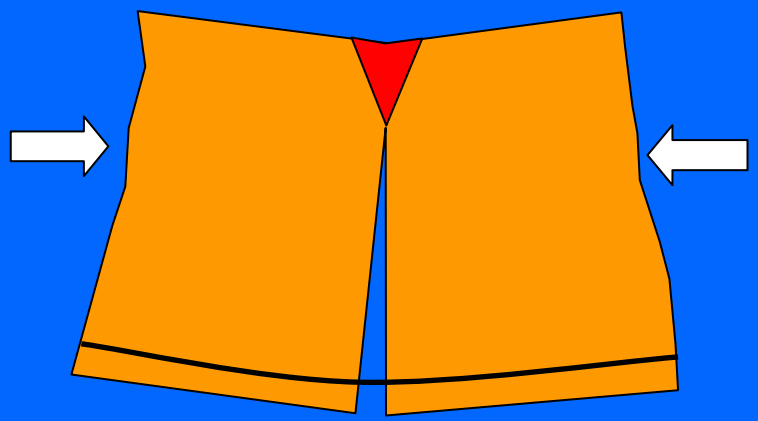
Sandstone at the springing provides rebar anchorage resulting in a second reinforced hinge

Analysis

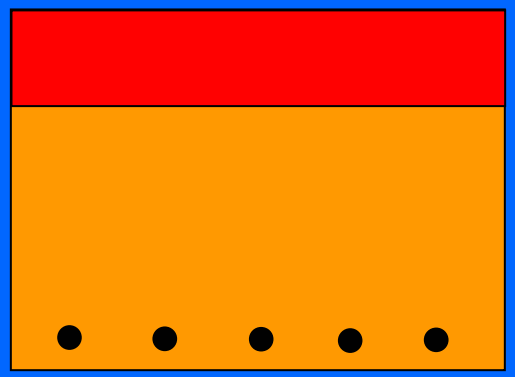


Taking moments about hinge positions gives collapse load. Hinge positions are moved until minimum value of load found.

