

# Strengthening metallic bridges

## Network Rail's experiences

Brian Bell

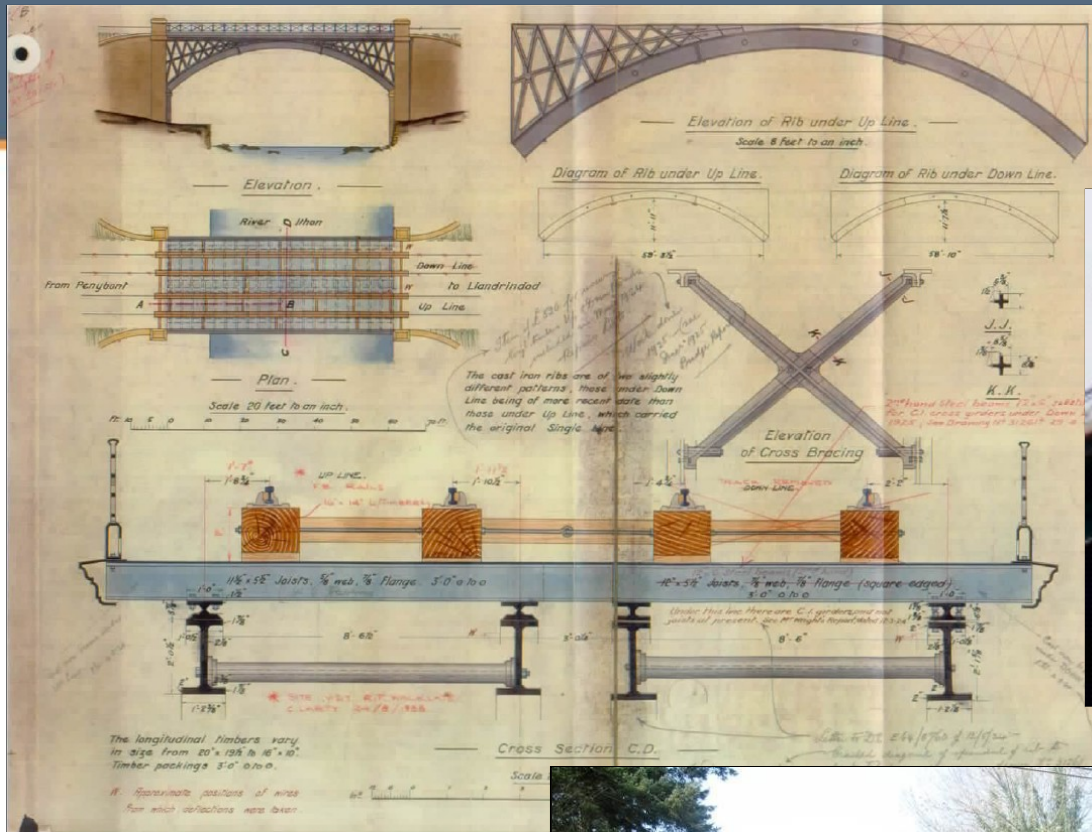
# Presentation outline

- Network Rail's metallic bridges
- Why do we strengthen metallic bridges?
- Network Rail case studies
- Further reading
- Conclusions

# Network Rail's metallic bridges

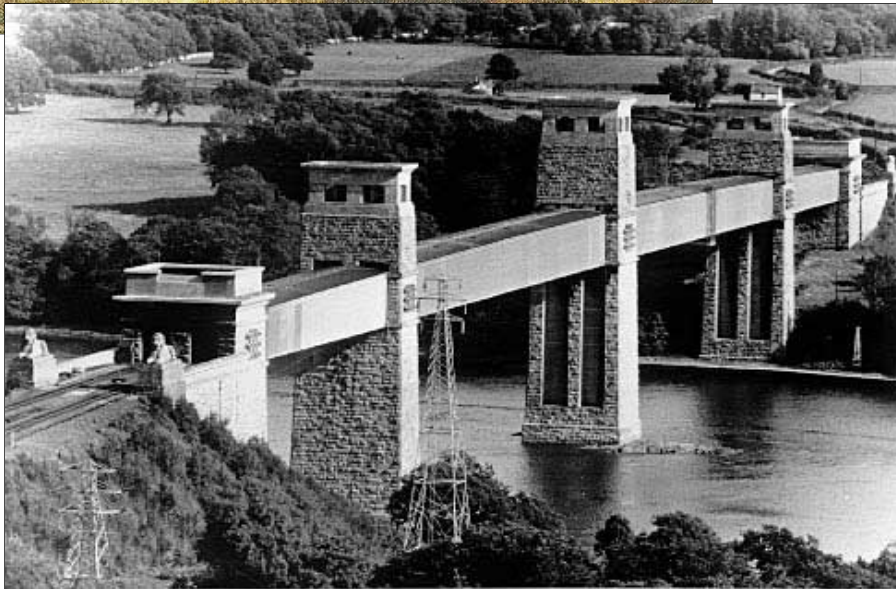
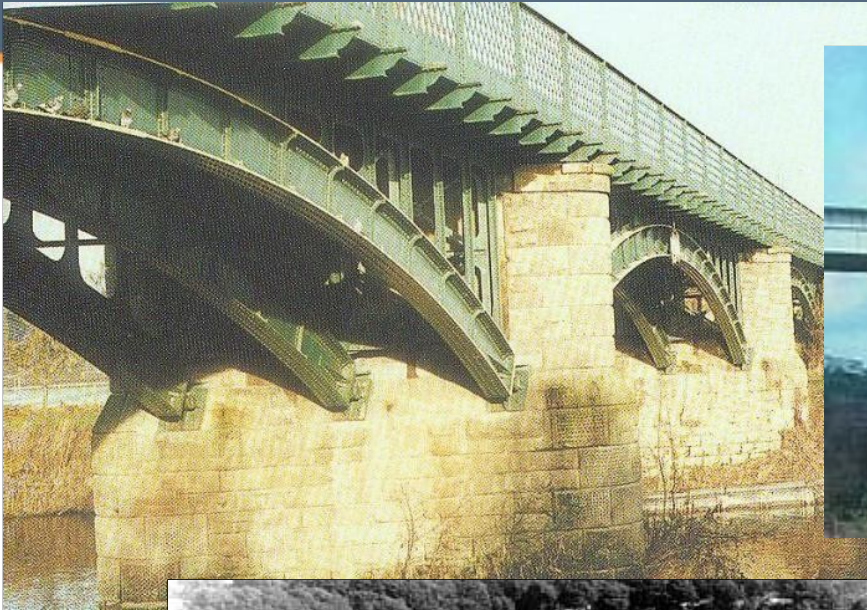
- Materials
  - 680 cast iron, 5,600 wrought iron, 9,700 steel
- Age
  - 10% <10 yrs, 10% 20-50 yrs, 30% 50-100 yrs, 50% >100yrs.
- Span profile
  - 70%<10m, 15% 10-40m, 15% >40m
- Traffic
  - 20% public roads, 20% private roads, 60% railways

