# Wind energy and fundamentals of nuclear energy (472MI-1) (a module of Alternative energy technologies 2) a.y. 2025/26

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# Content of this lecture

1) Technical report of a wind turbine farm

2) Loading conditions for a turbine power plant

3) Presentation of loading data information

4) Materials, Codes/Regulation-Eurocodes

5) Types of check for the design

6) Example of calculations

# Loading conditions

DNV·GL

STANDARD

DNVGL-ST-0437 Edition November 2016

**Loads and site conditions for wind turbines**

# Materials

Table 1 – Steel properties

| Element | Standard and steel grade | Nominal thickness of the element t [mm] | | | |
|---|---|---|---|---|---|
| | | $t \leq 40$ mm | | 40 mm $< t \leq 80$ mm | |
| | | $f_y$ | $f_u$ | $f_y$ | $f_u$ |
| | | [MPa] | [MPa] | [MPa] | [MPa] |
| Flange | S355 | 355 | 510 | 335 | 470 |
| Tower | S355 | 355 | 510 | 335 | 470 |

According to EN1993-1-8:2005 [5] bolt class and relevant properties are reported below:

Table 2 – Bolt properties

| Bolt class | $f_{yb}$ | $f_{ub}$ |
|---|---|---|
| | [MPa] | [MPa] |
| 8.8 | 640 | 800 |

**Tower cold climate material**: S355J2G3, pr equivalent with charpy impact values of 27 J average at -40 °C.

**Flange materials, cold climate material**: S355NL.

# List of Eurocodes

EN 1990 Basis of design

EN 1991 Eurocode 1: Actions on structures

EN 1992 Eurocode 2: Design of concrete structures

**EN 1993 Eurocode 3: Design of steel structures**

EN 1994 Eurocode 4: Design of composite steel and concrete structures

EN 1995 Eurocode 5: Design of timber structures

EN 1996 Eurocode 6: Design of masonry structures

EN 1997 Eurocode 7: Geotechnical design

EN 1998 Eurocode 8: Design of structures for earthquake resistance

EN 1999 Eurocode 9: Design of aluminium structures

# Relevant sections of EC3 (Design of steel structures)

**EN 1993-1-6:2007** DESIGN OF STEEL STRUCTURES – STRENGTH AND STABILITY OF SHELL STRUCTURES

**EN 1993-1-8:2007** DESIGN OF STEEL STRUCTURES – DESIGN OF JOINTS

**EN 1993-1-9:2007** DESIGN OF STEEL STRUCTURES – FATIGUE

# Background

NORMA EUROPEA

**Eurocodice 3**
**Progettazione delle strutture di acciaio**
**Parte 1-1: Regole generali e regole per gli edifici**

**UNI EN 1993-1-1**

AGOSTO 2005

Eurocode 3
Design of steel structures
Part 1-1: General rules and rules for buildings

La norma fornisce i criteri generali di progettazione di edifici e opere di ingegneria civile di acciaio. Si riferisce solamente ai requisiti di resistenza, esercizio e durata delle strutture. Altri requisiti, quali per esempio quelli dell'isolamento termico ed acustico, non sono considerati. Non contiene i requisiti particolari per la progettazione in zone sismiche. Le regole inerenti a tali requisiti sono fornite nell'Eurocodice 8 che integra o adatta in modo specifico le regole dell'Eurocodice 3 a questo scopo. I valori numerici delle azioni sugli edifici e opere di ingegneria civile che devono essere considerati nel progetto non sono forniti nell'Eurocodice 3. Essi sono forniti nell'Eurocodice 1 che è applicabile a tutti i tipi di costruzione.

# Types of check for design

- Ultimate limit state (ULS)
  - Plastic limit (tower, joints)
  - Buckling (tower)
  - Fatigue (tower, joints)
- Serviceability limit state (SLS)
  - Slip resistance check (joint)
- Avoidance of resonance (vibration frequency)
- Blade clearance
- Transportability