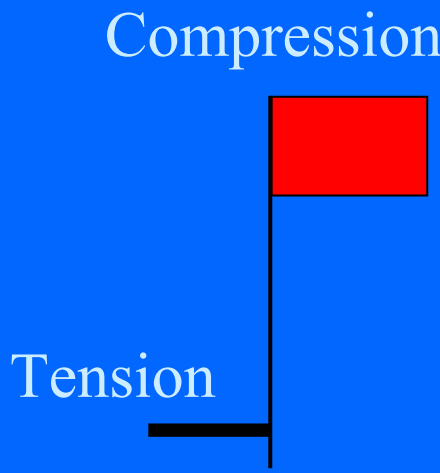
Hinge detail



Hinge model

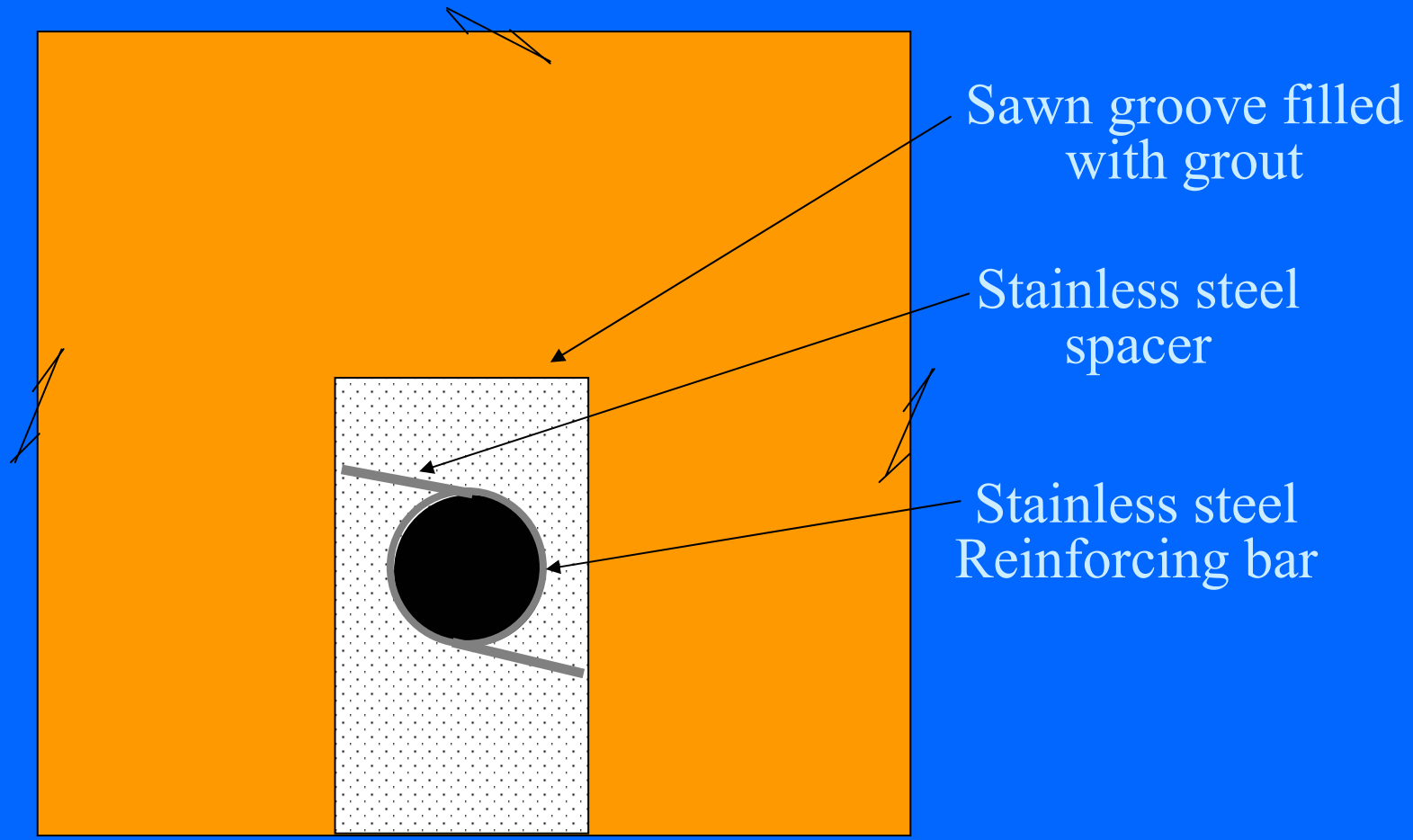


Cross section



Stress distribution

Longitudinal reinforcement



Cutting grooves

Completed intrados

Transverse bars are not seen but longitudinal bars in slots are

