Concrete Inspection and Repair Strategy for Onshore Wind Turbines

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This presentation reviews key industry best practices to perform quality construction and could help establishing the basis of inspection programs related to concrete foundations, grouts and concrete components.
Why monitoring and inspecting?

Monitoring

Observe and check the progress or quality of (something) over a period of time; keep under systematic review.

Condition assessment / condition evaluation

Investigation and appraisal of the condition of a structure.

Non destructive testing (NDT)

Examination of materials and structures in ways that do not impair future usefulness and serviceability in order to detect, locate, and measure discontinuities, defects, and other imperfections to assess integrity, properties, and uniformity, and to measure geometrical characteristics.

“We are starting to see more and more validation for testing & inspection & I think it is essential in our industry.” - Robin Bellamy #WOC2018
“A wind turbine is a complete, dynamic system: interactions are felt from blade tip to foundation. Better understanding of the relations and capturing them in models helps reduce material use and further increase the cost effectiveness of turbines”

EWEA 2013 conference announcement

• Loads need to be transferred by the grout connecting the tower to the foundation structure.

• A careful design and selection of the grouting material is therefore of utmost importance.

• Safe and durable installation of wind turbines largely depend on the materials which connect the tower to its base / foundation.
Current Situation

- Current tests for concrete and grouts on projects
  - Compressive strengths (concrete and grout)
    - Cement grout: ASTM C-1107 (confined cubes in mold)
      - Not CSA A23.2, not ASTM C-109
    - Epoxy grout: ASTM C-579
  - Slump testing (concrete)
  - No fatigue tests requirements (eg. DNV-OS-C502-458) in design, but suggested in *CSA Guide to Canadian wind turbine codes and standards*
- Shim packs stay in place (contrary to API RP 686)
- No expansion joints (API RP 686)
GUIDE TO CONCRETE REPAIR (ACI 546R-14)

Repair Methodology

- Symptoms
- Preliminary evaluation
- Comprehensive evaluation
- Assess problem
- Condition survey
- Assemble repair team
- Repair evaluation
- Prevention evaluation
- Protection evaluation
- Operational constraints to be considered
- Develop response plan
- Document preparation
- Repair implementation

- Owner discovers problem
- Assess problem
- Condition survey
- Assemble repair team
- Repair evaluation
- Prevention evaluation
- Protection evaluation
- Operational constraints to be considered
- Develop response plan
- Document preparation
- Repair implementation

- Life safety risk
- Identity cause
- Safe assessment
- Structural concern
- Quantity problems
- Repair contractor
- Methodology
- Safety
- Corrosion analysis
- Increase repair life
- Security and public safety
- Effect on owner operation
- Repair documents
- Cost analysis
- Engineer oversight
- Contractor execution

- Structural
- Design professionals
- Design parameters
- Structural
- Safety
- Corrosion analysis
- Aesthetic
- Corrosion barriers
- Environmental
- Schedule
- Testing requirements
- Project qualifications
- Final review

- Environmental risk
- Identify urgency
- Material specialist
- Applicable materials
- Recommended response strategy
- Testing firm
- Pre/post testing
-Environmental risk
- Identify urgency
- Material specialist
- Applicable materials
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- Schedule
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- Project qualifications
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Note:
Each of the above boxes can have a supplemental reference identifying possible components of each activity.

Symptoms:
- Water intrusion
- Cracking
- Settlement
- Deterioration
- Reflecting
Inspection and Monitoring Approach

- Global visual inspection
  - Detection of obvious or extensive damage
  - Performed at distance (e.g. Binoculars)

- Close visual inspection
  - Examination of specific surface area (e.g. Drones)

- Non-destructive inspection/testing

- Destructive testing

- Instrumentation based condition monitoring
Onshore wind turbine installations
Anchor cage design foundations

**Current situation**
- Increasing number of failures
  - Concrete foundation
  - Grout materials
- Failures occur within 1 – 2 years
- Complex installation prone to mistakes

**Major causes:**
- Too low characteristic strength
  - Need meeting specs
- Too slow strength development
  - “Good enough”
  - No safety factor built-in
- Not resistant to loads
  - Thermal
  - Mechanical
Onshore wind turbine installations
Can design foundations - Challenges

**Current situation**
Increasing number of failures observed in foundation areas

- 30% of all installed wind turbine installations have revealed problems
- Failures occur within 3 – 5 years

