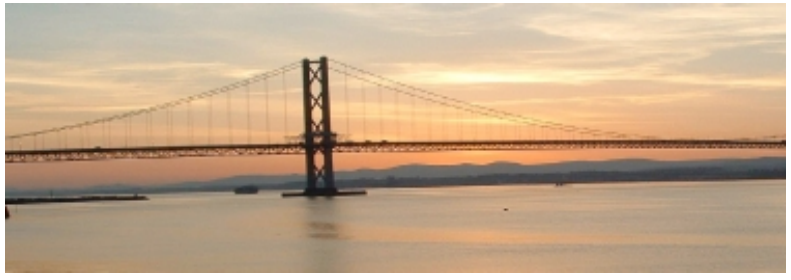
FORTH ROAD BRIDGE

OPENED 1964 2.5 KM LONG
MAIN SPAN 1006 METRES

Relevant Research for Bridge Owners

Barry Colford
Chief Engineer & Bridgemaster
18 January 2012



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Research Priorities

- How do bridges actually behave in reality are the structural models and analyses correct.
- Traffic Loadings and Wind loadings – are our models correct.
- How can we measure future deterioration of elements we cannot access readily.

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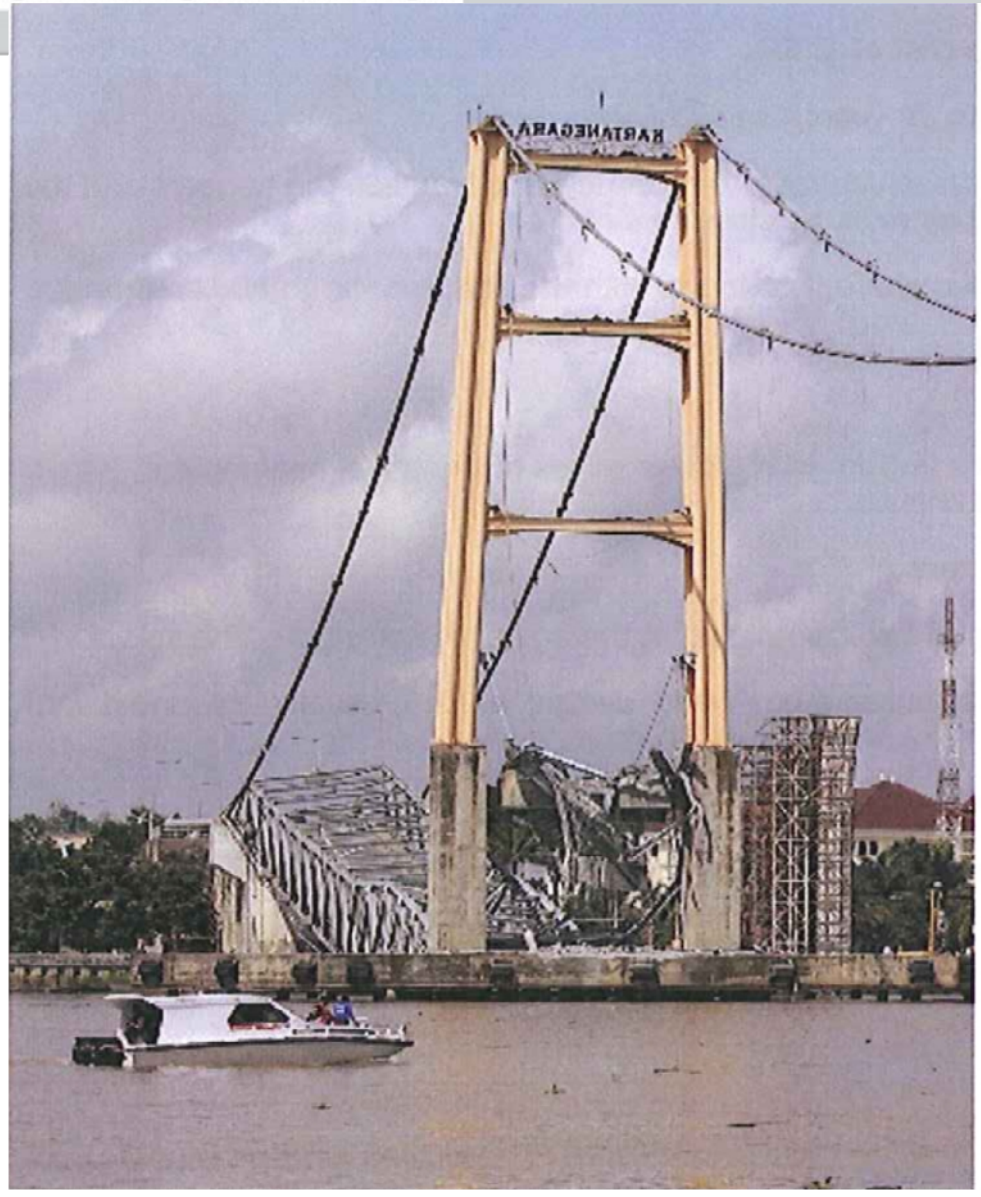

Kutai Kartanegara Bridge

Indonesia

How do bridges actually behave in reality?

Traffic Loadings and Wind loadings – are our models correct.

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Forth Road Bridge statistics

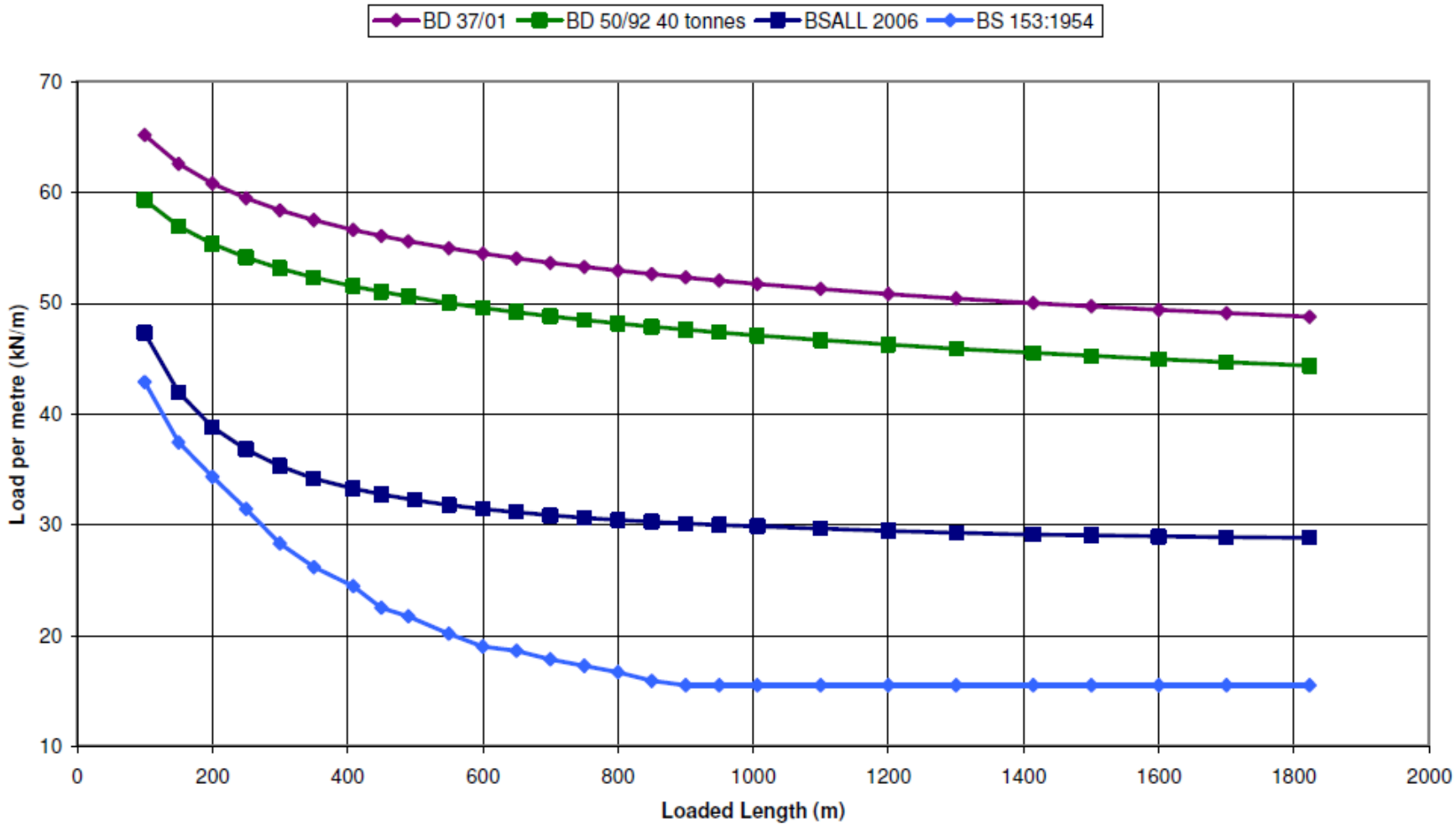
- Main span: 1006m
- Side spans: 2 x 408m
- Opened: 1964 – longest span outside US (4th in world)
- Now 22nd on list
- 1000 miles north of New York City

Structural Challenges

- Design based on 24 ton lorries
- The 38 tonne lorry introduced 1983
- The 44 tonne lorry introduced 2001
- Traffic increase from 4 to 24 million
- Bridge presently carries almost double original traffic loading
- Super single wheel loads

Loading Specific to Forth Road Bridge

Figure 1 :Comparison between Bridge Loading (Nominal) - Bridge Total



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The Operational Challenge

- How do we keep maintain this vital infrastructure throughout a design life of 120 years while minimising disruption to the 24 million vehicles that cross per year and meet the needs of the local communities?