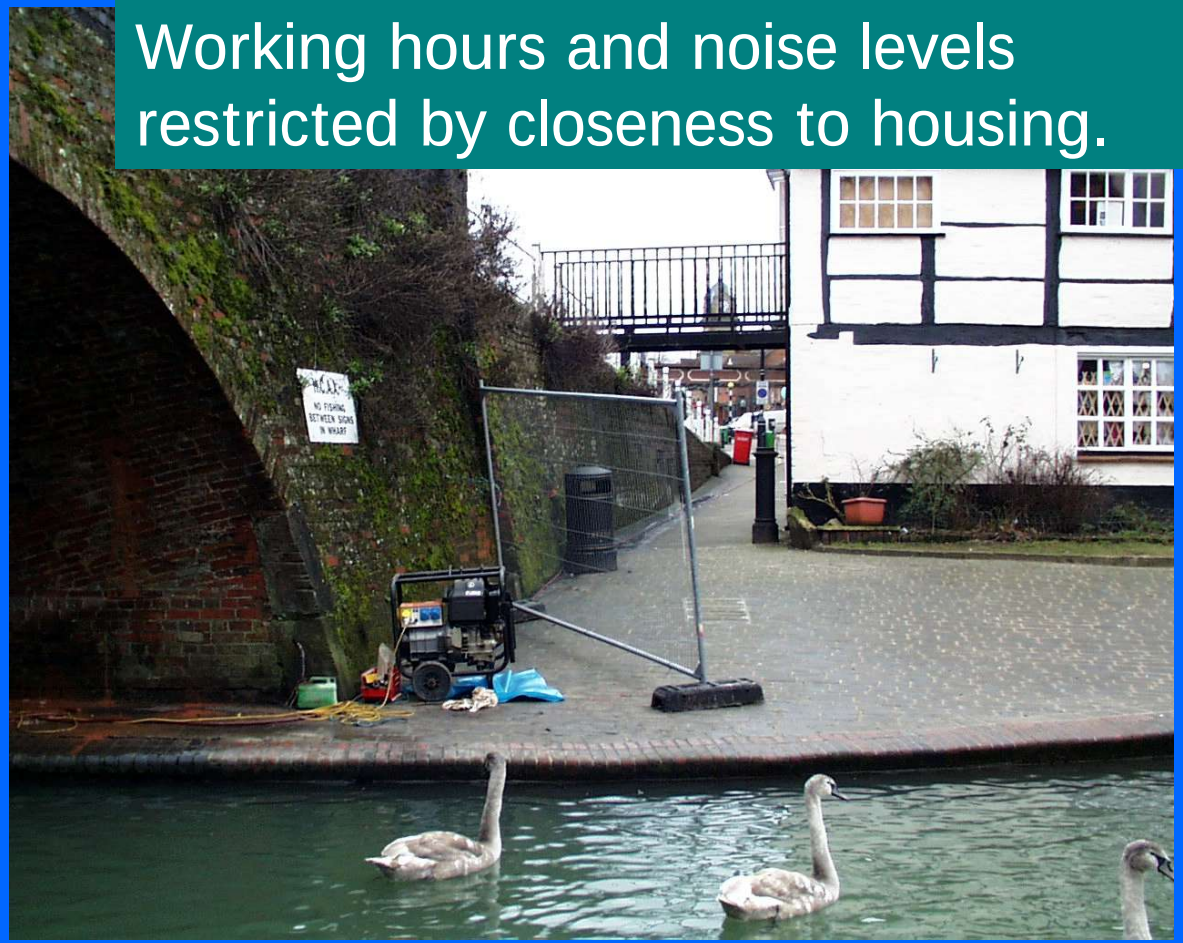
Hungerford Bridge

Hungerford Bridge

Establishing arch ring thickness and height of backing by trial drilling

Hungerford

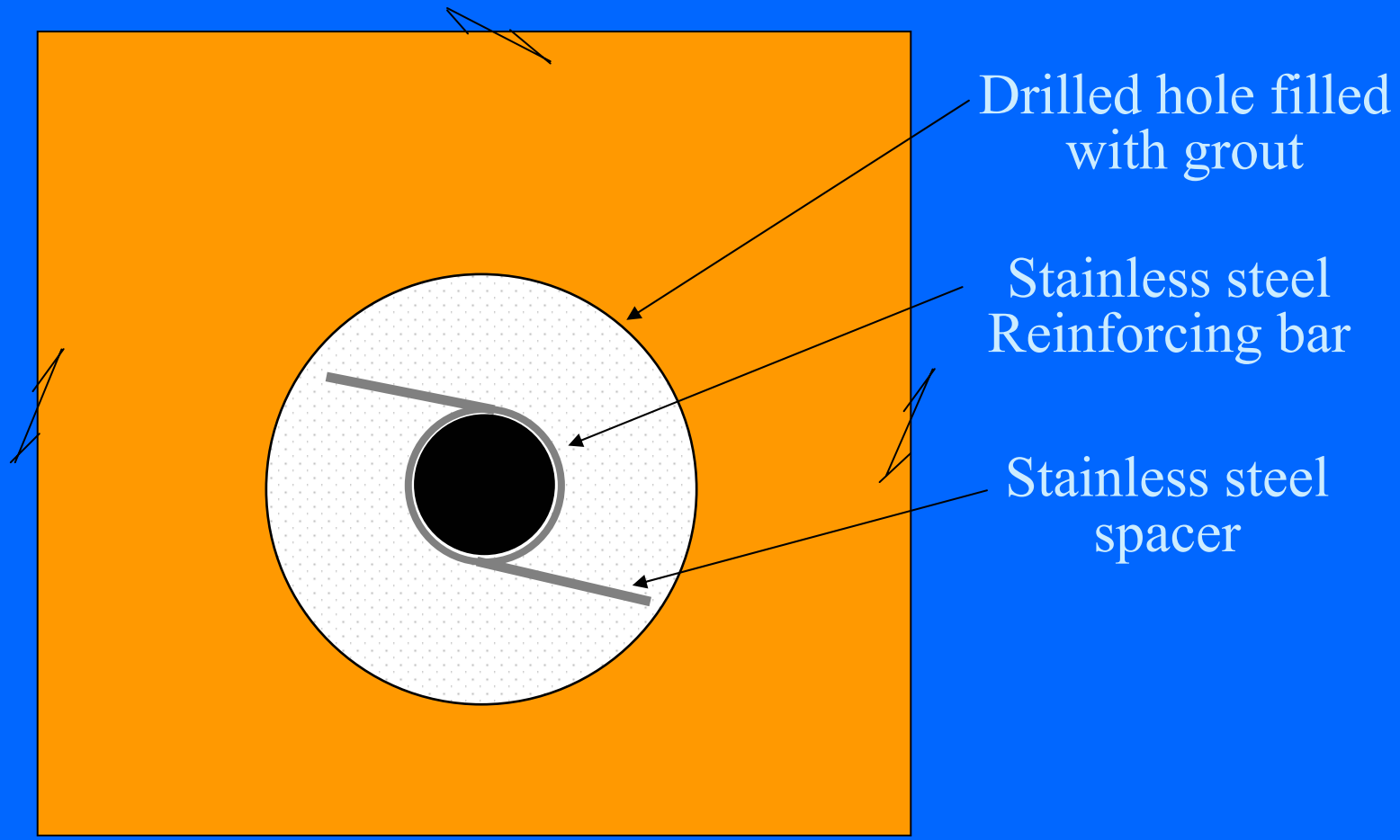
Working hours and noise levels restricted by closeness to housing.



