

# Yüksek Yapıların Tasarımı

*Gebze Teknik Üniversitesi, 2017*

Yüksek Yapılara Giriş, Rüzgar Yükleri Altında Davranış

Dr. Barış Erkuş (İTÜ)

# Yüksek Yapıların Tasarımı

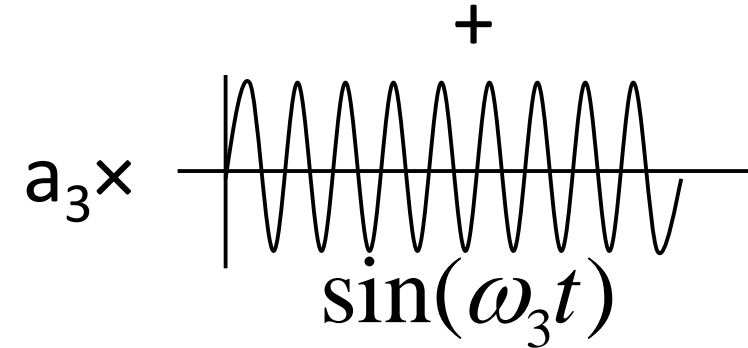
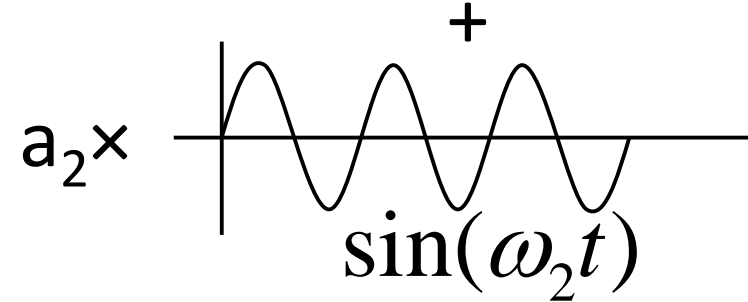
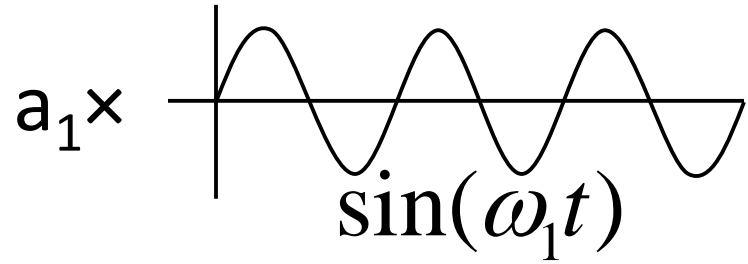
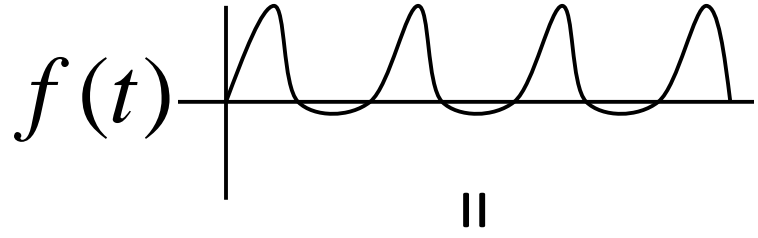
## 1. BÖLÜM: Tasarım Konuları (3 Hafta)

- Yüksek Yapılara Giriş
- Taşıyıcı Sistemler
- Taslak Deprem Yönetmeliği Kapsamında Tasarım
- Sünme ve Rötire Etkileri
- Yapısal Elemanların Davranışı ve Tasarımı
  - Betonarme ve Çelik Bağ Kirişleri
  - Burkulması Engellenmiş Çelik Çapraz
  - Kompozit Kolon
- Rüzgar Yükleri Altında Davranış ve Konfor
- Yüksek Yapı Tasarımında Dikkat Edilmesi Gereken Hususlar
- Özel Konular

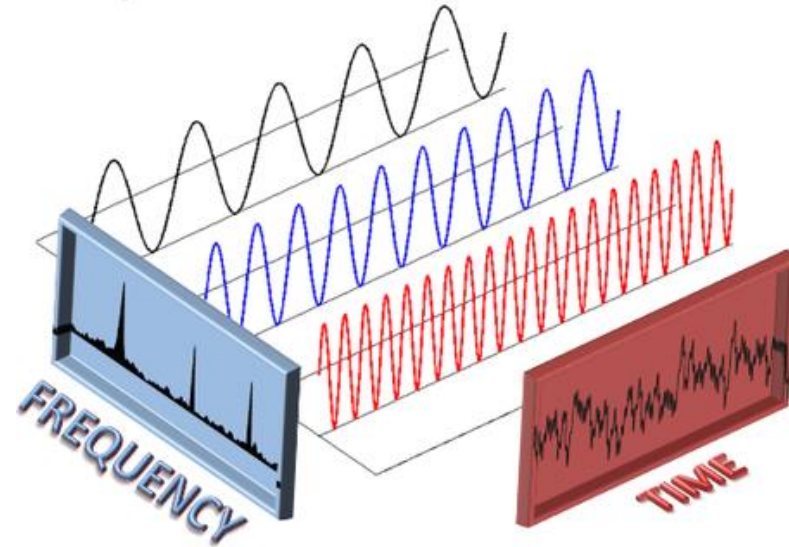
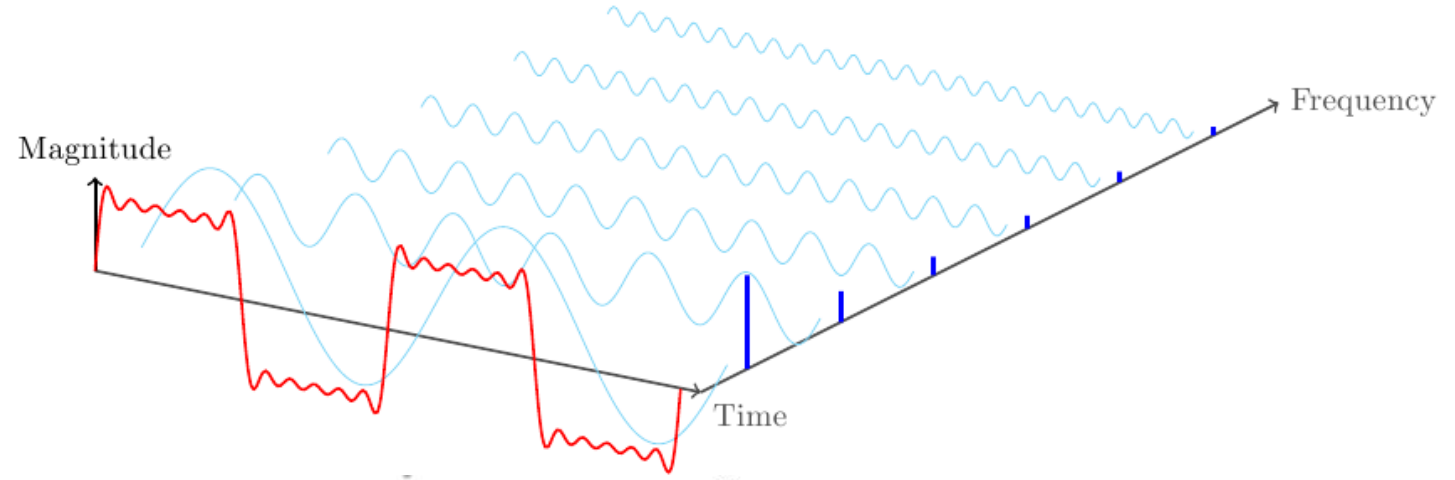
## 2. BÖLÜM: Performansa Dayalı Tasarım ve Uygulamalar (3 Hafta)

- Yapısal Elemanların Doğrusal Olmayan Davranışı ve Modellenmesi
  - Bağ Kirişleri
  - Betonarme Perde Duvar
  - Kiriş ve Kolon Plastik Mafsallı Modelleri
  - Dışdestek Sistemleri
- PERFORM 3D Örneği – 1. Örnek:
  - Betonarme Perde Duvar Çekirdek
  - Çelik Bağ Kiriş
  - Kompozit Kolon
  - Deprem Analizleri ve Davranışın İrdelenmesi
- PERFORM 3D Örneği – 2. Örnek
  - 1. Örnek + Dışdestek Sistemi

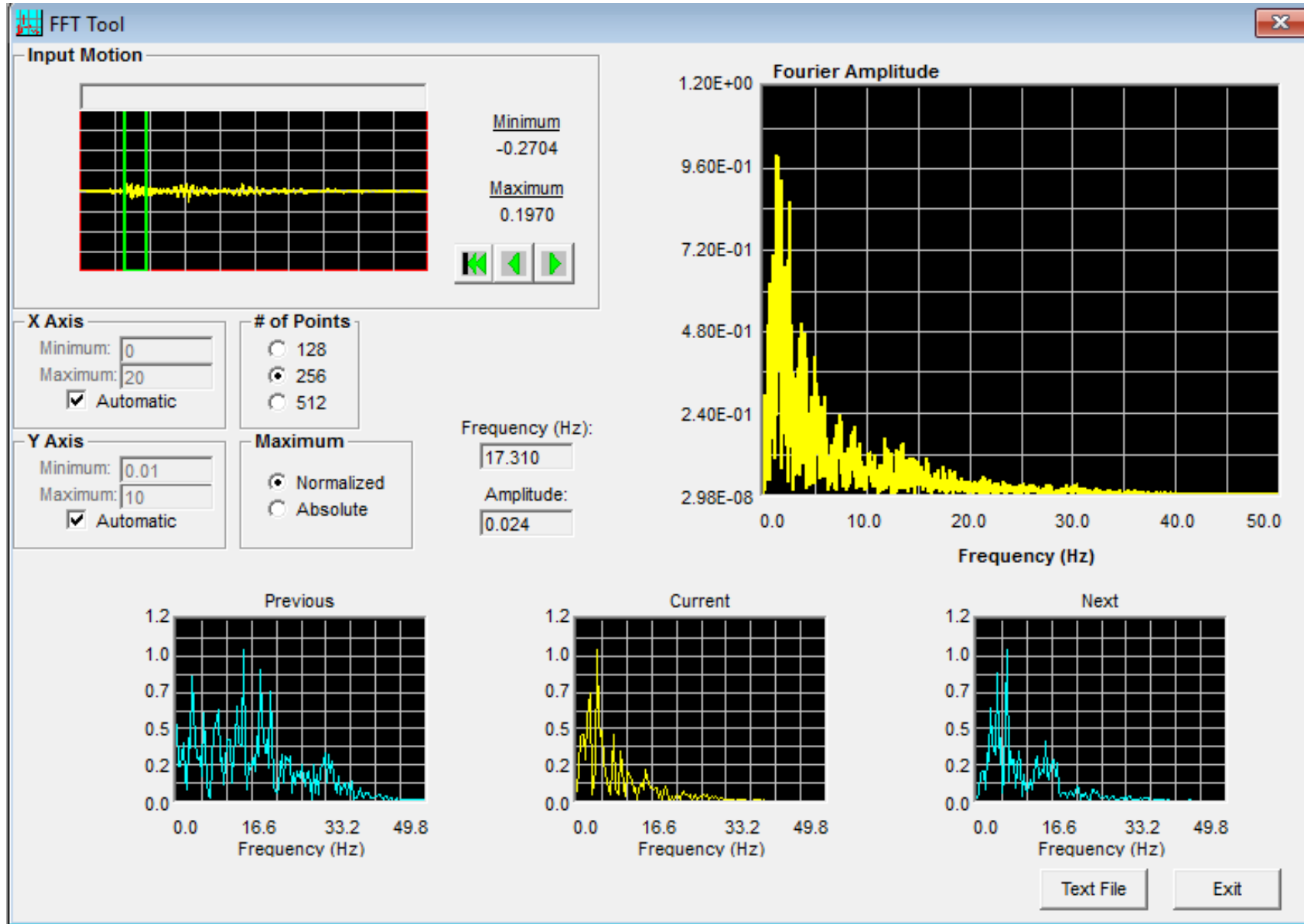
# Giriş: Frekans Alanında Analiz



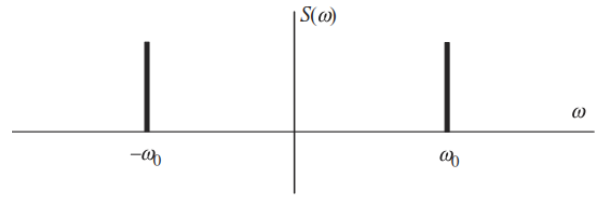
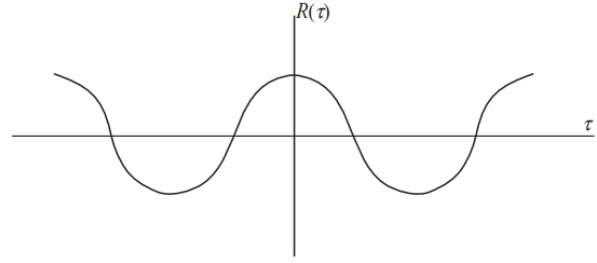
$$f(t) = \sum_i^N a_i \sin(\omega_i t)$$



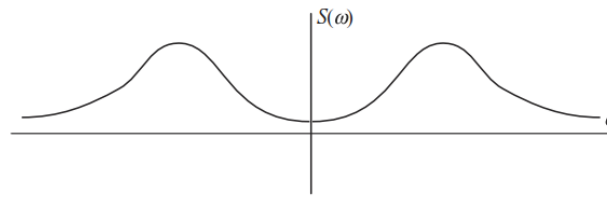
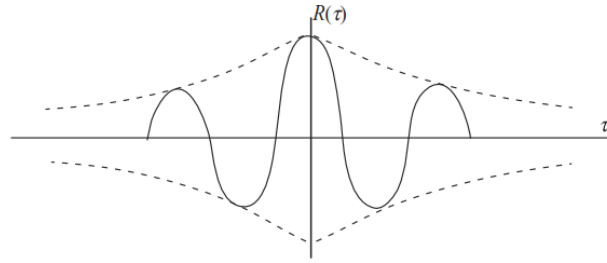
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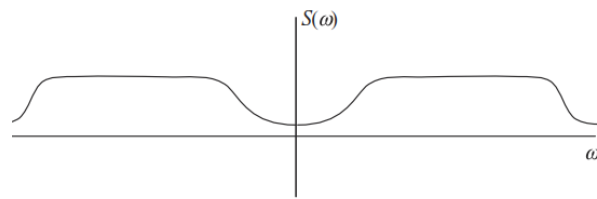
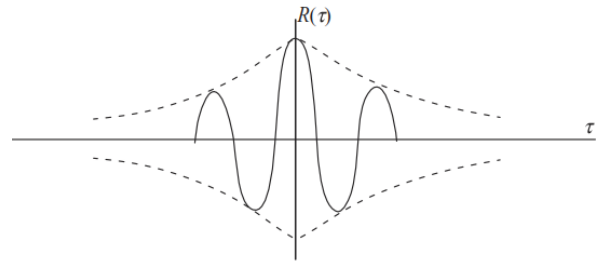
# Giriş: Frekans Alanında Analiz



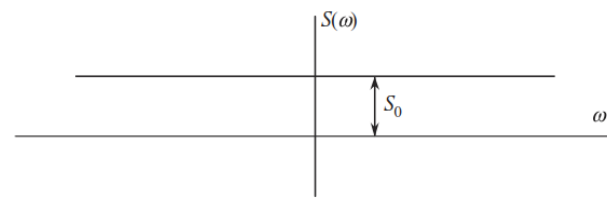
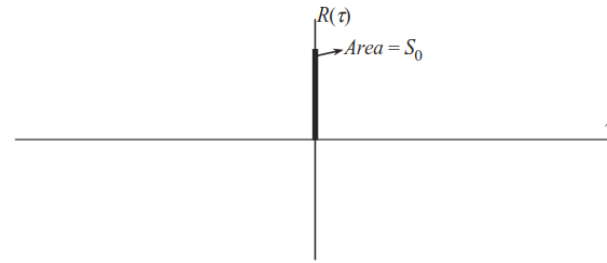
(a) Periodic