- Allowing for changing loading and design requirements and the changes in society's expectations of risk with respect to health and safety.

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Effective structural health monitoring

Bearings & Concrete Condition

- Existing structure:

Typical Steel Roller Bearing

Typical Steel Rocker Bearing

Roller Bearings

- Not free to roll – uneven wear due to stress and/or corrosion
  - Higher stresses in pier than considered in original design
  - Justified by use of cracked section properties but box stresses too high
- Bearings assessed according to BS5400-9-1:1983 and BS EN 1337-4
  - Modern geometrical limits not met
  - Significant codified overstress
- Roller bearing at end of North viaduct near the side tower is near limit of movement range limit

Roller bearing at north side tower

How can we measure future deterioration of elements we cannot access easily.

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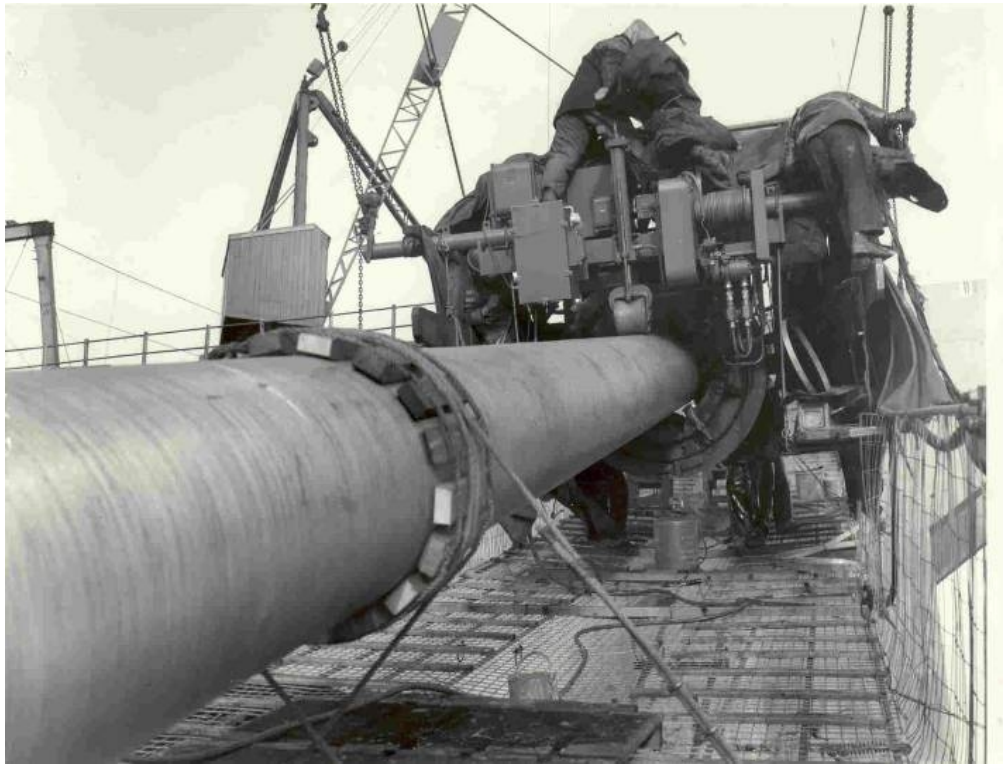
Main Cables

- Cable comprises 11618 wires in 37 strands (4.98mm dia.)
- Cables constructed using aerial spinning techniques
- Cable diameter 600mm
- Wire specification 100 – 110 Tons/sq.in (1544 – 1698 N/mm^2)

Cable construction

- Traditional corrosion protection: galvanising on each wire, compaction, red lead paste, wire wrapping and painting.
- Cable has been regularly inspected externally and repainted



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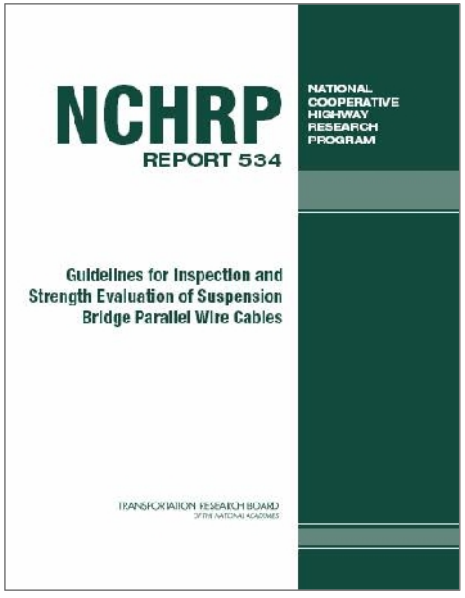
Background to inspection

- FETA have been involved in early ICSBOC conferences and workshops & had awareness of emerging problems with some US suspension bridges
- FETA aware of NCHRP Guidelines and recommendation to carry out first inspection at 30 years
- Forth Road Bridge was approaching 40 years and although there were no outward signs of internal corrosion, the decision was taken to undertake an internal inspection



