The use of Post-Tensioning in Marine Structures

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Summary

- Introduction
- A few examples of PC marine structures
- Durability of PC in marine environment
- High performance PT for marine structures

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Advantages of concrete in marine structures

- Durability
- Low maintenance
- Resistance to:
  - fatigue
  - abrasion
  - cold temperatures
  - fire
- Use of local materials
- Economy

Aggressions in marine environment

- Mechanical
  - Waves
  - Ship / iceberg impact
- Chemical
  - Sulfatic reaction (ettringite expansion)
  - Carbonation in tidal areas (pH drops from 13 to below 9)
  - **Chloride ions impede passivation of steel in concrete**

Prestressed concrete in marine environment

- Thinner elements to resist higher loads
- Section fully compressed under permanent load:
  - no cracking
  - slower chloride migration
  - watertight structures, suitable for floatation
- Assembly of precast elements

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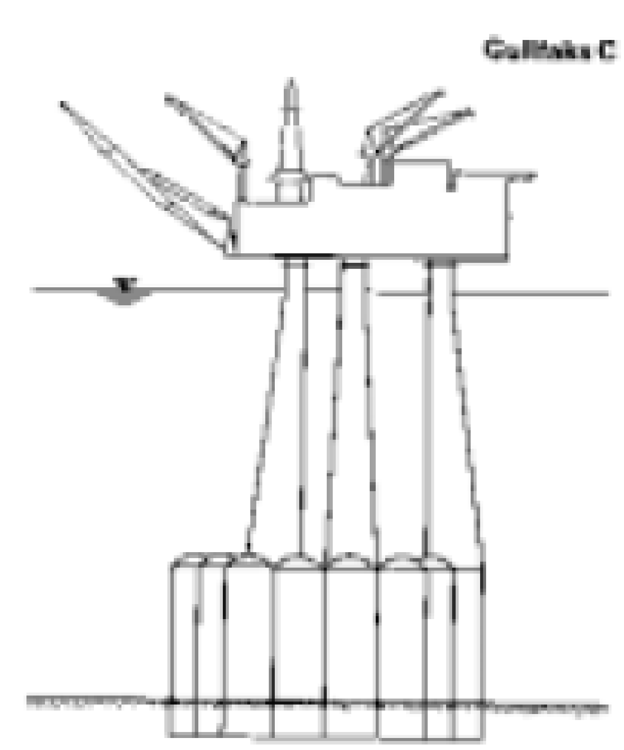
Pre-tensioned girders wharves

- Pre-tensioned prefabricated elements (I-girders)

Antifer
oil-terminal,
1976,
Le Havre,
France

Offshore concrete oil & gas platforms

- CGS (Concrete Gravity Structure) or Condeep (Concrete Deepwater) system developed in 1970’s for oil exploration in the North Sea
  - Floating concrete structures built in a dry dock
  - Deepwater oil storage in PC cells sitting on the seabed
  - steel topsides supported by 3 or 4 PC columns
  - 30 installed to date
  - Up to 300 m deep



Ekofisk CGS (Norway, 1973)

- Concrete tank (235,000 t)
- Concrete wave protection barrier (384,000 t)
- 73 m deep

Hibernia CGS (Canada, 1997)

- The largest CGS in the world with ice-protection crown
  - Oil storage
  - Drilling and operation facilities on topside
- 1,200,000 t
- 7,000 t of PT
- 100 m deep

Wandoo B CGS (WA, 1997)

- Oil production platform with oil storage facilities, processing equipment & accommodation
- North West Shelf: The first (CGS) in Australian Waters
- 81,000 t
- 60 m deep

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Wharves and Jetties

- Hay Point Wharf 2, QLD (1973)
- Made of caissons cast in Mackay Harbour and floated to Hay Point
  - 680 t of PT
  - Average P/A 5.3 MPa

Floating Bridge

- 3rd Lake Washington floating bridge, Seattle, USA (1984-87)
  - 750 m long, 32 m wide, floating PC bridge
  - Each pontoon is a PC box prestressed in 3 dimensions
  - 1,680 t of PT

Monaco Floating Dike

- Extension of Monaco Harbour
- 352 m long floating dike, with pin connection to land (160 000 t)
- 120 years design lifetime

Confederation Bridge (Canada)

- 12.9 km PC bridge, 43 nos. 250 m spans

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Confederation Bridge (Canada)