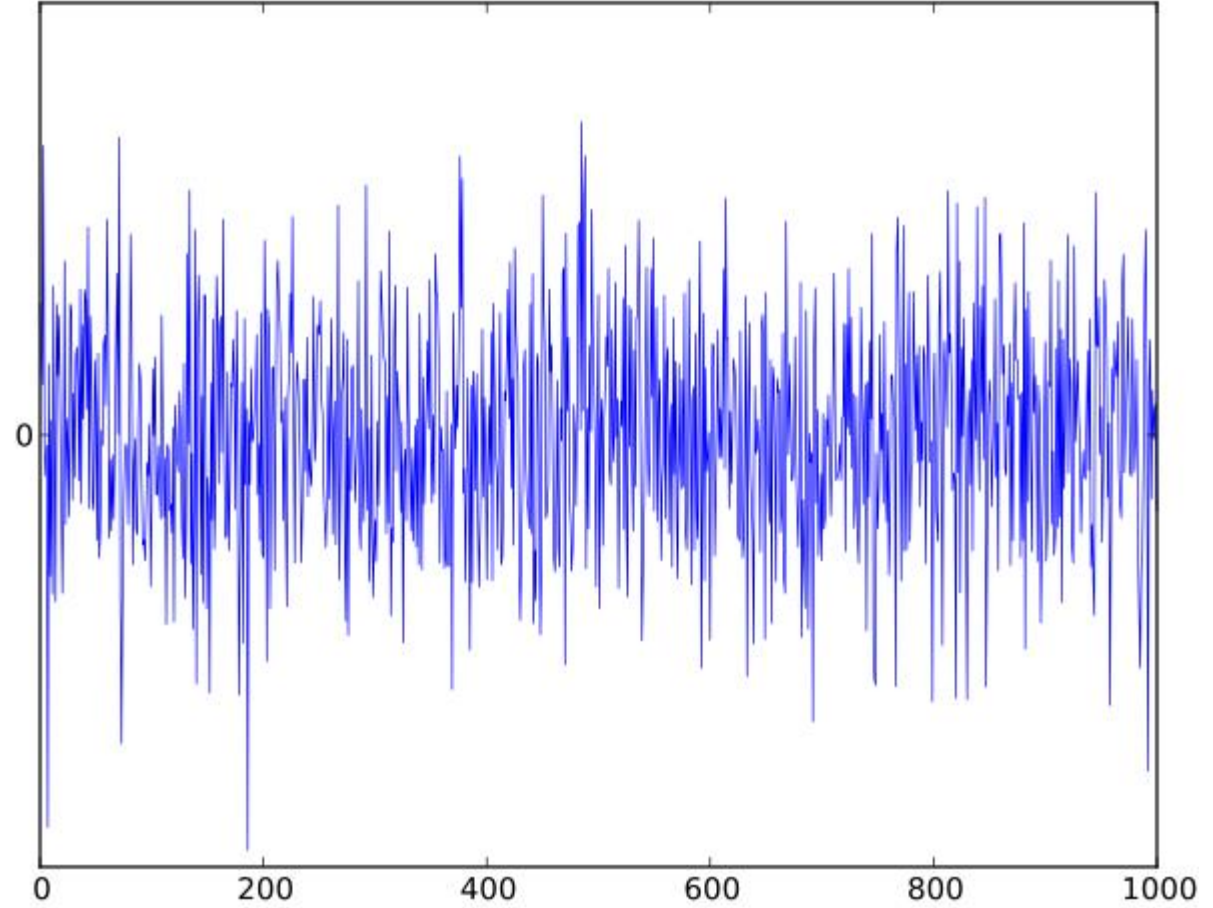
(b) Narrowband



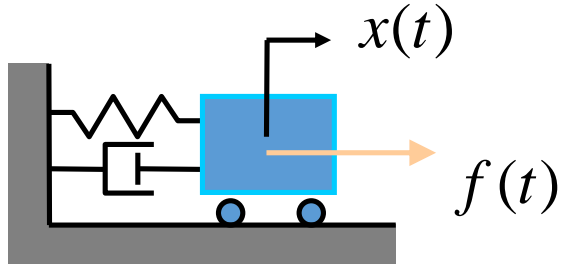
(c) Wideband



(d) White Noise



# Giriş: Frekans Alanında Analiz

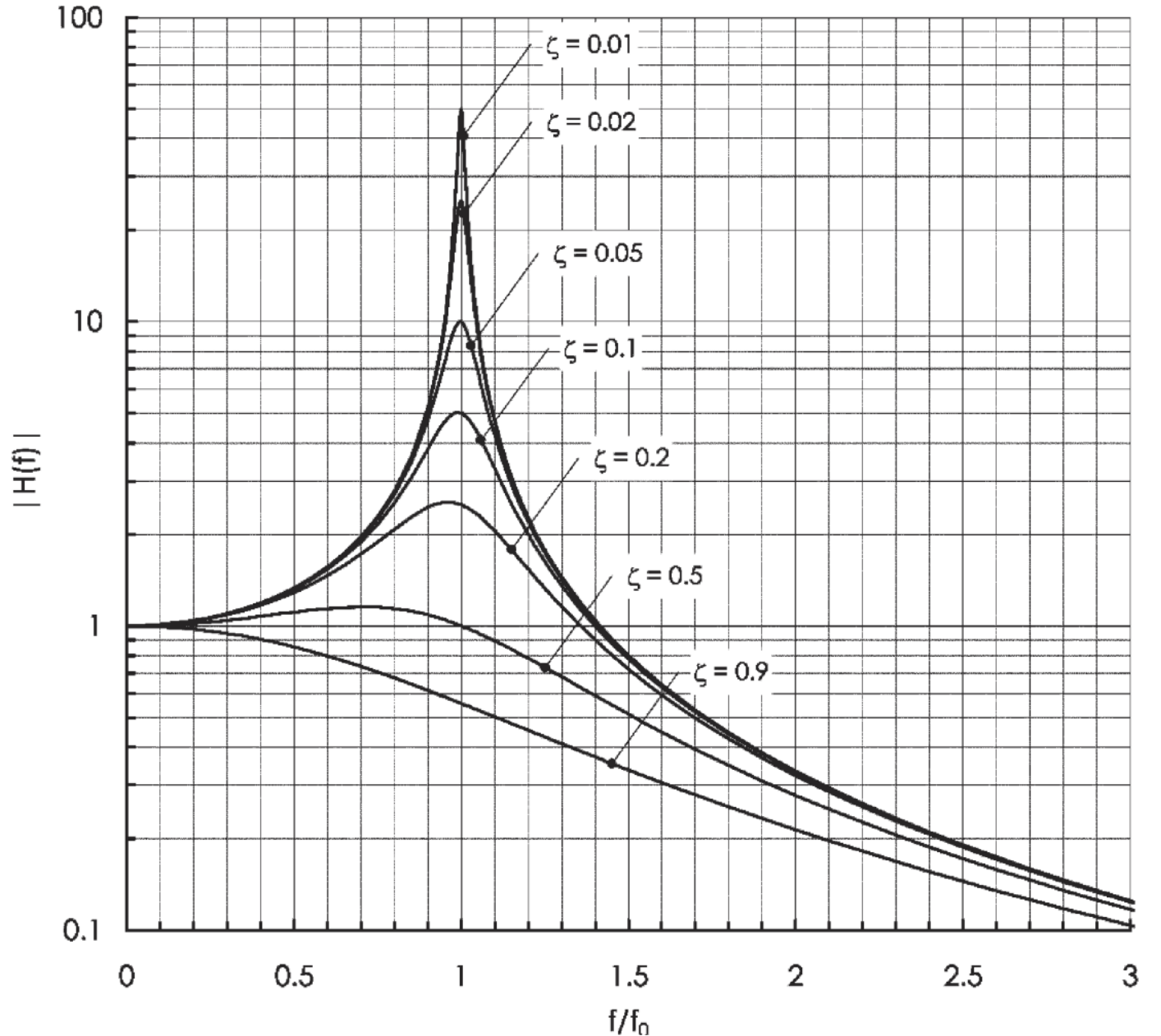


$$m\ddot{x} + c\dot{x} + kx = P_0 \sin 2\pi ft$$

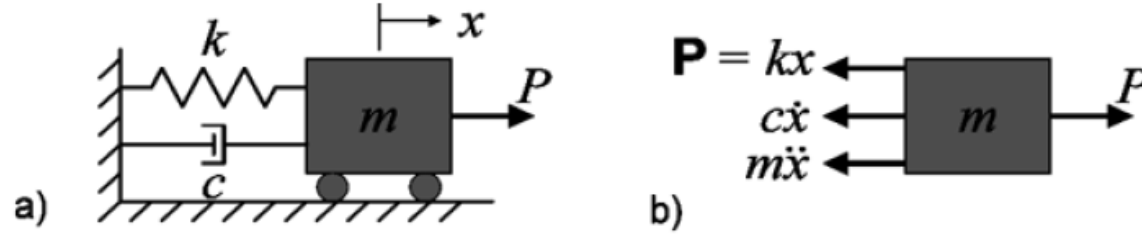
$$x(t) = \frac{P(t)/k}{\sqrt{\left[1 - \left(\frac{f}{f_0}\right)^2\right]^2 + \left[2\zeta \frac{f}{f_0}\right]^2}}$$

$$|H(f)|^2 = \frac{1}{\left[1 - \left(\frac{f}{f_0}\right)^2\right]^2 + \left[2\zeta \frac{f}{f_0}\right]^2}$$

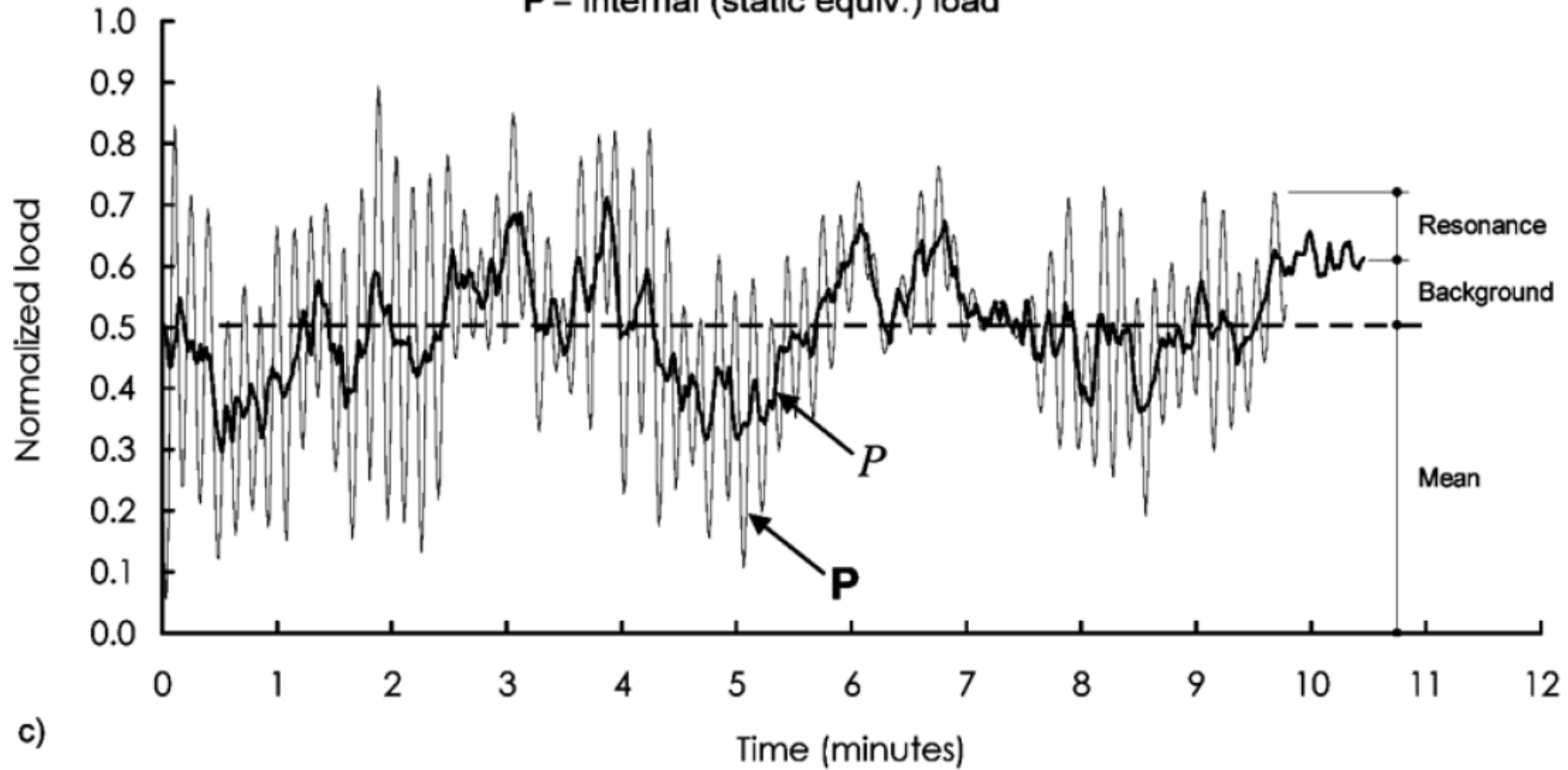
$$\mathbf{P} = |H(f)|P \quad \mathbf{x} = |H(f)|x$$



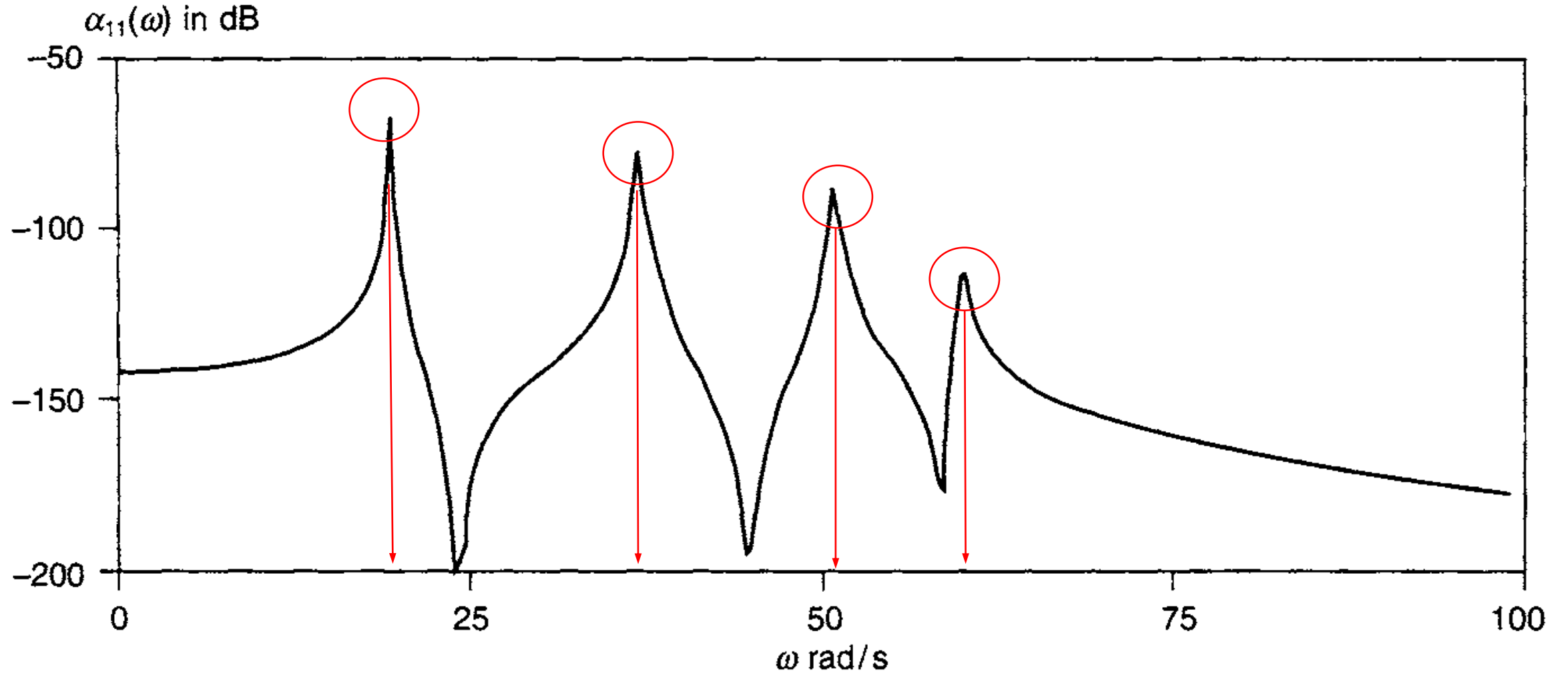
# Giriş: Frekans Alanında Analiz



$P$  = external (aerodynamic) load  
 $\mathbf{P}$  = internal (static equiv.) load

