OSNOVNI ASPEKTI FUNDIRANJA VETROGENERATORA U NAŠIM USLOVIMA
THE BASIC ASPECTS OF WIND TURBINE FOUNDATIONS IN OUR CONDITIONS

Aleksandar SAVIĆ
University of Belgrade, Faculty of Civil Engineering, sasha@imk.grf.bg.ac.rs
Slobodanka JOVAŠEVIĆ
University of Coimbra, Faculty of Civil Engineering, sjovasevic@uc.pt
Milica VLAHOVIĆ
University of Belgrade, IHTM, m.vlahovic@ihtm.bg.ac.rs
Sanja MARTINOVIĆ
University of Belgrade, IHTM, s.martinovic@ihtm.bg.ac.rs
Tatjana VOLKOV-HUSOVIĆ
University of Belgrade, Faculty of Technology and Metalurgy, tatjana@tmf.bg.ac.rs
ABSTRACT

• The most common types of wind turbine foundations will be presented
• Problems of the load analysis of these structures will be given in brief, and also the conceptual requirements in their design.
• Connection between the tower and the foundation will be briefly described
• In specific cases, number of issues regarding component materials, application of standards and design codes, which are usually not adjusted to the design of wind turbine foundations still remains.
INTRODUCTION

Naturally, the larger turbines are used primarily in large utility grids, at first mostly in Europe and the United States, and more recently in China and India.

In Serbia, according to the public information from the press, the first wind park was made in November of 2015, in Štolic-Kula, with three installed Vestas V-117 3.3 MW wind turbines.
INTRODUCTION

According to their constructional design:

- Rotors with a vertical axis of rotation (e.g. Savonius-, Darrieus- and H- rotor types)
- Rotors with a horizontal axis of rotation
INTRODUCTION

The load bearing structures of a wind power turbine:

• Rotor blades
• Machinery structures
• Nacelle covers and spinners
• Bolted connections
• Tower
• Foundation
INTRODUCTION

The tower can be made of several materials following different design concepts:

• Concrete tower
• Free-standing steel tubular towers
• Lattice towers
• Hybrid towers
INTRODUCTION

• General location:

Onshore

Offshore
BASIC WIND POWER TURBINES
FOUNDATIONS TYPES

Shallow foundations:

- Rock or competent soil
- Spread footing
- Soil improvement?

<table>
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<tr>
<th>Type</th>
<th>Diagram</th>
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<td>Plain Slab</td>
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<td>Stub and Pedestal</td>
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<td>Slab Held Down by Rock Anchors</td>
<td><img src="image4" alt="Slab Held Diagram" /></td>
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Deep foundations:

(a) Piles,

(b) Drilled shafts,

(c) Concrete-filled corrugated pipes with post-tensioned anchor bolts.
BASIC WIND POWER TURBINES
FOUNDATIONS TYPES

Competencies:

• structural design
• material design
• production

Type and size of foundations used for the wind turbines are governed by geotechnical conditions of the site, maximum power of the turbine and type of the tower.
LOAD ANALYSIS AND DESIGN REQUIREMENTS

Current trends:

Trend: not to site-optimise wind turbines, but rather to produce a selection of standard wind turbines

Foundation design must always be site-specific.

Soil investigations and data:

- Survey
- Geological
- Seismic
- Hydro-geological and
- Geomechanical
LOAD ANALYSIS AND DESIGN REQUIREMENTS

Shallow onshore foundations:

Minimum embedment below frost depth
Bearing capacity
Settlements (elastic, consolidation and differential)
Safety factors against sliding and overturning
Drainage
Foundation stiffness accounting for modulus degradation due to cyclic loading
Dynamic analysis for avoiding resonance of soil-foundation-structure system
LOAD ANALYSIS AND DESIGN REQUIREMENTS

**Bearing capacity formulas**

\[
q_{ult} = c'N_c + q'N_q + \frac{1}{2}\gamma' b_{eff} N_{\gamma}
\]

- Fully drained (long-term) conditions:
  \[
  q_{ult} = c'N_c + q'N_q + \frac{1}{2}\gamma' b_{eff} N_{\gamma}
  \]
- Undrained (short-term or rapid loading) conditions in clay:
  \[
  \phi_u = 0, \quad N_{\gamma} = 0, \quad N_q = 1,
  \]
  \[
  q_{ult} = c_u N_c + q
  \]

**Settlement:**

- \(s_e\) – elastic settlement (immediate), which is the most important for sands;
- \(s_c\) – consolidation settlement (due to evacuation of water and air from pore space), which is the most important for clays;
- \(s_s\) – secondary settlement (long term rearrangement of soil structure under constant effective stress).
LOAD ANALYSIS AND DESIGN REQUIREMENTS

Safety factor against sliding – the sum of resisting forces divided by sum of driving forces

Safety factor against overturning – the sum of restoring moments divided by sum of overturning moments

Both factors have to be at least 1.5 for stable foundation

Water drainage has to be provided

A complete natural frequency analysis has to be performed

- Ellipse is used for reduced area:

\[ A_{\text{eff}} = 2 \left[ R^2 \cos^{-1} \left( \frac{e}{R} \right) - e \sqrt{R^2 - e^2} \right] \]
LOAD ANALYSIS AND DESIGN REQUIREMENTS

Design of piles

More difficult

axial pile resistance ⇛ lateral pile resistance

Pile groups (clusters)
CONSTRUCTION REQUIREMENTS

Proper design of reinforced concrete has to be practiced, followed by proper execution on field.

Materials requirements:
• Water/cement ratio for the concrete is determined in consideration of the environmental class, typically less than 0.55
• Maximum aggregate size < 32 mm
• Minimum distance between reinforcement bars
• Minimum distance between non-prestressed reinforcement bars: 150-200 mm and re-diameters: 12-20 mm
CONSTRUCTION REQUIREMENTS

High strength cementitious and epoxy grouts can be used more in 2+ MW turbines, and higher strength concrete in the pedestals, enhanced reinforcing details at the bearing area in 3+ MW turbines.

Important details include higher flange bearing stresses and fatigue requirements of the anchor bolts and the grout/concrete.

Additionally, designers may begin to evaluate the plastic capacity for the bearing area.
CONSTRUCTION REQUIREMENTS

Used design codes:

• ACI Chapter 10 – simple column bearing
• ACI Chapter 18 – post-tensioned anchorage
• AASHTO 5.7.5, 5.10.9 – bearing / post-tension / reinforcement
• PTI anchorage zone design
• Eurocode 2 – 5.10, 6.5, 8.10.x
• Eurocode 7 - geotechnical design
• Eurocode 8 – geotechnical design under seismic loading
• DNV Offshore Standards – J101
• C502 – concrete fatigue and others
• CE 561 (deep foundations)
CONNECTION BETWEEN THE TOWER AND THE FOUNDATION

Two different principal arrangements to connect the tower to the foundation:

• Insert ring cast in the foundation

• Steel adapter fixed by stud bolts
CONCLUSIONS

Bigger footings with more concrete and reinforcement are expected

Foundations must be designed for the site conditions of each project

On-site activities can lead to reduced service life of wind turbines – have to be avoided

Recommendations of wind turbine foundations design in Serbian conditions are in accordance with international Guidelines and handbooks – have to be developed
THANK YOU!

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