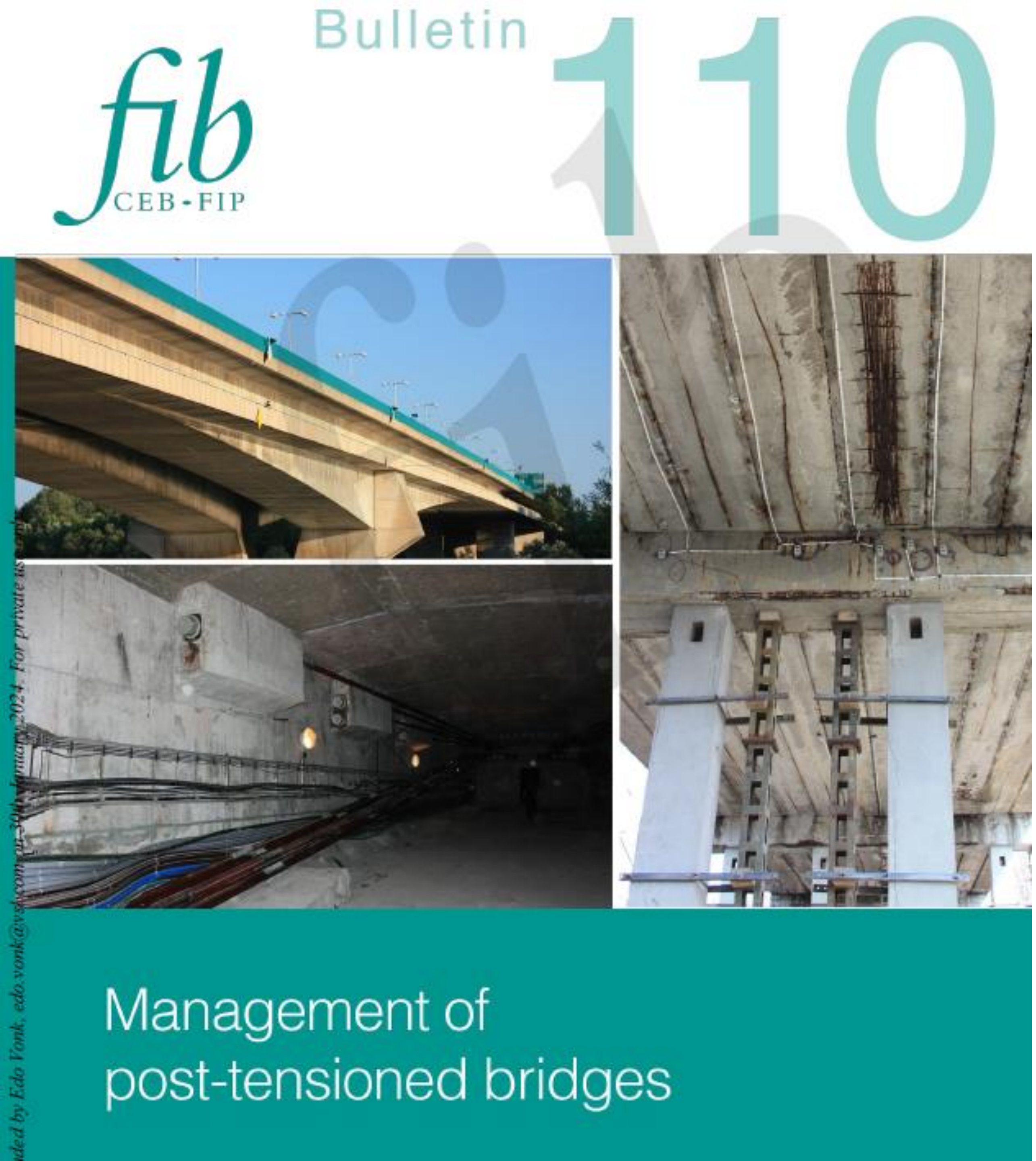

Management of PT bridges

VSL
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MANAGEMENT OF PT BRIDGES

ACKNOWLEDGEMENTS

Acknowledgements

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Management of post-tensioned bridge

Contents

Management of PT bridges

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Management of PT bridges

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Management of PT bridges

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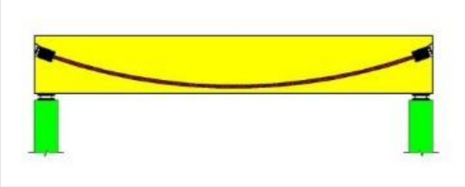
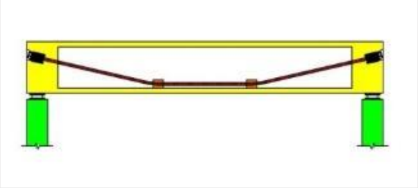
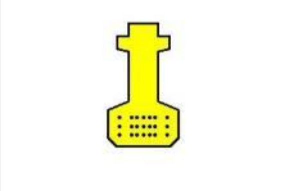
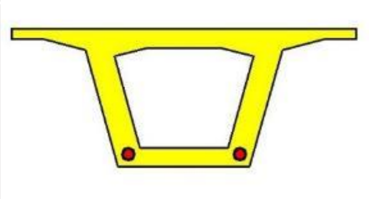
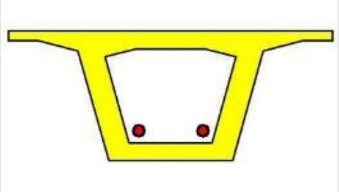
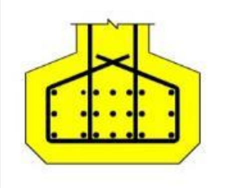
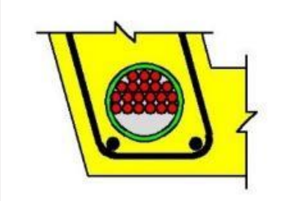
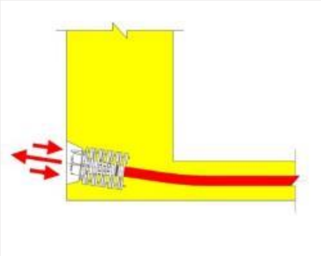
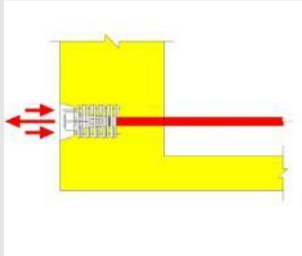
MANAGEMENT OF PT BRIDGES
DAY PROGRAM

