TURBULENT WIND EXCITATION

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CONSTANT FLOW AND TURBULENCE

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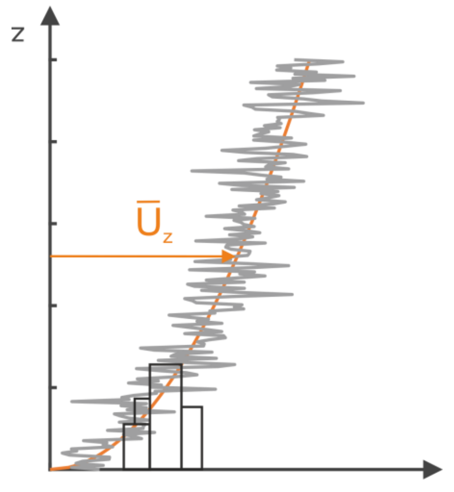
Wind excitation profile

Constant wind and turbulence



Wind forces :

$$f_{tot}(t) = \frac{1}{2}\rho C_d \Omega \left[U + u(t)\right]^2$$

$$\simeq \underbrace{\frac{1}{2}\rho C_d \Omega U^2}_{f_{avg}} + \underbrace{\rho C_d \Omega U u(t)}_{f_{turb}(t)}$$

Aerodynamic forces

Constant flow

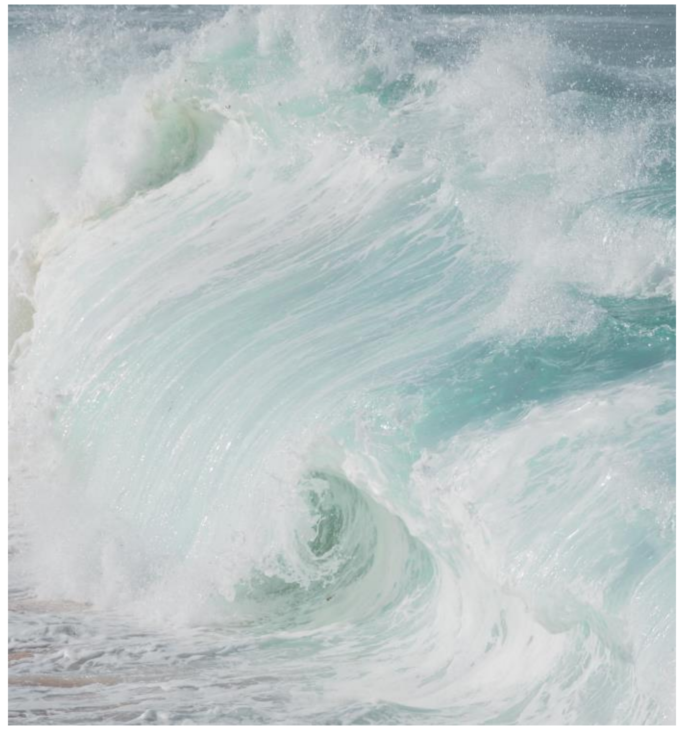
- Constant force
- Dynamic vortex excitation
- Self-excited vibrations
  - Galopping
  - Divergence
  - Flutter

Turbulent flow

- Dynamic force

→ resonance

TURBULENT WIND MODEL



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Stochastic wind speed model

Wind speed is assumed to be a stationnary gaussian process characterized by:

A mean $$U = \frac{1}{T}\int_0^T v_{tot}\,dt \qquad v_{tot} = U + u(t)$$ u has zero mean

A standard deviation $$\sigma_u^2 = \frac{1}{T}\int_0^T u^2(t)\,dt$$

A power spectral density (PSD) $$S_u(f) \div |\tilde{U}(f)|^2 \qquad \sigma_u^2 = \int_{-\infty}^{\infty} S_u(f)\,df$$

Frequency dependent

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Energy Spectral density and Power Spectral Density

Energy spectral density (ESD):

$$\int_{-\infty}^{\infty} u(t)^2 dt = \int_{-\infty}^{\infty} |\tilde{U}(f)|^2 df$$