# Cast iron





# Wrought iron





# Steel



# Why strengthen?

- Long term
  - To deal with under design
  - To deal with increased loading
    - Heavier axle weights, higher speeds, increased ballast depth
  - To extend fatigue life by reducing live load stresses
  - To deal with deterioration/damage
- Short term
  - To minimise disruption by spreading planned reconstructions
- But mainly to avoid reconstruction

# Network Rail case studies

- Underline bridges
  - Flexural and shear deficiencies treated by the addition of new steel
    - Standard solutions
    - Bespoke solutions
- Overline bridges
  - Flexural deficiencies treated by the use of CFRP plates
    - Bespoke solutions



# Stoney Weir

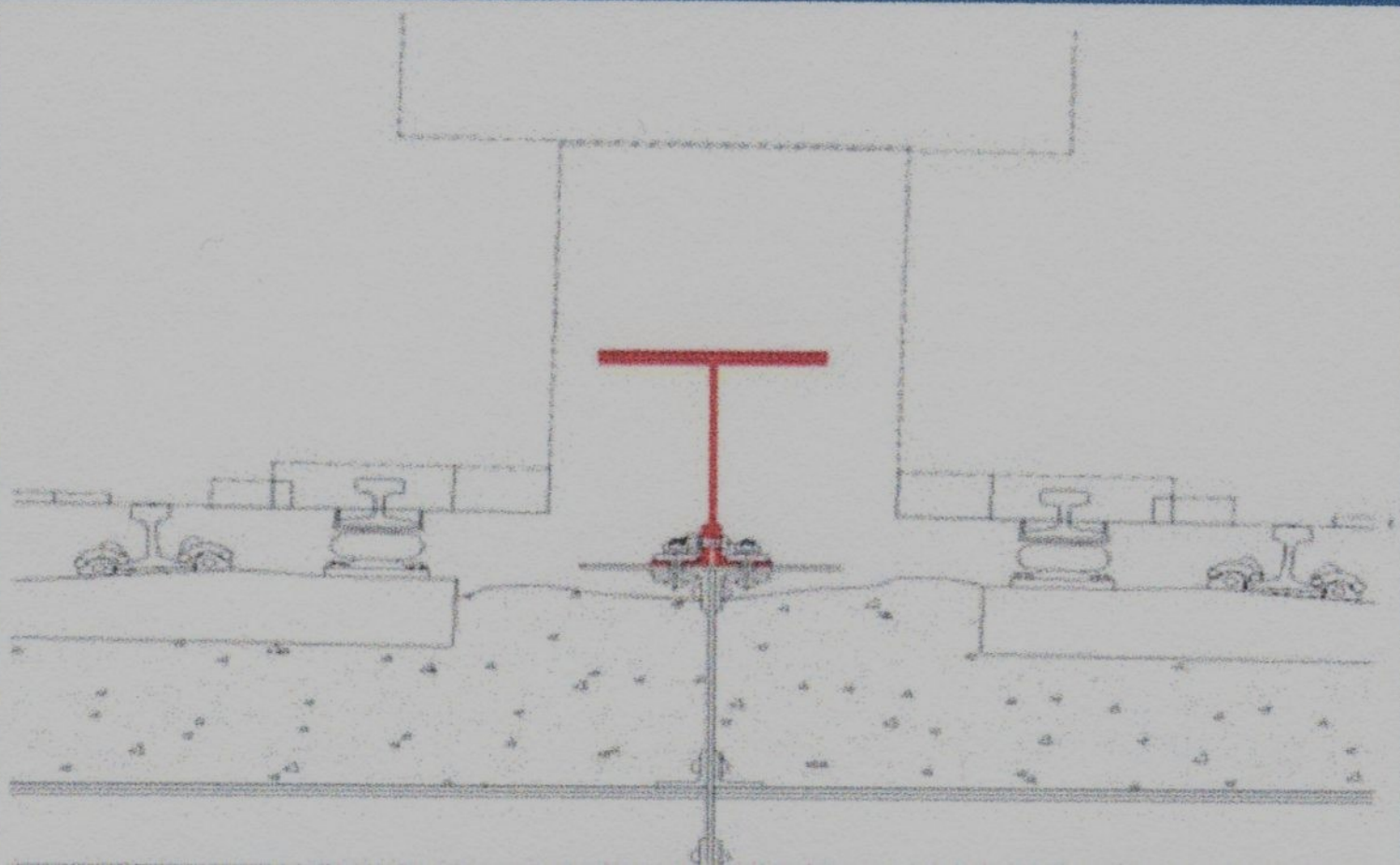
- Typical small span steel or wrought iron bridge
  - Three equally dimensioned main girders and pressed steel trough decking
- Centre girder weak
  - Partly due to historic use by lightweight EMU traffic
- Standard “top hat” solution used
- Three similar bridges dealt with as one contract at a total cost around £300k

# Stoney Weir



# Stoney Weir

Figure 3 - Typical Top Hat Solution





# Stoney Weir



# Rockingham Street

- 1890s wrought iron bridge, carrying principally suburban EMUs and weekend engineering trains.
- Cross girders weak in shear and bending
- Reconstruction estimate £3.5m
- Modified “top hat” solution, known as a “bottom hat”, possible as adequate headroom available.
- Bridge now full strength, final contract cost around £1m.