Ice loading on piers

Massive
prefabrication

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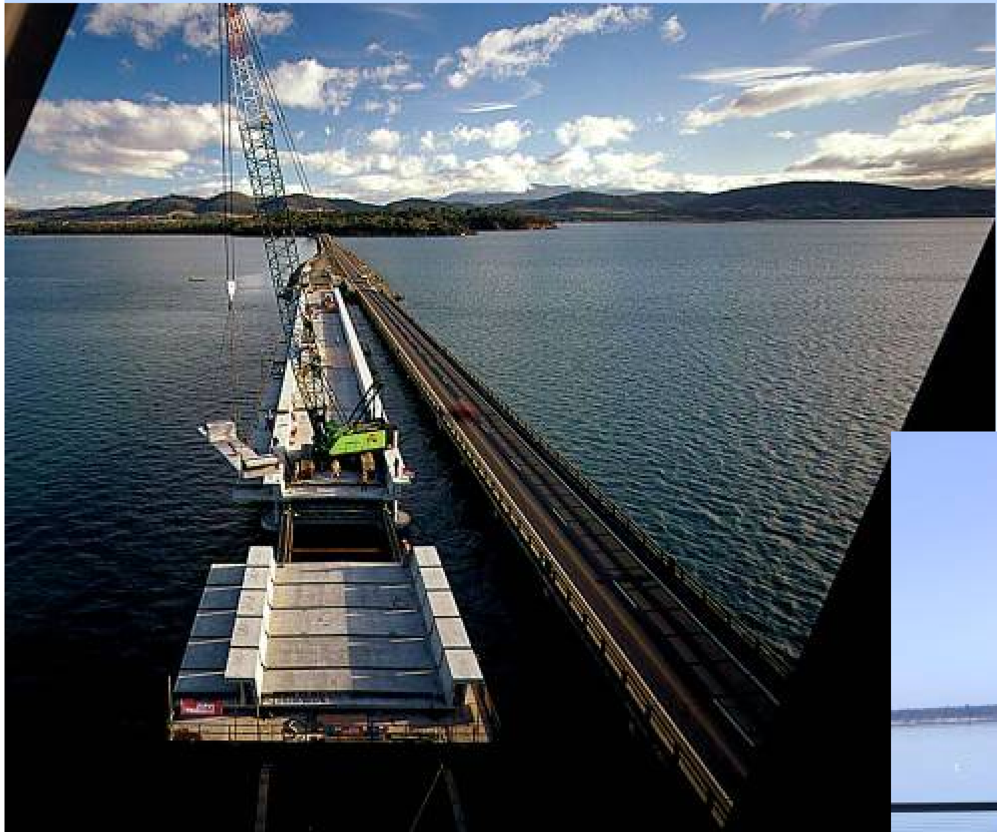
Sorell Causeway (Tasmania, 2003)



Precast Channel segments

Span by span erection and stressing

- 150 t of PT
- 460 m long

Lawrence Hardgrave Drive (NSW)

- Cast in situ balanced cantilever
- Incrementally launched approaches
- Plastic duct PT (VSL)

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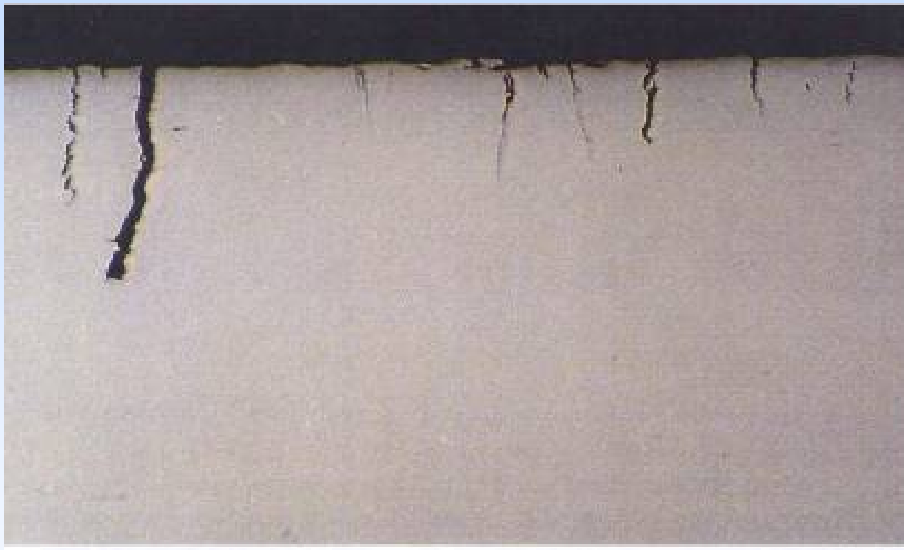
Design life

- Design life depends of the type of structure:
  - Off shore platforms: design life = time of extracting crude oil i.e. 20 to 30 years
  - Marine wharf: 40 to 60 years
  - Bridge: 100 years
  - Monaco Dike: 120 years
- Lifetime depends on durability of PT tendons and passive reinforcement

Stress cracking corrosion

- Passive reinforcement:
  - General corrosion (dissolution)
  - Pitting rust
- Prestressing steel:
  - Stress cracking corrosion & hydrogen embrittlement
  - faster penetration,
  - sudden brittle failure after enough crack initiation