Using Parseval's theorem

ESD (energy/Hz)

For stationnary gaussian processes, ESD is not bounded

→ Power spectral density (PSD):

$$lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{\infty} u(t)^2 dt = \int_{-\infty}^{\infty} lim_{T\to\infty} \frac{1}{T} |\tilde{U}(f)^2| df$$

$S_u(f)$ PSD (Power/Hz)

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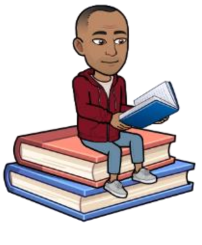
Power Spectral Density and Standard Deviation

$$\sigma_u^2 = lim_{T\to\infty} \frac{1}{T} \int_0^T u^2(t) dt = \int_{-\infty}^{\infty} S_u(f) df$$

$$= 2 \int_0^{\infty} S_u(f) df$$

If u(t) is real



→ When the PSD is known, the standard deviation is known

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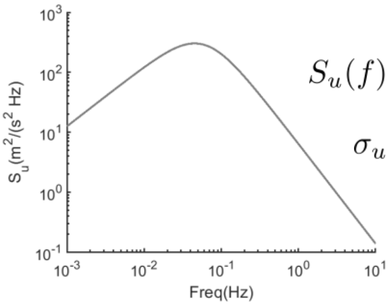
Davenport Spectrum



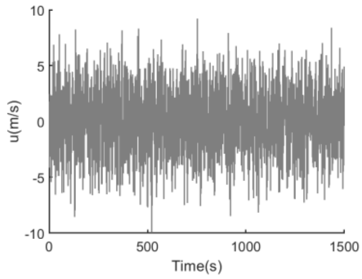
$$S_u(f) = \sigma_u^2 \frac{2}{3} \frac{L}{U_{10}} \frac{x}{(1+x^2)^{4/3}}$$

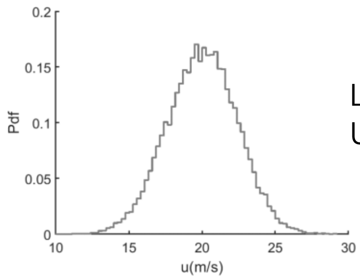
$$\sigma_u = 8m/s; U_{10} = 70m/s$$

Non-dimensional PSD

$$\frac{f S_u(f)}{\sigma_u^2} = \frac{2}{3} \frac{x^2}{(1+x^2)^{4/3}}$$

$$x = \frac{fL}{U_{10}}$$ Non-dimensional frequency





L=1200 m (turbulence length scale)

U_{10} =mean speed at 10m

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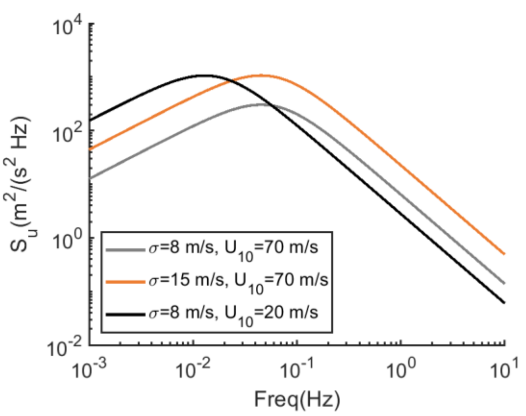
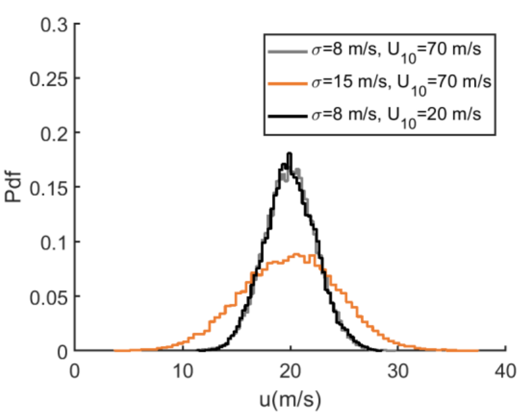
Davenport Spectrum