Time	Content	Speaker
9:00 – 9:15	Introduction	Edo Vonk
9:15 – 10:15	What is prestressing? How is it used in Singapore?	Surya Kusuma
10:15 – 10:45	Morning Break	
10:45 – 12:00	Durability and risk assessment - worldwide	Edo Vonk
	Singapore	Surya Kusuma
12:00 – 13:00	Lunch Break	
13:00 – 14:00	Inspection and investigations	Edo Vonk
14:00 – 14:45	Afternoon break	
14:45 – 15:45	Interventions	Edo Vonk
15:45 – 16:15	Case Study	Edo Vonk
16:15 – 17:00	Questions and Answers	Edo & Surya

WHAT IS POST-TENSIONING

TYPES OF PT TENDONS: Required protection levels

Pre-tensioning	Post-tensioning	
	Internal	External
		
		
		
		

VSL Strand Post-tensioning system

CORROSION IN GROUTED PT TENDONS: CONSEQUENCES




HISTORICAL REVIEW

1950s

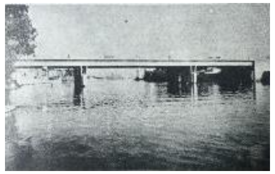
- Joints are epoxy glued when internal PT tendons pass across (with compressible rubber sponge rings)

Use of internal PT tendons in corrugated steel ducts with cement grout: after 2nd World War (~70 years ago)

- Strands as MTEs anchored by wedges become the standard solution

1963

Precast segmental box girder bridge deck construction with match cast joints between segments produced in industrial scale (Choisy Le Roi)



1979

Use of external PT tendons in smooth HDPE pipes with cement grout

1988

Development of the **VSL PT-Plus duct system**: leak tight encapsulation of internal bonded PT & enhancement of tendon's fatigue strength

1992

First application of **VSL's electrically isolated tendon (EIT)** for PT bridge in Switzerland: monitoring of leak tight tendon and protecting against stray current

1992

The investigation into the collapse of the precast segmental concrete bridge Ynvs-y-Gwas in the UK attributed to strand corrosion of internal tendons in 1985 triggered the ban on use of internal grouted PT tendons in the UK in 1992

Observation in the 1990's of corrosion in internal and external grouted PT in other countries – **however majority of structures with grouted PT are perfectly durable**

Extensive R&D work by international organizations like FIP {now *fib*}, ASBI, PTI, FDOT and RTA and specialist companies like VSL between 1992 and 2000 to develop new technologies and re-emphasize importance of good practices

1996

Publication of TR47 - best practices for grouting of PT tendons

- air tight testing of ducts
- detailing to prevent water ingress into anchorages

1996

Lifting of ban of use of internal grouted PT tendons in UK

2000

First wave of failed PT tendons due to corrosion observed in Florida (Mid-Bay Bridge): actions by FDOT (and other authorities in US):

- grouting by certified staff
- post grout inspection of anchorages
- use of factory pre bagged grout
- use of duct couplers over match cast segmental joints

2002

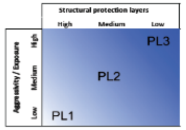
Publication of

- **VSL's Technical Report No 5 "Grouting of post-tensioning tendons"**
- fib bulletin 20 "Grouting of tendons in prestressed concrete"

proposing new grout specifications, test methods and testing frequencies (adopted by EN in 2007 when revising its grouting standard EN445)

2005

fib publishes bulletin 33 "Durability of post-tensioning tendons" introducing the concept of protection levels PL1 to PL3



2007

EN 445, 446, 447 covering grout mix and grouting requirement. Bleeding spec. reduced from 2% to 0.3%.

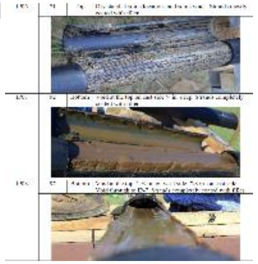
2010

Phenomena "Soft Grout" - very localized and aggressive corrosion is initiated within grout matrix at interface between soft and good grout (without external factors) observed on bridges in Italy, Switzerland (Ponte Tieda) in 2010

2010s

Second wave of failed PT tendons observed in Florida: actions by FDOT

- use of soft filler instead of cement grout made mandatory for all strand PT tendons except for internal cantilever PT, transverse deck slab PT and straight tendons in U-beams and girders in 2015



Financial argument

From fib bulletin 17 (2002) Management, maintenance and strengthening of concrete structures

- An integrated life cycle cost concept
- Influence of investments at different stages of a project life cycle
- Law of 5's — $1 spent in getting the structure designed equals
  $5 spent in preventive maintenance in the pre-corrosion phase equals
  $25 spent in repair and maintenance when local corrosion is taking place equals
  $125 spent in major repair and possible replacement of member

It is better to spend money on preventive maintenance now, before it gets more expensive later.