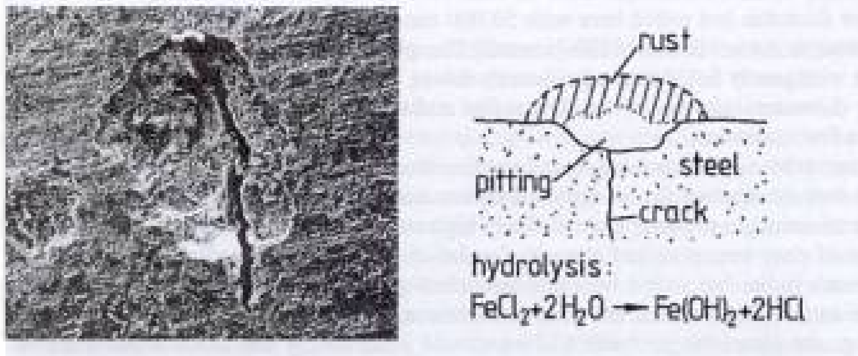


Fig. 1: Pitting induced stress corrosion cracking

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PT Protection by Design

- Appropriate concrete cover
- Compact concrete through HP concrete mix
- No cracks: compression under permanent loads
- (Surface) passive reinforcement for local effects: transverse bending, bursting forces, surface shrinkage
- Waterproofing
- Avoid pre-tensioned elements

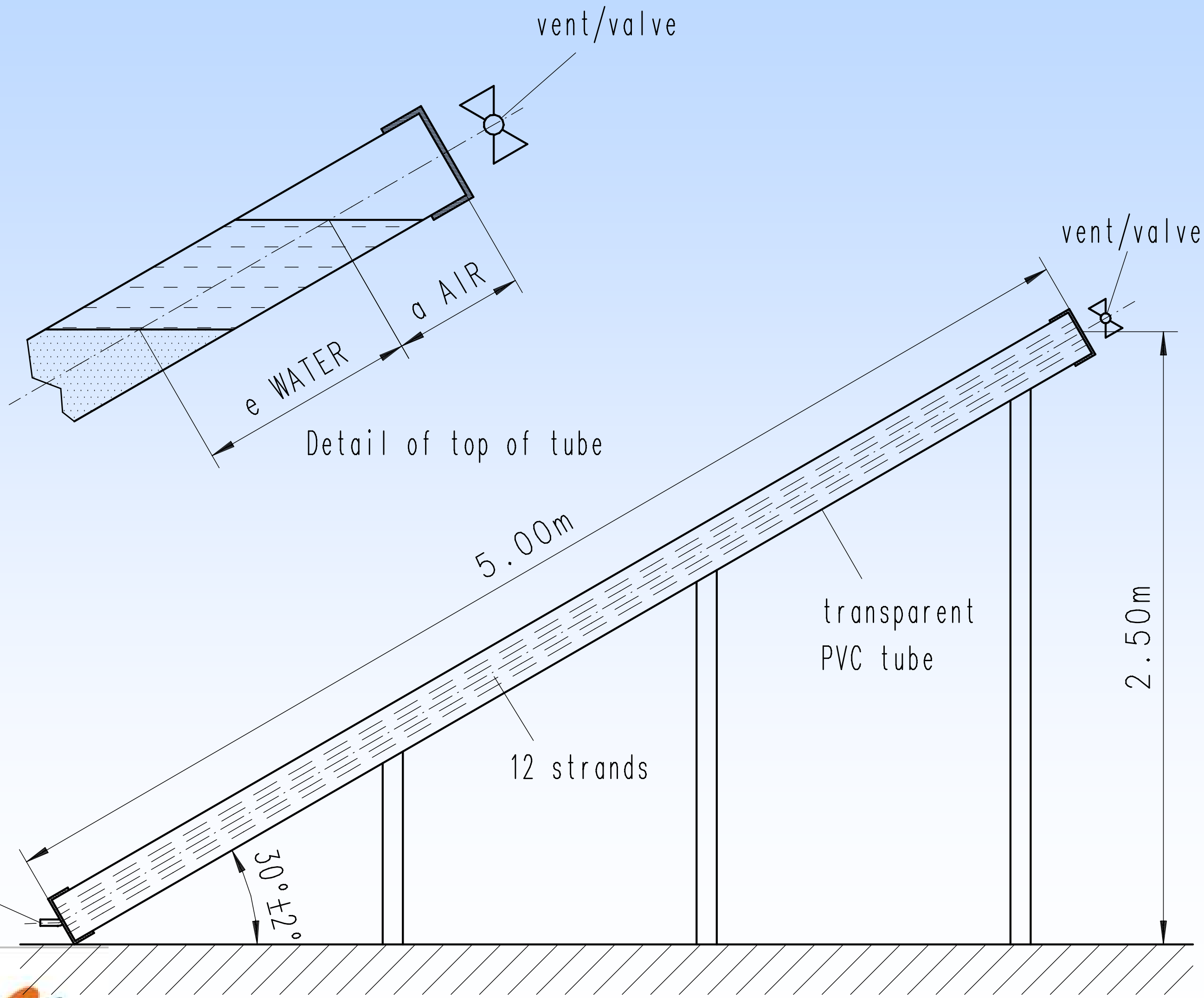
Protection of PT tendons

- Proper injection and anchor protection: complete filling with compact grout
  - skilled personal
  - grout mix design
- Full steel encapsulation
- Full plastic encapsulation (plastic ducting)
- Cathodic prevention
- **The solution depends of the design life which is targeted**