Higher wind speeds → Higher frequencies

Higher standard deviation → Wider histogram, higher S_u

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Eurocode Spectrum

Van der Hoven Spectrum

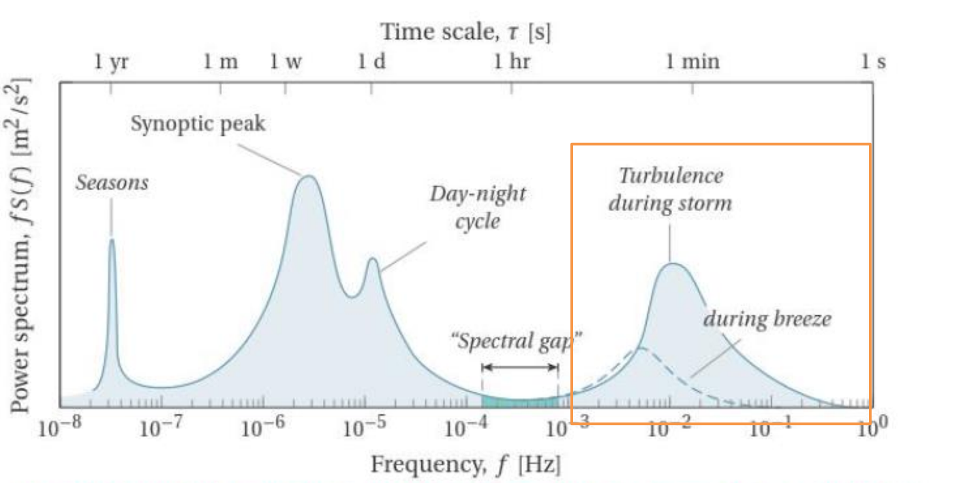

Figure 2.2: Van der Hoven spectrum (1957) as drawn by Alan Davenport (Isyumov, 2012).

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Eurocode Spectrum

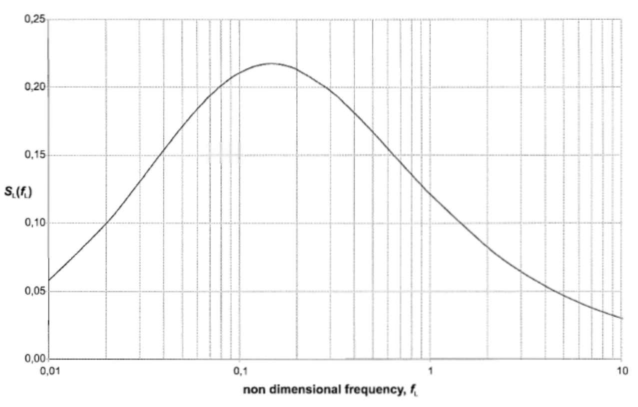

Figure B.1 —Power spectral density function $S_L(f_L)$

$$S_L(z,n) = \frac{nS_v(z,n)}{\sigma_v^2}$$

$$= \frac{6,8 f_L(z,n)}{(1+10,2 f_L(z,n))^{5/3}}$$

$$f_L(z,n) = \frac{nL(z)}{v_m(z)}$$

n = frequency (Hz)

Eurocode annex B1

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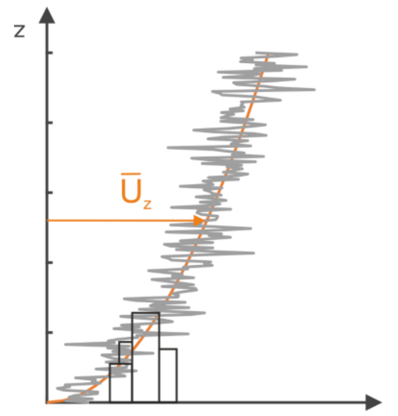
Influence of height

Turbulence intensity

$$I_u = \frac{\sigma_u}{U} \qquad I_v = \frac{\sigma_v}{V} \qquad I_w = \frac{\sigma_w}{W}$$