Working platform

Floating platform as canal kept open during the works

Longitudinal reinforcement



Longitudinal drilling

Three bricks removed to gain access to correct depth for drill head

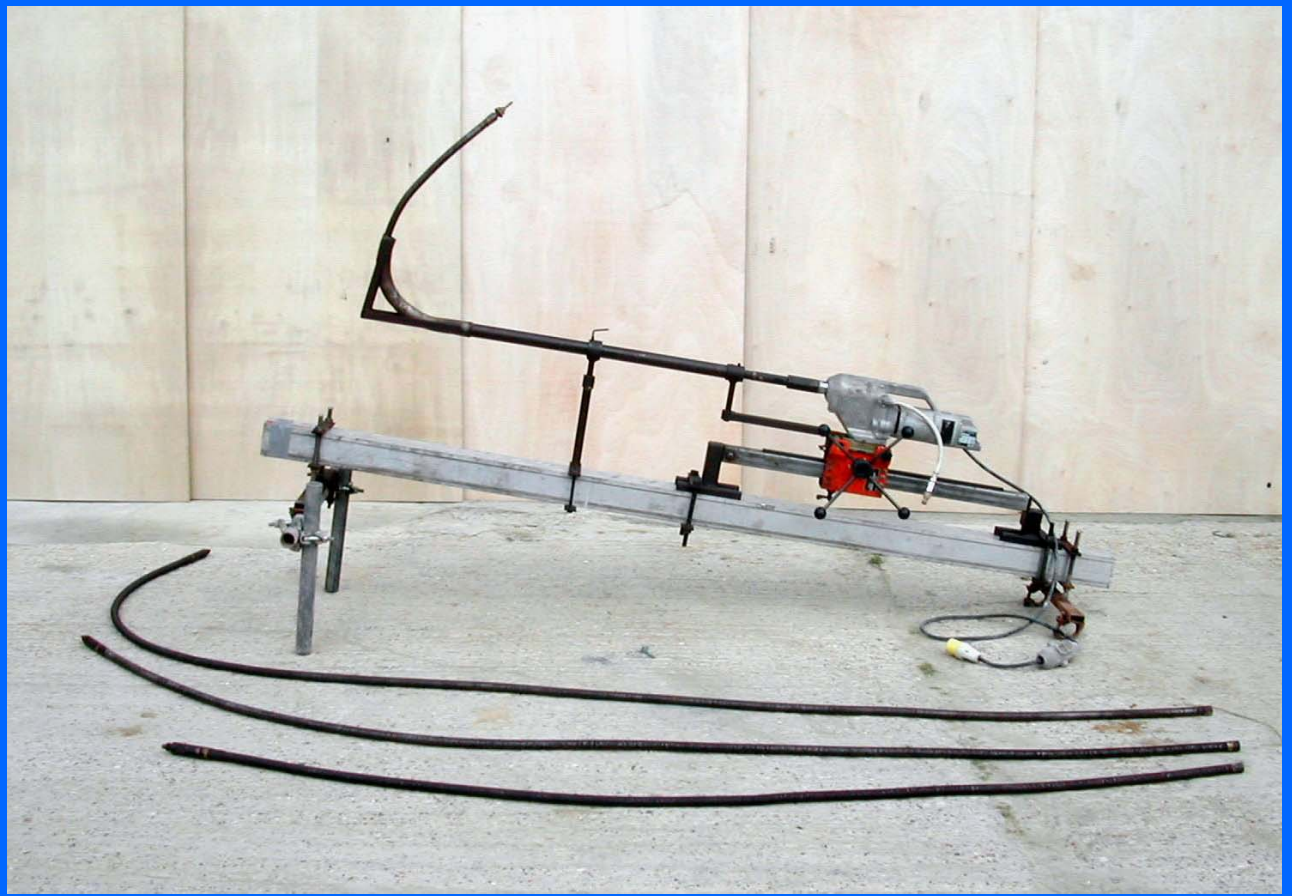
Longitudinal drilling

Longitudinal drilling

Drill bits & Flexible drive