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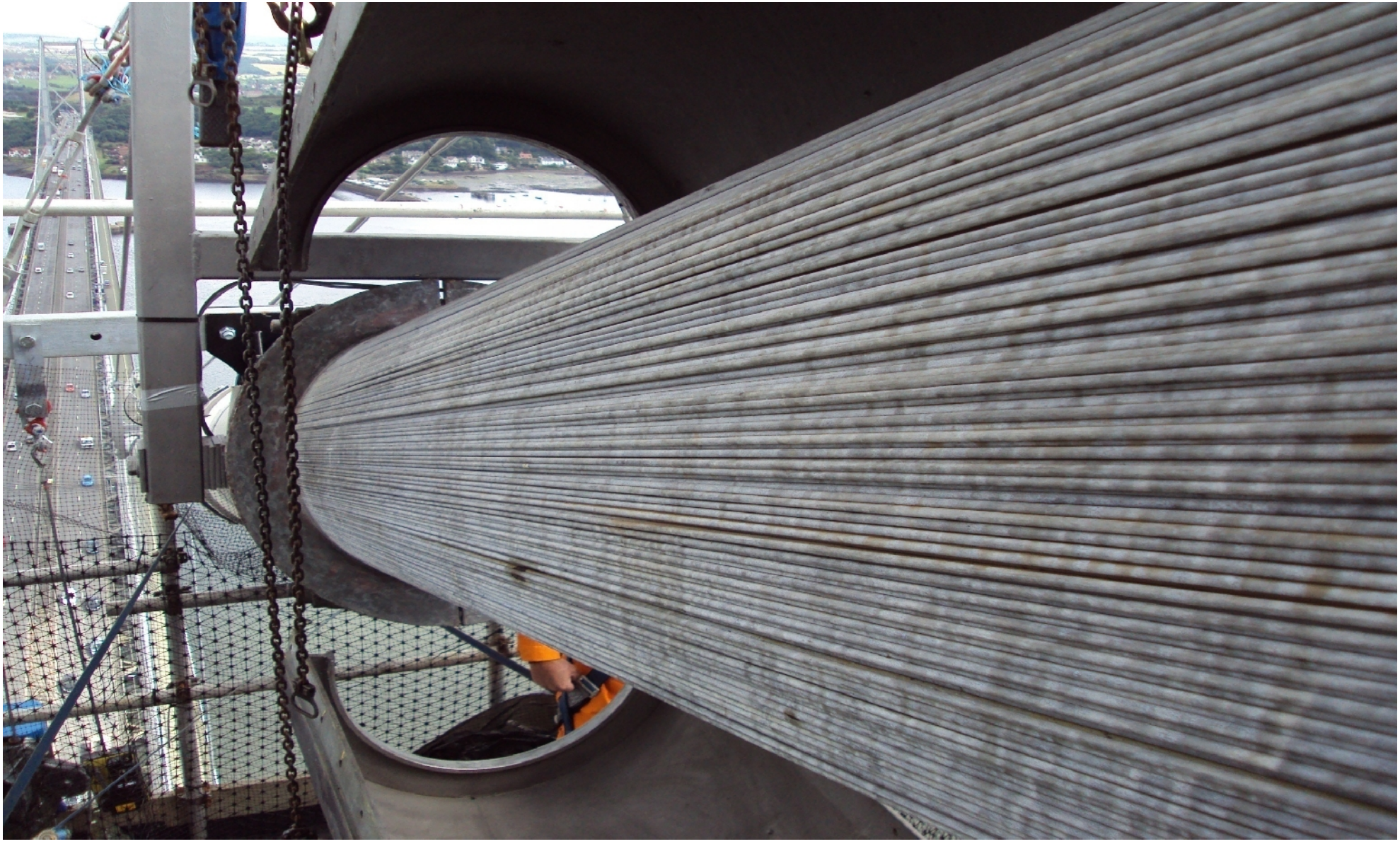
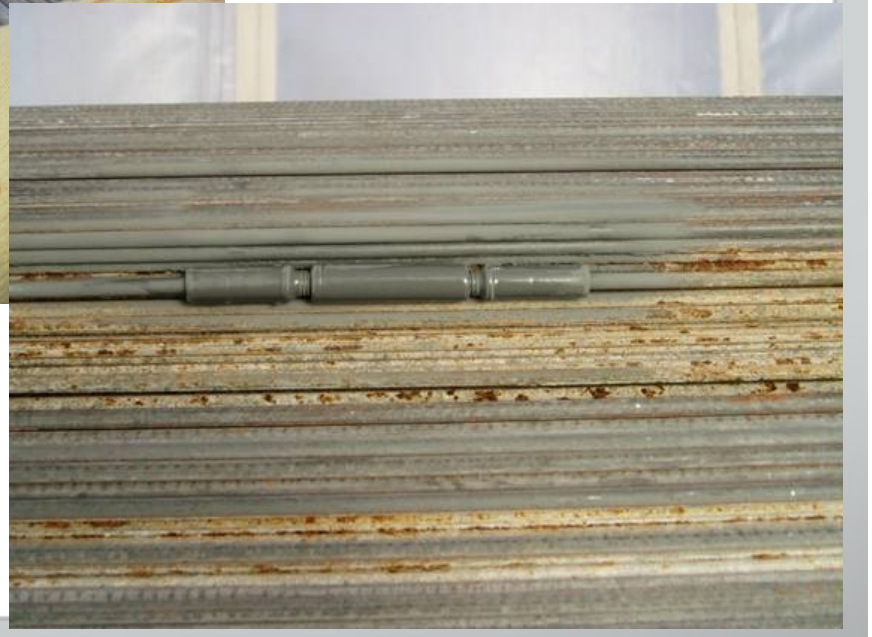