# Rockingham Street





# Rockingham Street



# River Mole

- 3 span wrought iron bridge built around 1880
  - External main girders trusses
    - Full strength
  - Inner main girders fish bellied plate construction
    - weak in compression and shear.
- Top flange strengthened with extra plates
- Web strengthened with discrete plates to resemble a truss.
- Total cost £800k

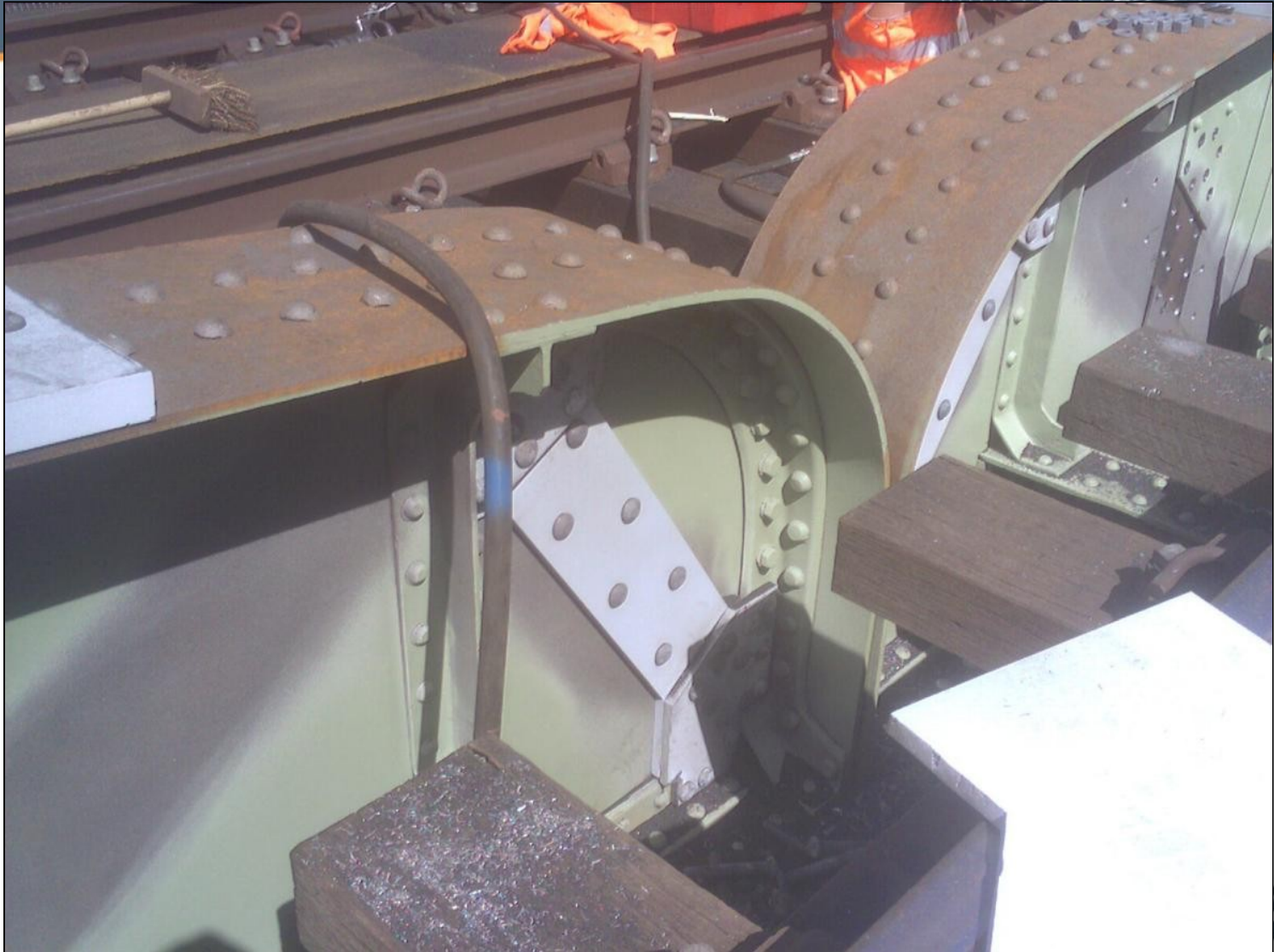


# River Mole





# River Mole



# Four span

- Built 1866 using wrought iron plate girders
  - Carries 3 tracks of main London to Brighton line over a secondary route.
  - As name implies, 4 spans consisting of main girders, cross girders and rail bearers
- Cross girders weak
  - Additional cross girders fabricated to fit around main girders.
  - New cross girders installed during 54hr weekend closures of lower route
  - Bolted in position mid week with trains running on main line
- Had main line been lower tracks this option would have been feasible