Drilling rig

Drilling rig extended



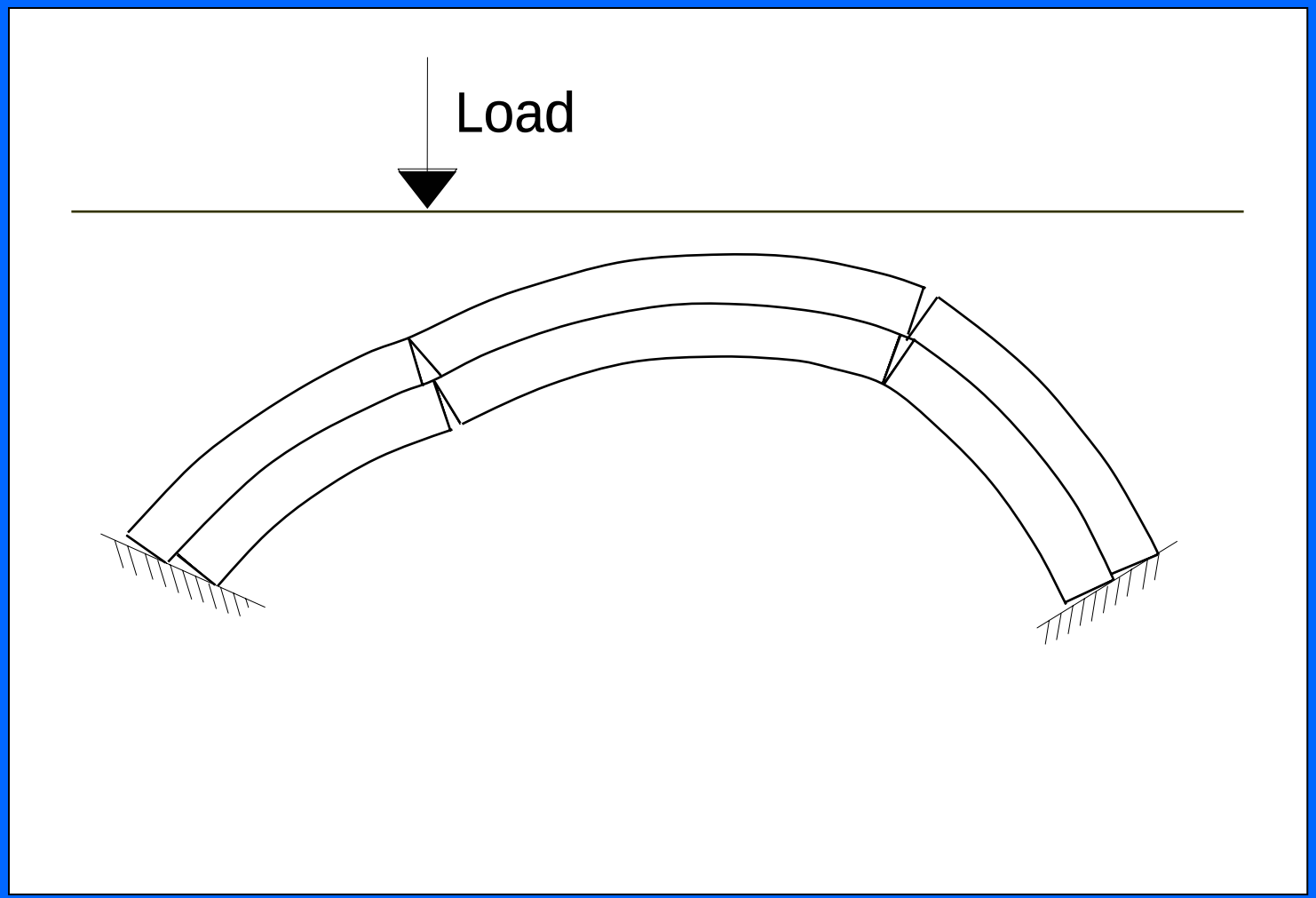
Grouting

Low pressure grouting to prevent damage to arch

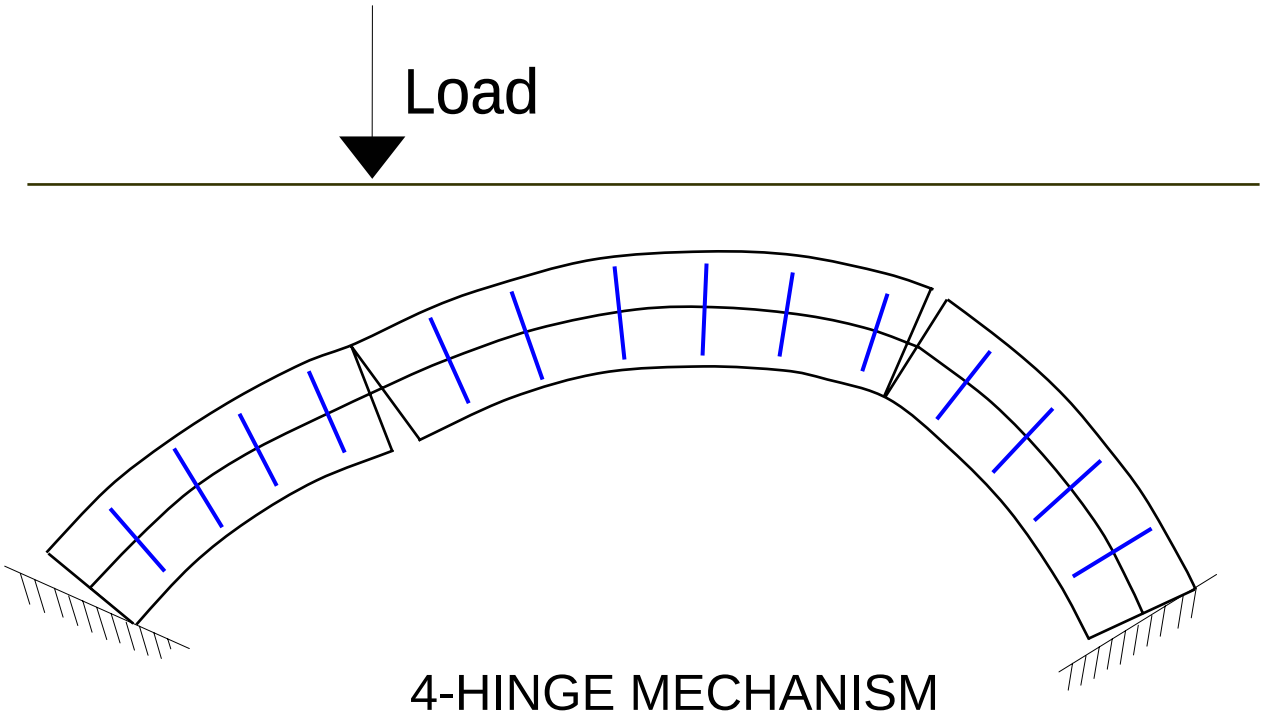
Cold weather grouting

B-R grout can be used down to –3deg C

Ring separation



Radial ties

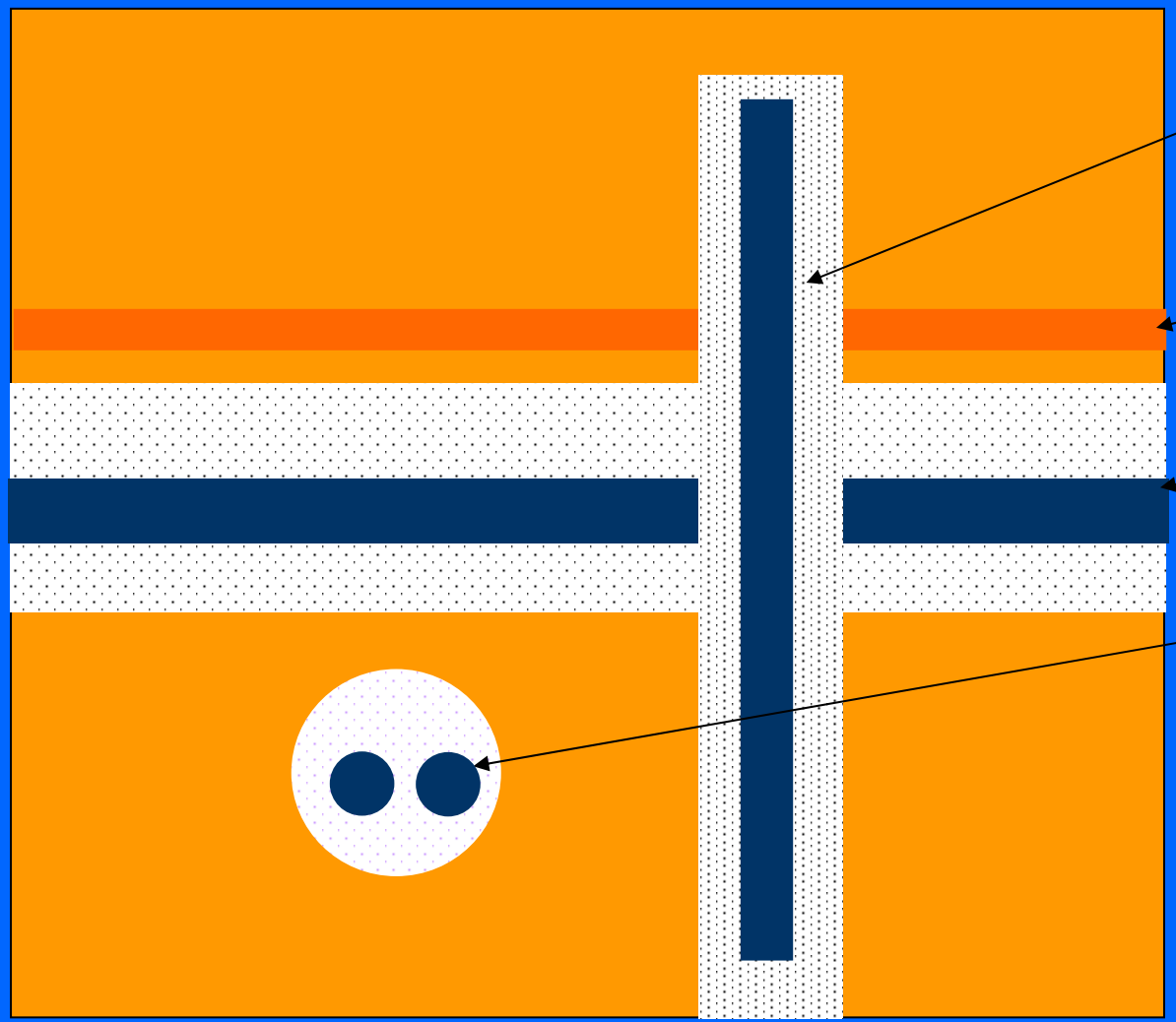