**Causes:**
- Dynamic loads - load cycles
- Design mistakes
- Material selection
  - “use the same as last job”
- Ever growing wind turbines
Objective of Concrete Repairs

- Concrete repairs is directly linked to the quality of the inspection and assessment performed.
- Not all NDE tools will work for all issues.
- Examiner needs to have a comprehensive knowledge of the tools and techniques that are available. Common techniques include:
  - In-situ concrete strength (relative strength comparison unless correlated with laboratory strength tests, e.g. core compressive strength tests)
  - Location and extent of reinforcement
  - Location and extent of concrete cracking
  - Severity, location and delaminations due to reinforcement corrosion
  - Location, size and distribution of frost damage
  - Location and extent of void/honeycombing
  - Thickness of concrete members
  - Presence and rate of reinforcement corrosion activity
Visual Inspection

- General
- Description of Structure
- Material used
- Nature of Environmental and Loading Conditions
- Distress indicators
- Present condition of structure (surface condition only)
Non-Destructive Evaluation Techniques

- Improved understanding of concrete conditions prior to repair
- Better repair methodology
  - Repair design
  - Repair materials
  - Repair methods
- Alternative to drilling and coring
### Table 7.2: NDE Methods for Structural and General Concrete Condition Assessment

<table>
<thead>
<tr>
<th>NDE methods</th>
<th>Visual methods</th>
<th>Acoustic impact</th>
<th>Acoustic emission</th>
<th>Ultrasonic/sonoic pulse velocity</th>
<th>Ultrasonic/sonoic tomography</th>
<th>Ultrasonic pulse echo</th>
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<td>A.2.24</td>
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### Property/condition

<table>
<thead>
<tr>
<th>Property/condition</th>
<th>Band quality (absence of voids at interface)</th>
<th>Injection of cracks or voids</th>
<th>Thickness/depth (dimensions)</th>
<th>Density/porosity</th>
<th>Moisture/humidity</th>
<th>Degree of consolidation</th>
<th>Voids (internal)</th>
<th>Voids (below slabs, behind walls, within cell walls)</th>
<th>Cracking (internal)</th>
<th>Delamination (delamination)</th>
<th>Delamination (deep)</th>
<th>Delamination (sulfate, frost action, ASR, etc.)</th>
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### Table 7.3: NDE Methods for Foundation Condition, Integrity, and Length

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Sonic Echo (ASTM D5882), Impulse Response and Impedance Imaging

- Sonic echo reads waves echo
- Impulse Response reads frequency domain off sonic echo tests
- Impedance imaging can give idealized axisymmetric 3D pile shape

Source: ICRI Guideline 210.4-2009
Ultrasonic Pulse-Echo

- Short ultrasonic pulses (50-70 kHz) transmitted to concrete
- Reflects changes in stiffness
- Reflects changes in density, eg. Voids, cracking, honeycombing, etc…
- Helps to locate flaws, hence identifying repair location and sizes
Cracks in concrete and grout

**Situation**
- Fatigue occurs when material is subjected to repeated loading and unloading
- Cracks begin to form
- Cracks reach a critical size and further damage occur, e.g. Fracture, water ingress, failure, etc..

**Solutions (ACI 224.1)**
1) rout and seal the crack, thus treating it as a joint;
2) establish a joint that will accommodate the movement and then inject the crack with epoxy or other suitable material;
3) install additional support or reinforcement at the crack location to minimize movement.

Source: Cracks in onshore wind power foundations, causes and consequences. Elforsk rapport 11:56, Manouchehr Hassanzadeh, January 2012
Example of cracks in concrete and grout

Shrinkage cracking (Non-Critical)

Segregation / Separation (Critical)

Excess material (Non-Critical)

Voids (Critical)
When to inspect?

- During construction (first 28 days)
  - Surface sealing of surface cracks
  - Repair as needed
  - Surface preparation for repairs (!) – ICRI

- Higher frequency in first year to identify early problems
  - Non-critical cracks VS critical cracks
    - MTO/AASHTO’s : 0.3mm for injection
    - Active cracks vs passive cracks (ACI 224.1)

- Reduce/Increase frequency as needed
  - On damaged foundation, inspection to be carried every 6 months
  - Verify success of repairs

- Every climate is different and every project is different

- Need to build historical data in Canada
  - Large country
  - Different project locations (eg. Ontario vs BC)

Camera inspection