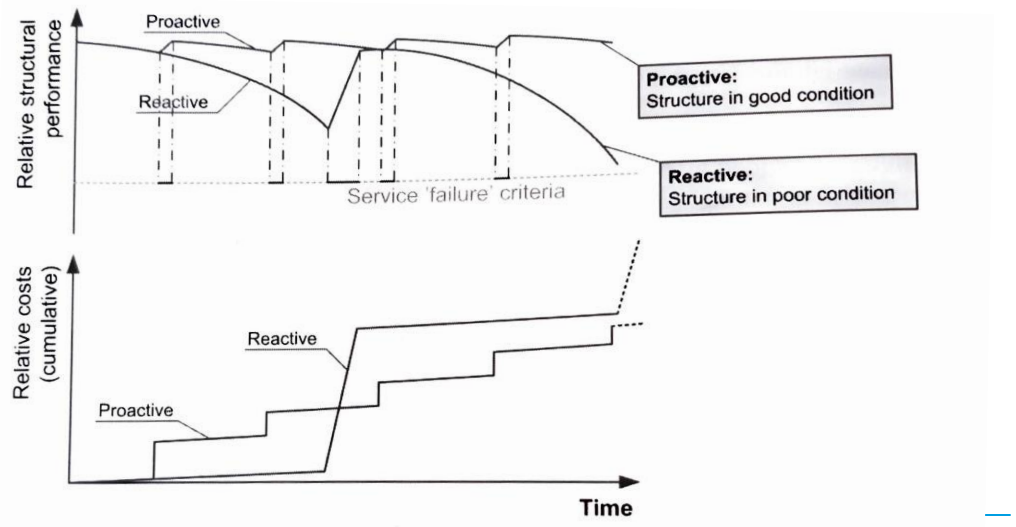
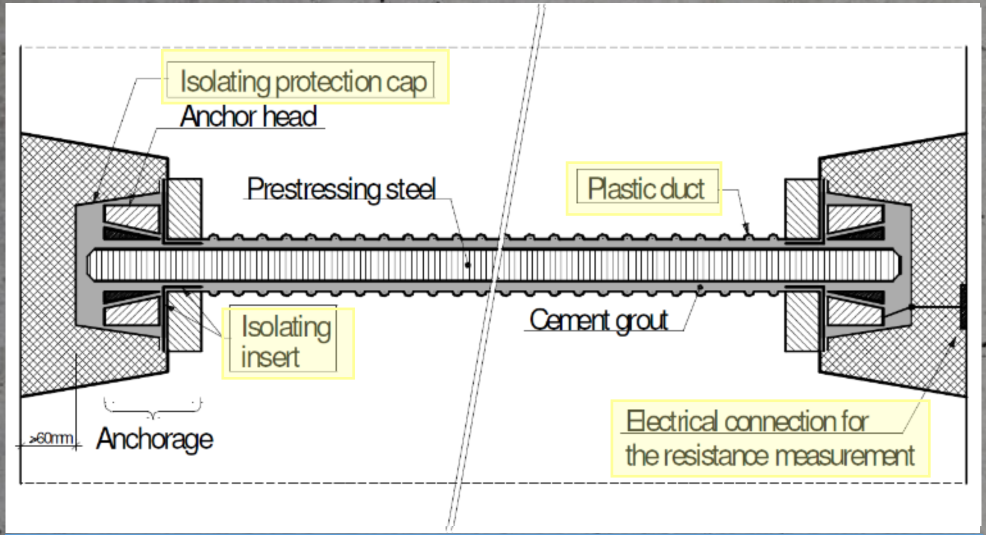


Figure 4-1: Relative costs of reactive and proactive structure management, fib Bulletin 44

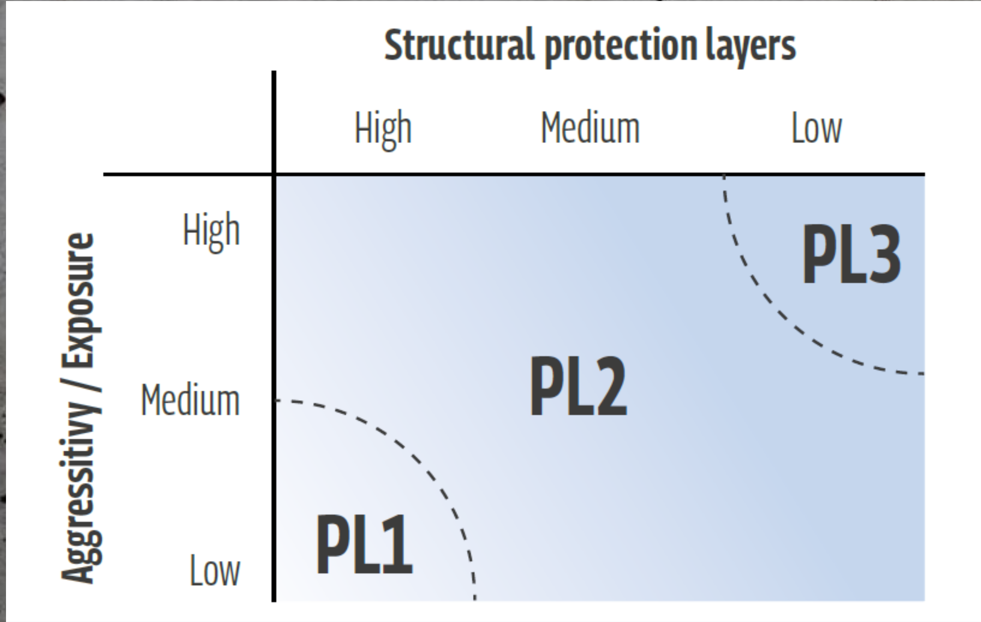
DURABILITY OF POST-TENSIONING TENDONS

- fib Bulletin 33 defines 3 protection levels (PL) for PT tendons.
  - **Protection Level 1 (PL1)**
    - "A duct with a filling material providing durable corrosion protection"
  - **Protection Level 2 (PL2)**
    - "PL1 plus an envelope, enclosing the tensile element bundle over its full length and providing a permanent leak-tight barrier"
  - **Protection Level 3 (PL3)**
    - "PL2 plus the integrity of the tendon or encapsulation to be monitored at any time"

- Choosing the appropriate protection level
  - The protection level to PT tendons is chosen from:
    - Aggressive nature of the environment
    - Particular exposure conditions of the structural element
  - **PL1** for low aggressivity and high structural protection layer
    - Internal PT in buildings – slab, beam
  - **PL2** for medium aggressivity and structural protection layers
    - External PT
  - **PL3** for high aggressivity and low structural protection layers
    - PT in bridges and structures located in aggressive environment