Qualification of grouting mix

- Cement grout: Grouting mix not always stable in tendons
  - accumulation of air, water and whitish paste at the top point of tendons
- Traditional tests with small glass or plastic cylinder fail to identify unstable grouting mix
  - Filtration effect
- Inclined tube test developed in Europe in 1995, and endorsed by *fib* bulletin 20

LCPC 5 meter inclined tube test



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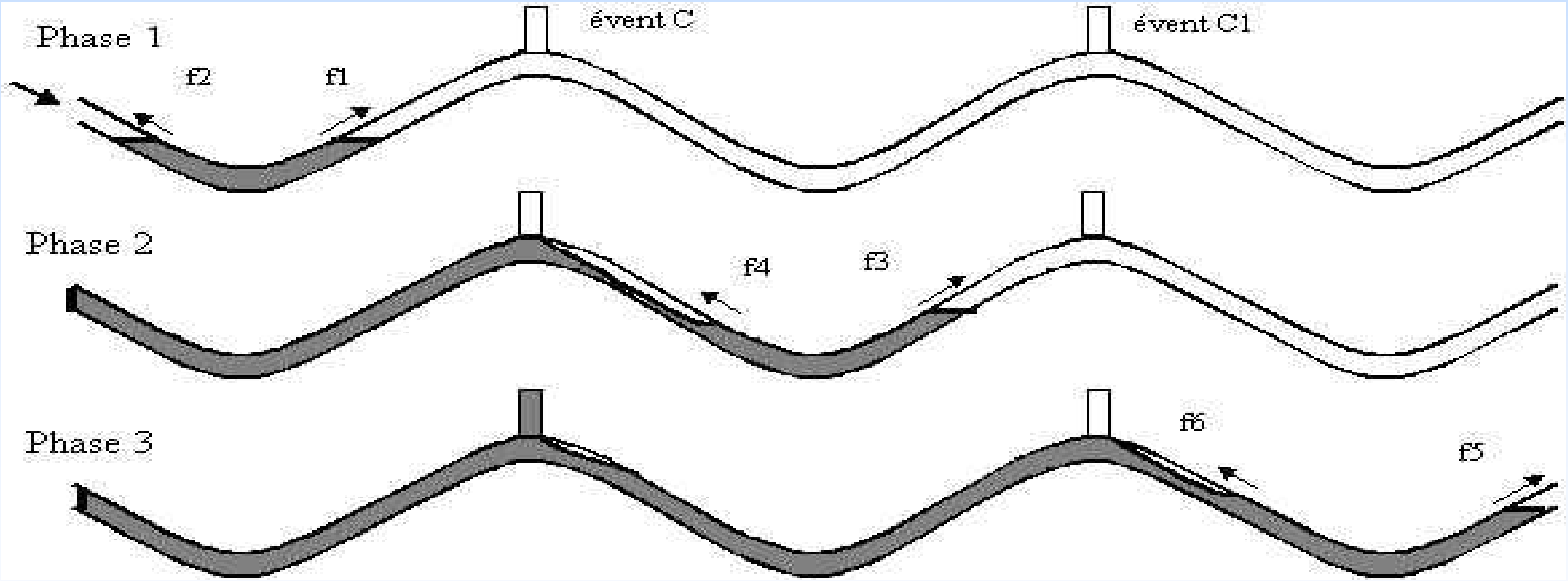
Technical Approval of Grouting

- Mandatory in France since July 1996
  - Qualification of grouting mix
  - Qualification of plant & equipment, and grouting procedures
- In practice, only prebagged grout is currently used in France:
  - SuperstressCem

Influence of injection procedure

- Grouting of horizontal undulating draped tendons is sensitive



- Entrapment of air at the high points is possible

Full size injection tests

- Even a grout "stable" with inclined tube test may be excessively fluid and leave air pockets
  - – Vacuum injection
  - – Thixotropic grout

Cathodic prevention / protection of PT structures

- Mostly relevant for pre-tensioned structures (no ducting)
- Design of CP should be more precise:
  - Polarize strands adequately
  - Avoid risk of overprotection (risk of hydrogen embrittlement below -900 mV Ag/AgCl)
- Usually variable density anodes

CP on Calliope Wharf (NZ, 2007)

- Constructred 1982
- Pre-tensioned I girders (22 strands per beam)