Pins drilled across bed joints prevent premature ring separation

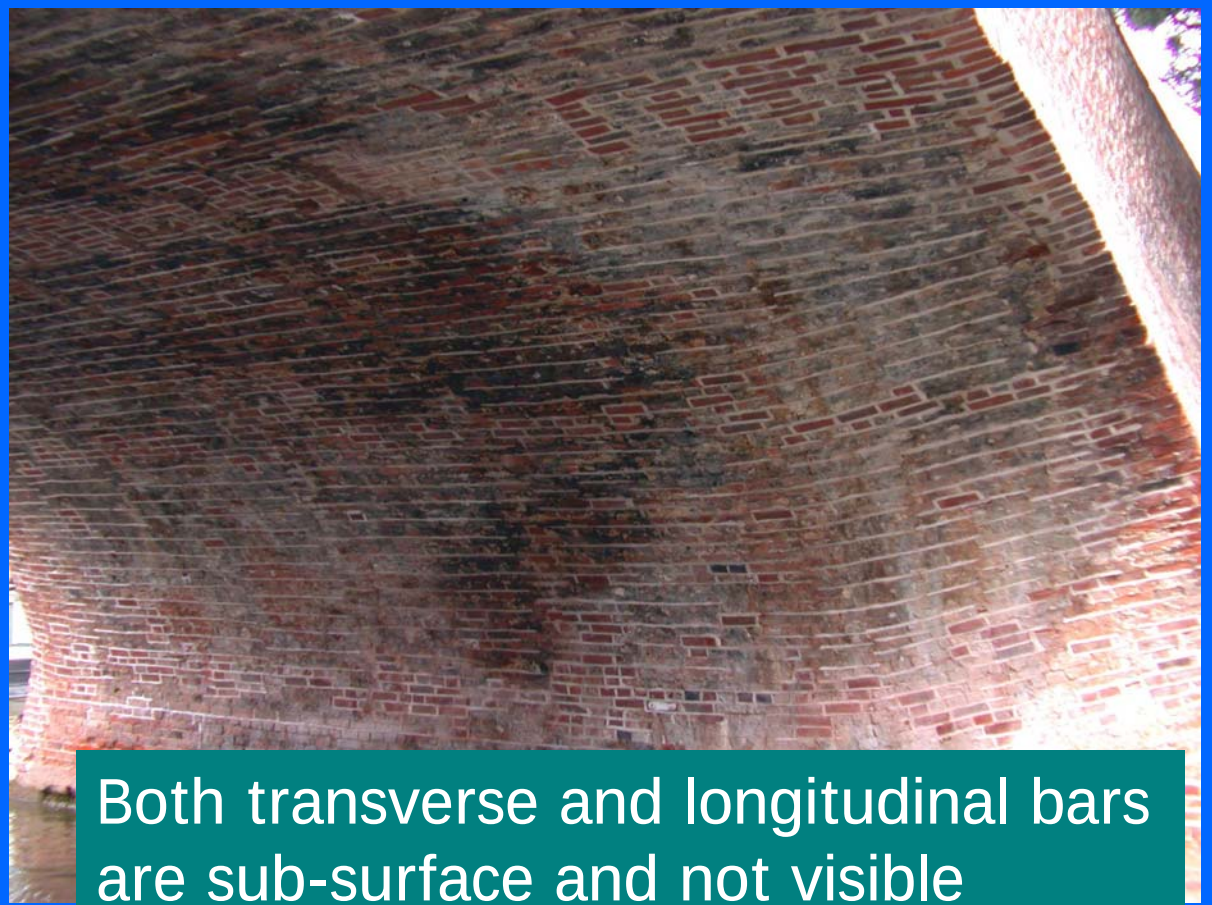
Radial ties

Various types of pin were tested with no significant difference in performance therefore the simple straight pin was adopted

Complete reinforcement