- Mean velocities increase with height
- Turbulence is quasi-constant with height

$$I_u = \frac{1}{ln(\frac{z}{z_0})}$$

Turbulence intensity decreases with height

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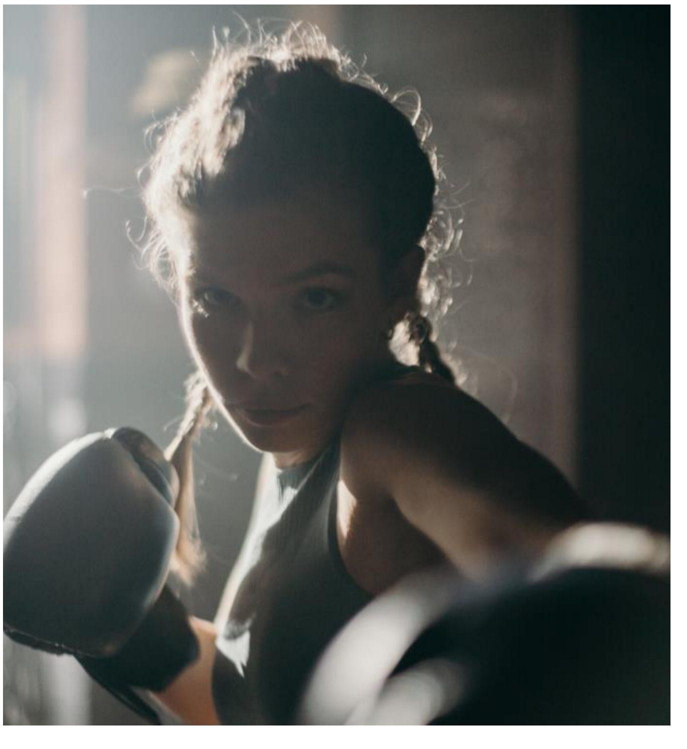
FORCES DUE TO TURBULENT WIND



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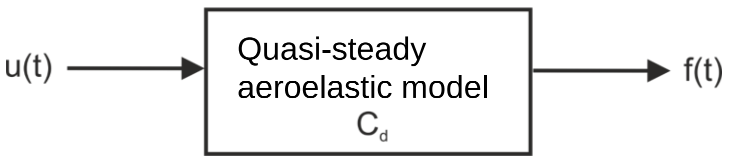
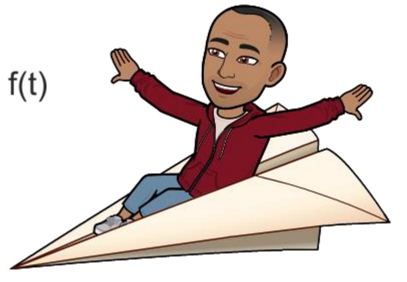
From wind velocity to wind forces

$$f_{tot}(t) = \frac{1}{2}\rho C_d \Omega \left[U + u(t)\right]^2 \simeq \frac{1}{2}\rho C_d \Omega U^2 + \underbrace{\rho C_d \Omega U u(t)}_{f_{turb}(t)}$$





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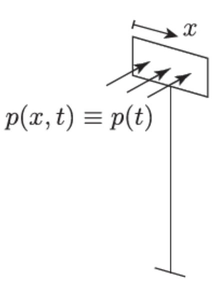
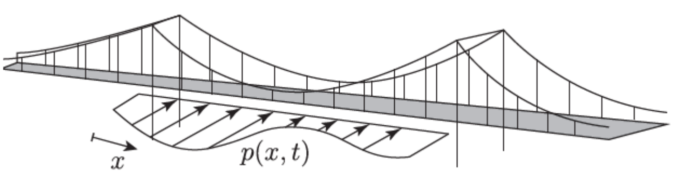
Aerodynamic admittance