# Four Span

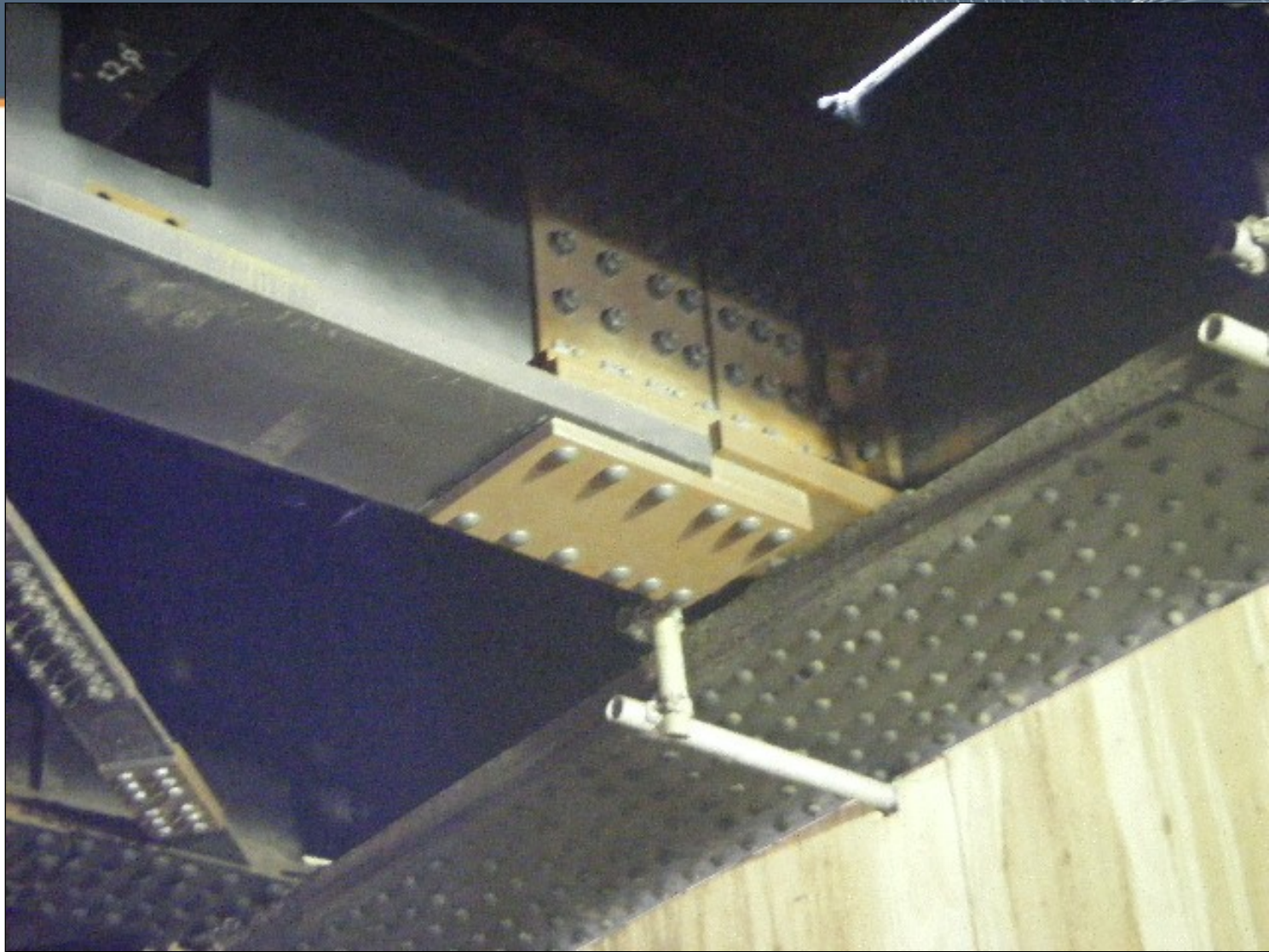




# Four span



# Four span





# River Hamble

- 1890s built 6 span wrought iron bridge over tidal river
  - Plate main girders, cross girders and pressed troughing flooring
  - Main girders theoretical zero live load capacity
    - Lateral torsion buckling of compression flange and web shear deficiencies
  - Cross girders not aligned with main girder stiffeners
- New stiffeners provided at each cross girder location
  - To provide “U” frame action
  - Each fabricated in 24 parts to facilitate man handling into position
  - Installed during standard 8hr overnight weekend line closures
- Over 350 tons of steel added and over 35,000 bolts utilised
- Final project cost (including repainting) £3.5m
  - Total time on site about a year



# River Hamble



# River Hamble





# River Hamble





# Arun River

- Bridge dates from around 1860
  - 4 spans with four continuous main girders
  - Structural timber decking resting on top flanges spans between main girders
  - Track supported by longitudinal timbers
- Main girders weak in bending and shear at intermediate supports
- “Wing” horizontal stiffeners provided over piers

# Arun River





# Arun River





# Jamestown Viaduct

- Six span viaduct constructed 1887-1890 as part of Forth Bridge railway
- Four central spans steel
  - 2 truss main girders with cross girders and steel deck plates
  - 33.4m span at 70° skew angle
- Assessment results
  - Truss top and bottom booms weak in flexure
  - Truss ties weak in tension
  - Truss struts weak in compression
  - Cross girders weak in shear

# Jamestown Viaduct



# Jamestown Viaduct

- Bridge “listed” so intervention options limited
  - Original strengthening options considered
    - Strengthen by adding new steelwork where necessary
    - Install third main truss between existing trusses
    - Post tension existing main trusses
  - Following tendering preferred options became
    - Install new truss
    - Provide insitu concrete deck slab acting compositely with original steelwork
  - Final option chosen
    - Insitu slab (to assist both main girder booms and cross girders)
    - Strengthen main girder twin plate ties by the addition of a beam section
    - Replace minor components (sway bracing, gusset plates etc) with new as necessary
    - Provide ballast plates
    - Repaint in Forth Bridge red paint
  - Main works carried during 8 day line closure pre-arranged for work on Forth Bridge in 2005
- Total scheme cost £5.3m



# Jamestown Viaduct



Diaphragm between main girder top boom and deck plates to transfer shear loads



Strengthening of main truss ties with new "H" beams



8,600 shear studs attached for new concrete deck

# New Moss Road

- Two span bridge carrying public road over railway
  - North span cast iron main girders and brick jack arches spanning open lines, built 1873
  - South span concrete slab spanning disused formation, built 1956
- North span capacity assessed as 17 tonne vehicle, local council wanted 40 tonne capability
  - Strengthened with 2No. 140mm wide UHM CFRP plates per beam with a maximum thickness of 24mm
- Final cost £450k, saving around 75% when compared to reconstruction