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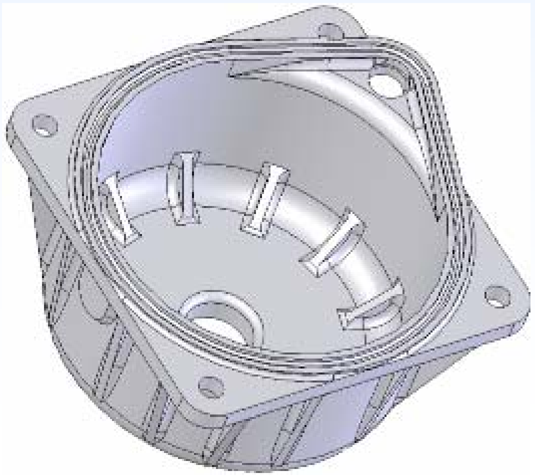
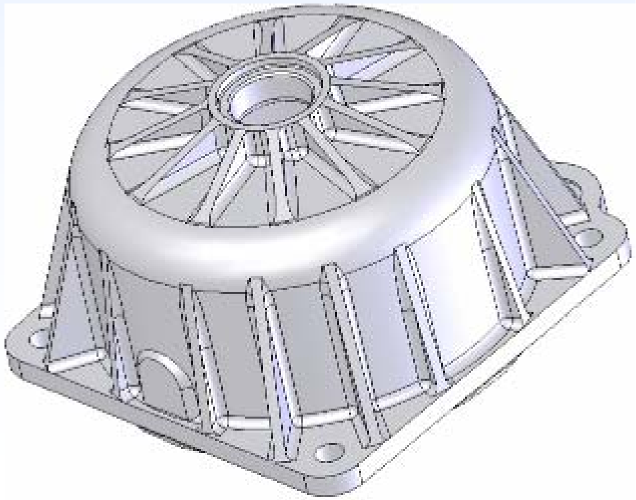
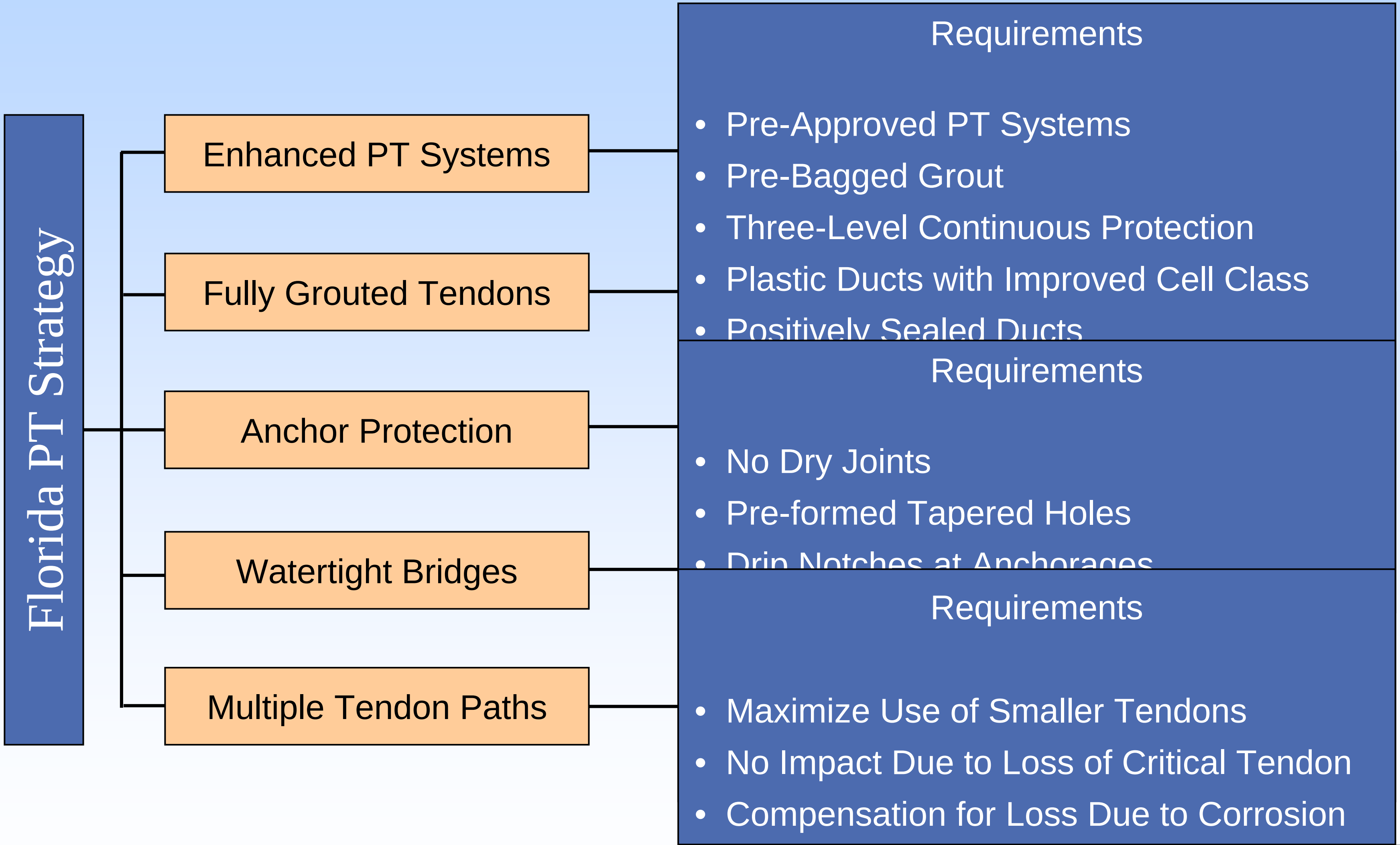
Full encapsulation