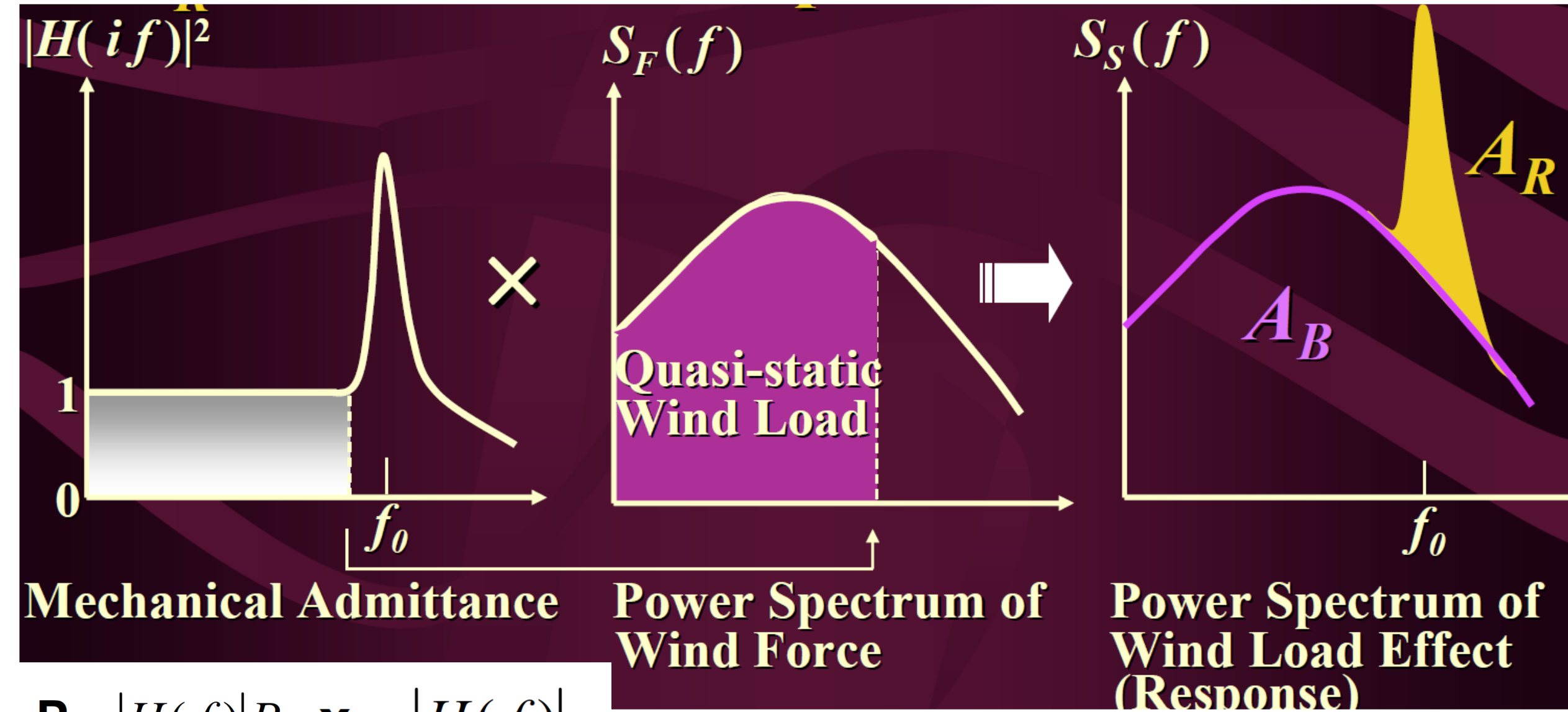


# Giriş: Frekans Alanında Analiz



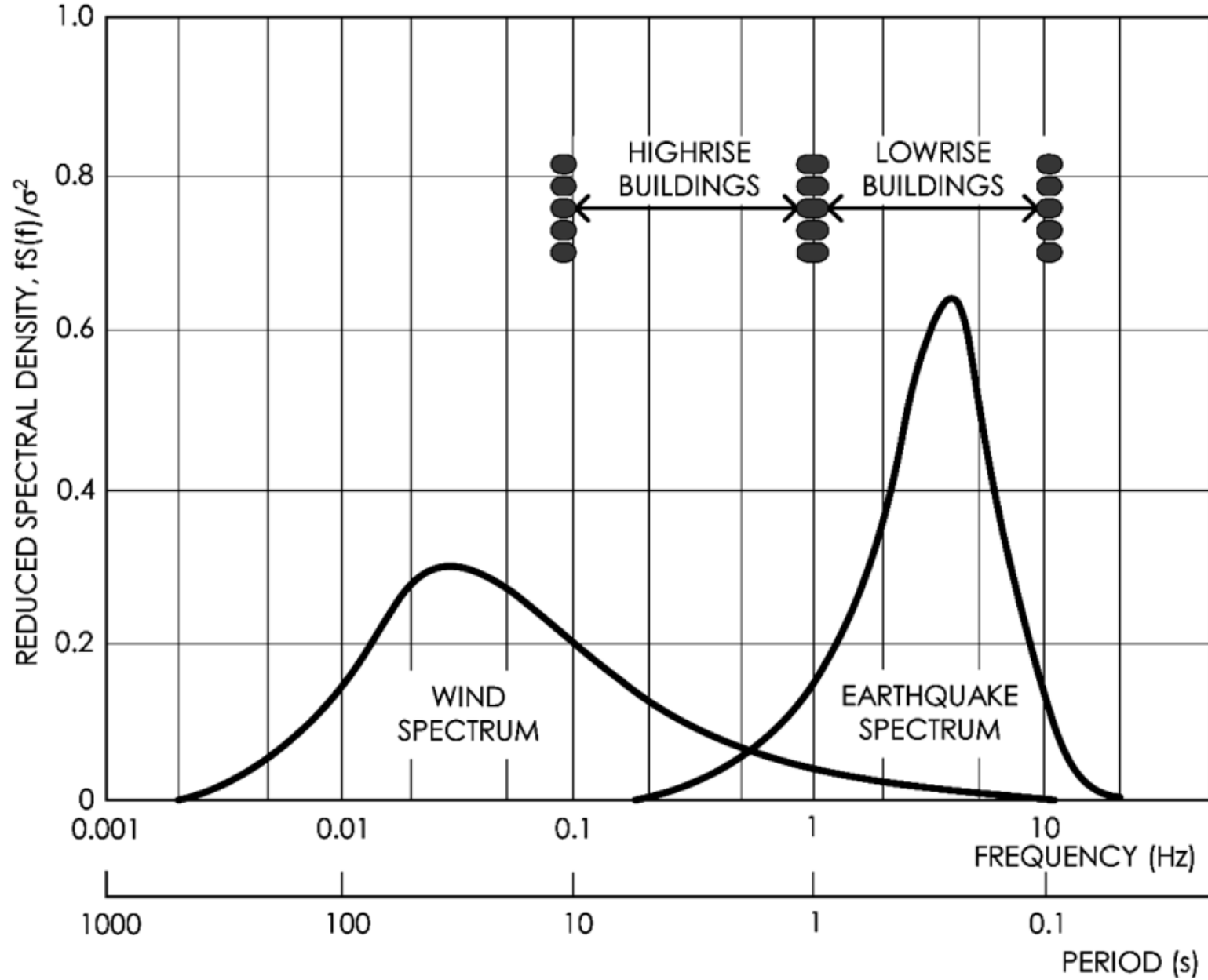


# Giriş: Frekans Alanında Analiz



$$\mathbf{P} = |H(f)|P \quad \mathbf{x} = |H(f)|x$$

# Giriş: Frekans Alanında Analiz

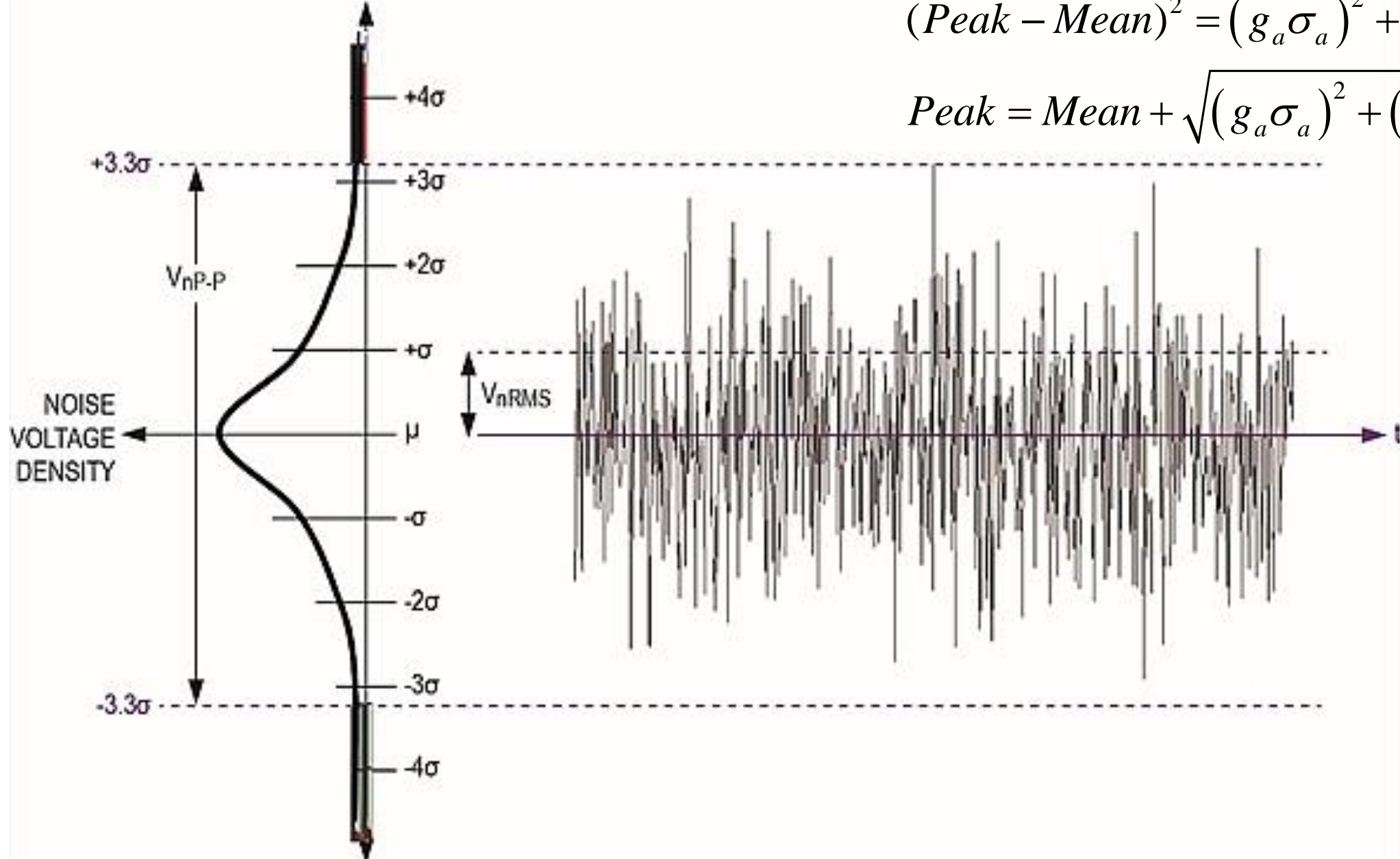


# Giriş: Stokastik Analiz

$$Peak = Mean + g\sigma$$

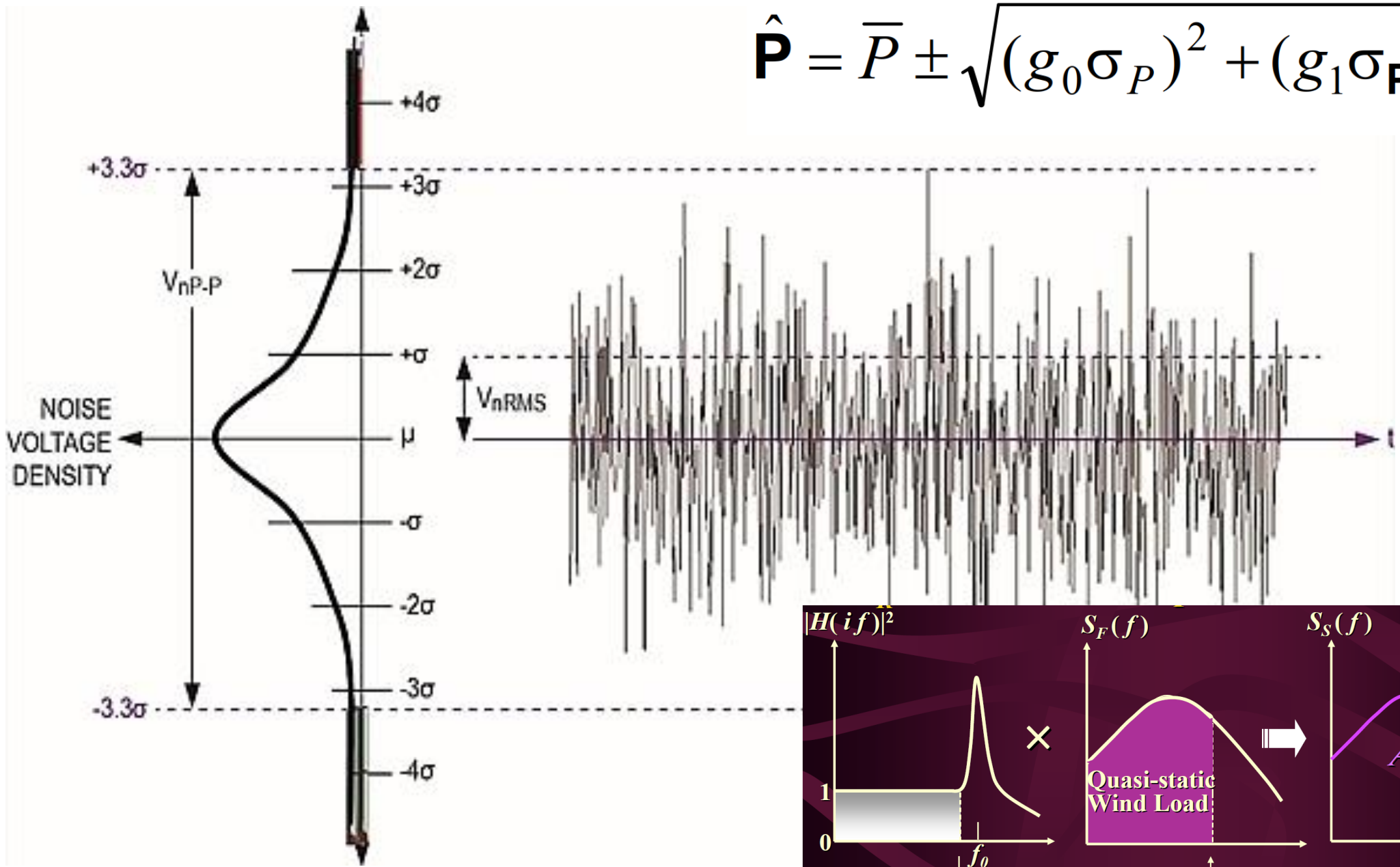
$$(Peak - Mean)^2 = (g_a\sigma_a)^2 + (g_b\sigma_b)^2$$

$$Peak = Mean + \sqrt{(g_a\sigma_a)^2 + (g_b\sigma_b)^2}$$



# Giriş: Stokastik Analiz

$$\hat{P} = \bar{P} \pm \sqrt{(g_0 \sigma_P)^2 + (g_1 \sigma_{P,R})^2}$$



# Rüzgar Yüklerinin Özellikleri

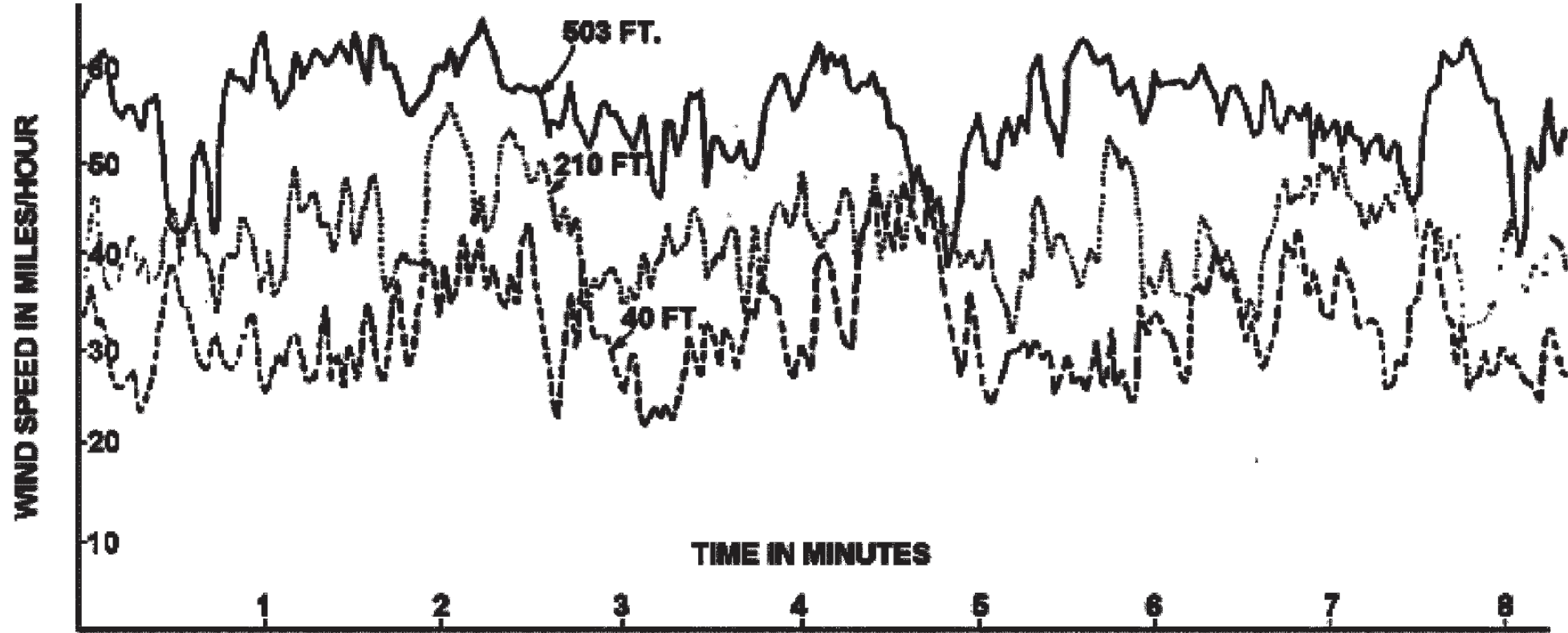
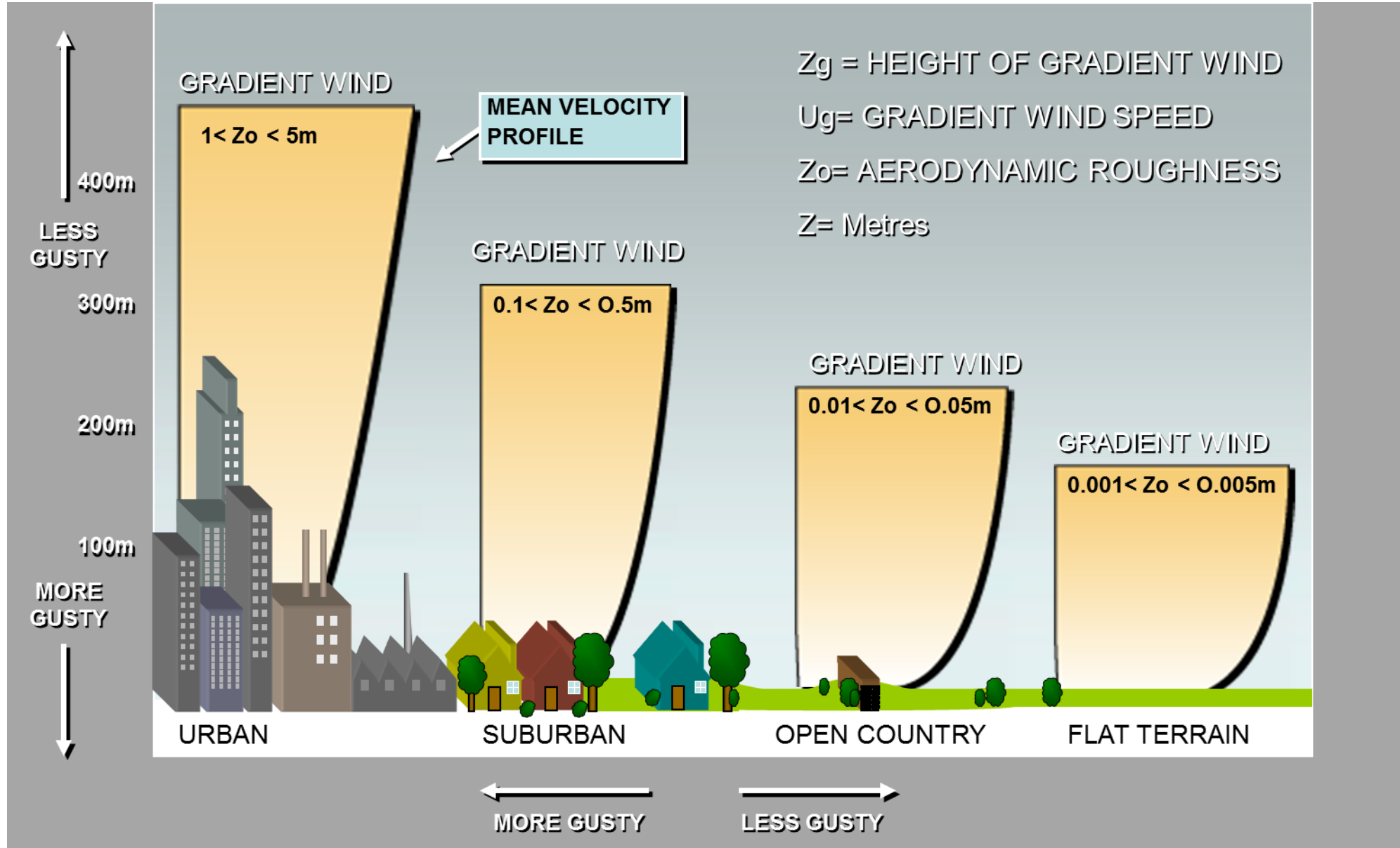