Internal inspection method

Wedging for inspection

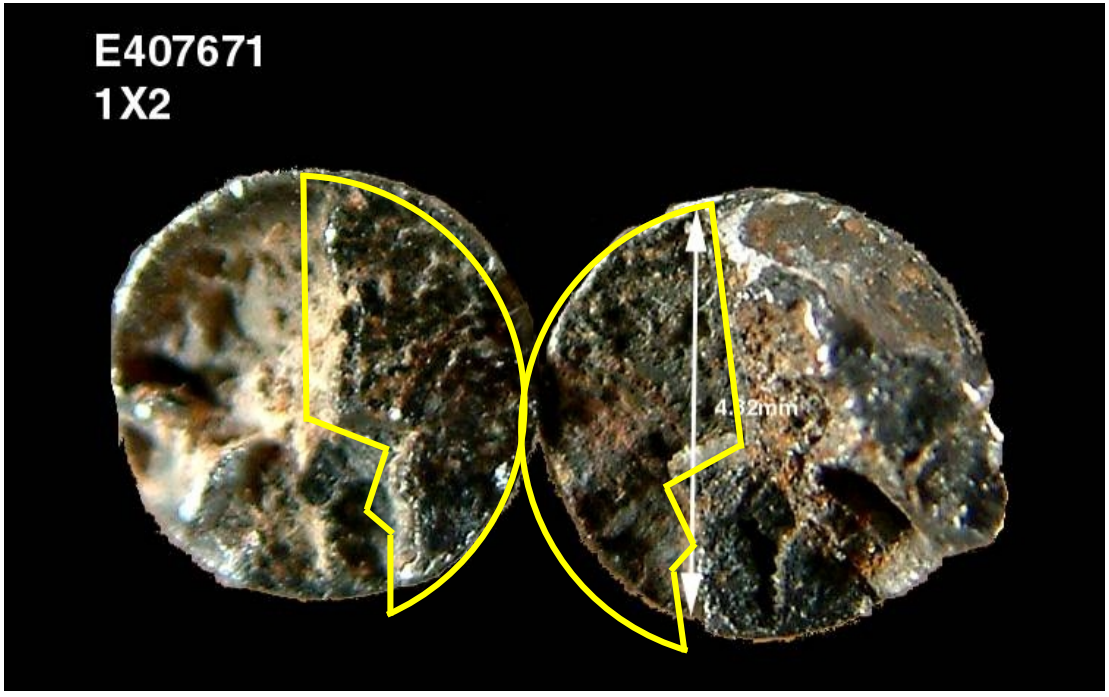
Removal of wire samples



Turnbuckle ferrule

Inspection Findings

Broken wires



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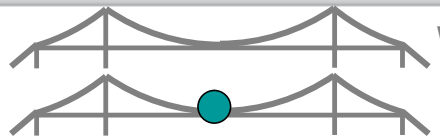
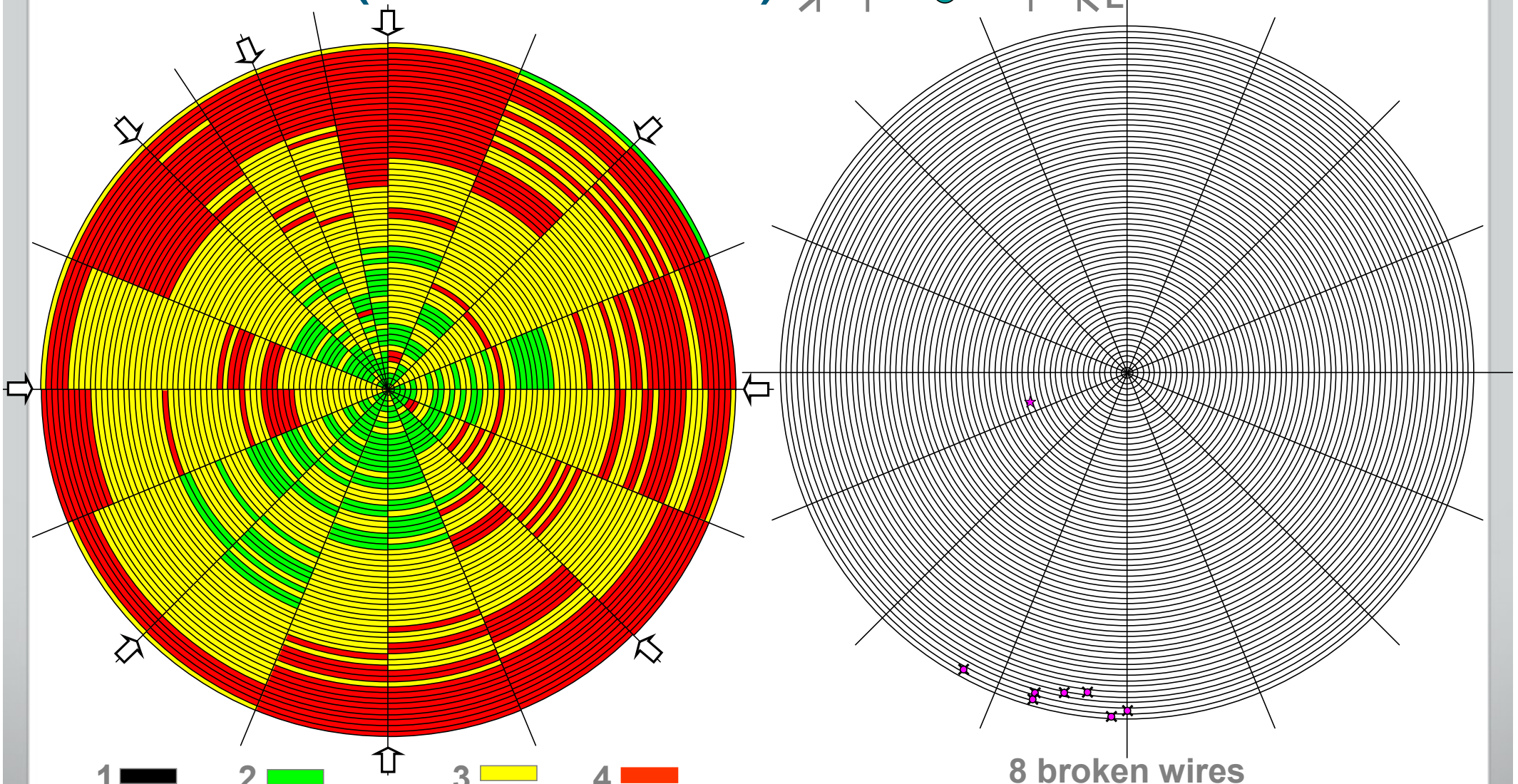
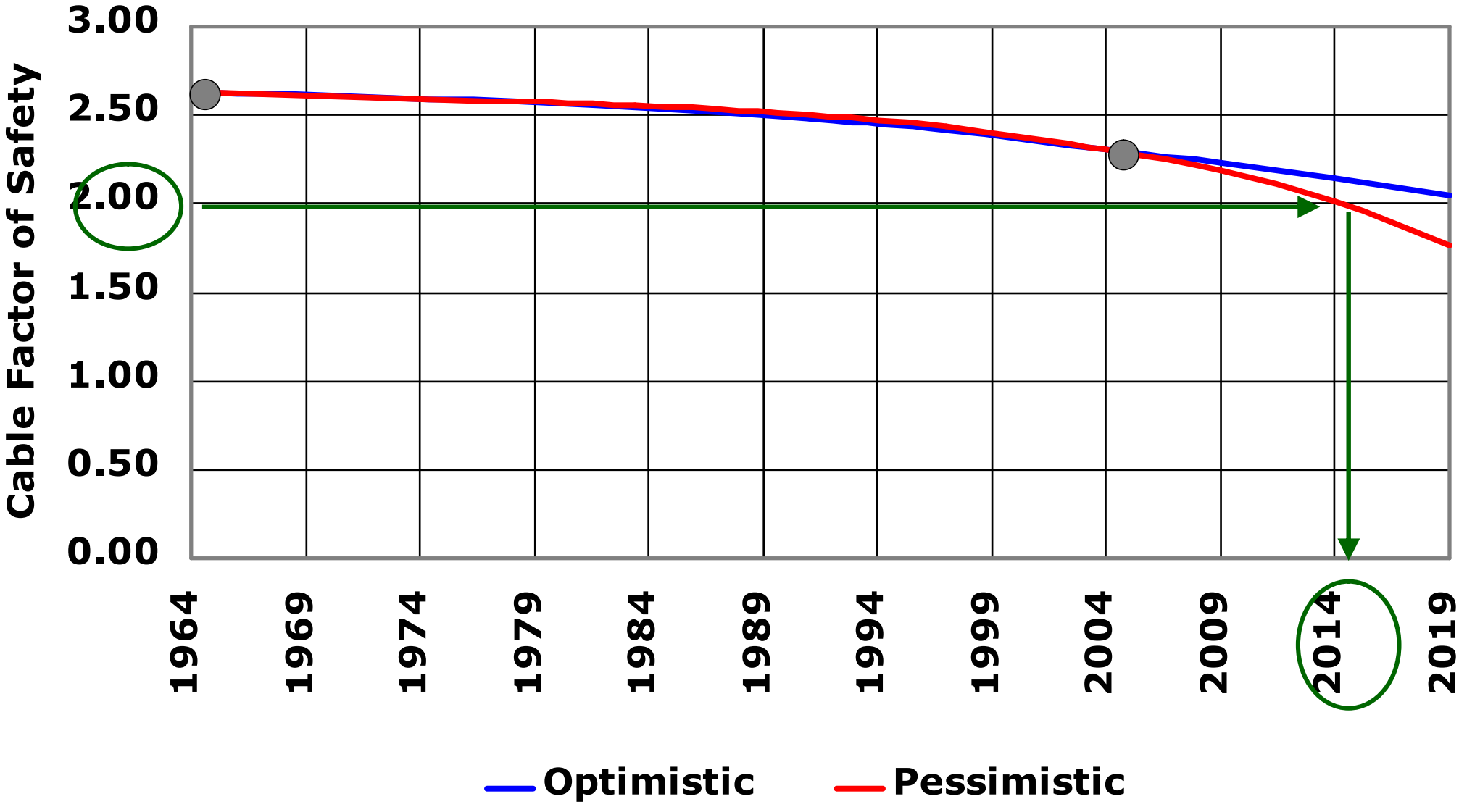
Panel 1 (100–100E)





Projected cable strength:
First internal inspection 2004



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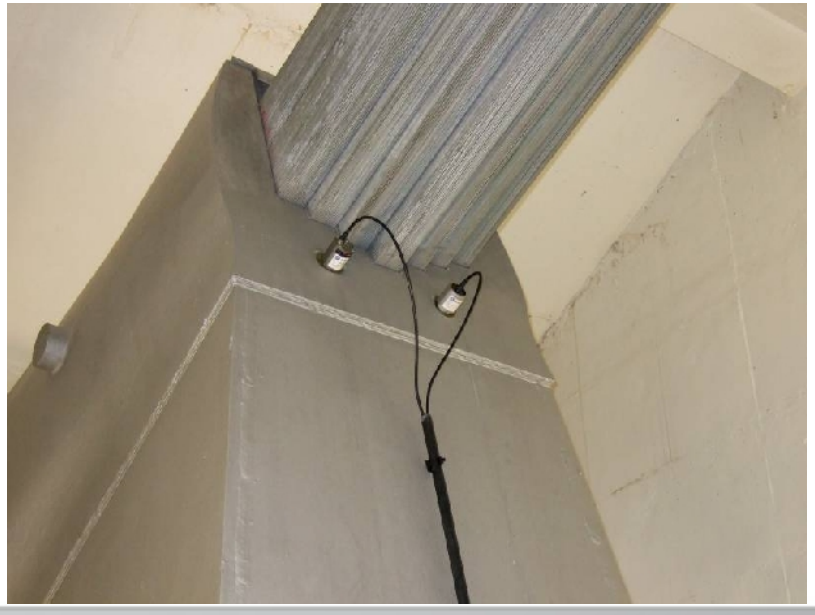
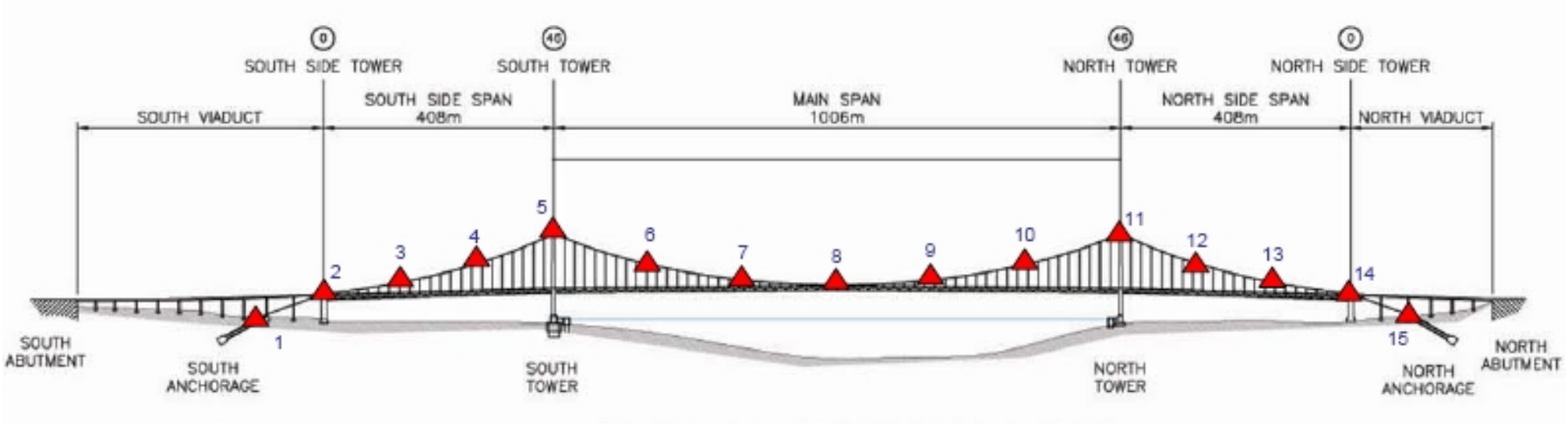
Acoustic monitoring installation