- Plastic duct (PE or PP) for bonded PT
  - Freyssinet Plyduct
  - VSL PT+


- Permanent plastic cap (PP)

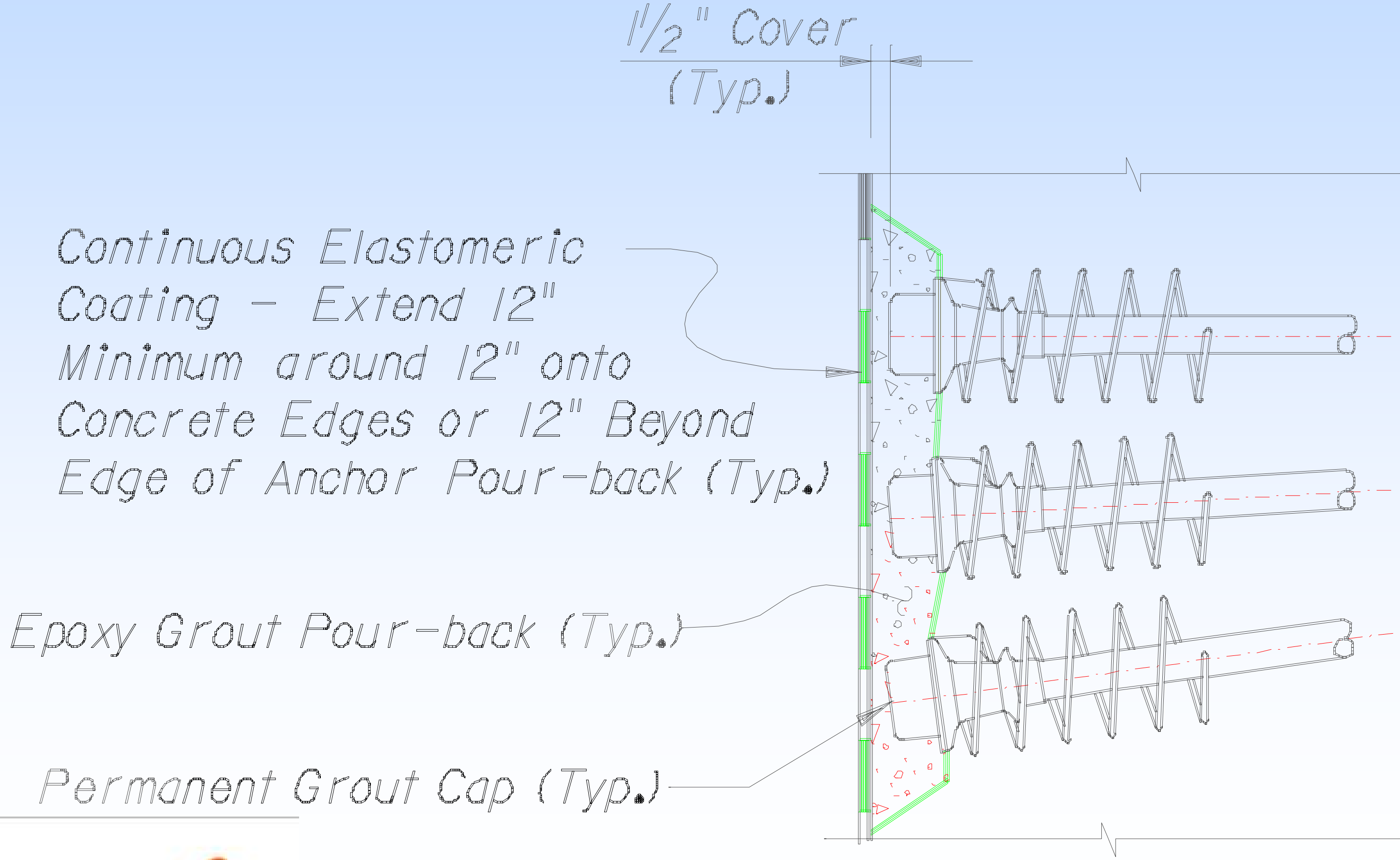



Florida DOT: PT strategy



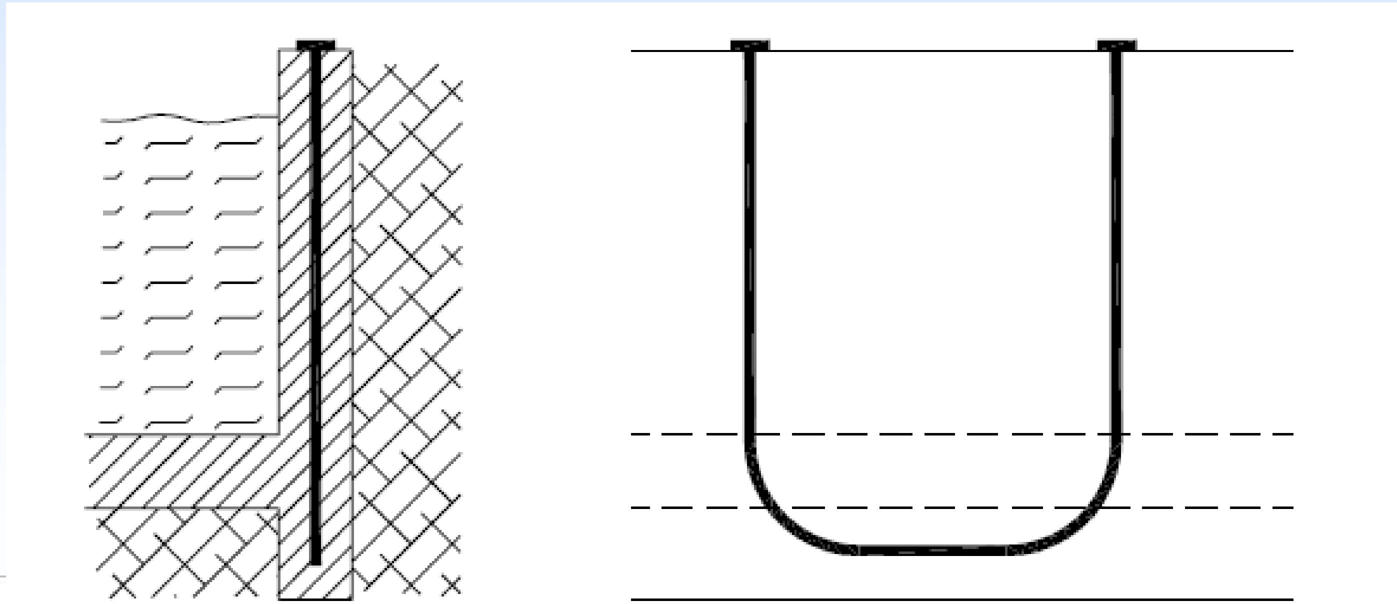
Florida DOT: Anchorage Protection

- Exposed surfaces and expansion joints



