The use of Post-Tensioning in Marine Structures

Benoit Lecinq
Austress Freyssinet
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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- A few examples of PC marine structures
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- High performance PT for marine structures
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
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
Confederation Bridge (Canada)

Ice loading on piers

Massive prefabrication
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 on 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
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 on 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
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)

- Constructed 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

- Enhanced PT Systems
  - Pre-Approved PT Systems
  - Pre-Bagged Grout
  - Three-Level Continuous Protection
  - Plastic Ducts with Improved Cell Class
  - Positively Sealed Ducts
- Fully Grouted Tendons
- Anchor Protection
- Watertight Bridges
- Multiple Tendon Paths

- Florida PT Strategy

Requirements

- No Dry Joints
- Pre-formed Tapered Holes
- Drip Notches at Anchorages
- Maximize Use of Smaller Tendons
- No Impact Due to Loss of Critical Tendon
- Compensation for Loss Due to Corrosion

Florida DOT: PT strategy

Enhanced PT Systems

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Fully Grouted Tendons

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Anchor Protection

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- No Impact Due to Loss of Critical Tendon
- Compensation for Loss Due to Corrosion

Watertight Bridges

- Multiple Tendon Paths

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Multiple Tendon Paths
Florida DOT: Anchorage Protection

- Exposed surfaces and expansion joints

Continuous Elastomeric Coating – Extend 12"
Minimum around 12" onto Concrete Edges or 12" Beyond Edge of Anchor Pour-back (Typ.)

Epoxy Grout Pour-back (Typ.)

Permanent Grout Cap (Typ.)
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

  Cevolit plate (GFRP)

  Plastic trumpet (PE)
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