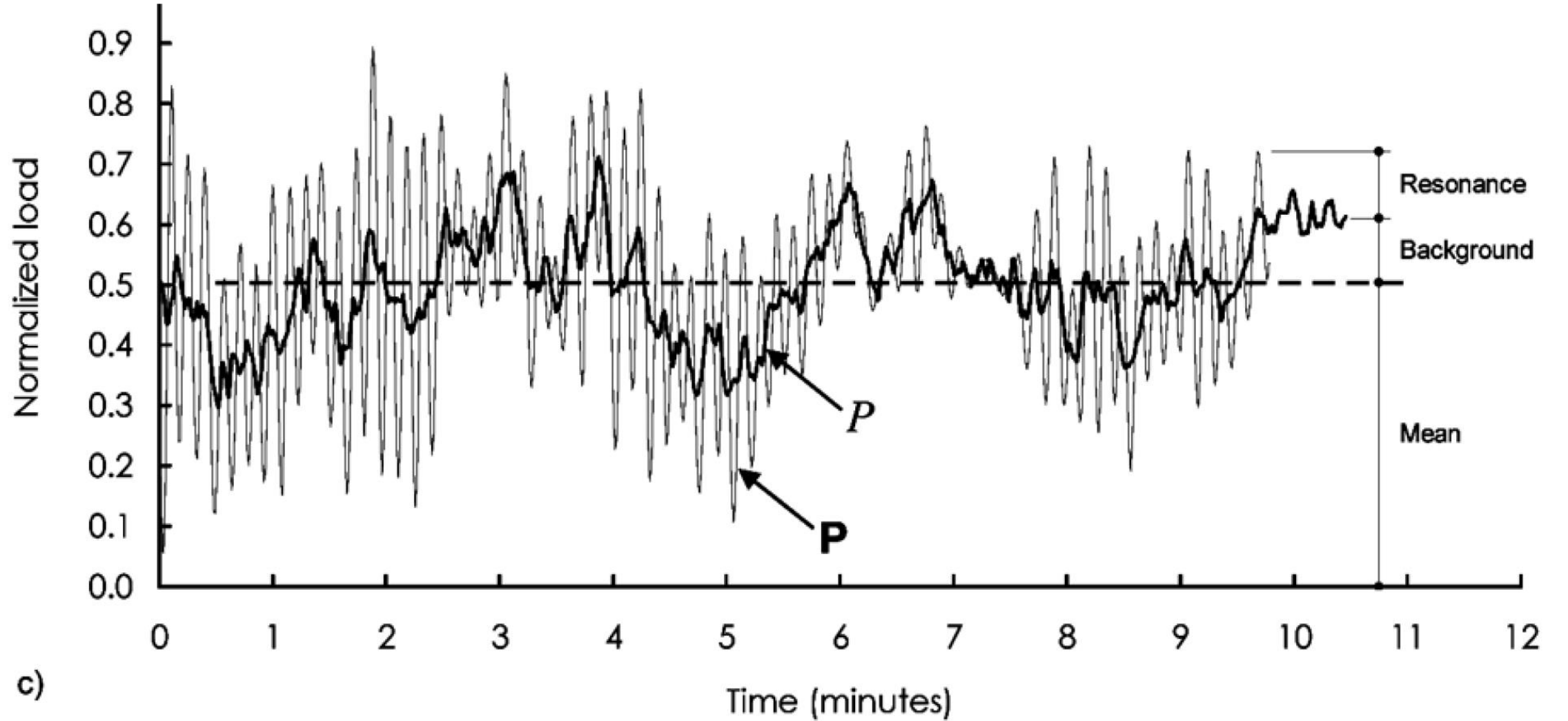
Figure 1 — Wind speeds at three heights on a 500-ft mast (Davenport 1966, 1967).

# Rüzgar Yüklerinin Özellikleri



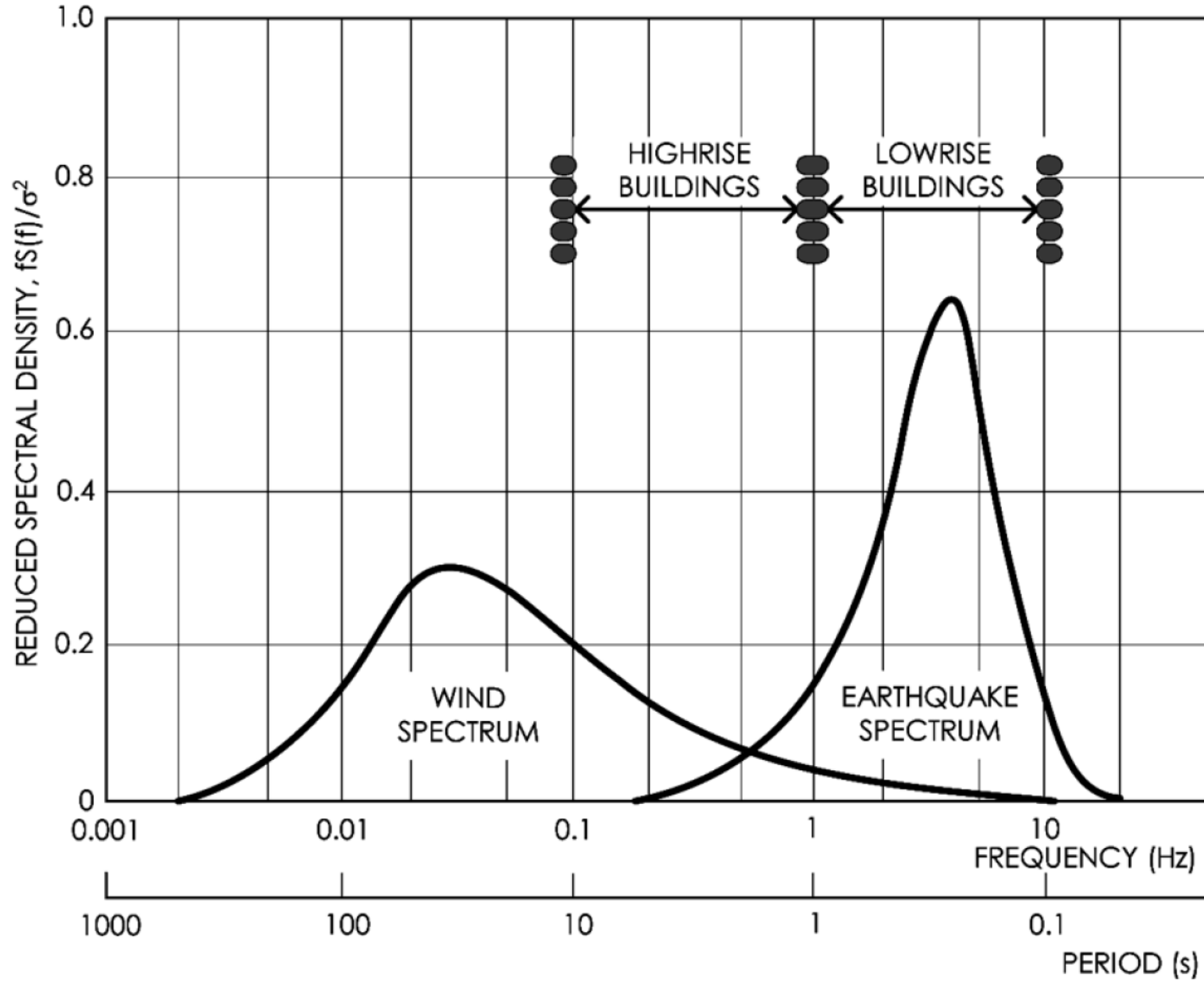
# Rüzgar Yüklerinin Özellikleri

Maksimum Değer = Ortalama + Standart Sapma x Peak Faktör



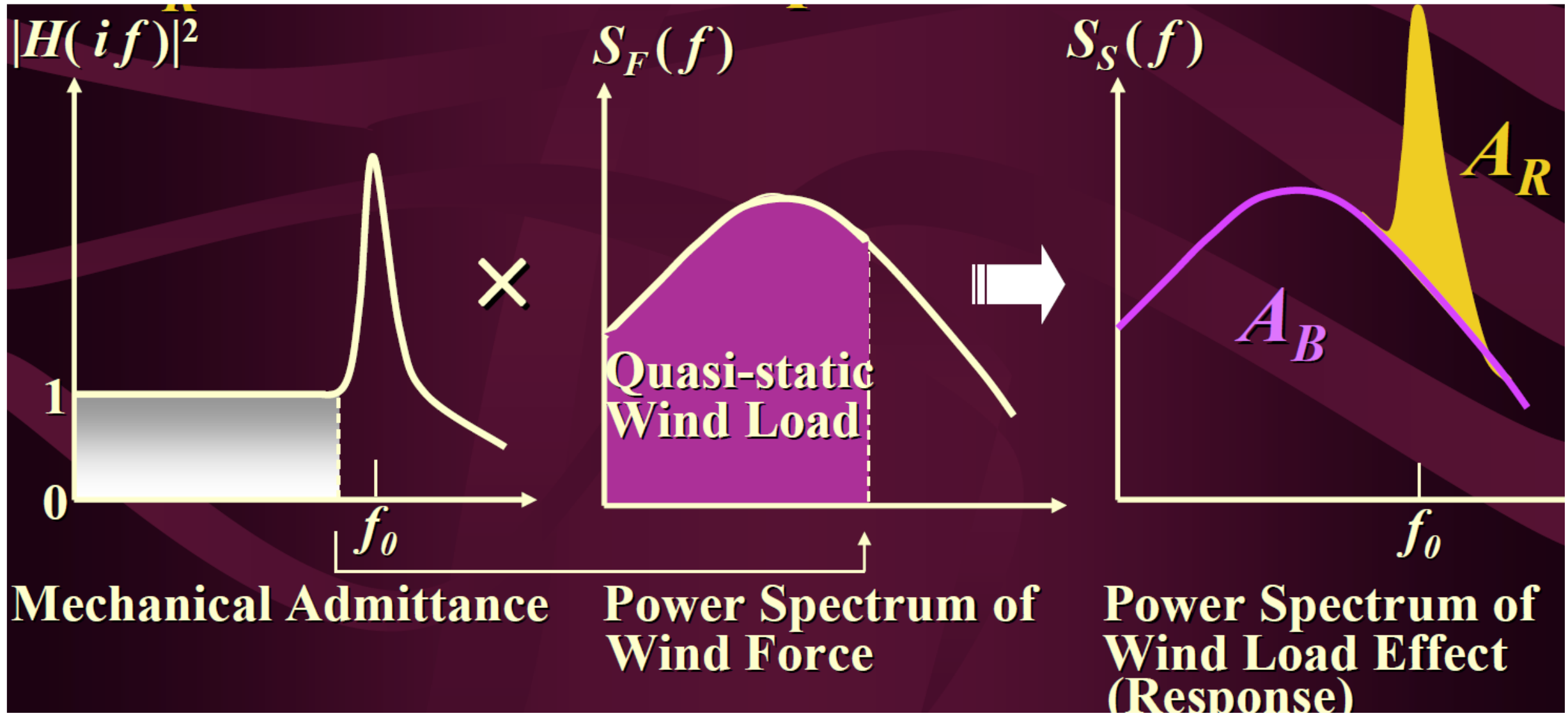
c)