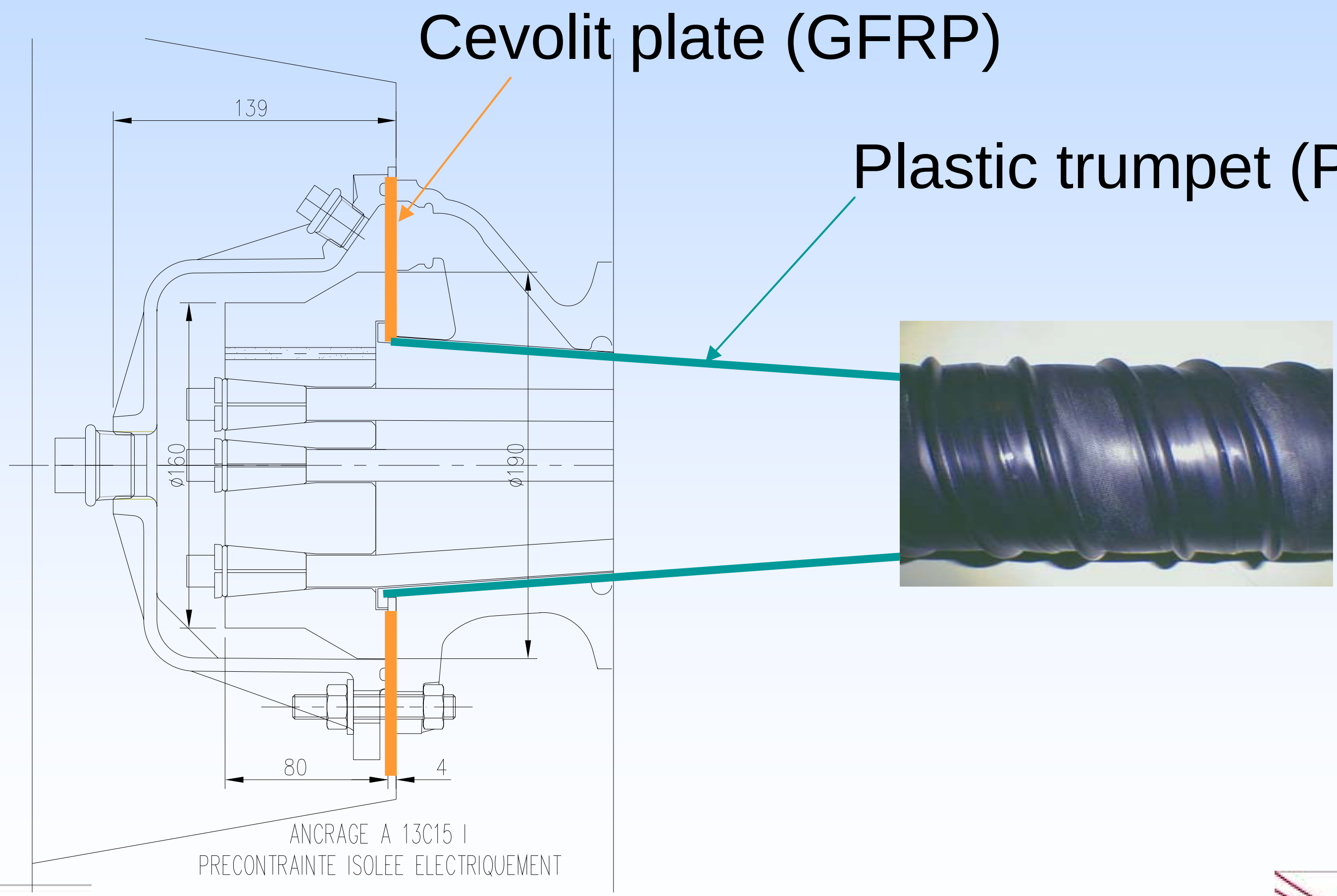
Monitoring and maintenance

- Periodic inspection
  - Visitable / replaceable tendons / anchorages
  - Avoid inaccessible anchor head: e.g. U shape tendons vs dead end



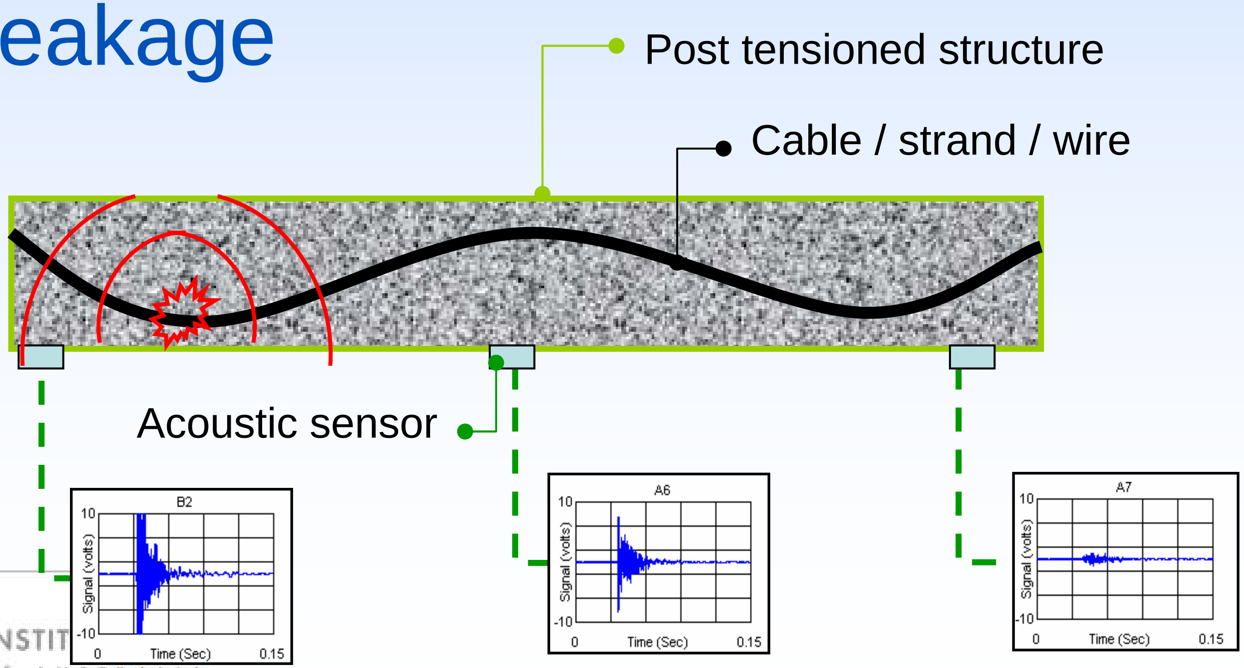
Monitoring: electric insulation

- Full encapsulation + electrically isolated PT: check electric resistance with steel reinforcement



Acoustic monitoring: Soundprint

- Acoustic sensors distributed on the structure allow a continuous monitoring
- The system detects and localizes the sounds emitted by the energy released during wire breakage



The end