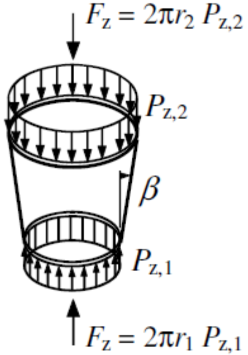
# Plastic limit

Reference: **EC3-1-6**, sect 4.1 etc (tower), Annex A

$$\sigma_{eq,Ed} = \sqrt{\sigma_{z,Ed}^2 + 3\tau_{z\theta,Ed}^2}$$

$$\sigma_{\mathrm{eq,Ed}} \leq f_{\mathrm{eq,Rd}}$$

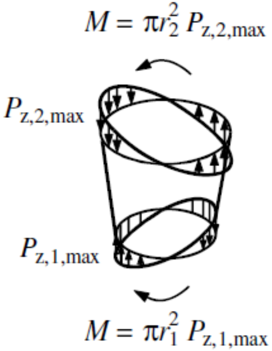
**A.3.1 Uniform axial load**




$$\sigma_x = -\frac{F_z}{2\pi r t \cdot \cos\beta}$$

$$\sigma_\theta = 0$$

**A.3.2 Axial load from global bending**




$$\sigma_{x,\max} = \pm\frac{M}{\pi r^2 t \cdot \cos\beta}$$

$$\sigma_\theta = 0$$

# Buckling

Reference: **EC3-1-6**, sect 8 (tower),

For a **perfect** cylindrical shell
under axial load,

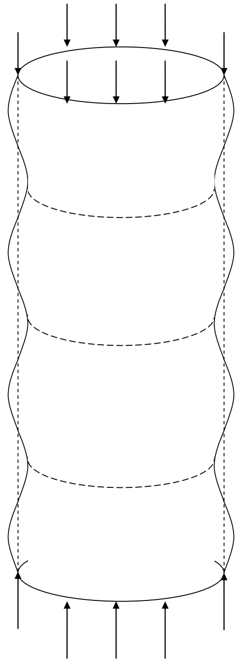
$$\sigma_{cr} = 0.605\ E\ (t/R)$$

E = Modulus of elasticity,

t = Wall thickness, R = Shell radius

**Imperfections**

- are magnified by applied compression
- result in earlier onset of yield
  (on concave surfaces)



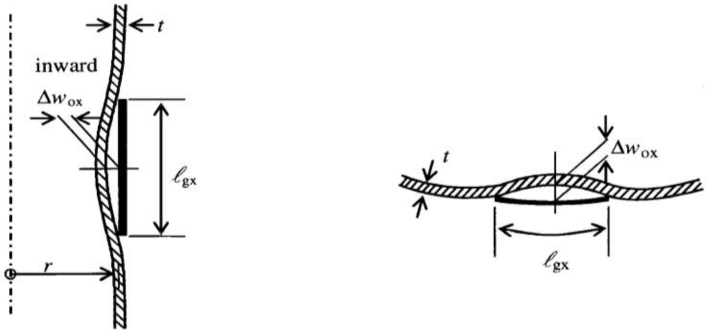
# Imperfections decreasing buckling load

The % imperfections of the finished tower section will be checked, using

a) a straight rod of length L = $4(Rt)^{0.5}$ placed vertically anywhere

b) a curved gauge of same length placed circumferentially

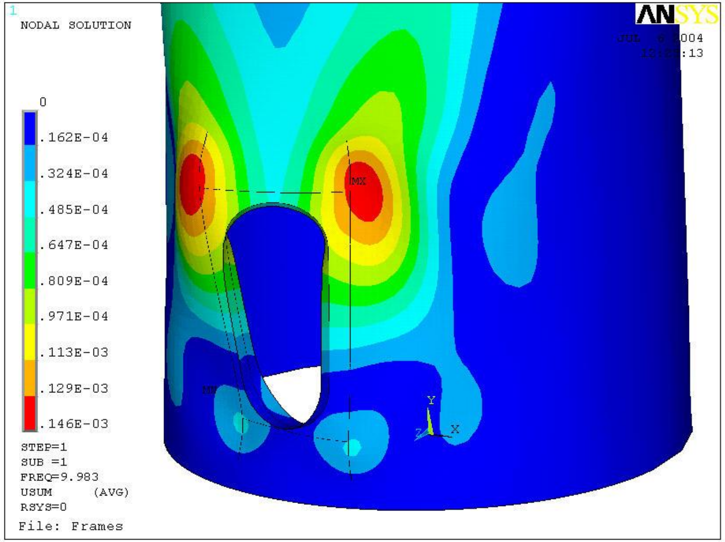
c) a straight rod of length L = 25t placed vertically across horizontal welds




a) Measurement on a meridian (see 8.4.4(2)a) b) First measurement on a circumferential circle (see 8.4.4(2)a)

# Local buckling: tower doorways

Tower doorways are always stiffened round the edge, but standard rules for a cylindrical shell no longer apply. FE analysis can be used.