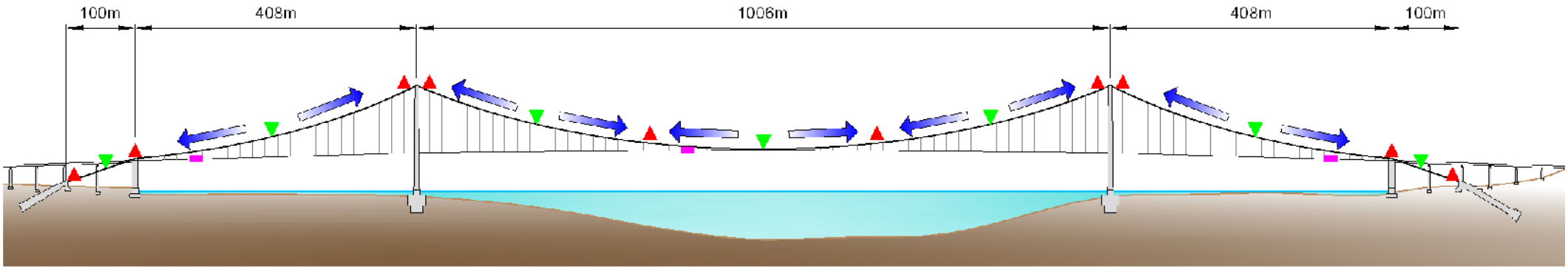


Acoustic monitoring

- Internal inspection only looked at a small proportion of wires.
- No guarantee that the worst deterioration has been found.
- Rate of deterioration is uncertain.
- Acoustic monitoring can provide information on the whole cable, and over a long time period.



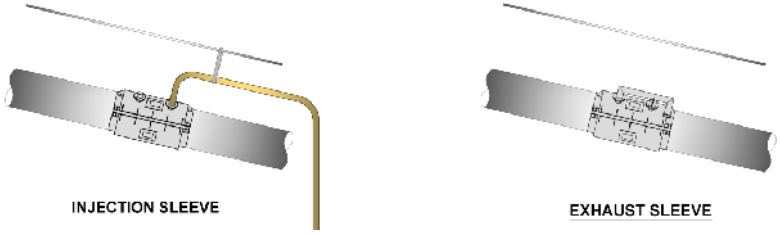
System Layout



- Injection sleeve

  Exhaust Sleeve

  Dehumidification Plant Room / Plenum chamber



Objectives of Cable dehumidification System

- Introduce dry air into the cable to remove moisture and to maintain a level of condition that will suppress further corrosion
- Improve air tightness of the main cables and prevent moisture ingress
- Installation without closing the bridge to traffic, i.e. minimum inconvenience to bridge users
- Plant designed to provide economy of operation
- Remote web-based control and monitoring systems to record key data from a safe distance