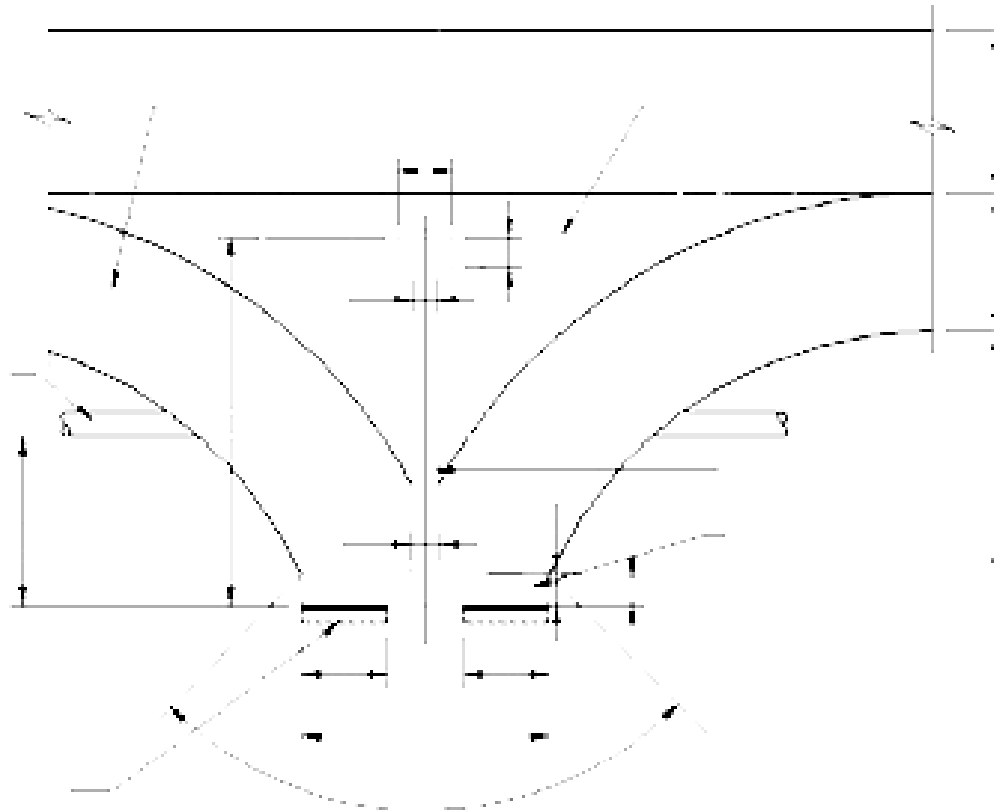


# New Moss Road





# New Moss Road

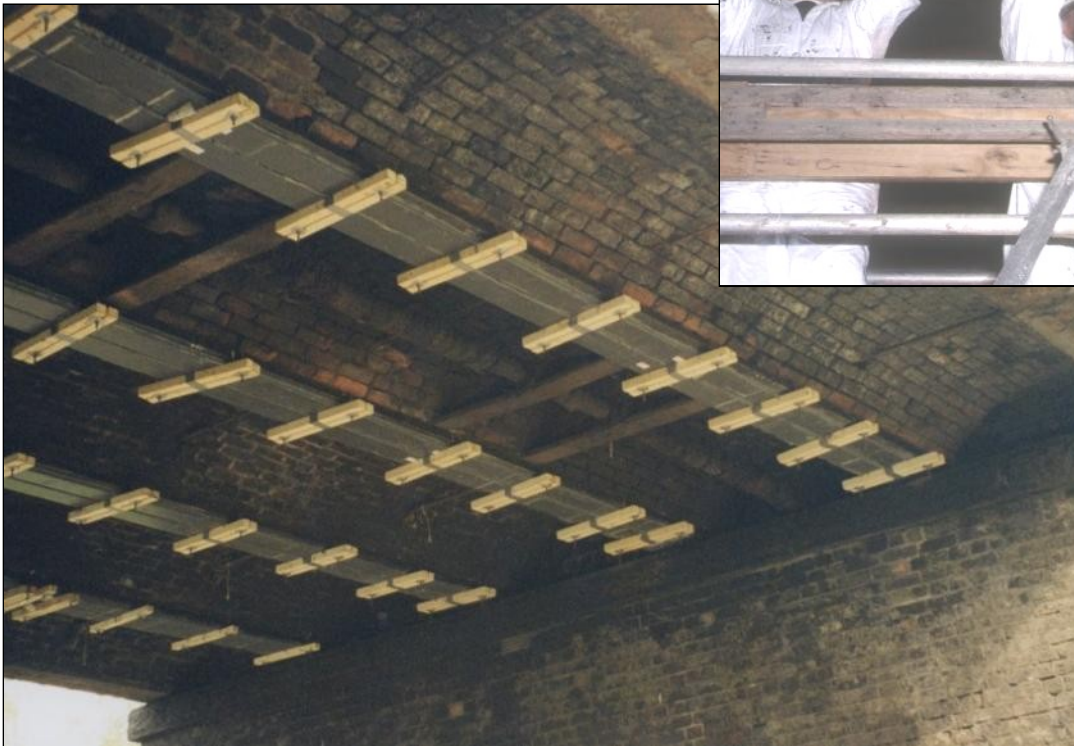


# New Moss Road





# New Moss Road



# New Moss Road





# Maunders Road

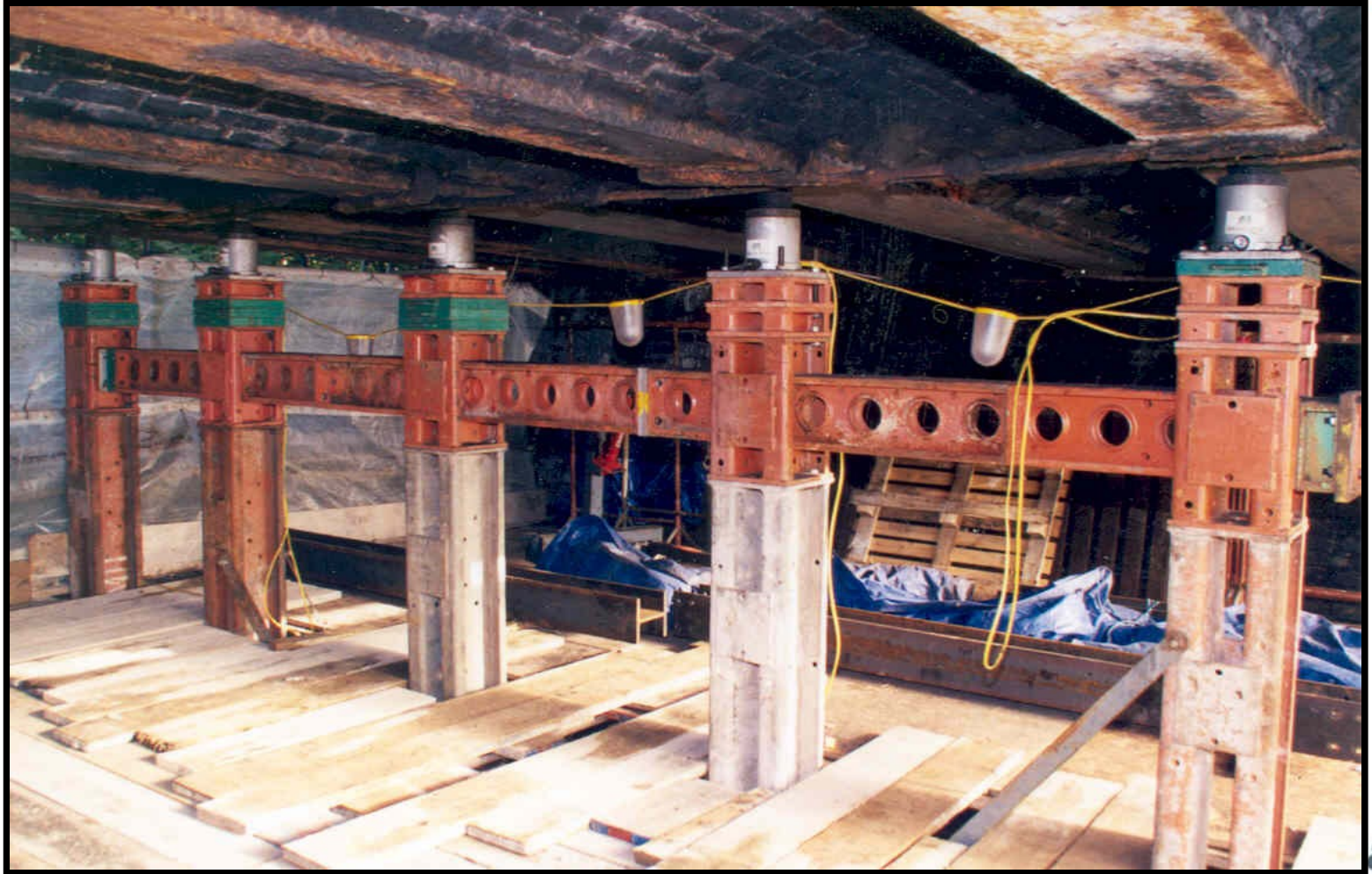
- Built around 1900, consisting of cast iron longitudinal main girders and jack arches
  - Capacity of edge girders assessed as 3 tonne vehicle and internal girders as 7.5 tonne vehicle
- Carries a local road over a mothballed railway
- Bridge provides only access to a nearby industrial area
  - Council required 40 tonne capability
- Novel design using UHM CFRP plates incorporating load relief
  - Edge beams required 2 plates 90mm wide x 32mm thick
  - Internal beams required 2 plates 140mm wide x 37mm thick
- Final cost £300k, saving around 50% when compared to reconstruction