Pressures are not uniform, and not in phase on large structures





→ The total force is reduced → Admittance χ

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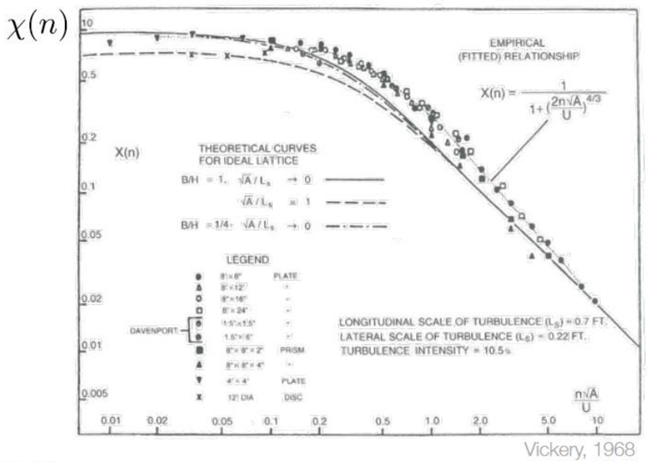
Aerodynamic admittance



Vickery's law

$$\chi(n) = \frac{1}{1 + \left(\frac{2n\sqrt{A}}{U}\right)^{4/3}}$$

Non-dimensional frequency

Admittance decreases with

- Size of the building
- Frequency of turbulence

Admittance increases with

- Mean wind velocity

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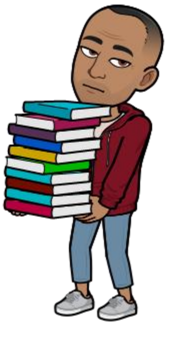
Aerodynamic admittance in codes

	Expressions of GWL-AAF
ASCE 7	$\chi(f) = R_H R_B (0.53 + 0.47 R_D)$ $R_l = 1/\eta - 1/2\eta^2 (1 - e^{-2\eta})$, $\eta > 0$; $R_l = 1$, $\eta = 0$ $R_H, \eta = 4.6 fH / V_{\bar{z}}$; $R_B, \eta = 4.6 fB / V_{\bar{z}}$; $R_D, \eta = 15.4 fD / V_{\bar{z}}$
AS1170.2	$\chi(f) = \frac{1}{(1 + 3.5 fH / \bar{V}_H) \cdot (1 + 4 fB / \bar{V}_H)}$
NRCC	$\chi(f) = \frac{1}{(1 + 8 fH / (3\bar{V}_H)) \cdot (1 + 10 fB / \bar{V}_H)}$
RLB-AIJ	$\chi(f) = \frac{0.84}{(1 + 2.1 fH / \bar{V}_H) \cdot (1 + 2.1 fB / \bar{V}_H)}$
Eurocode	$\chi(f) = R_H R_B$ R_H and R_B are the same as those in ASCE7.



Eurocode annex B

R_H, R_B take into account a specific mode shape

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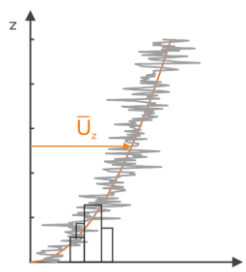
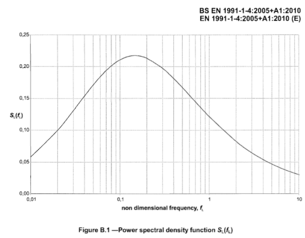
Summary



Wind PSD



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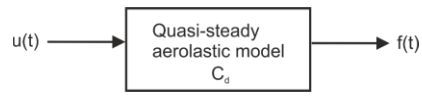
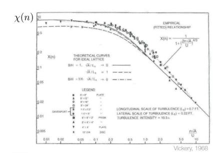
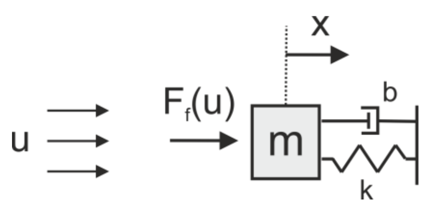
Admittance and Aeroelastic model







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