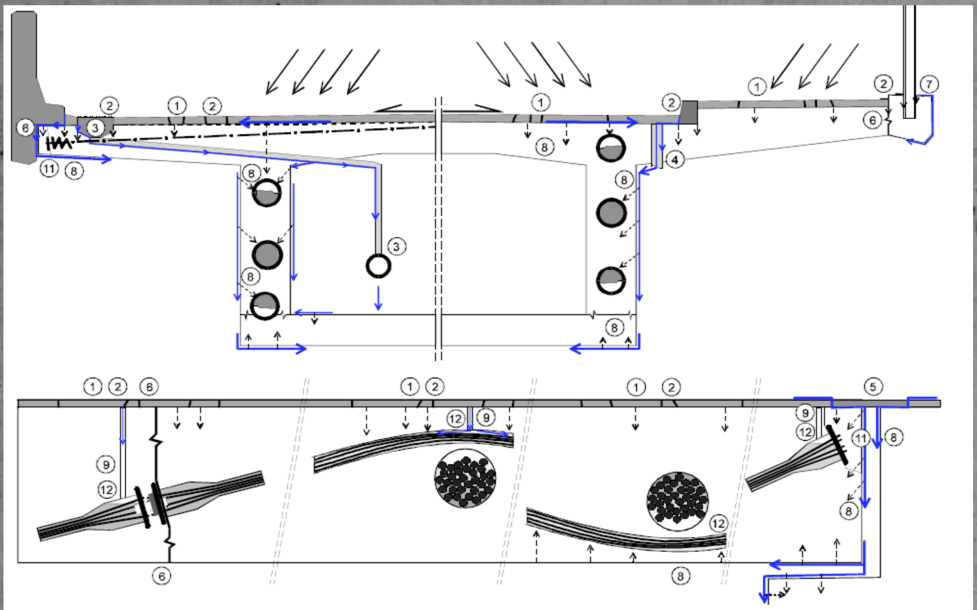


Definitions of protection level

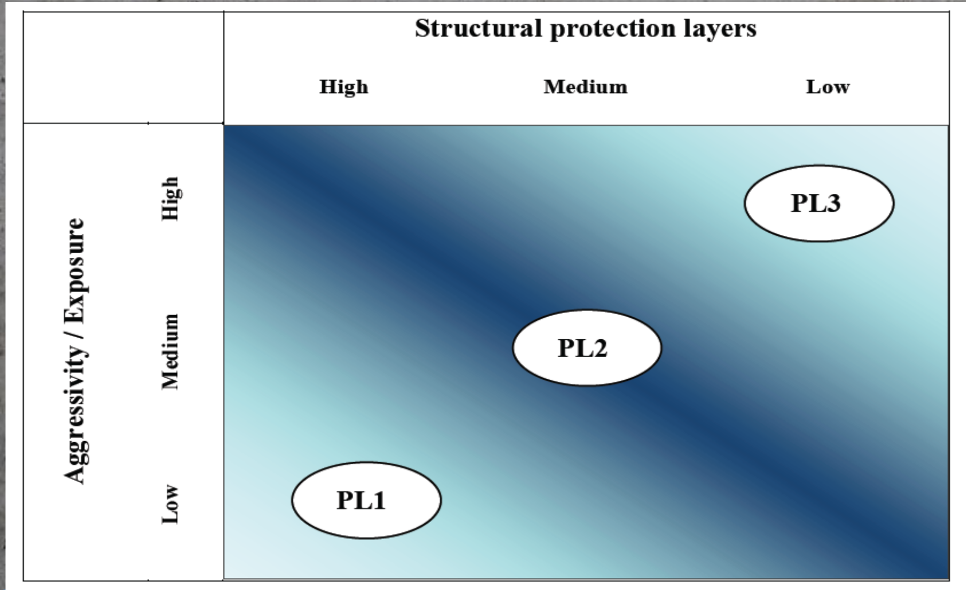


Evaluating required protection levels

* For details, refer to Table 1.3 of FIB Bulletin 33 and to EN 206-1 'Concrete – Part 1: Specification, performance, production and conformity'.



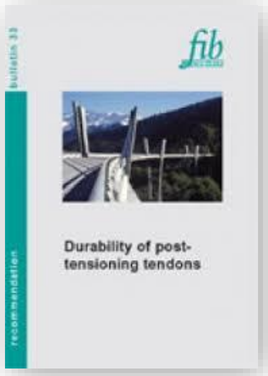
Hazard scenarios for PT tendons in a typical box girder bridge

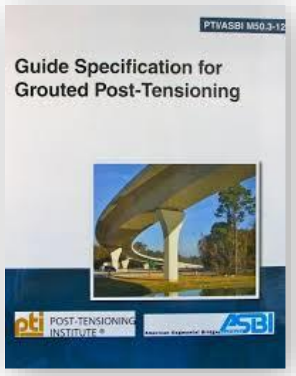


Protection levels for PT tendons

STRATEGY I: Leak Tight Encapsulation

- Recognized since 1996 in publication of TR47 - Leak tight encapsulation is key
  - Air tight testing of ducts
  - Detailing to prevent water ingress into the tendons, anchorages and ducts
- fib works started in 1997
- fib publication (bulletin 33) on Durability of PT tendons in 2005
  - Outlining design concepts for durable PT tendons
  - Introducing the concept of protection levels PL1 to PL3
- PTI 50.3 has fundamentally similar projection level concept
  - Slightly different (e.g. PL1 is subdivided to PL1A and PL1B)





STRATEGY II: Stable Grout, Complete Duct Filling

Quality grout mix

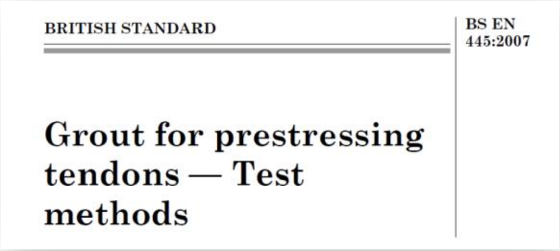
- New tests
- New acceptance criteria

Quality grouting procedure

- Interdependence between quality of grout mix and equipment used & mixing time
- Air leak-tightness test
- Grouting operation
  - Standard grouting
  - Vacuum-assisted grouting
- Venting quantity