# Rüzgar Yüklerinin Özellikleri

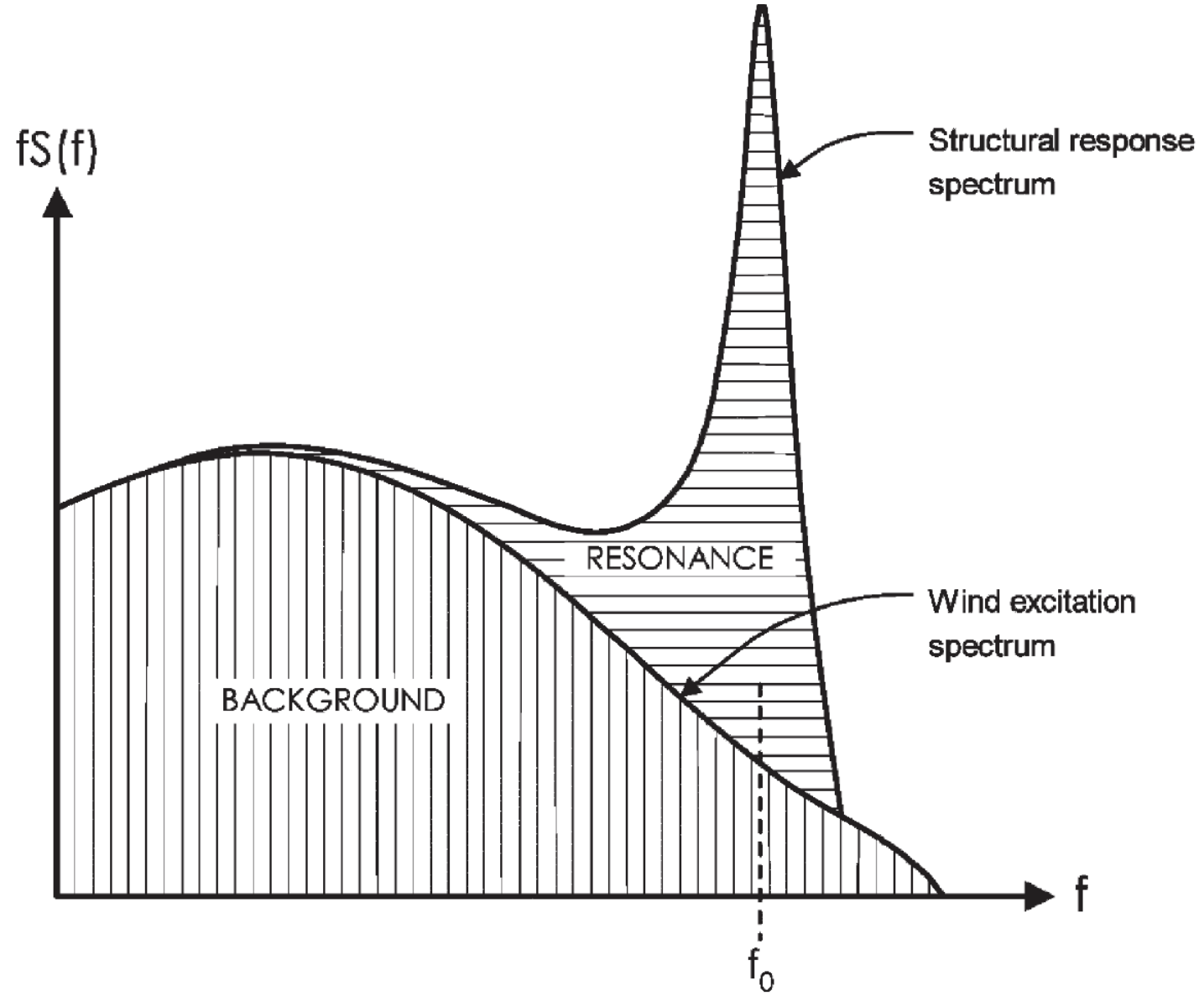




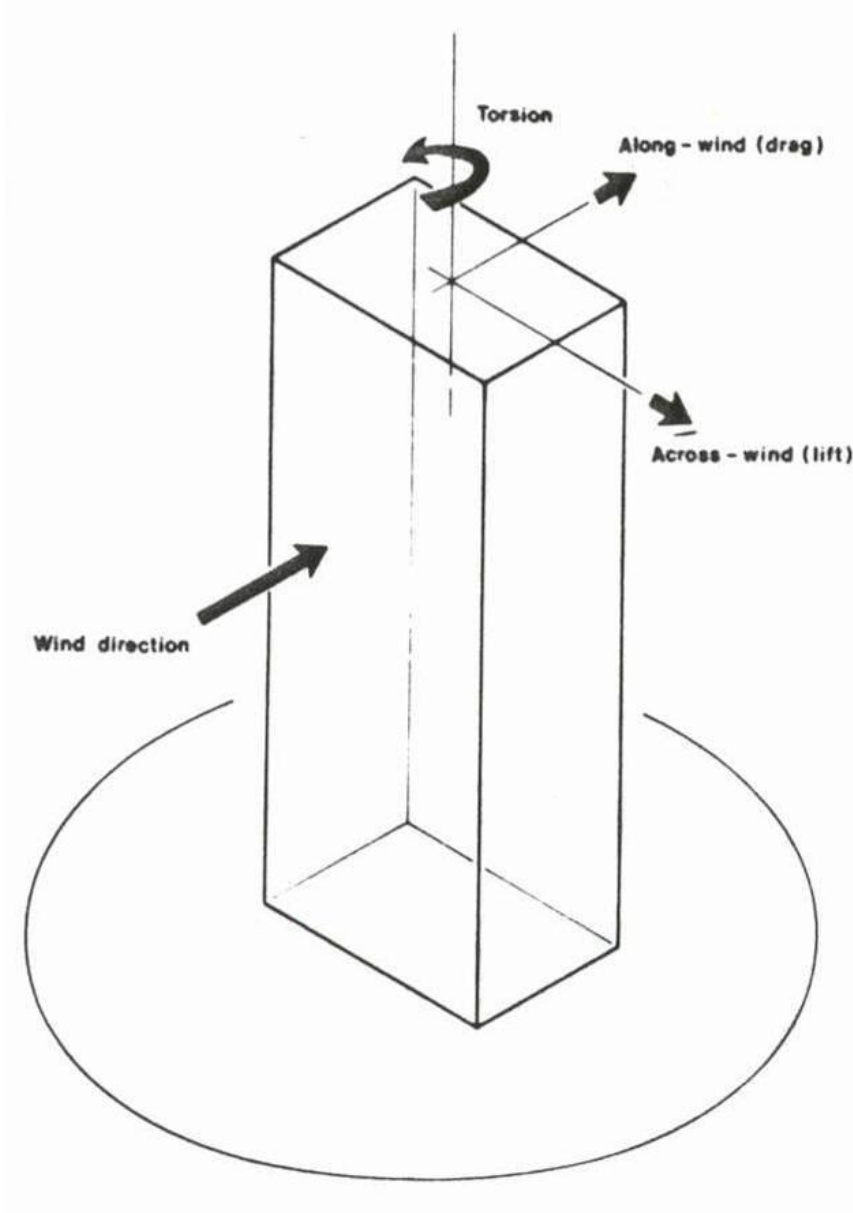
# Rüzgar Yüklerinin Özellikleri



# Rüzgar Yüklerinin Özellikleri



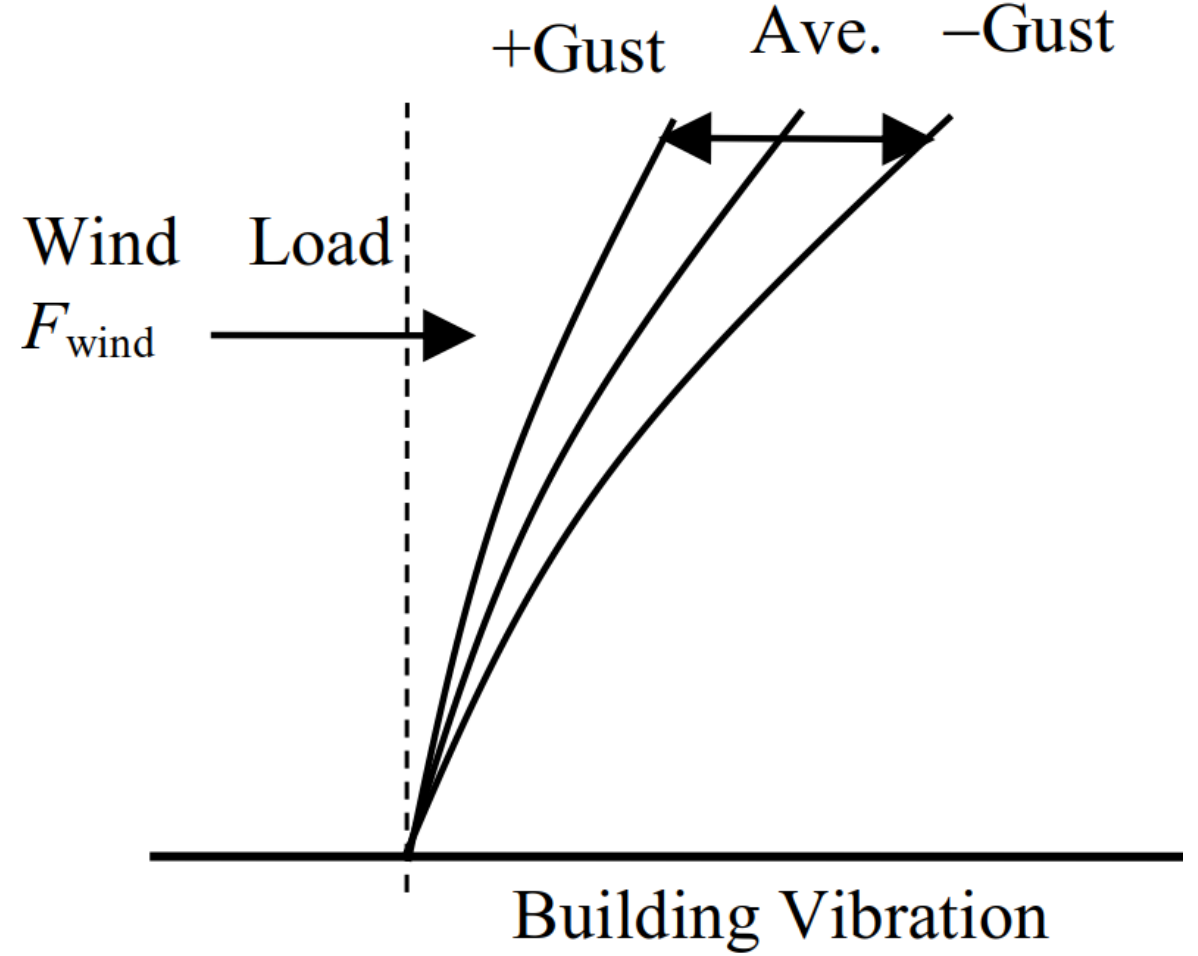
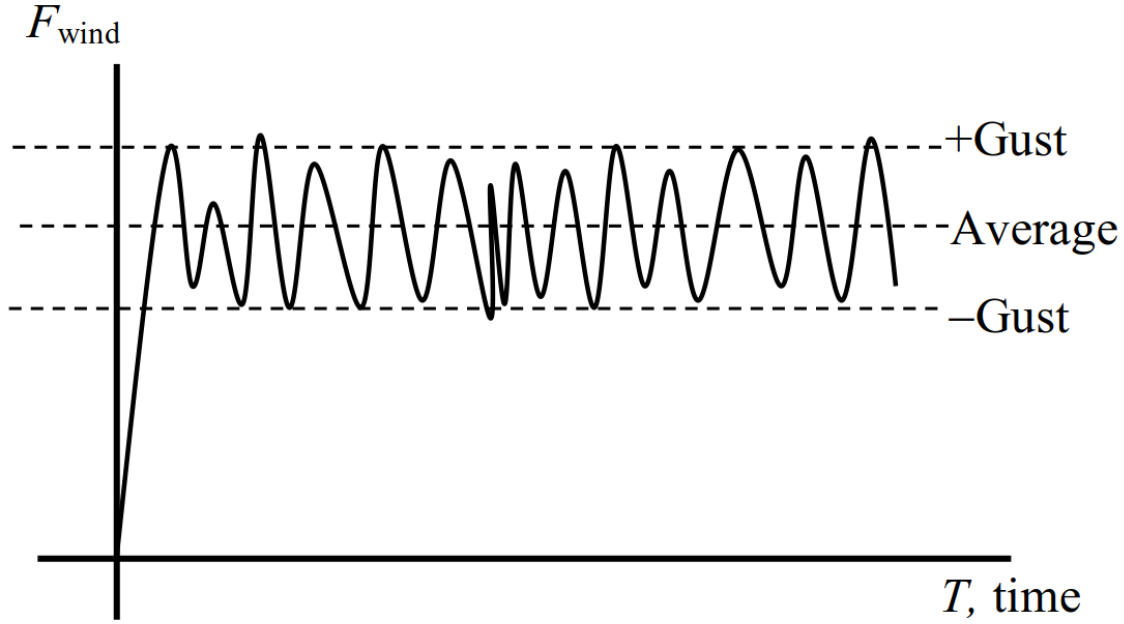
# Yüksek Yapıların Rüzgar Altında Davranışı



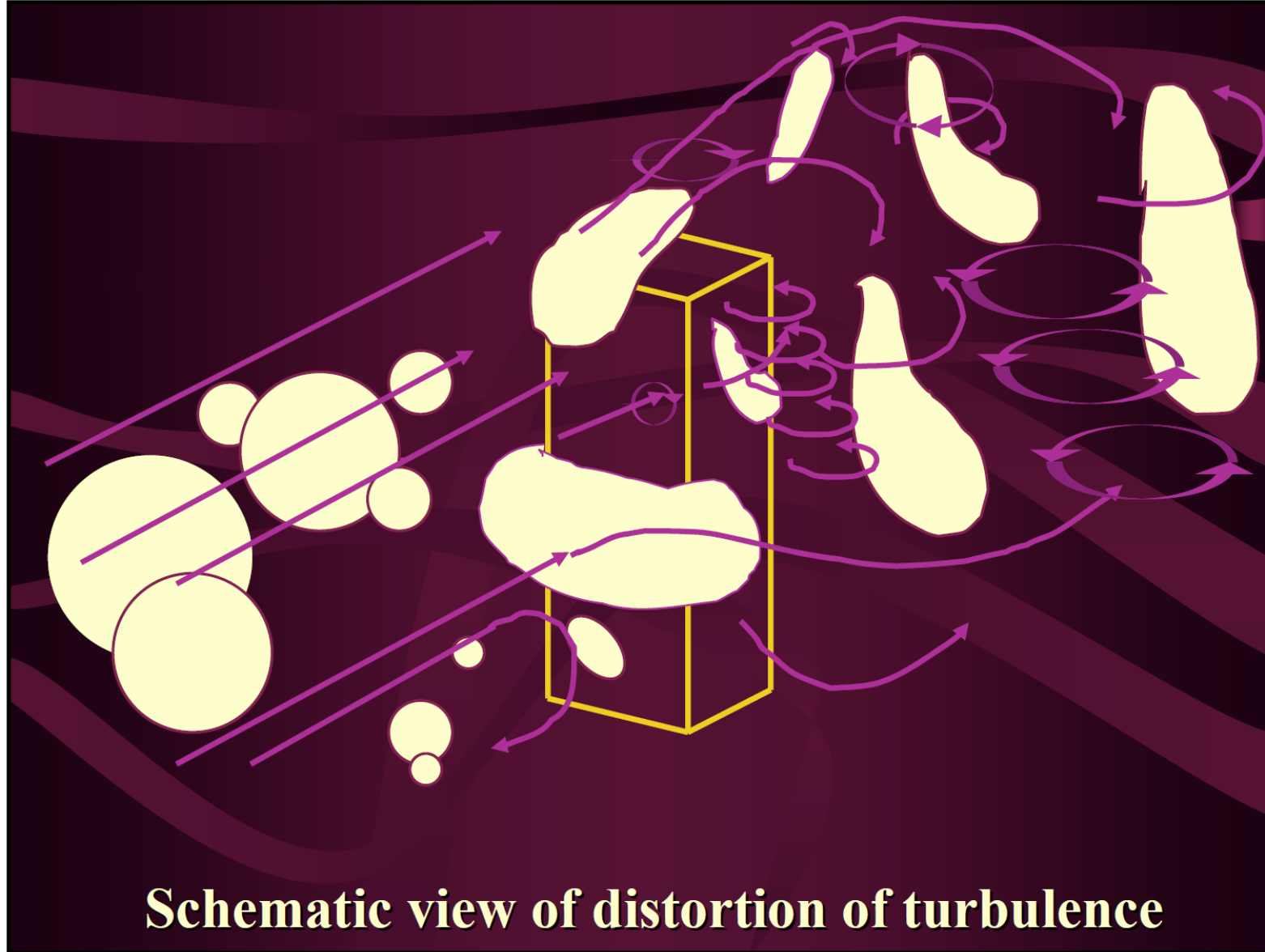
- Rüzgar Yönünde
- Rüzgara Dik Yönde
- Burulma