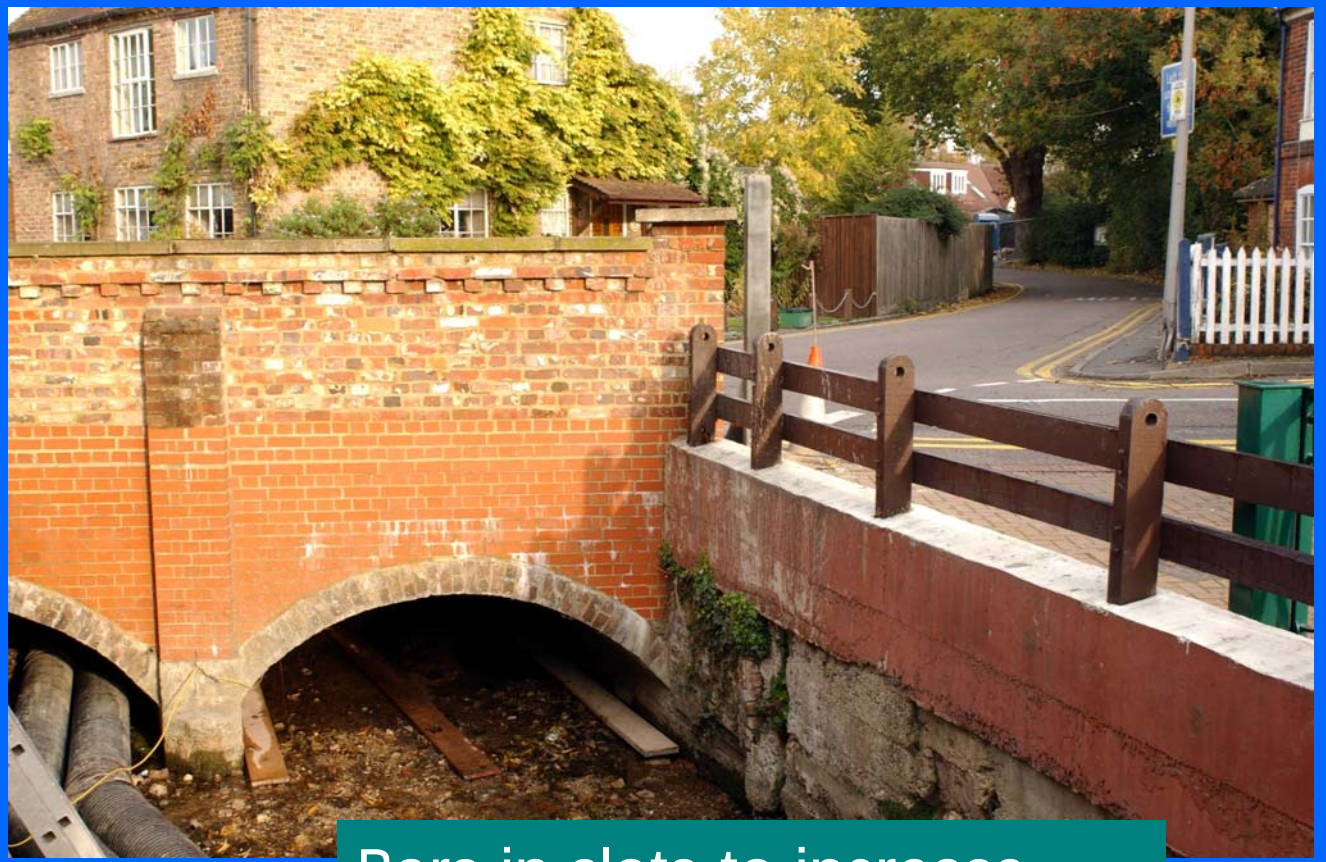
Completed arch



Both transverse and longitudinal bars are sub-surface and not visible

Completed bridge

Willow Bank 3



Bars in slots to increase axle load were installed

Willow Bank 1

Bars in slots to increase axle load were installed 10m upstream of the access point