# Maunders Road





# Maunders Road





# Maunders Road



# Hammersmith Road

- 3 span bridge built in the around 1860 to carry a very busy main road in west London
  - Main span crosses the principal cross London freight route to the Channel Tunnel
  - One side span crosses the London Underground District Line branch to Olympia
- Each span consists of 13 cast iron longitudinal girders
  - Assessed capacity 18 tonne vehicle
  - 10 internal bays have brick jack arches
  - Remaining 2 internal bays have cast iron floor plates
    - These limit the assessed capacity to a 3 tonne vehicle
- 40 tonne capacity required
  - Main girders strengthened with UHM CFRP plates
  - CI deck plates strengthened with specially manufactured cruciform stiffening made from UHM CFRP
    - Insitu wet lay up not chosen due to short duration of available rail closures.

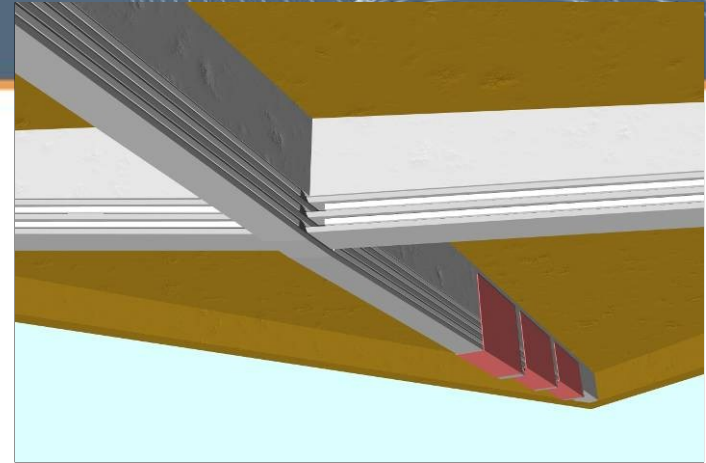
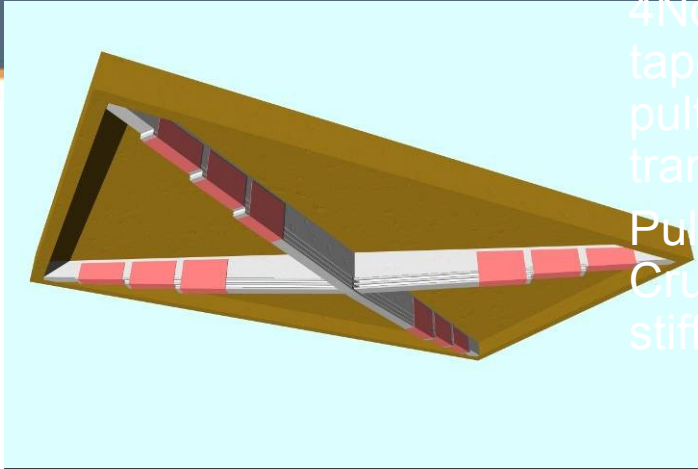