VSL tests of grout mix

VSL grout mixer



BRITISH STANDARD

BS EN 445:2007

Grout for prestressing tendons — Test methods

BRITISH STANDARD

BS EN 446:2007

Grout for prestressing tendons — Grouting procedures

BRITISH STANDARD

BS EN 447:2007

Grout for prestressing tendons — Basic requirements

BS EN 445, 446, 447 - 2007

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INSPECTION OF INTERNAL & EXTERNAL POST-TENSIONING TENDONS

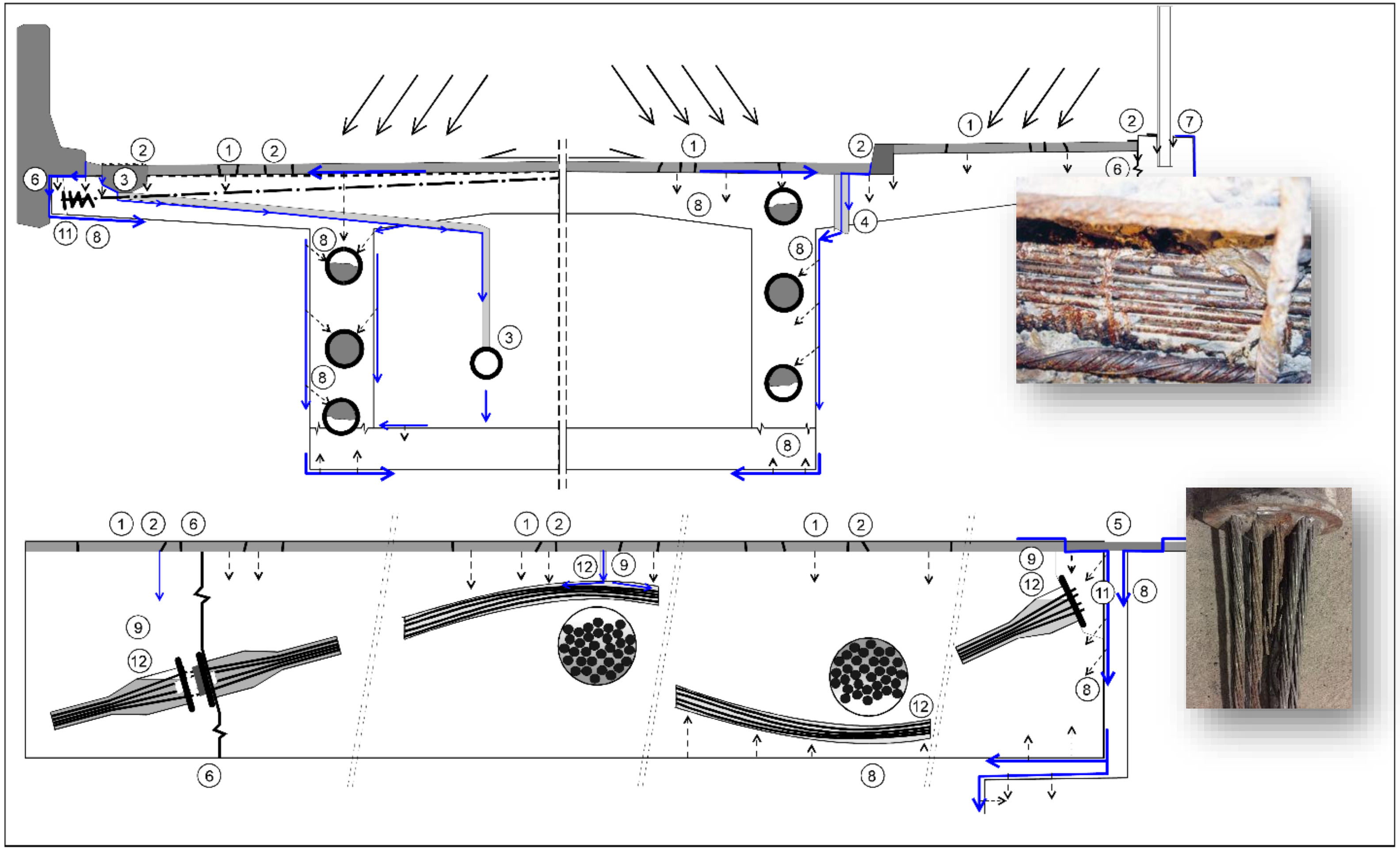
Edo VONK

Content

- **Why** must we inspect?
- **When** to inspect?
- Pathologies - **what** are we looking for?
- **How** - Inspection techniques and solutions

Pathologies - what are we looking for?

Most common defects in post-tensioning



External Risks

- Conventional corrosion of reinforced concrete (carbonation, chlorides)
- Corrosion of exposed anchorages

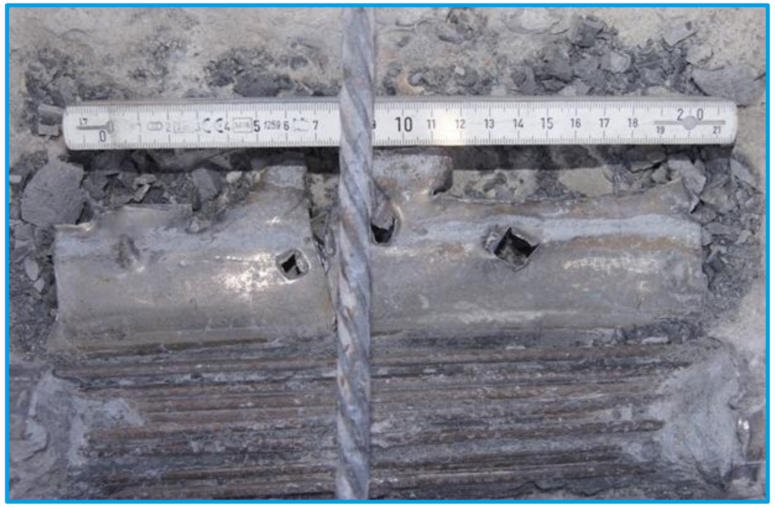
Internal Risks

- Voids inside PT ducts
- Bleeding of grout
- Accelerated corrosion of high strength steel

Pathologies - what are we looking for?

Most common defects in post-tensioning

- Voids
- Soft grout
- Chloride induced corrosion (pitting)
- High pH induced corrosion (pitting)
- Carbonation induced corrosion
- Cracks in concrete elements



PT inspections

Different types of inspections

Initial inspection

Routine inspection

Detailed inspection

Special inspection

PT inspections
What are the challenges?

- Structural dependency on PT cables
- Hidden from sights
- Ongoing developments in durability of tendons
- Do not destroy if possible
- Reliability of results
- Cost/benefit optimization

TECHNIQUES AND SOLUTIONS

A wide range adaptable to every project

	PREVIOUS		NON-DESTRUCTIVE					
PT / Techn.	Office	Slinging	Visual Inspection	Hammer	GPR	UPE	Magnetic Flux	X-ray
Internal	✓		✓		✓	✓	✓	✓
External	✓	✓	✓	✓				

	NON-DESTRUCTIVE			INTERMEDIATE		DESTRUCTIVE	
PT / Techn.	Acoustic Emission	Capacitive Probe	Guided Wave Ultrasound	Endoscopy	Force	Windows	Sample
Internal	✓	✓	✓	✓	✓	✓	✓
External	✓	✓	✓	✓	✓	✓	✓