# Yüksek Yapıların Rüzgar Altında Davranışı

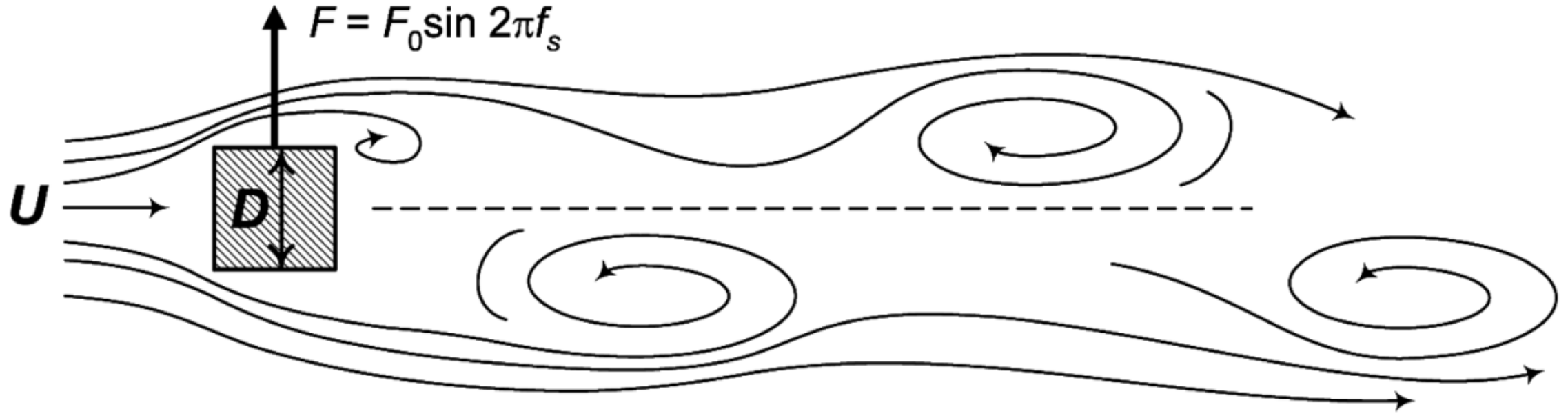
## Rüzgar Yönünde



# Yüksek Yapıların Rüzgar Altında Davranışı



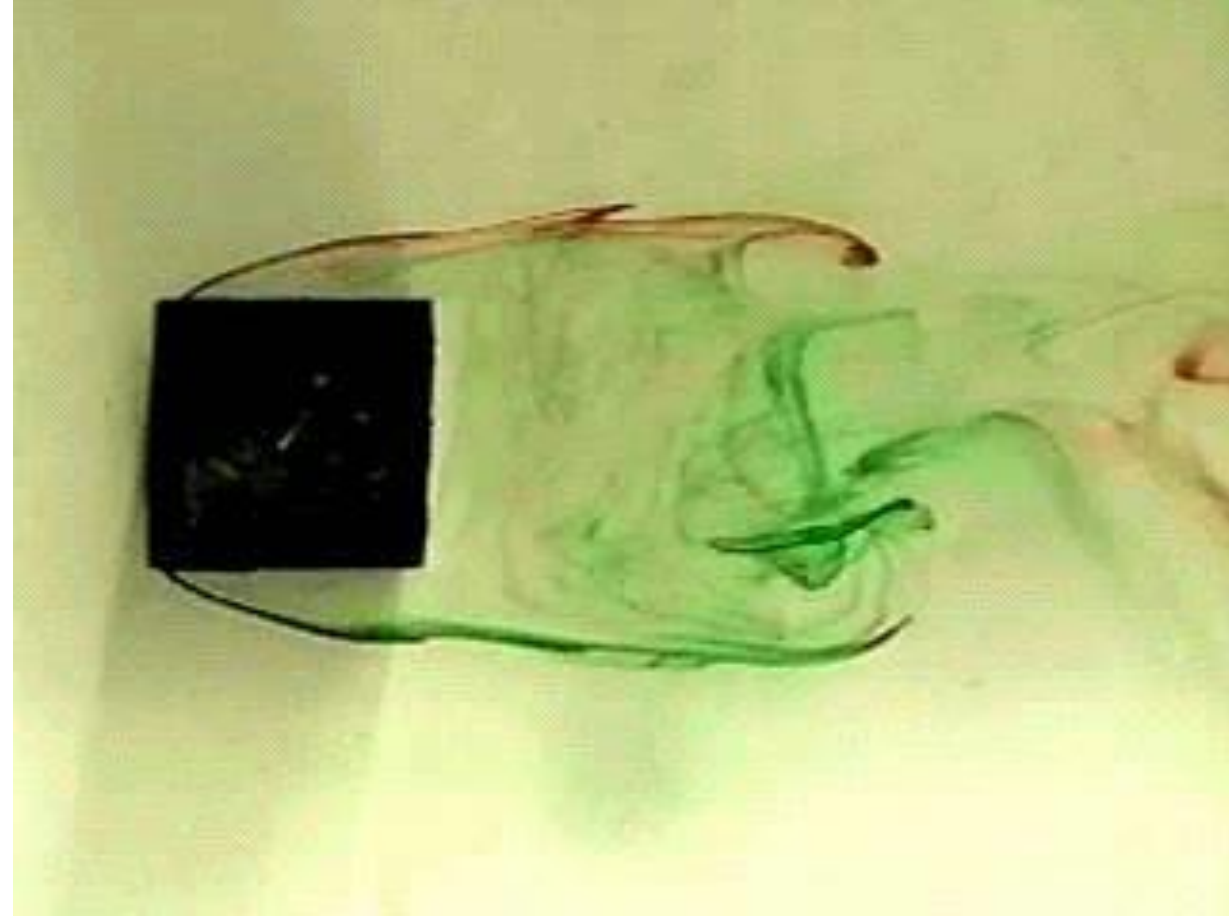
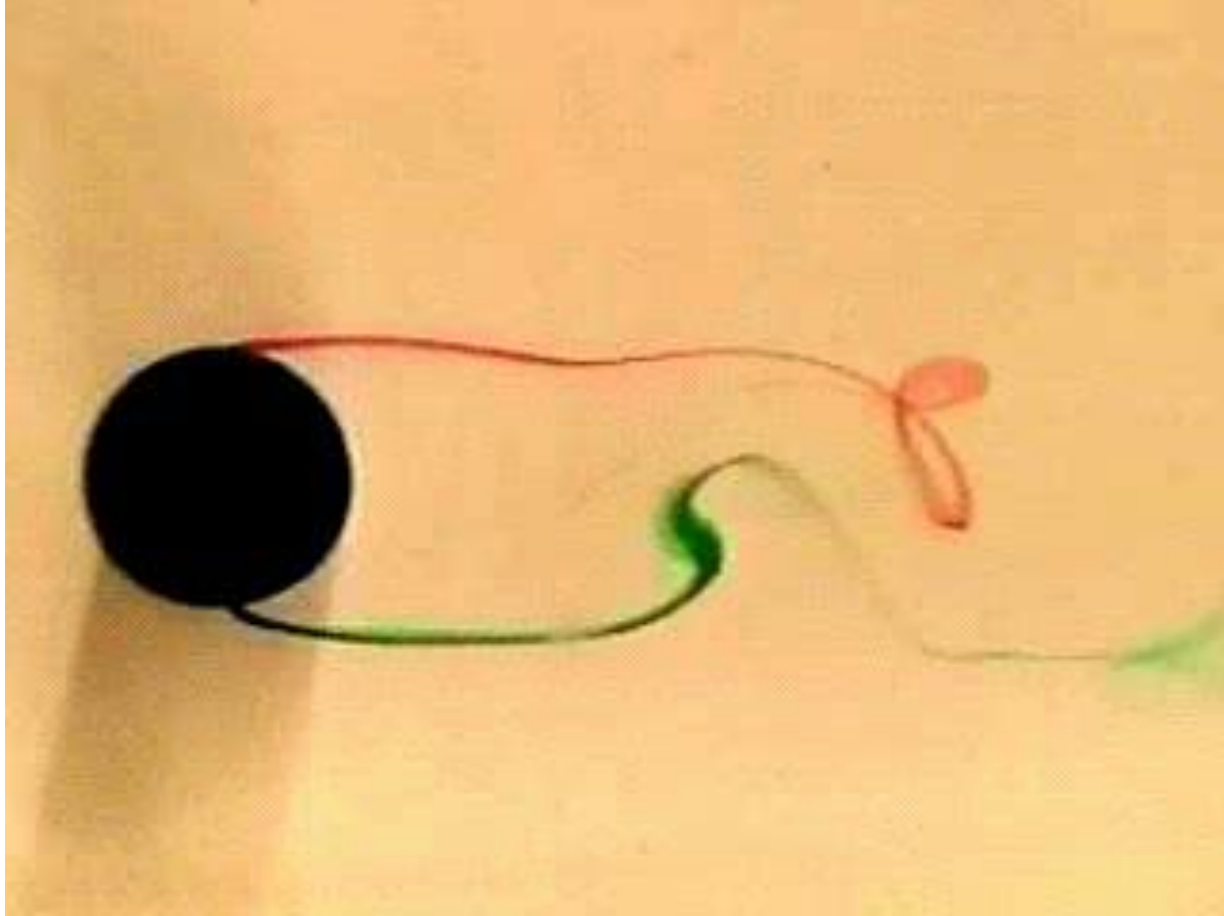
# Yüksek Yapıların Rüzgar Altında Davranışı


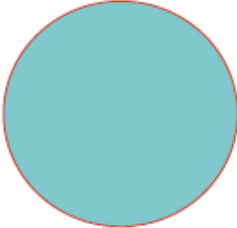
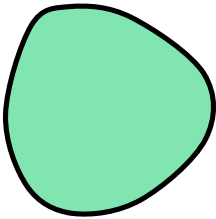
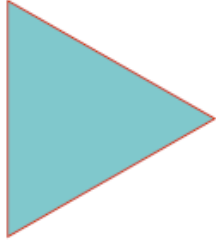
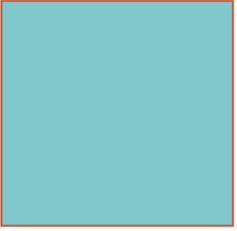


$f_s$  = vortex shedding frequency  
Strouhal no:  $St = f_s D / U$

Hortum Saçıntısı

# Yüksek Yapıların Rüzgar Altında Davranışı

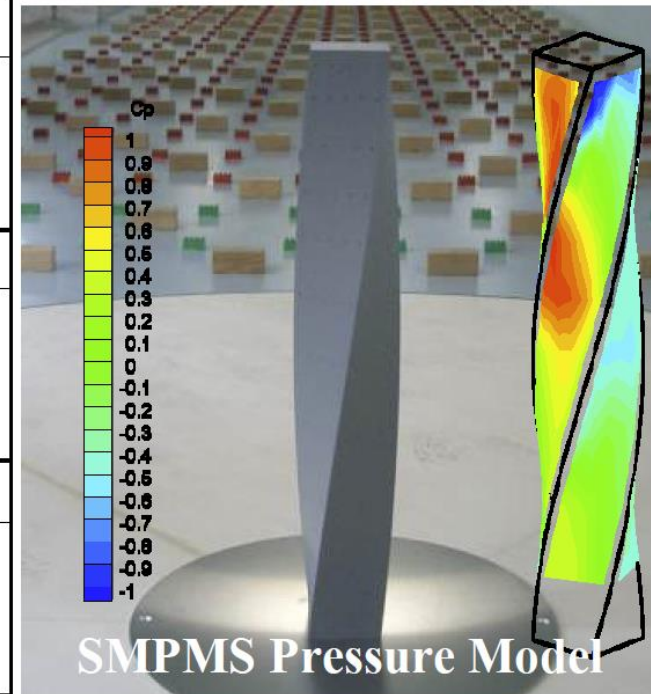
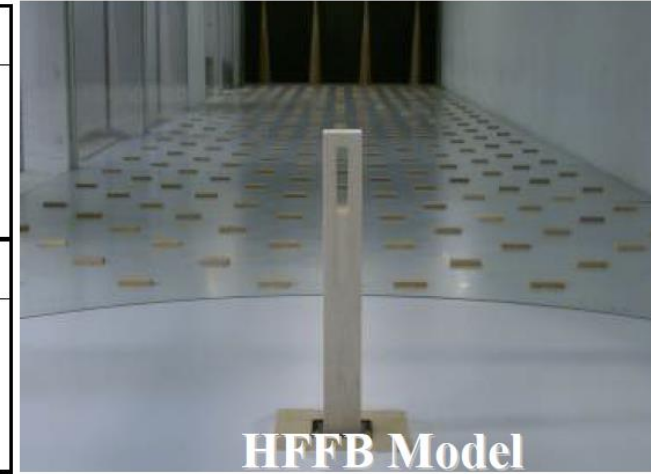


<b>WIND</b> 				
<b>Drag</b>	<b>0.6 - 0.7</b>	<b>0.8 - 1.3</b>	<b>1.4 - 1.8</b>	<b>1.5 - 2.0</b>
<b>Static Base Force</b> <small>(Drag * Area * U<sup>2</sup>)</small>	<b>F</b>	<b>~1.4 F</b>	<b>~2.5 F</b>	<b>~2.5 F</b>
<b>Vortex Shedding</b>	<b>From all directions</b>	<b>From three directions</b>	<b>From three directions</b>	<b>From four directions</b>



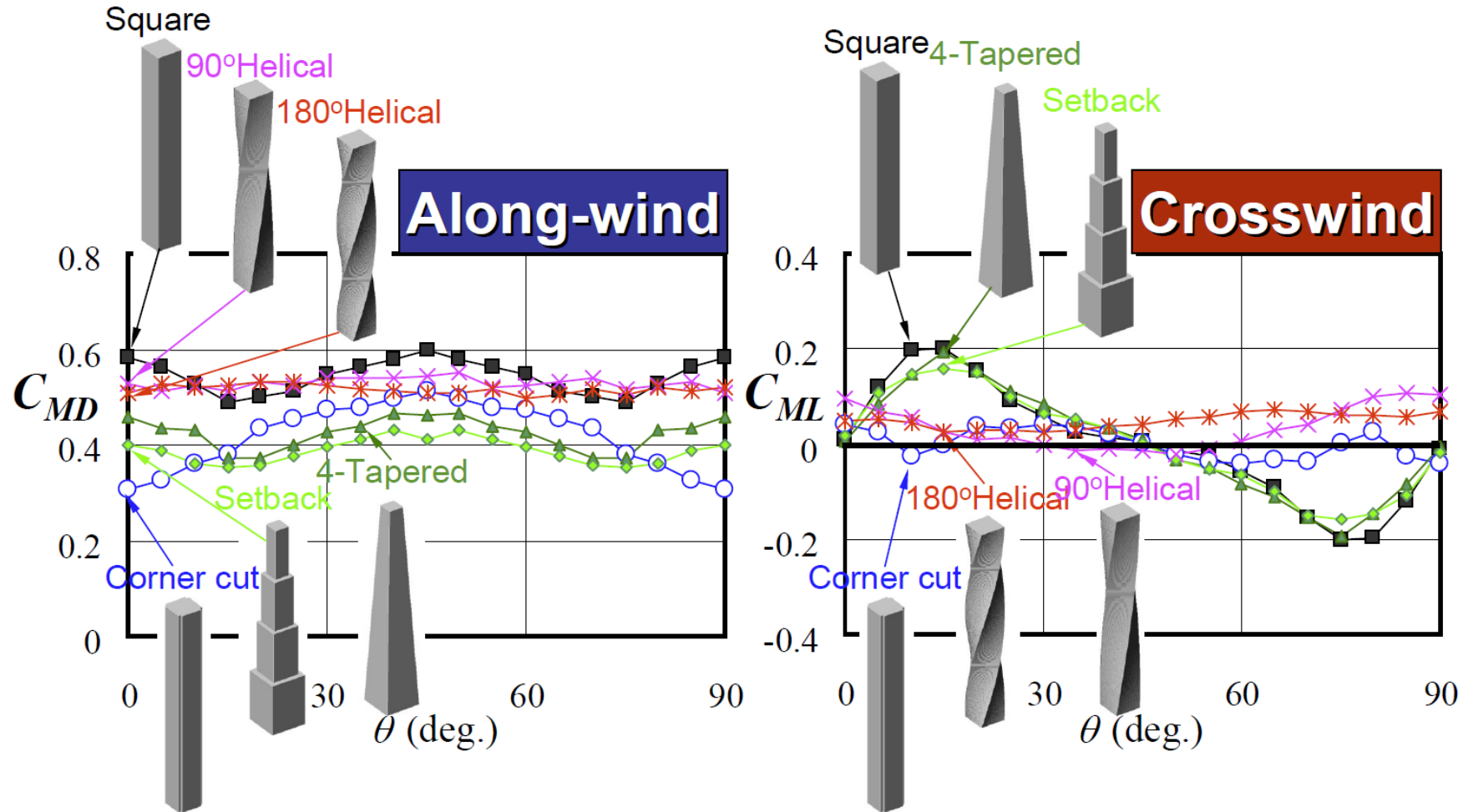
# Yüksek Yapıların Rüzgar Altında Davranışı

<b>Basic</b>	Square	Rectangle 1:2	Circle	Ellipse 1:2	<b>Corner Modified</b>	Chamfered	Corner cut	
<b>Tilted</b>	Tilted	Snaking	<b>Tapered</b>	2-Tapered	4-Tapered	Setback	Inverse 4-Tapered	Bulged
<b>Helical</b>	Helical Square 90°	Helical Square 180°	Helical Square 270°	Helical Square 360°	Helical Rectangle 180°	Helical Ellipse 180°	Helical Circle + Ellipse 180°	
<b>Openings</b>	Cross Void	Cross Void	Cross Void	Oblique Void	Oblique Void	Oblique Void	3-Circle	
<b>Composite</b>	Corner cut + Helical	Corner cut + Helical + Tapered	Setback + Corner cut	Setback + Rotation				