Alternative access

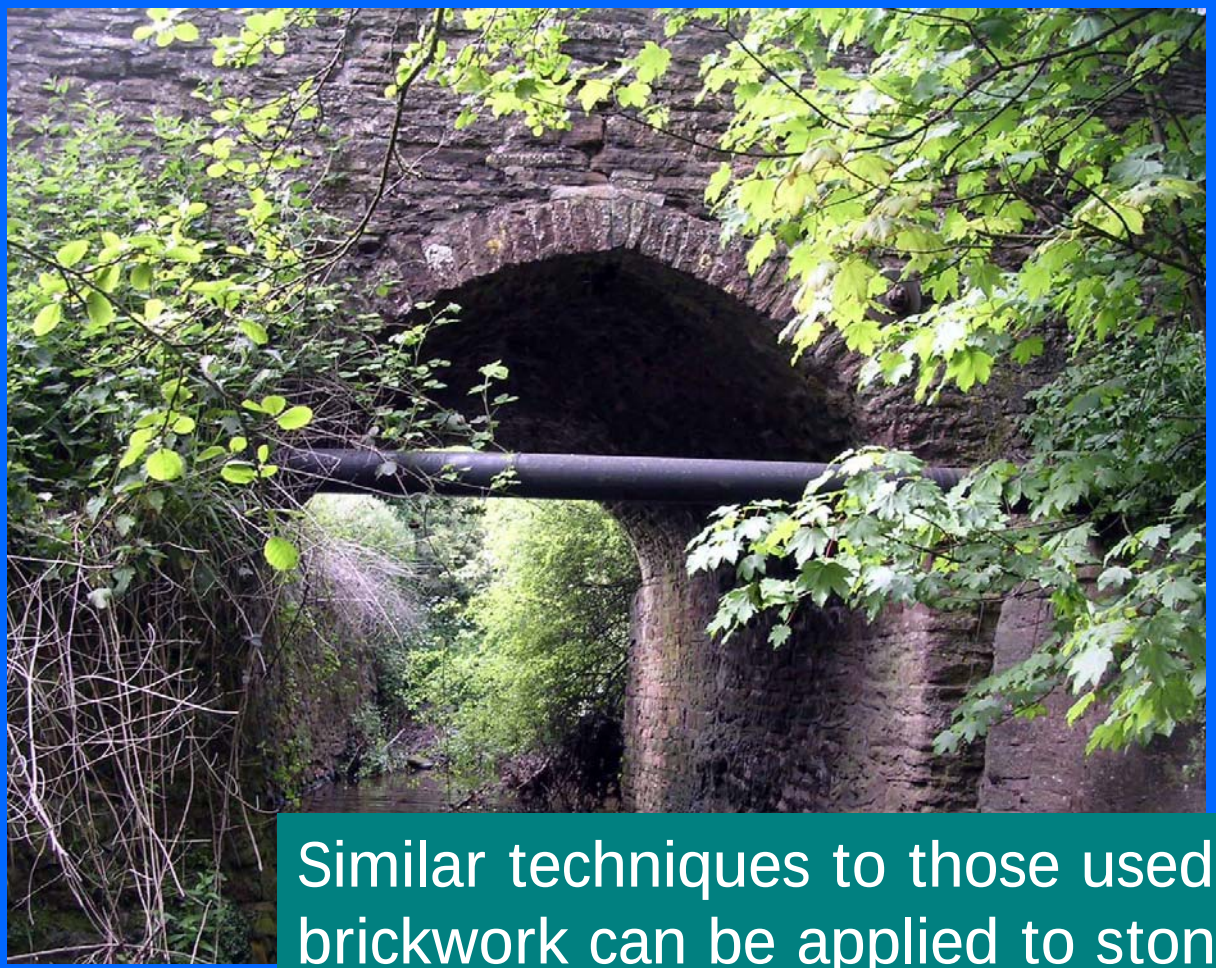
Low headroom

Vacuum cutting

Washing down

Pollution control

Stone masonry



Similar techniques to those used for brickwork can be applied to stone

Advantages

- Improves robustness, ductility and load distribution capability of existing structure
- Increases load carrying capacity of structure
- Does not change beneficial characteristics of masonry arch construction form
- Does not increase self weight of structure
- Minimum disruption to users of structure and buried services
- Arch profile is maintained
- Accommodates variations in the existing masonry
- Uses well tried durable materials

Hydraulic lime

Testing to establish the levels of creep using hydraulic lime mortars to bond reinforcement

Bersche-Rolt

Award Winner
for
Design and Execution

The I.C.E.Historic Bridge and Infrastructure Awards 2004