PT Inspections

Overview of NDT techniques

Visual inspection

Endoscopy

Tapping

Magnetic Flux

Electrical Capacitance

Acoustic Emission

PT Inspections

Overview of NDT techniques

Force measurement

Advanced GPR

Half cell potential measurement

Grout sampling

Ultrasonic Pulsed Echo

Radiography

Summary

Inspection of PT tendons

Existing pre-stressed bridges bear a residual risk for premature deterioriation of PT tendons as can seen from recurrent defects and tendon failures worldwide

Combining NDT methods and engineering judgement allows to optimize the condition assessment of PT tendons

By integrating inspection and assessment data making use of as-built BIM / Big Data it is possible to develop predictive structural models to facilitate a pro-active portfolio management in order to maximize the residual life of existing structures and to optimize overall life-cycle costs

Safety during inspection works has to be a priority

Interventions

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CONCLUSION

Extend the life of your post-tensioned structure

INTERVENTIONS

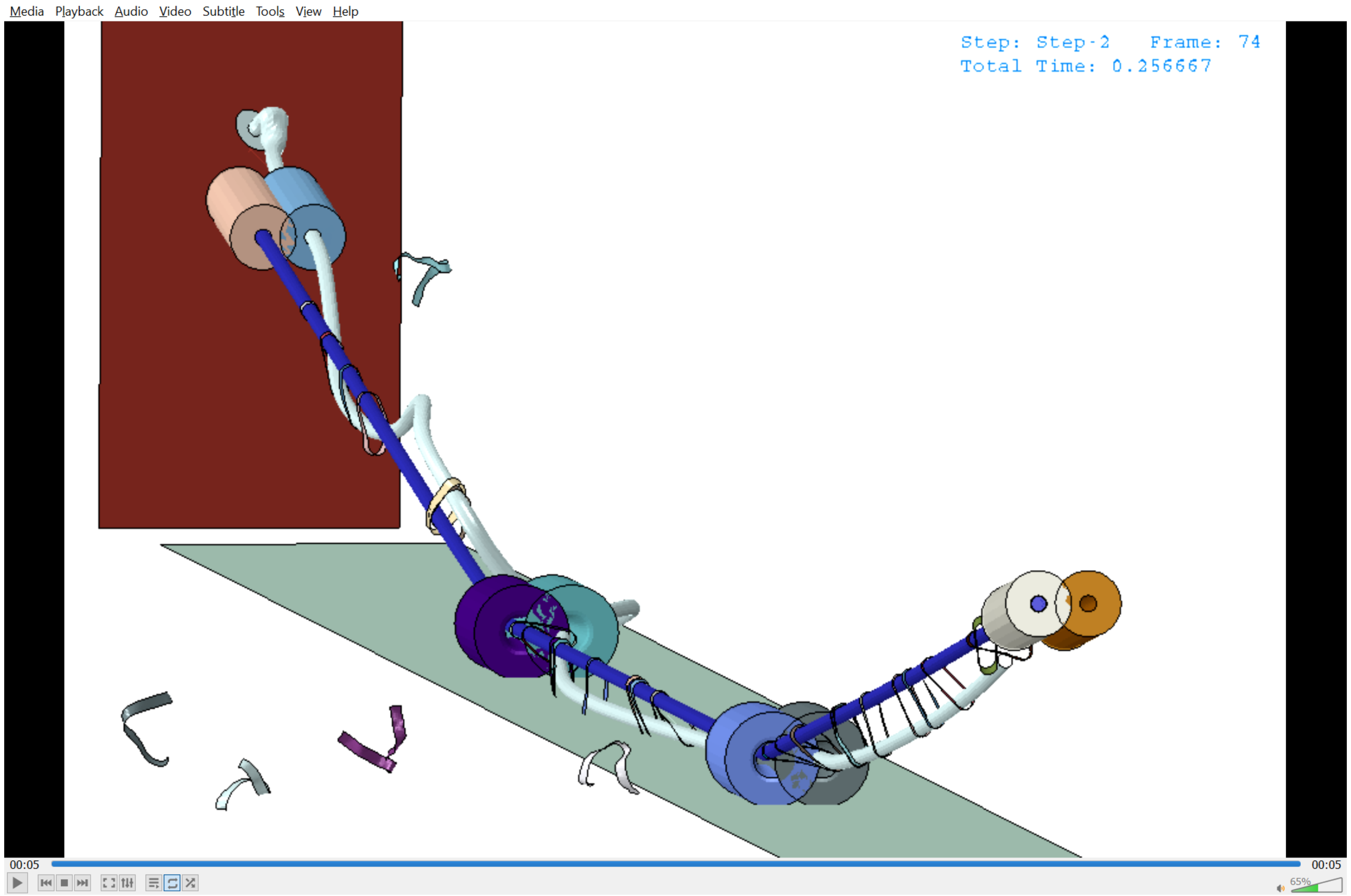
- Monitoring
- Repair and maintenance
- Bearing replacement
- Replacing tendons
- Strengthening with external PT
- Demolish and build new

Tendon failure due to corrosion

CONTROLLING ACCIDENTAL TENDON RELEASE

- Wrapping has established itself as 'standard' method, possibly combined with shock absorbers behind anchorages
- Alternative solutions using scaffold containments are expensive and difficult to deploy
- Need to design by simulation of dynamic behaviour
- Risk management strategy based on short intervention times