# Fatigue

A WTG tower may see 1,000,000,000 loading cycles in its life

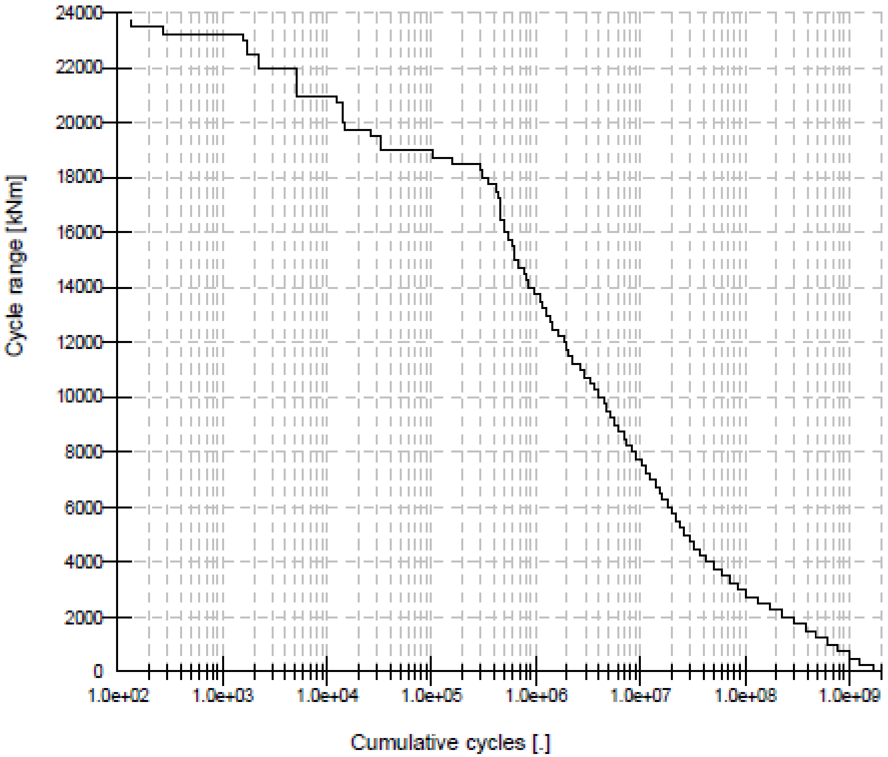
No. of load cycles = No. of blade passes
For 20 rpm 3 bladed machine operating continuously, this gives 20 x 3 x 60 x 8760 x25 = ca 800,000,000 cycles

The turbine manufacturer describes these loads in terms of **fatigue load spectra**.

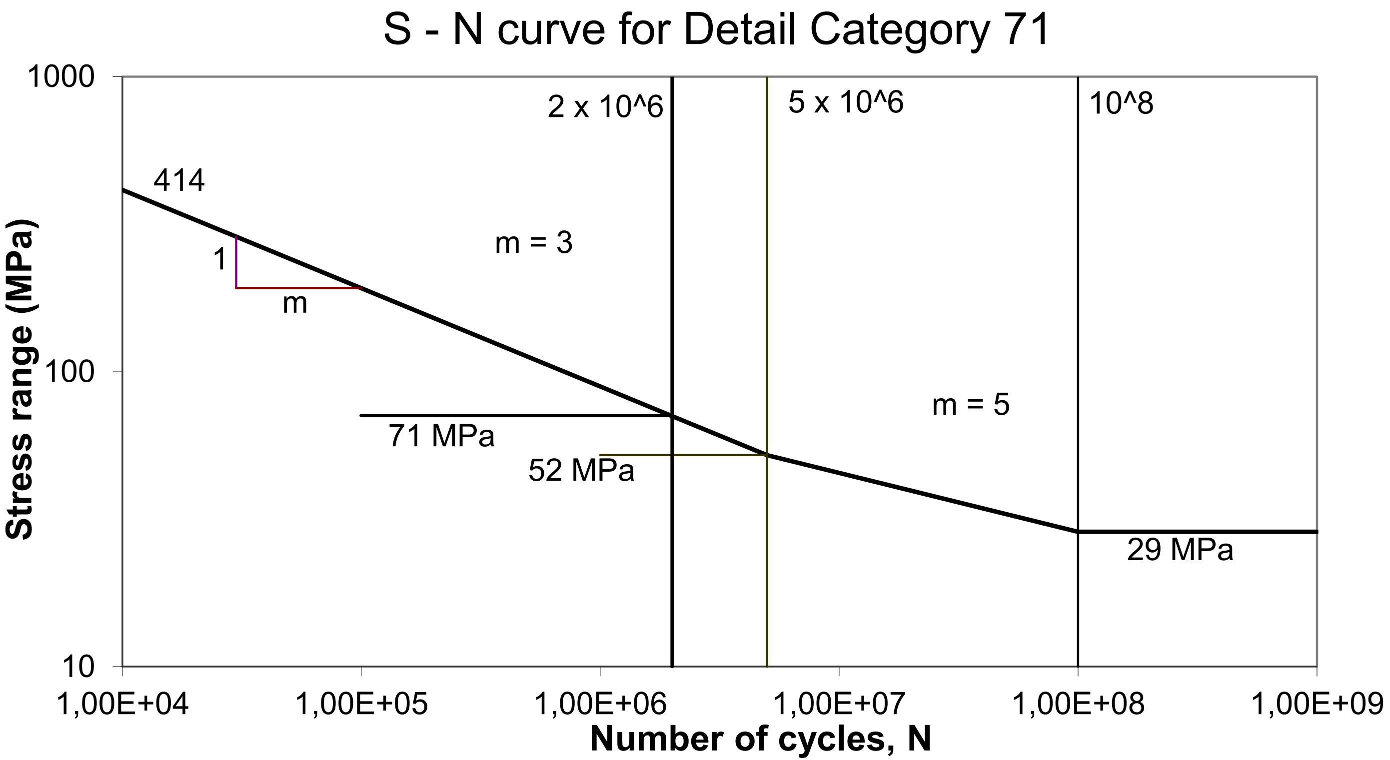
These are tables of load ranges (eg tower base bending moment or TBOM) against numbers of cycles.