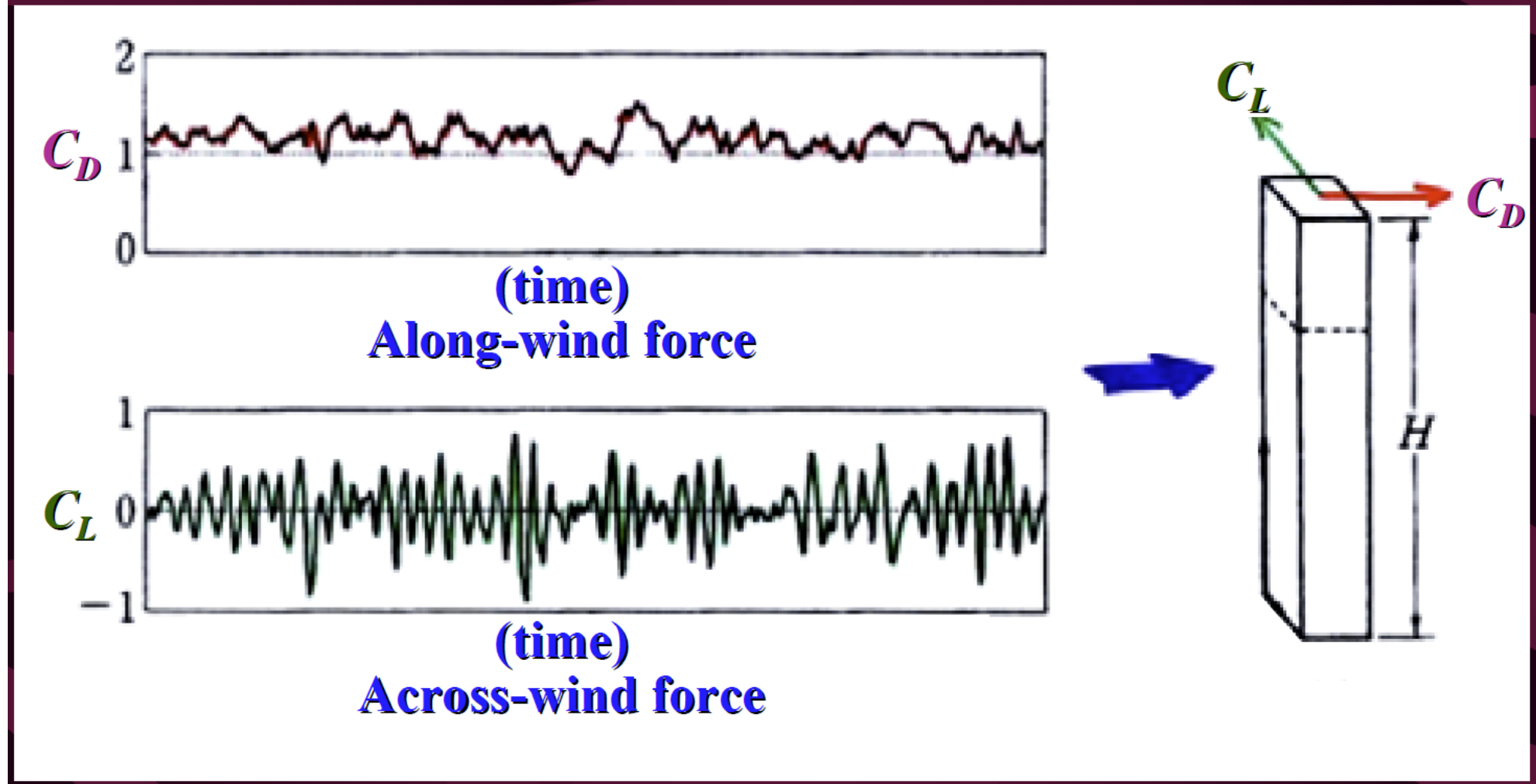


# Yüksek Yapıların Rüzgar Altında Davranışı

## Mean Over Turning Moment (OTM) Coefficient

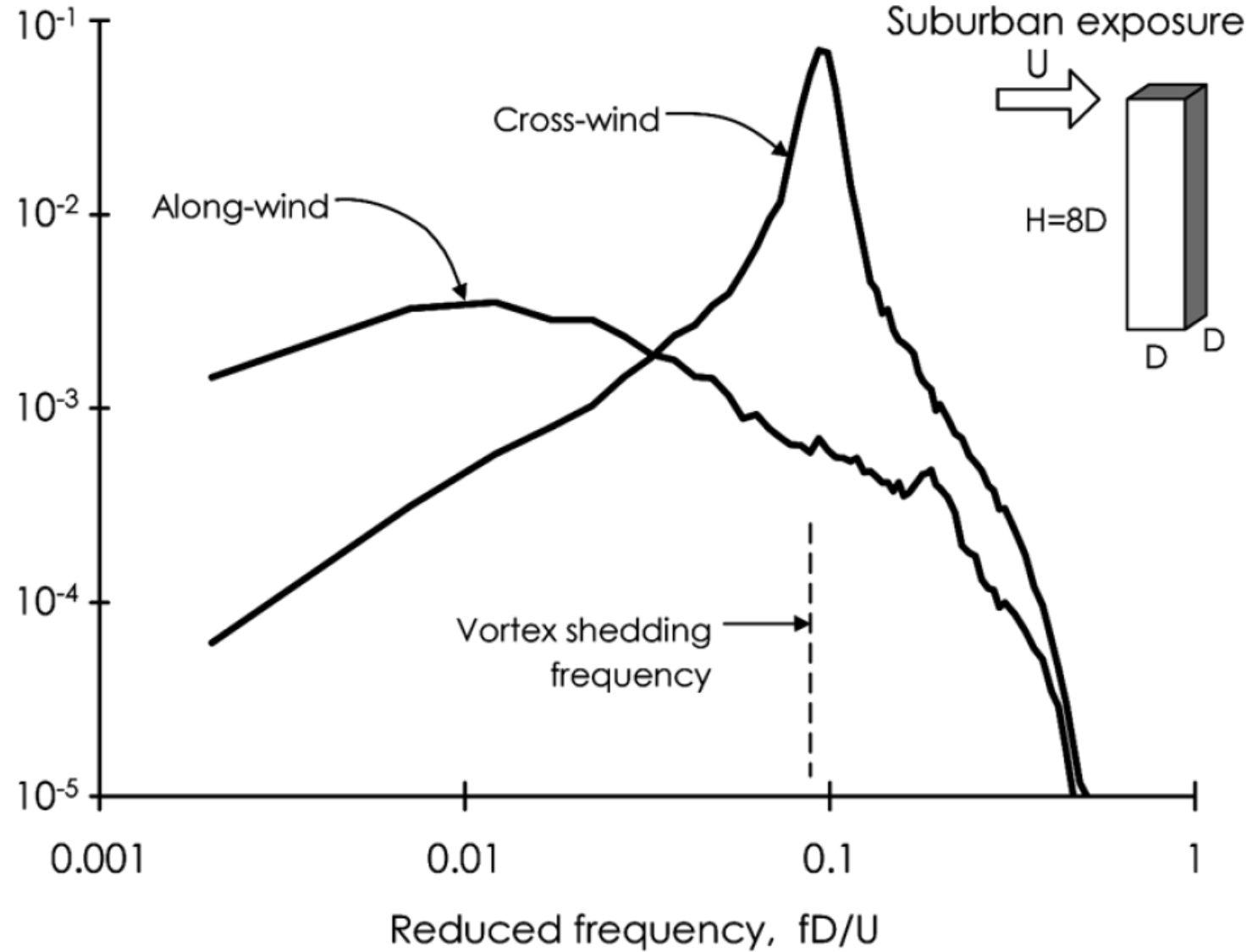


# Yüksek Yapıların Rüzgar Altında Davranışı

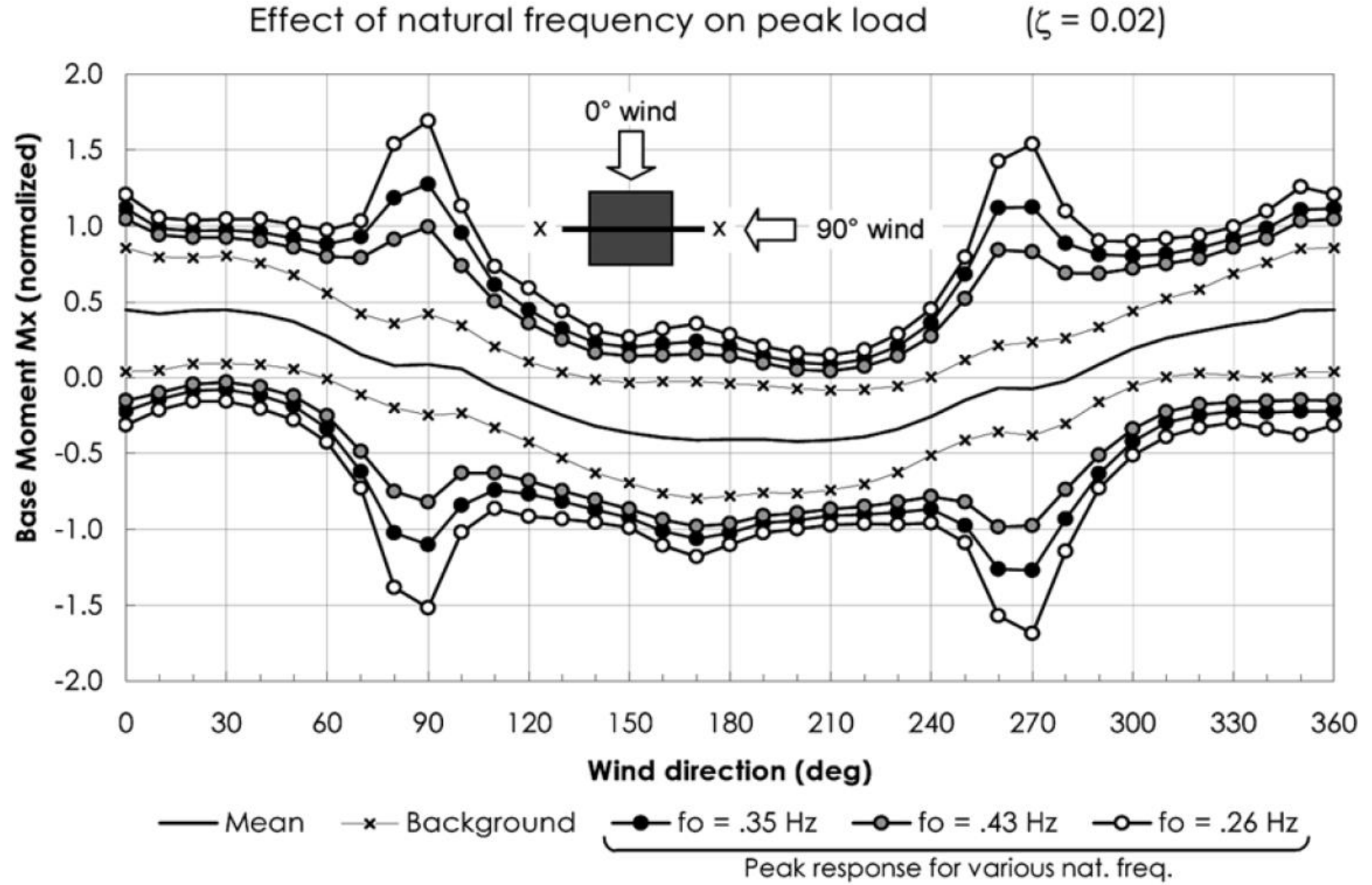


- Yapı yüksekliği arttıkça rüzgara dik yöndeki etkiler daha da artar.
- Rüzgara dik yöndeki kuvvetler ve salınım, rüzgar yönündeki değerlere göre çok daha fazla olur.

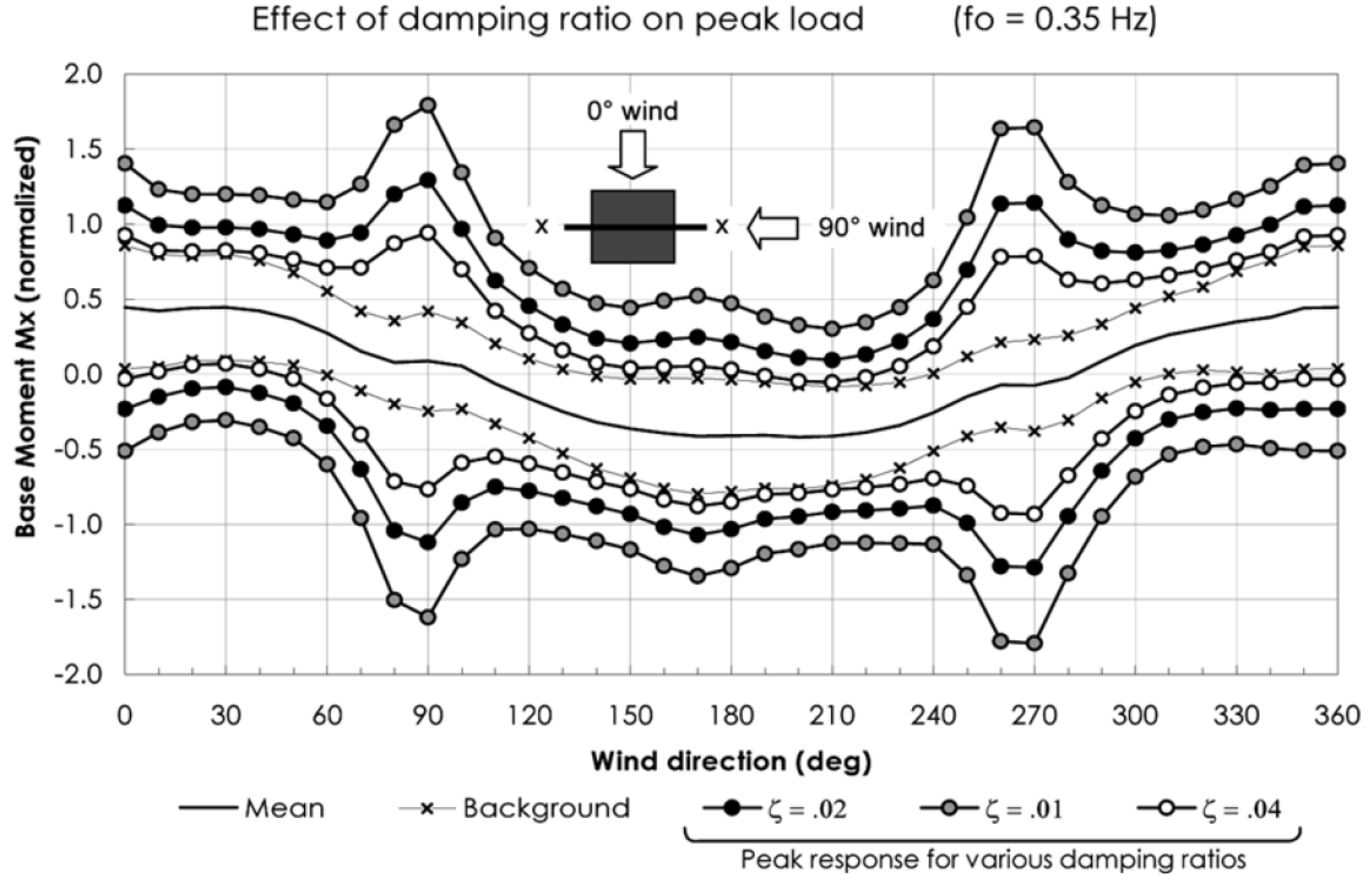
# Yüksek Yapıların Rüzgar Altında Davranışı



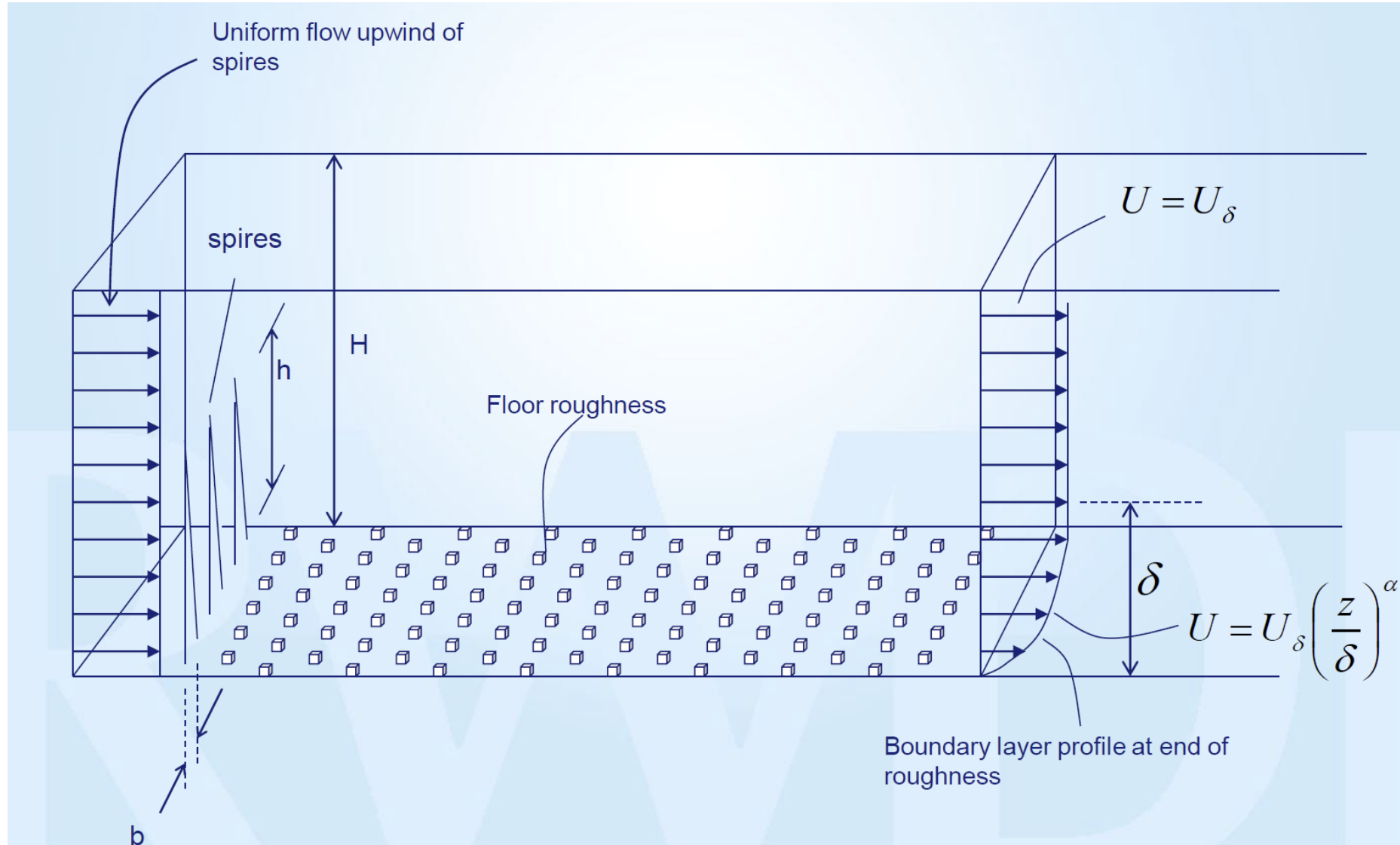
# Yüksek Yapıların Rüzgar Altında Davranışı