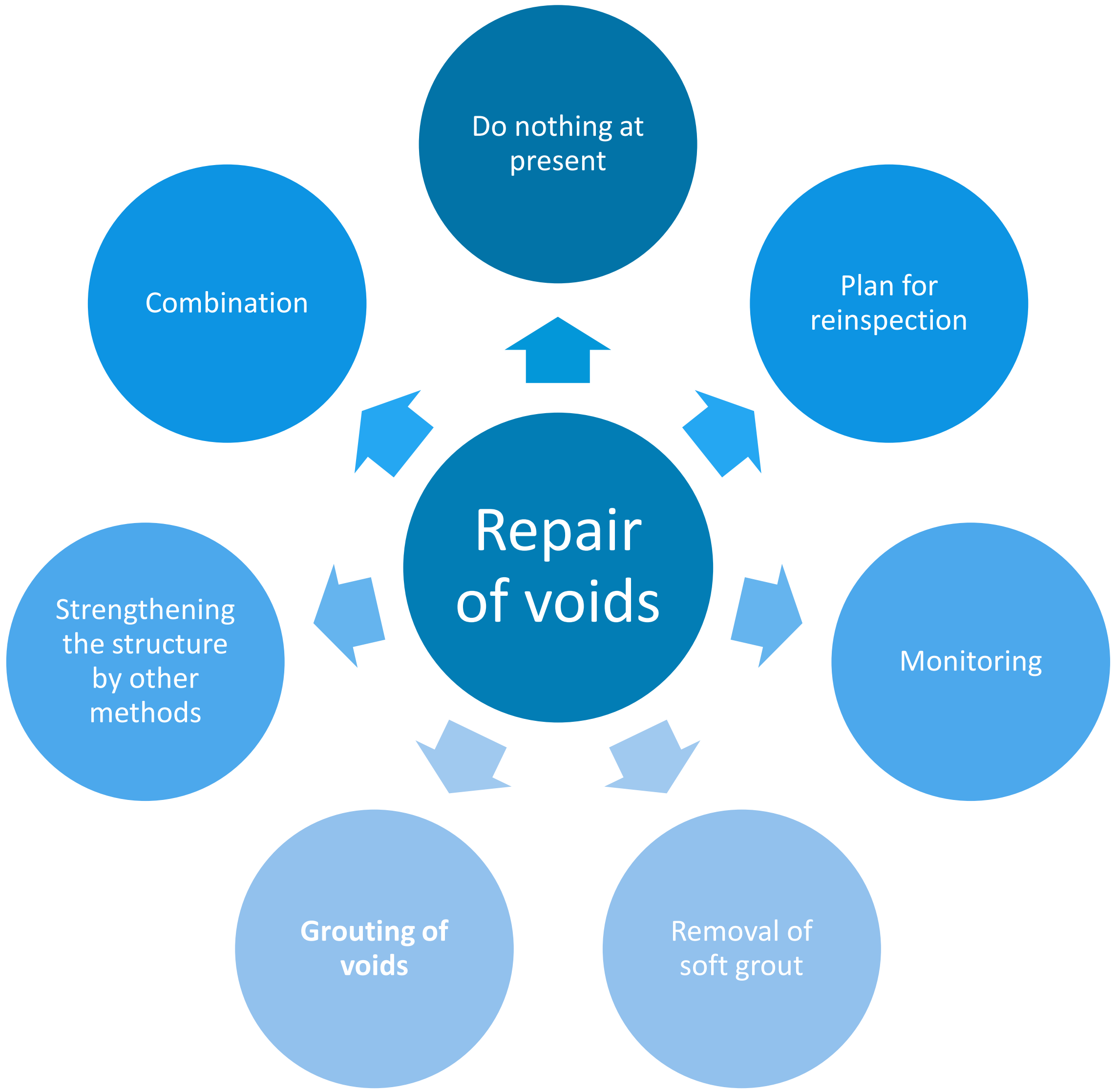
SIMULATION OF EFFECTIVENESS OF TENDON RESTRAINTS

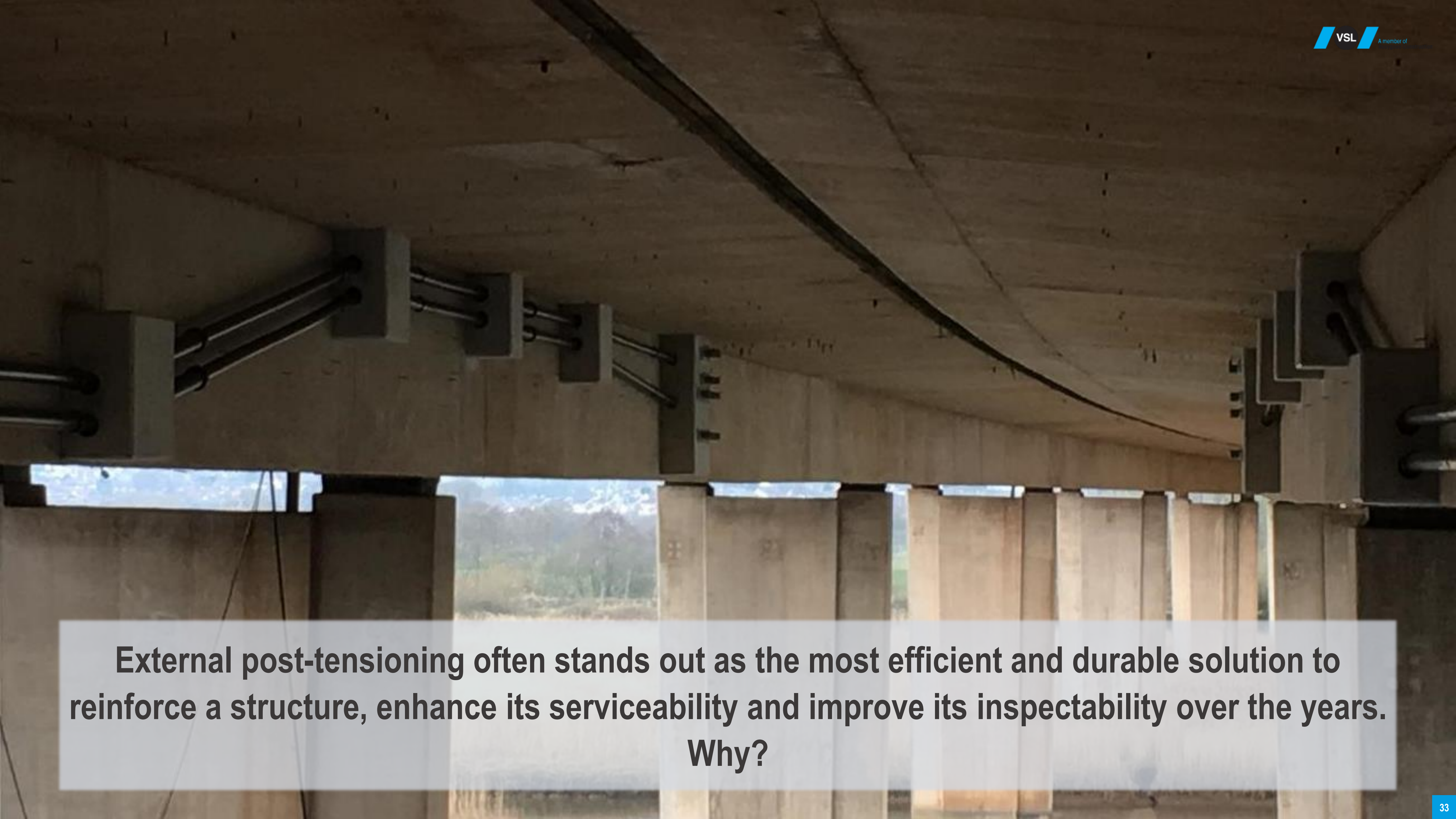


DUCT REPAIR

- Repair by HDPE half-shell welded in-situ
- Needs to be leak tight, durable and avoid ingress of moisture and pollutants
- Where no access, metallic half shells with sealing assembly to be used
- Treatment of grout / strand prior sealing depending on condition
- Injection of gap with wax or grout