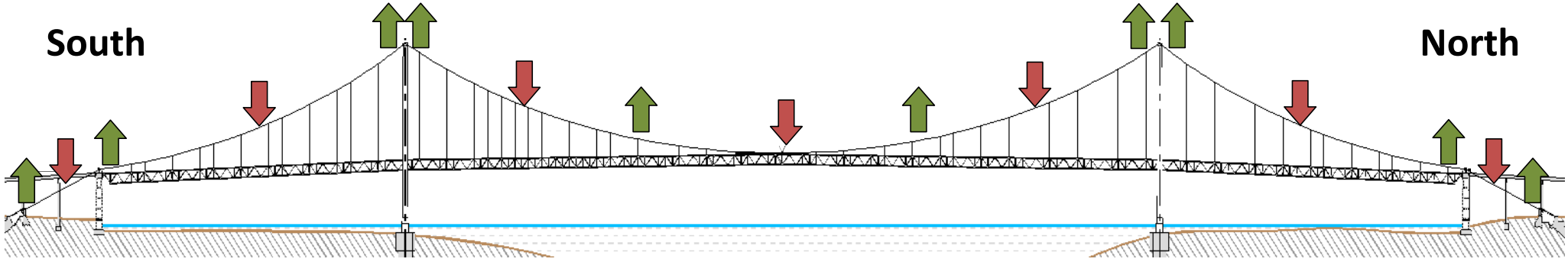
Injection and Exhaust Sleeves

Injection Sleeve

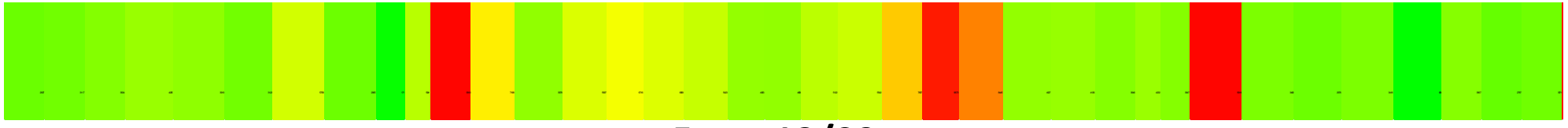
Exhaust Sleeve

East Cable

South

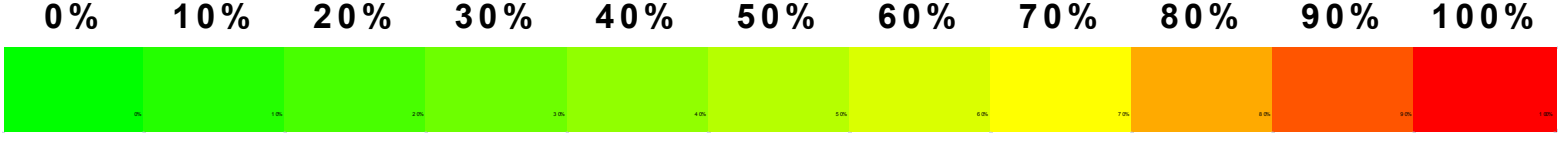


North

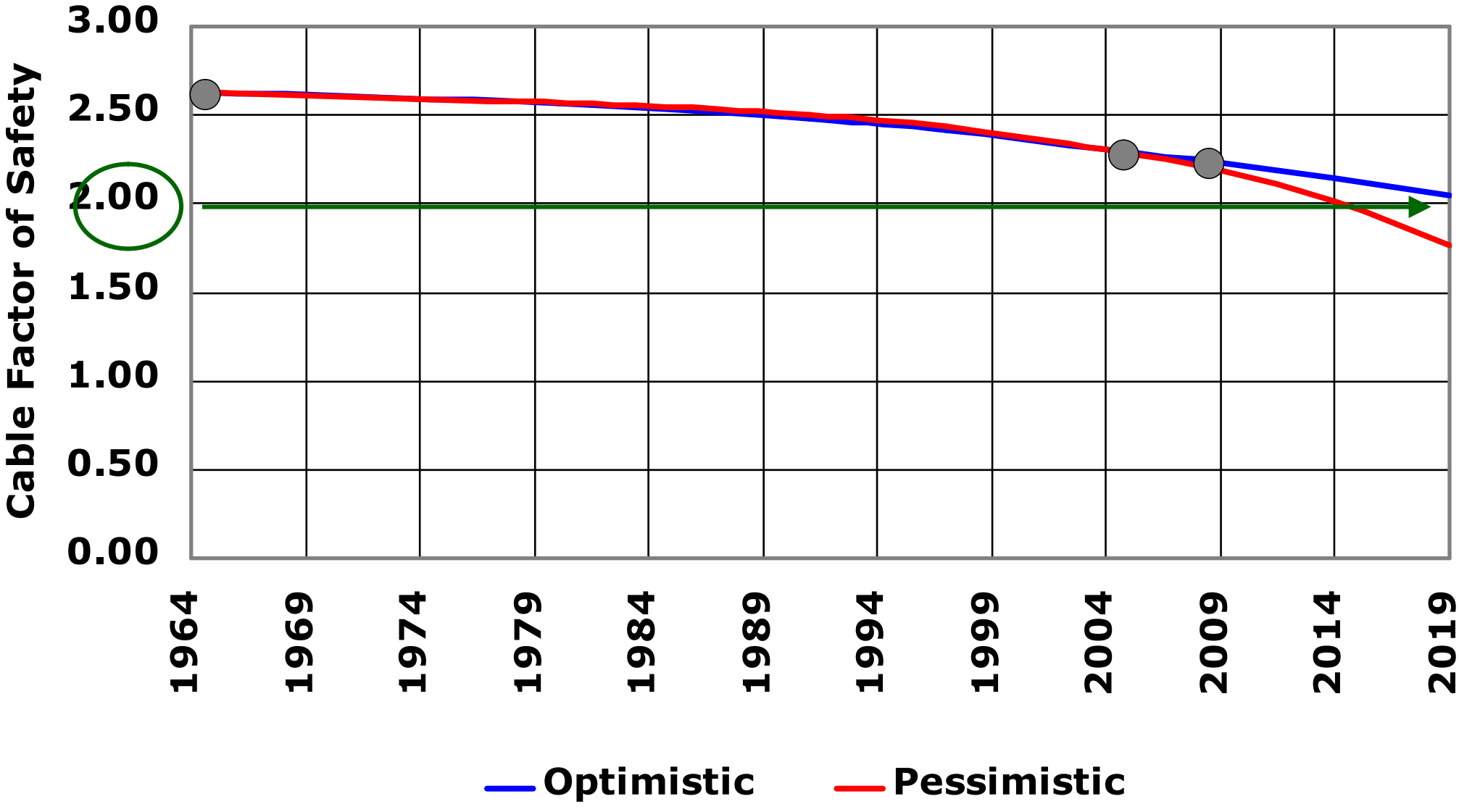


From 12/09

RH Key



Projected cable strength: Second internal inspection 2008



Third internal inspection 2011/12

- Will give another point of strength versus time graph strength
- Will not give an absolute answer as to whether dehumidification has worked
- Monitoring and inspection required for remainder of service life of bridge

Tancarville Bridge,
Normandy, France

Picture by: Jacques Mossot (Structurae)

Tagus Bridge,
Lisbon, Portugal

Conclusions

- It is possible to replace/augment the main cables on a suspension bridge in service
- It would take 7 to 9 years, cause significant disruption and risk to users could not be eliminated
- The alternative is to close the bridge for 3 years to carry out the work and eliminate all risk to users

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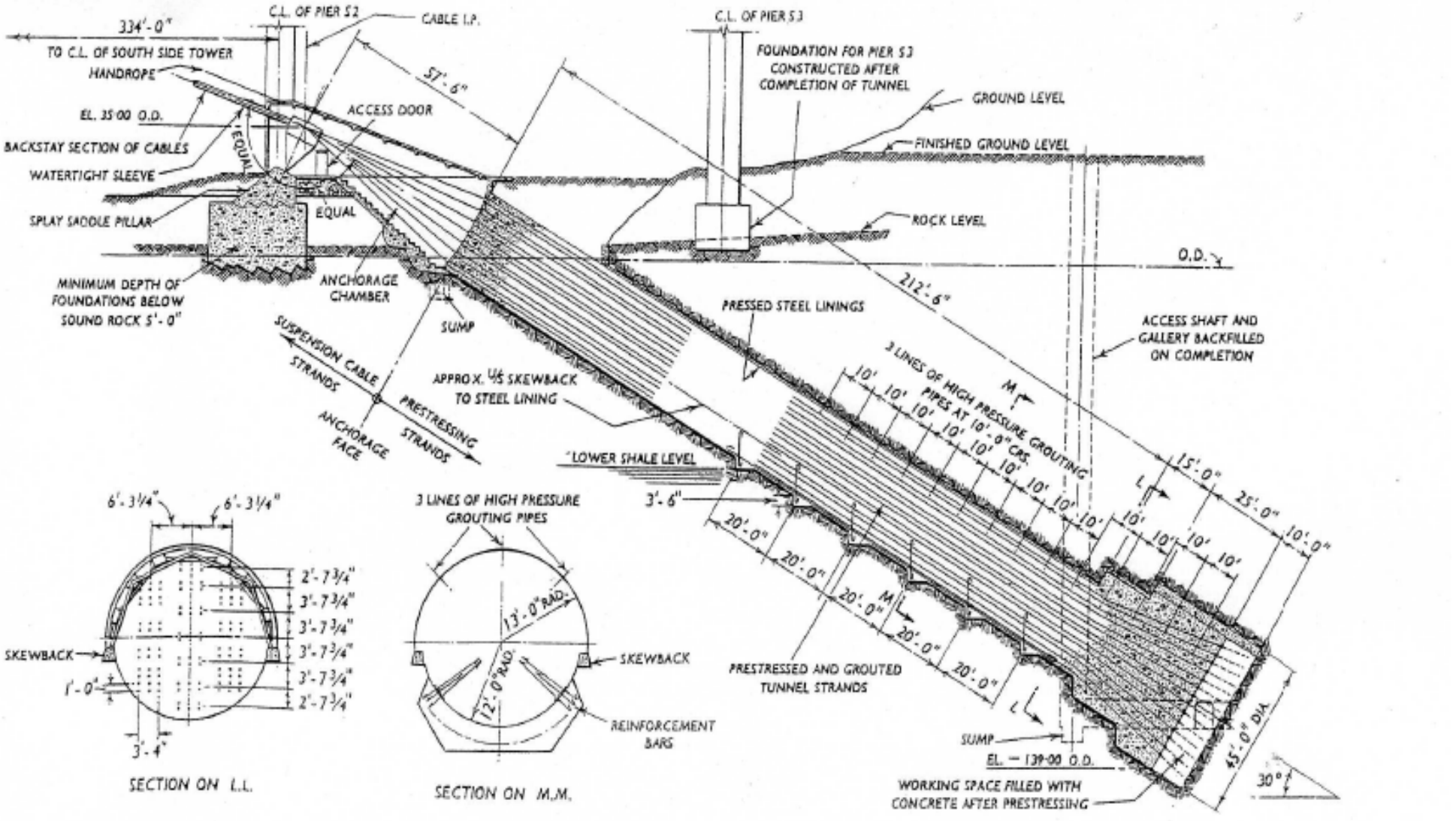
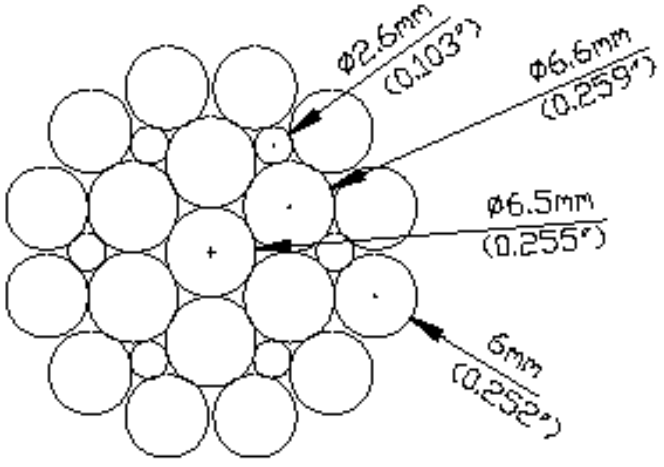
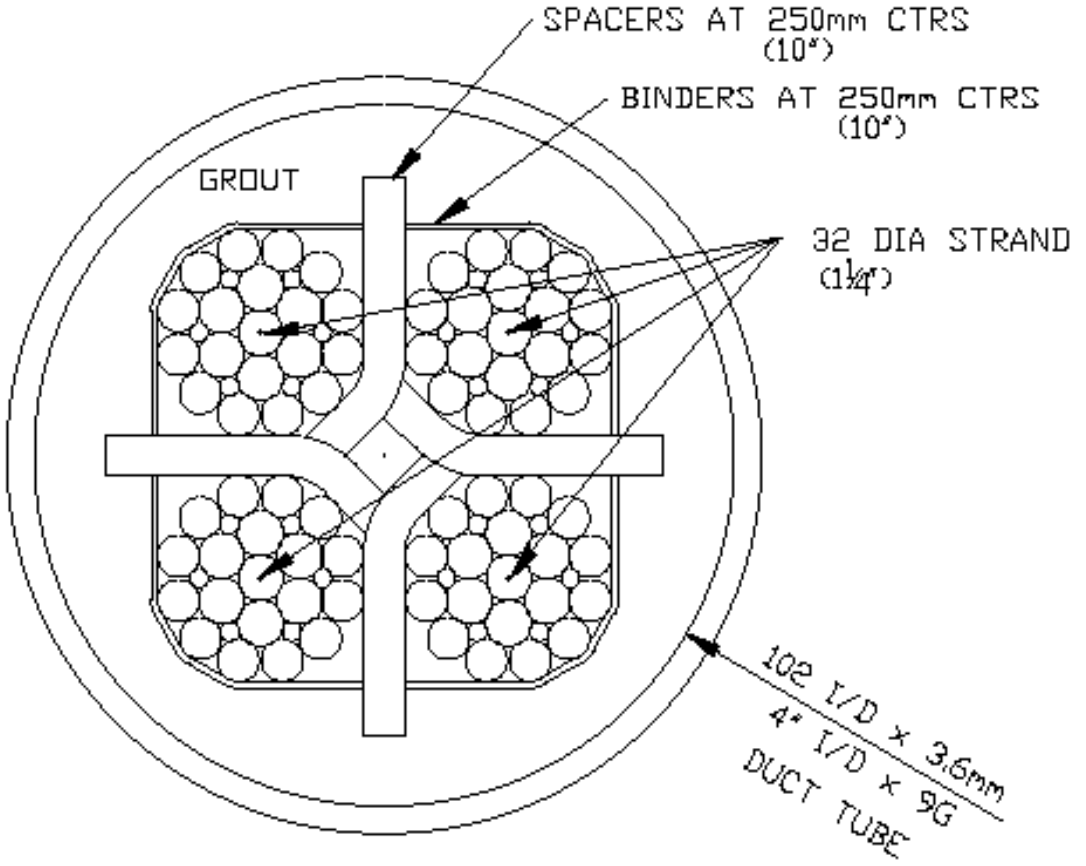


SOUTH CABLE ANCHORAGE.