# Hammersmith Road



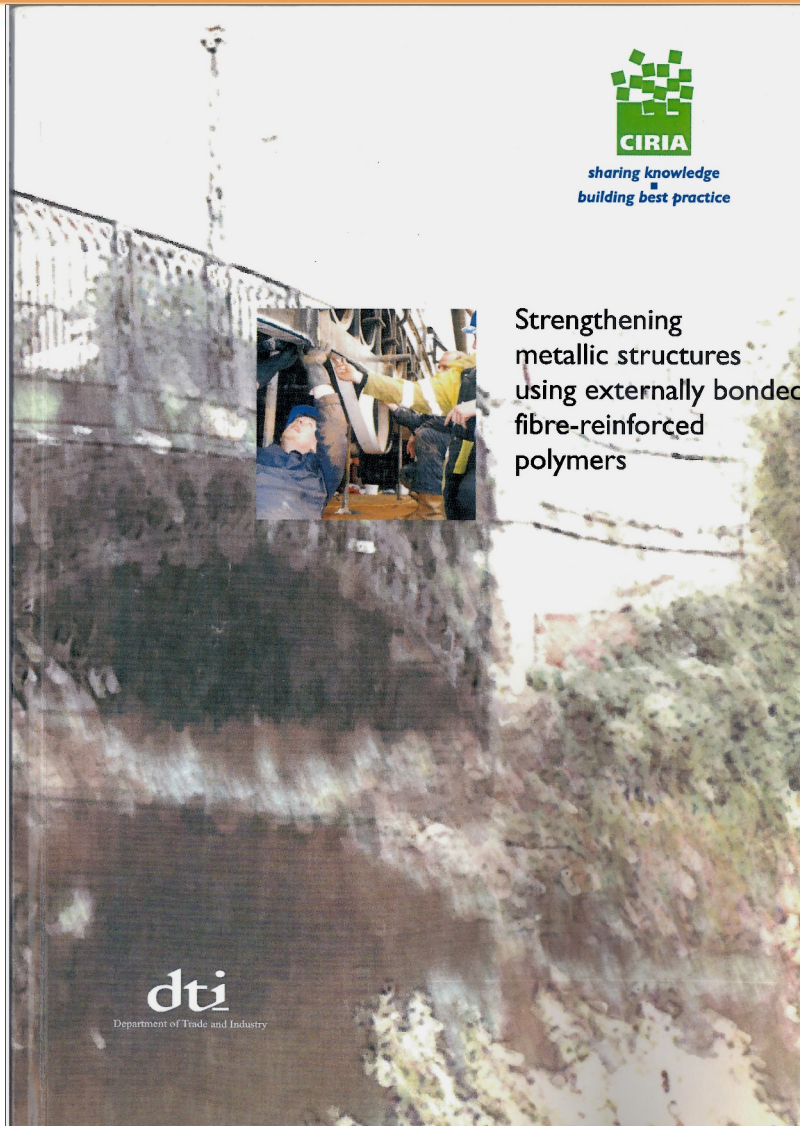
# Hammersmith Road

4No. 30mm wide  
tapered multi-layered  
pultruded FRP  
transverse stiffeners  
Pultruded FRP  
Cross stiffeners





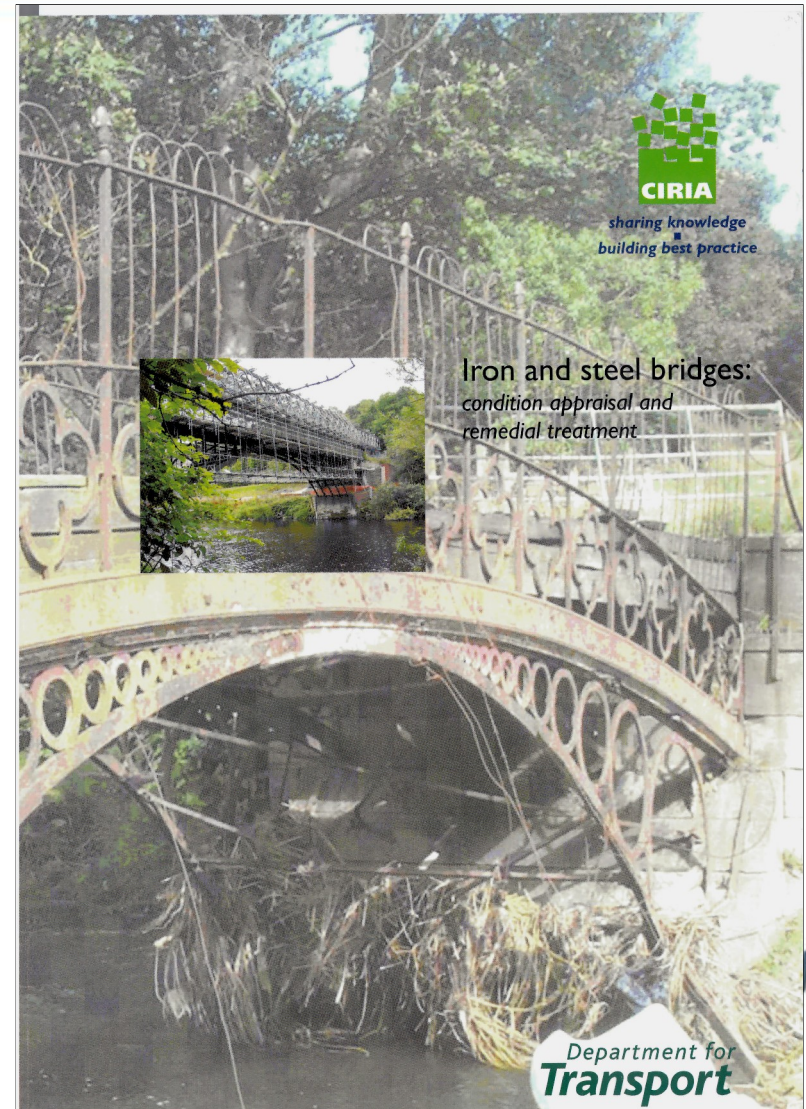
# Further reading



**CIRIA**  
sharing knowledge  
building best practice

**Strengthening  
metallic structures  
using externally bonded  
fibre-reinforced  
polymers**

**dti**  
Department of Trade and Industry



**CIRIA**  
sharing knowledge  
building best practice

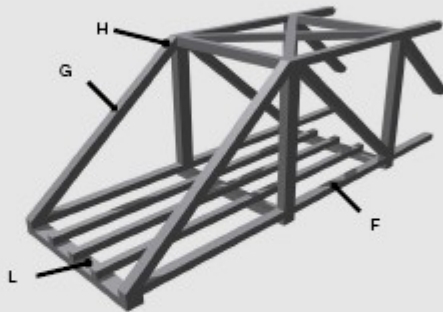
**Iron and steel bridges:  
condition appraisal and  
remedial treatment**