VOID REPAIR STRATEGY

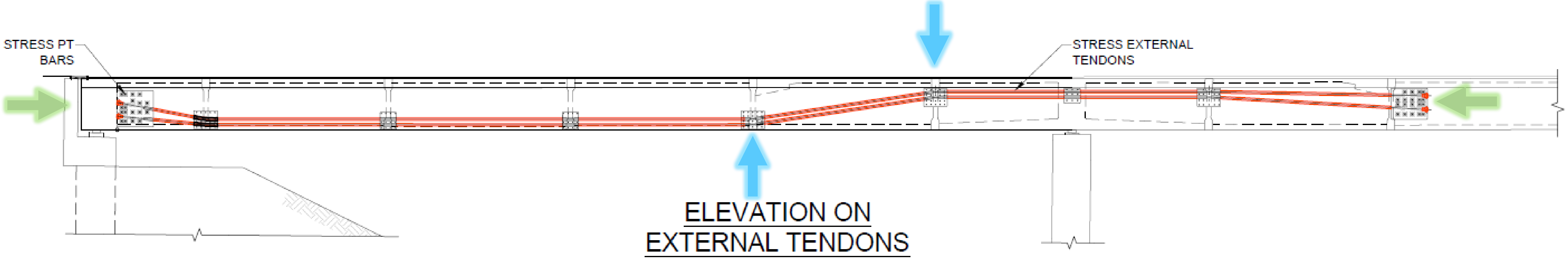


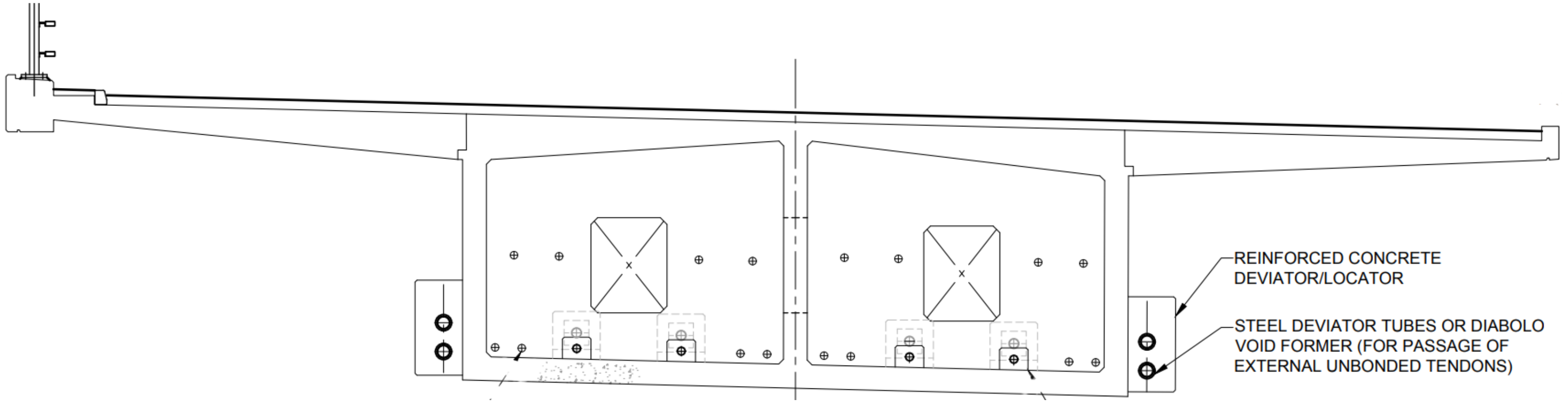


External post-tensioning often stands out as the most efficient and durable solution to reinforce a structure, enhance its serviceability and improve its inspectability over the years. Why?

What is External Post-Tensioning?

Active strengthening: a key solution to avoid any hindrance to traffic





Additional PT as an optimal solution

Efficient & non-invasive deployment

- Design and build approach for a fast-track solution
- Smart detailing right from the design to enhance constructability
- Minimum disruption to traffic with active strengthening

→ Cost-effective solution

Additional PT as an optimal solution

Durability

- Easy inspections and low maintenance over the years
- Robustness of the components and materials
- Low weight of additional components
- Suitable for a wide range of structures

THANK YOU FOR YOUR ATTENTION

ASSET PRESERVATION, STRUCTURAL REPAIRS & UPGRADING

1

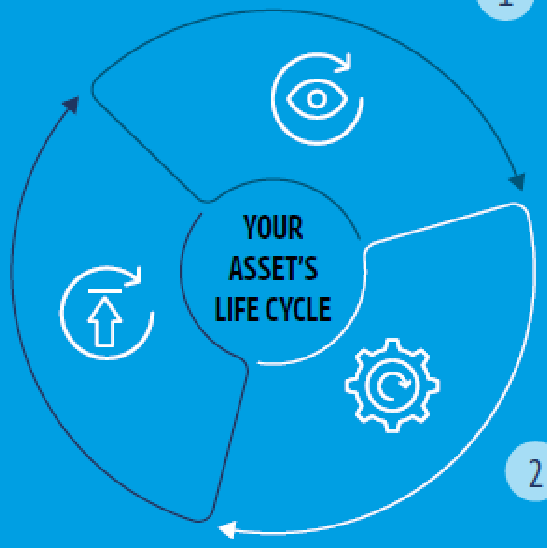
ASSET PRESERVATION

PREVENTIVE MAINTENANCE
INSPECTION
ASSESSMENT
MONITORING

3

UPGRADING

STRENGTHENING
CHANGE OF USE
RESILIENCE ENHANCEMENTS



2

STRUCTURAL REPAIRS

REPAIR
REPLACEMENT

- CREATIVE ENGINEERING & EFFICIENT METHODS
- IN-HOUSE STRUCTURAL TECHNOLOGIES
- OPERATIONAL SKILLS IN COORDINATION & EXECUTION