32 DIA STRAND WARRINGTON LAY
(1¼")

19No strands and 6No fillers



4No 32 DIA CABLES IN DUCT
(1¼")

FORTH ROAD BRIDGE
ANCHORAGE STRANDS

Forth Estuary Transport Authority
Forth Road Bridge Admin. Office,
South Queensferry,
West Lothian,
EH30 9SF

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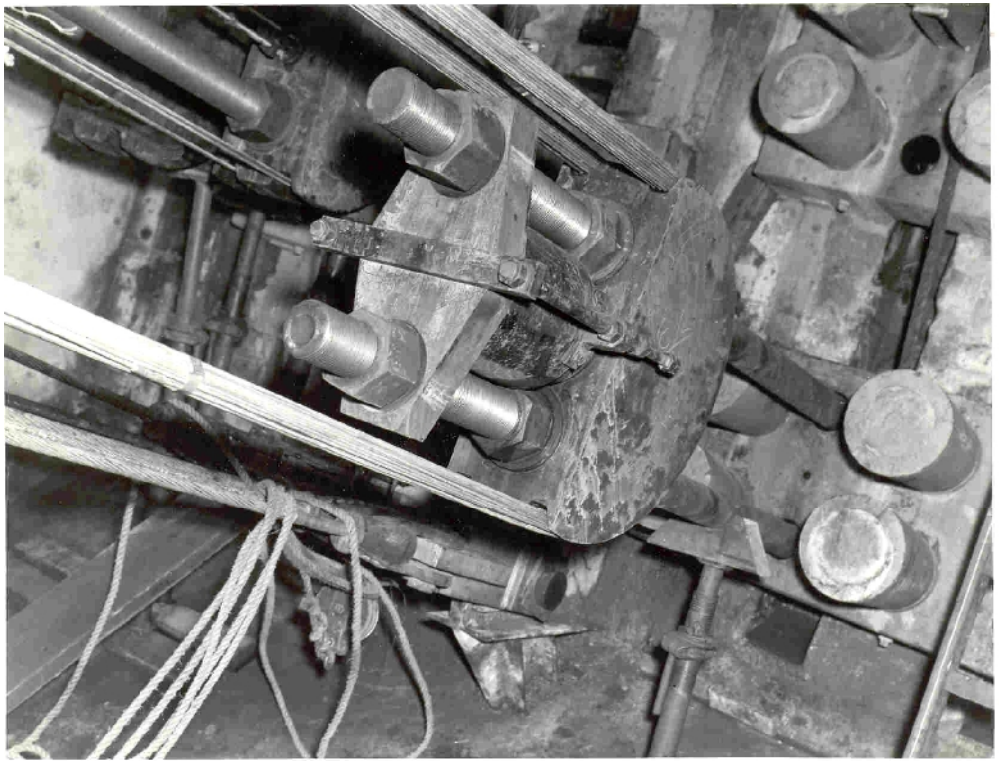
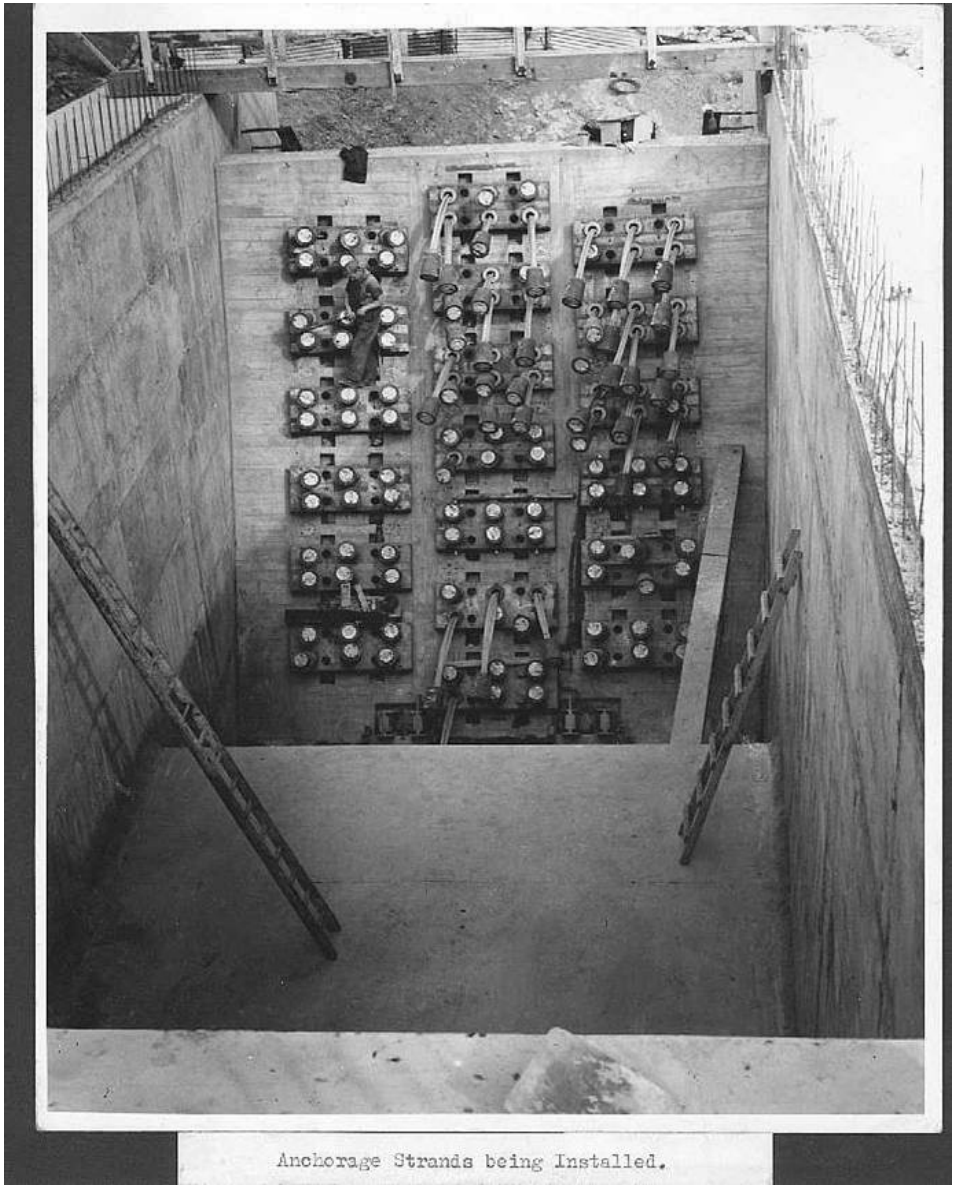




Anchorage Strands being Installed.