# Fatigue

## Example of fatigue load spectrum



# Fatigue


S - N curve for Detail Category 71
1000
100
10
Stress range (MPa)
2 x 10^6
5 x 10^6
10^8
414
m = 3
1
m
71 MPa
52 MPa
m = 5
29 MPa
1,00E+04
1,00E+05
1,00E+06
1,00E+07
1,00E+08
1,00E+09
Number of cycles, N

## Combining stress ranges of different sizes

Use Miner's rule.

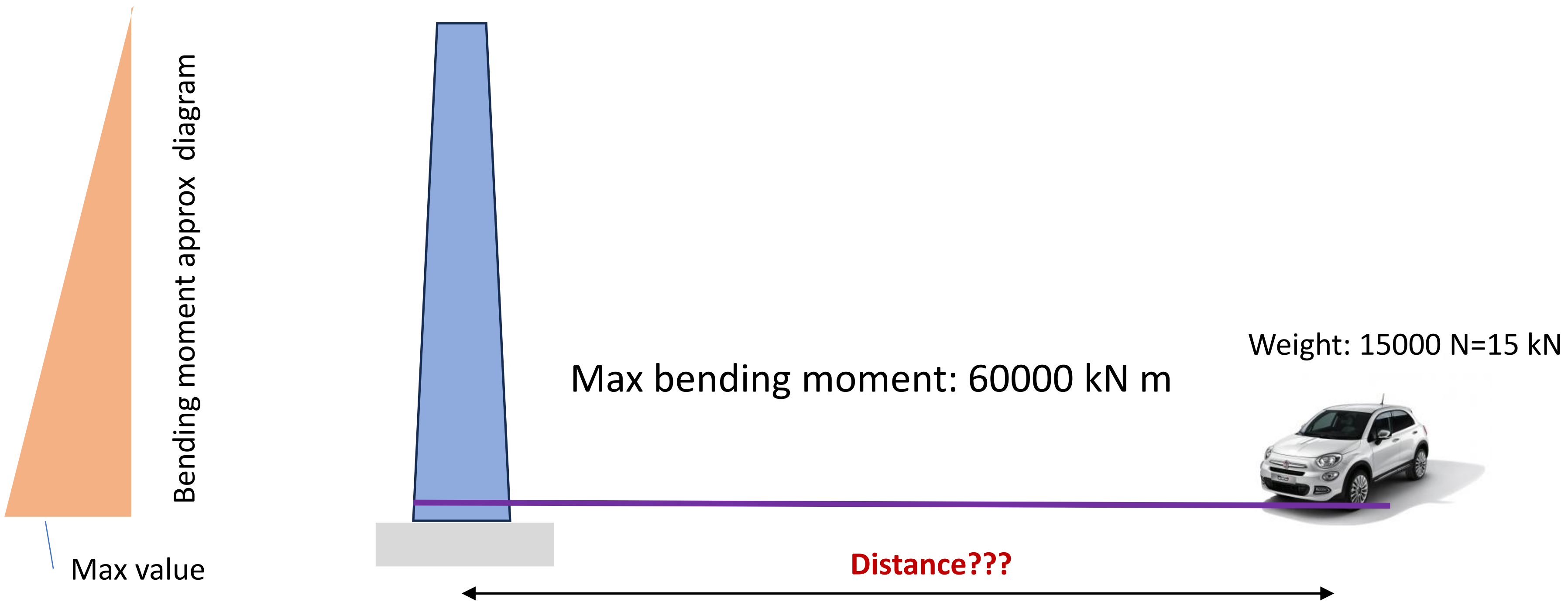
For *j* different stress ranges:

Fatigue Damage Sum = $\frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \cdots \frac{n_j}{N_j} < 1$

where $n_1$, $n_2$ etc are actual numbers of cycles in each stress range

& $N_1$, $N_2$ etc are permitted number of cycles for each stress range

# Severity of bending moments from external actions



# Severity of induced stress state from external actions