**Department for  
Transport**

# The Sustainable Bridges Report



## Repair and Strengthening of Railway Bridges - Guideline



PRIORITY 6  
SUSTAINABLE DEVELOPMENT  
GLOBAL CHANGE & ECOSYSTEMS  
INTEGRATED PROJECT

- Chapter 4.4 deals with novel methods
  - Gives method description
  - Describes case studies
- Appendix B deals with traditional methods

[www.sustainablebridges.net](http://www.sustainablebridges.net)

“project reports”

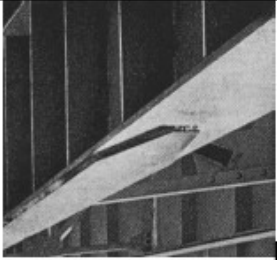



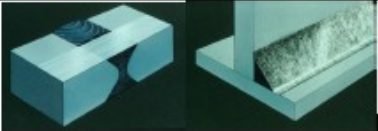


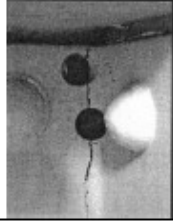
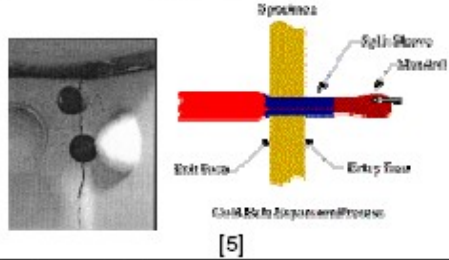

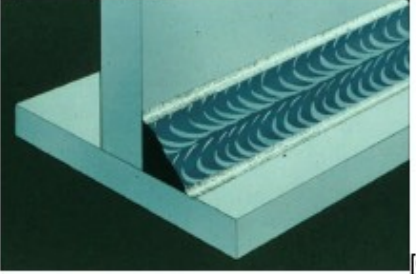


# Methods described in chapter 4.4

Problem	Method	Description	Case study
Tensile capacity	External prestressing External CFRP	MD103 MD101	- CS101
Global buckling	External CFRP plate/sheet Increase cross section Change structure	MD101/102 - -	CS101 - -
Fatigue in riveted members	External prestressing Replace components	MD103/104 -	CS03 -
Web shear	Longitudinal stiffeners Transverse stiffeners External CFRP	- - MD101	- - -
Fatigue in welded members	Weld cracks Drill stop holes External prestressing External CFRP	- - MD103 MD01	- - - -

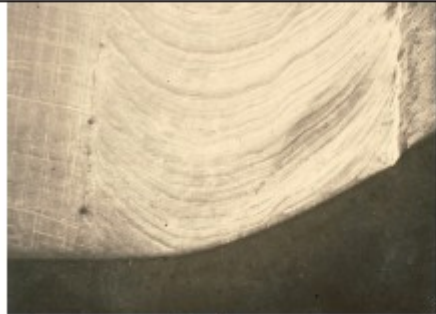

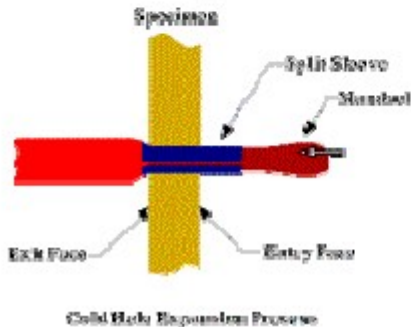
# Methods described in Appendix B

	Method	Principle
	Cover plates Welded steel plates	Cover plates in steel are welded to flanges or web
	Cover plates Bolt-on steel plates	Cover plates in steel are bolted to flanges
	Addition of new members	New members are added to the construction to insure carrying capacity for a part of the structure, e-g- span shortening. (Outcome of the method is dependable on the exchanged member). A column is shown here.
	Confinement with reinforced concrete	Jack up of structure and casting of reinforced concrete around the structural member. Mostly applicable for columns.
	Air arch gouge and fill	Weld is cleaned by melting the metal and blowing it away. New weld material is added. Possibility for introducing new defects with the new weld.
	Disc grinding	Weld is smoothed to reduce and remove stress raisers. Bad grinding may introduce new defects.

	Method	Principle
	Hole drilling	Stops cracks by decreasing stress intensity factor. Method is almost only applicable at large visible cracks. Many cracks will relatively fast reinitiate crack growth.
	Hole drilling and cold working of bearing	As above, but the hole is cold worked with a tapered mandrel. Introduces compressive stresses near the bearing and thereby decreases the stress intensity factor and risk of crack initiation
	Exchange of fastener to HS-prestressed bolt	Removes high bearing stresses and introduces triaxial stress state, beneficial for reducing risk of crack initiation
	Burr grinding and polishing	Burr grinding grinds away / reshapes the critical part of most welds, the weld toe. Quality control is well developed.



# Methods described in Appendix B

	Method	Principle
 [6]	Laser/TIG remelting	Remelting the weld to eliminate defects and gaps within the weld. Best to do at a workshop with controlled conditions. Usable for up to 6mm defects. Picture is laser remelt
 [6]	Peening methods. Impact treatment	Cold working of the weld toes by using rods or air blasting surface with steel and glass pellets. Picture shows performance of peening at weld toe and shot peening surface.
 [5]	Cold working holes	A tapered mandrel is pushed through the hole. Introduces compressive stresses near the bearing and thereby decreases the stress intensity factor and risk of crack initiation

# Conclusions

- Strengthening of steel bridges happens regularly
- A number of different techniques can be employed
- Traditional solutions dominate
- New materials can be useful, but care must be exercised
- Because
  - We don't want to see this kind of thing





Thank you