Main Cable Anchorages

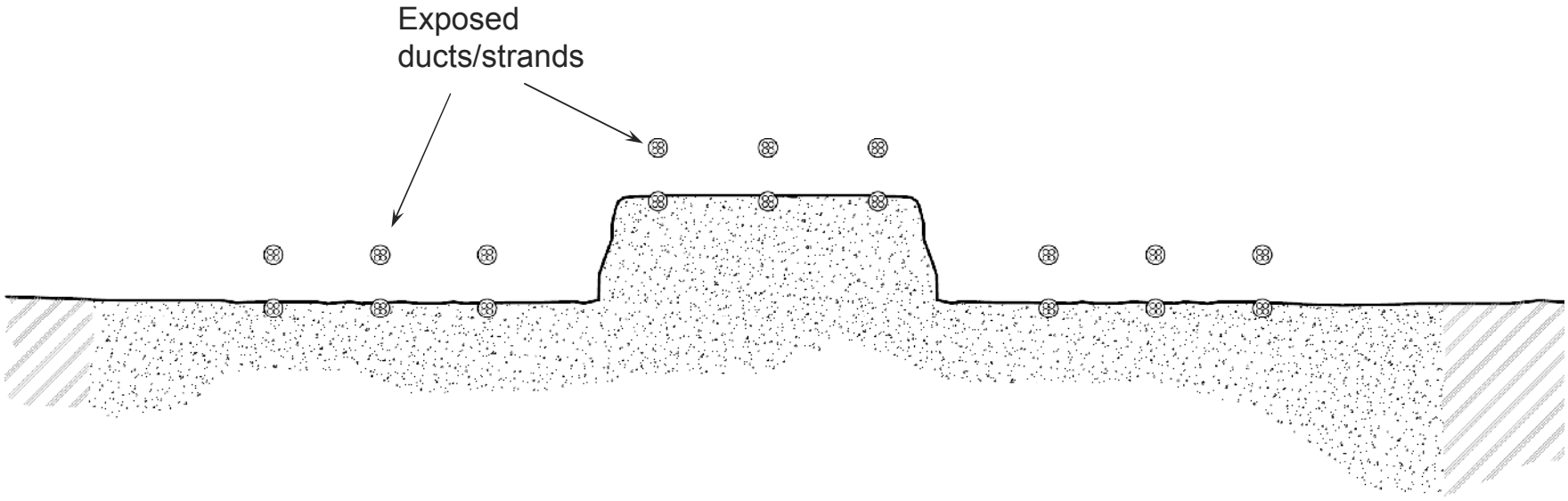
Stage 2 – Excavation

- Rock (sandstone) and concrete


GRAHAM
GRAHAM

Main Cable Anchorages

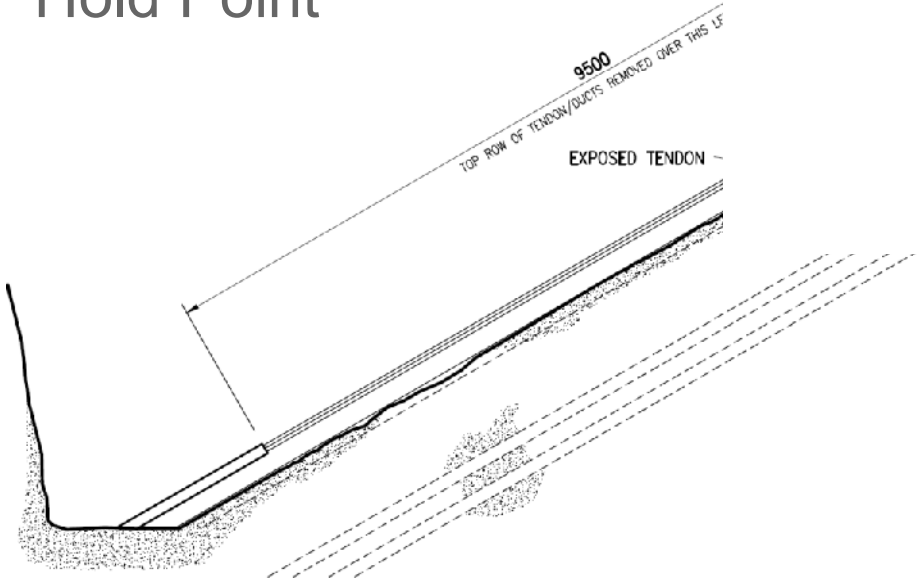
Stage 2 – Exposure of Ducts

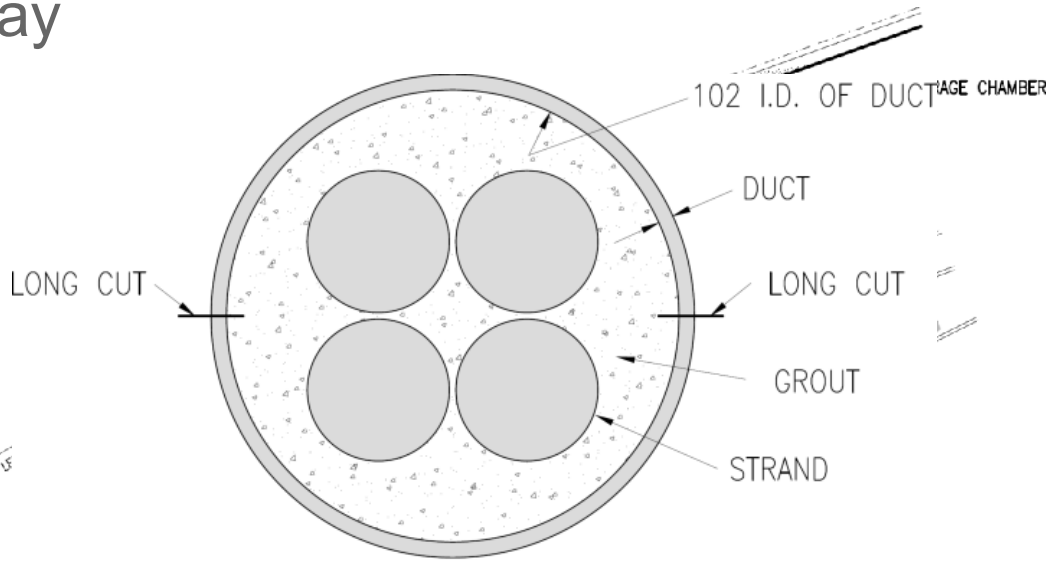


Main Cable Anchorages

Stage 3 – Exposure of tendons

- Visual inspection and X-ray
- Removal of ducts
- Removal of grout
- Visual inspection
- Hold Point

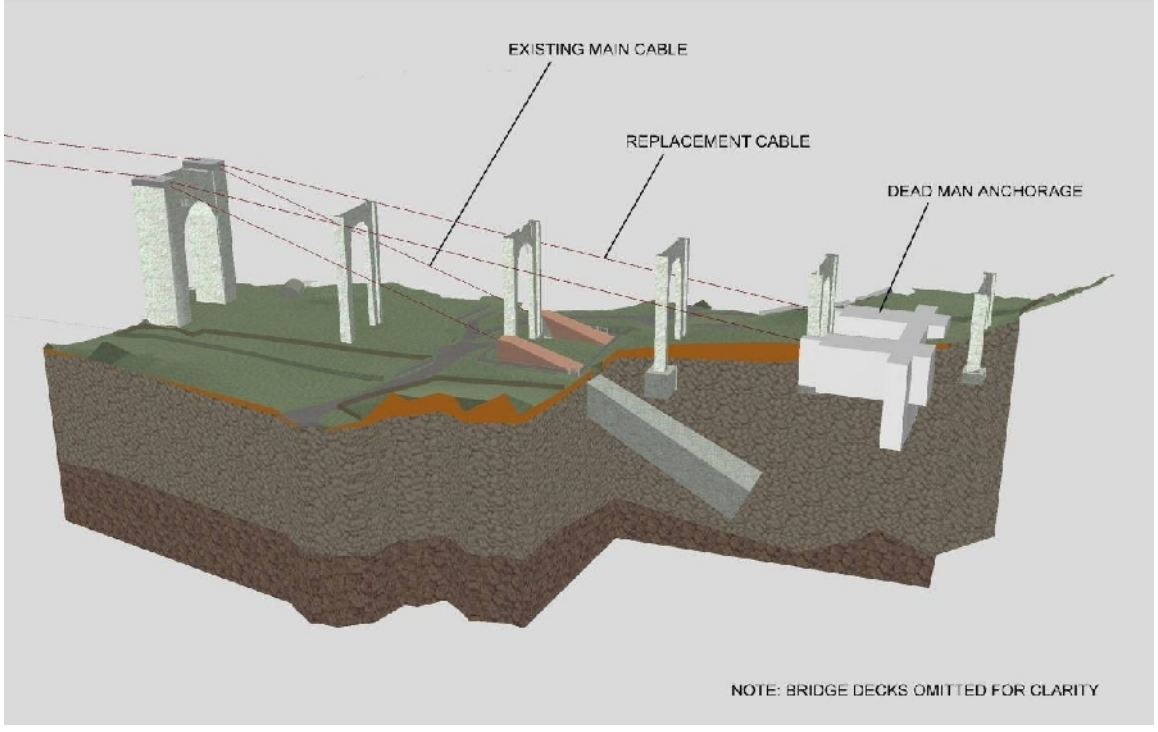




DUCT/STRANDS

Anchorages for new cables

- Dead Man Anchorage
  - Positioned beyond existing.
  - Formed so that can be inspected and maintained.



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ICSBOC June 2013
Edinburgh!