# Yüksek Yapıların Rüzgar Altında Davranışı

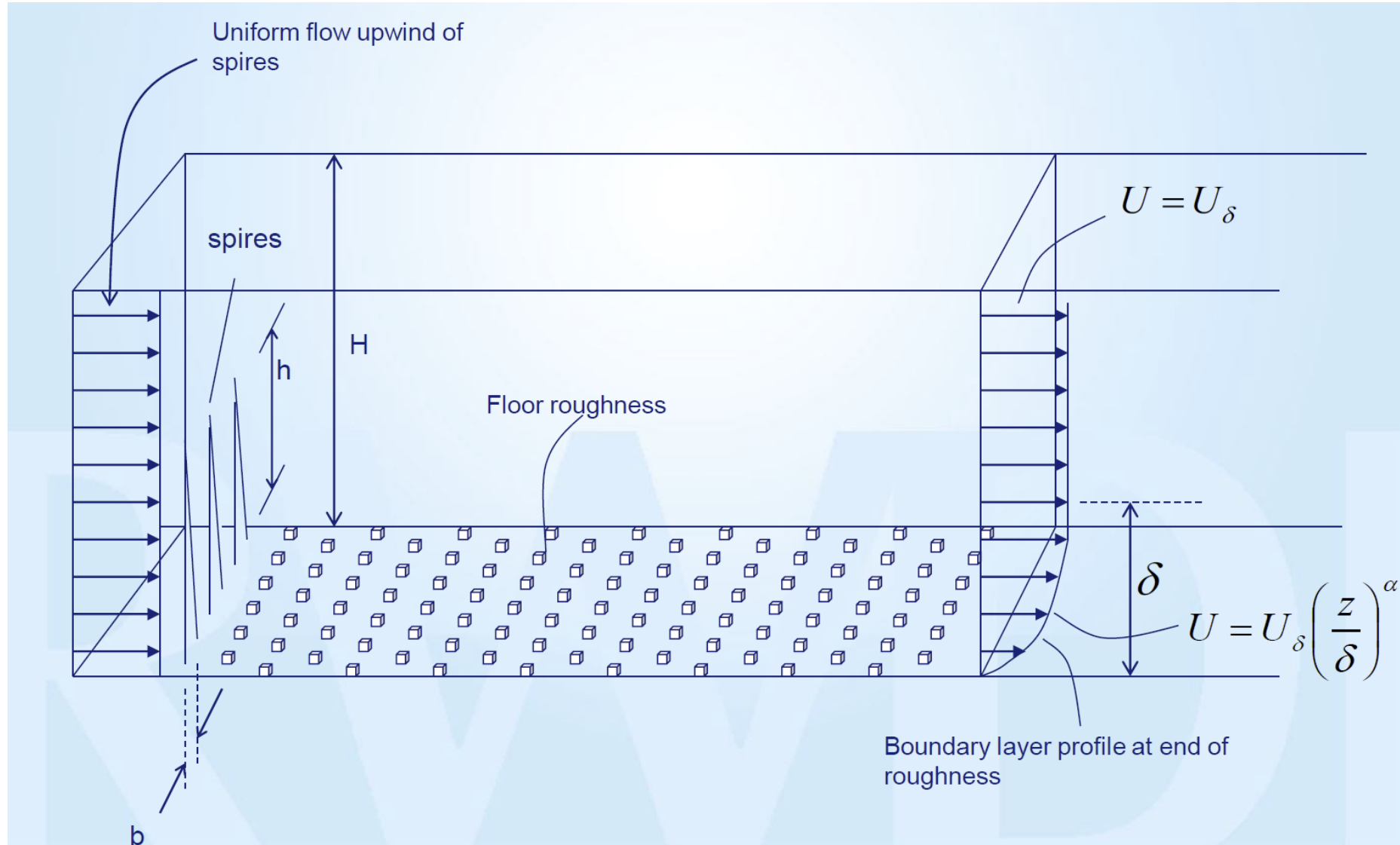


# Rüzgar Tüneli Testleri





# Rüzgar Tüneli Testleri

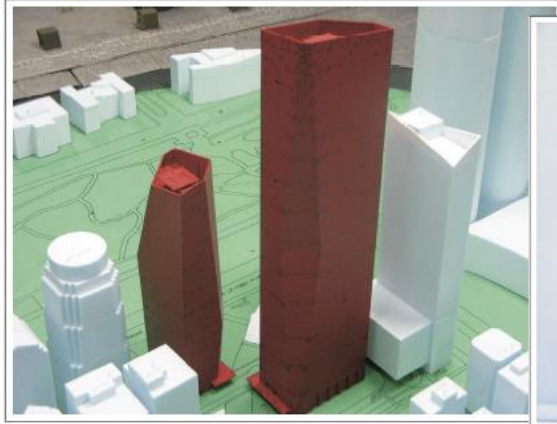




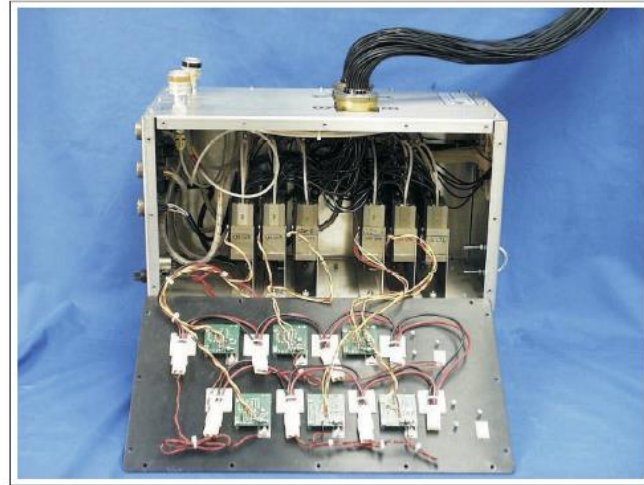
# Rüzgar Tüneli Testleri



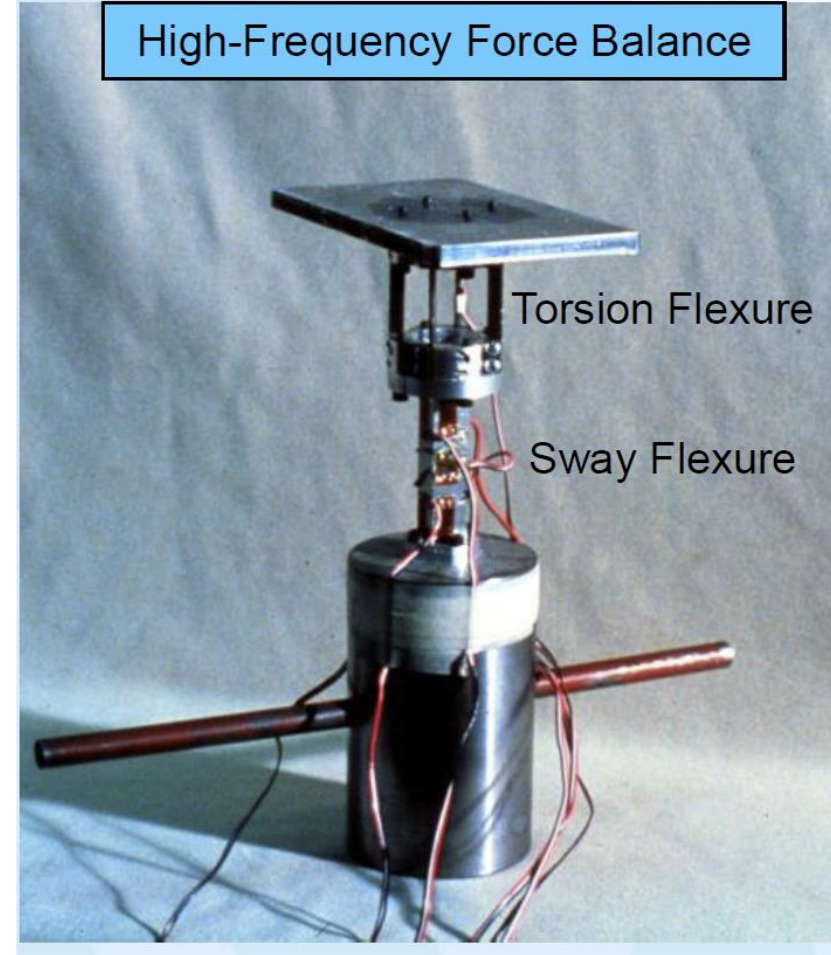
# Rüzgar Tüneli Testleri



(a) Typical Cladding Wind Load Study model

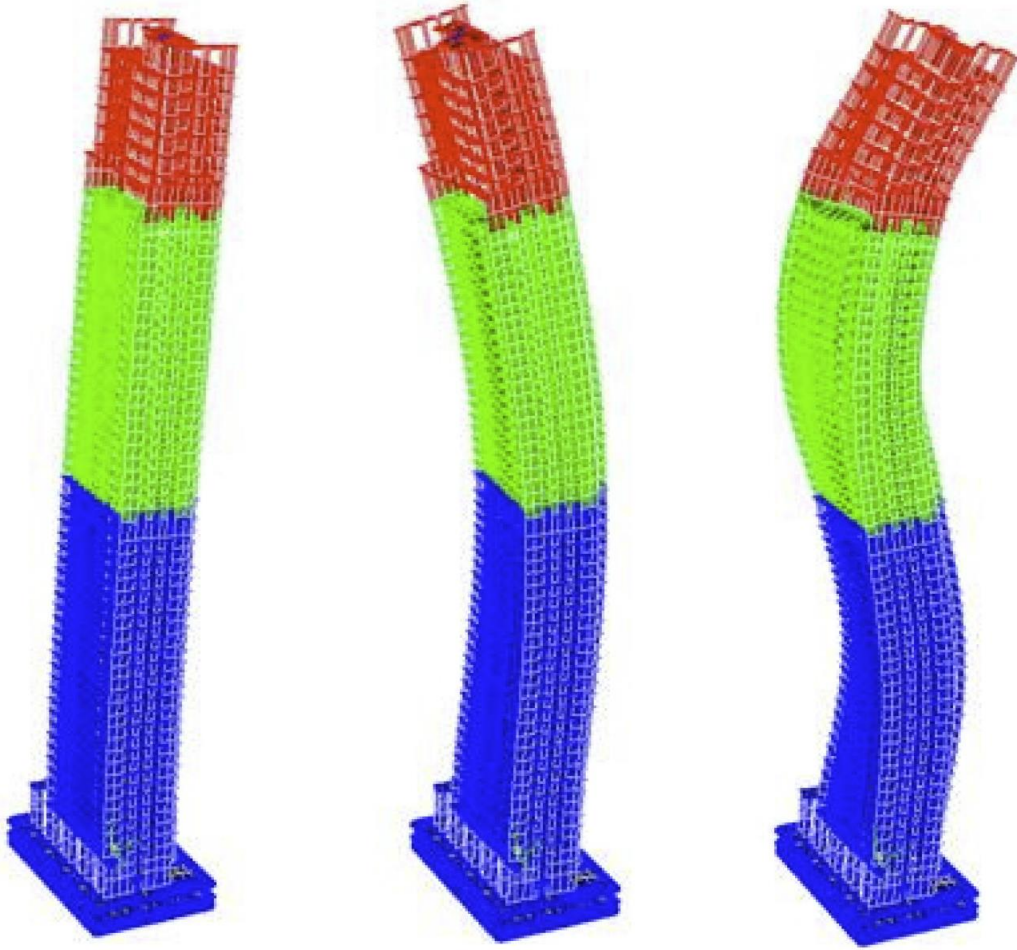


(b) Data Acquisition

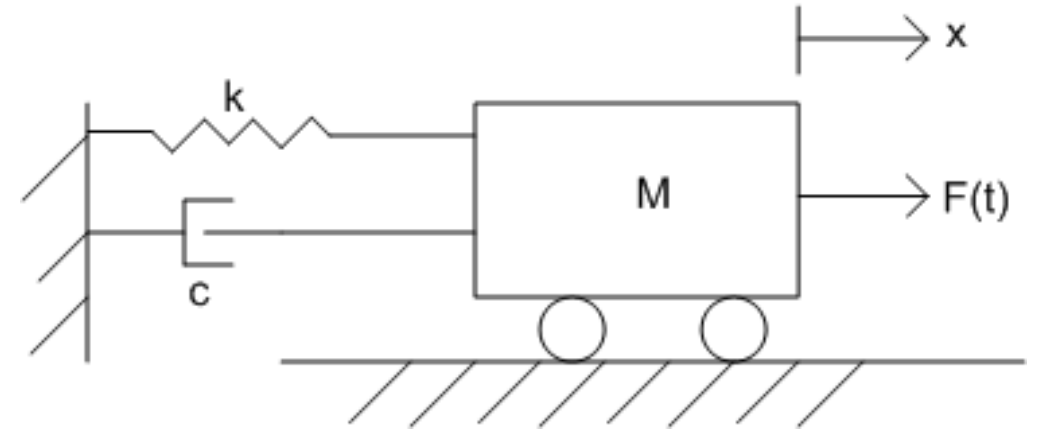




# Salınım ve İvmeler



- Her bir mod tek serbestlikli sistem gibi düşünülebilir.
- Her mod için eşdeğer kuvvet bulunabilir
- Bu kuvvetler altında ivmeler hesaplanabilir
- Mod birleştime uygulanabilir



# Salınım ve İvmeler

- Kanada Yönetmeliği
- Amerikan Yönetmeliği
- Avrupa Yönetmeliği
- Japon Yönetmeliği

Serviceability:	10-year recurrence
Nominal Strength:	50-year to 100-year recurrence
Ultimate strength:	500-year to 1000-year recurrence

# Salınım ve İvmeler

- Kanada Yönetmeliği

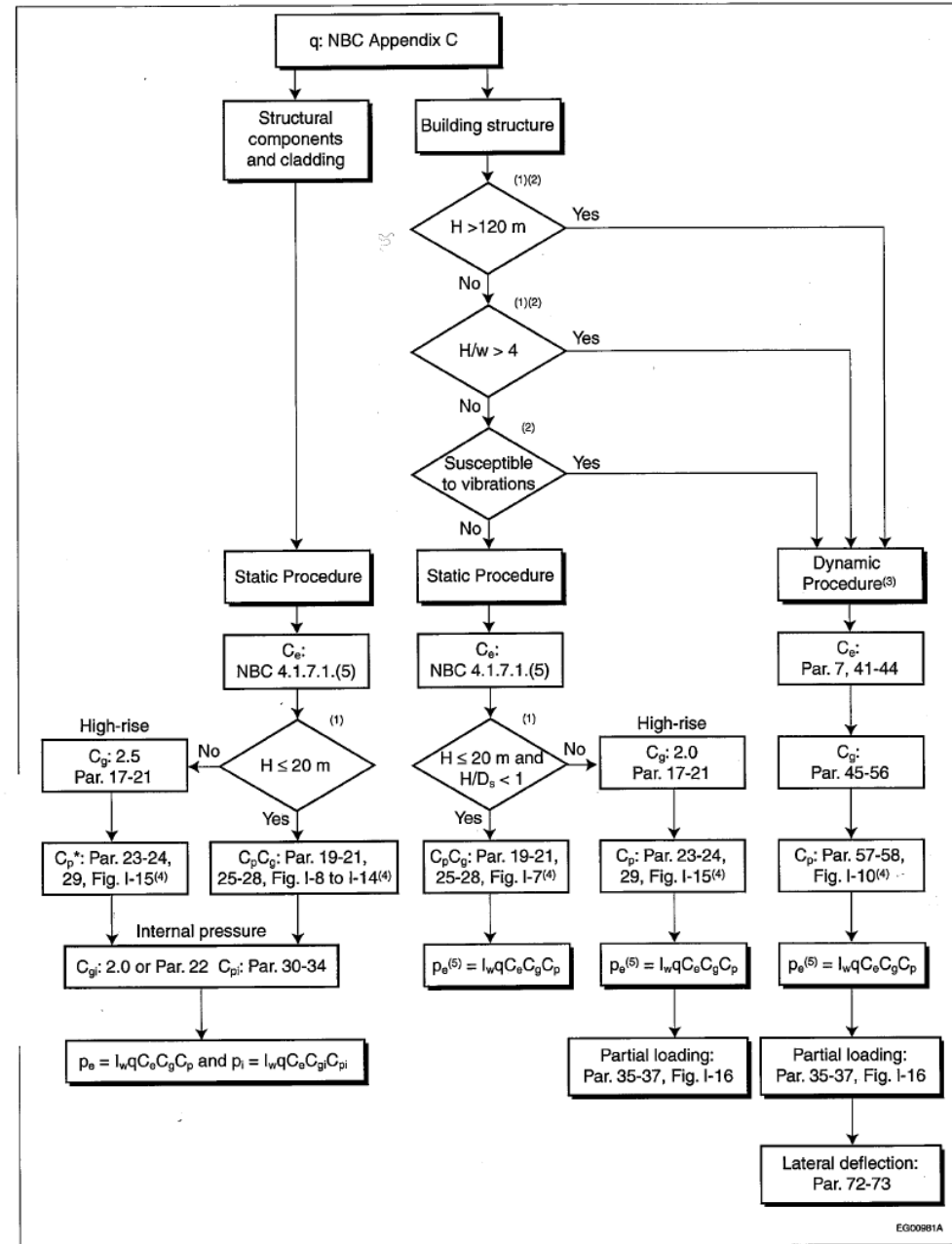
## National Building Code of Canada 2010

Volume 2

$$W_p = \mu + g_p \sigma$$

where

- $\mu$  = mean loading effect,
- $g_p$  = statistical peak factor for the loading effect, and
- $\sigma$  = "root-mean square" loading effect.



EG00981A

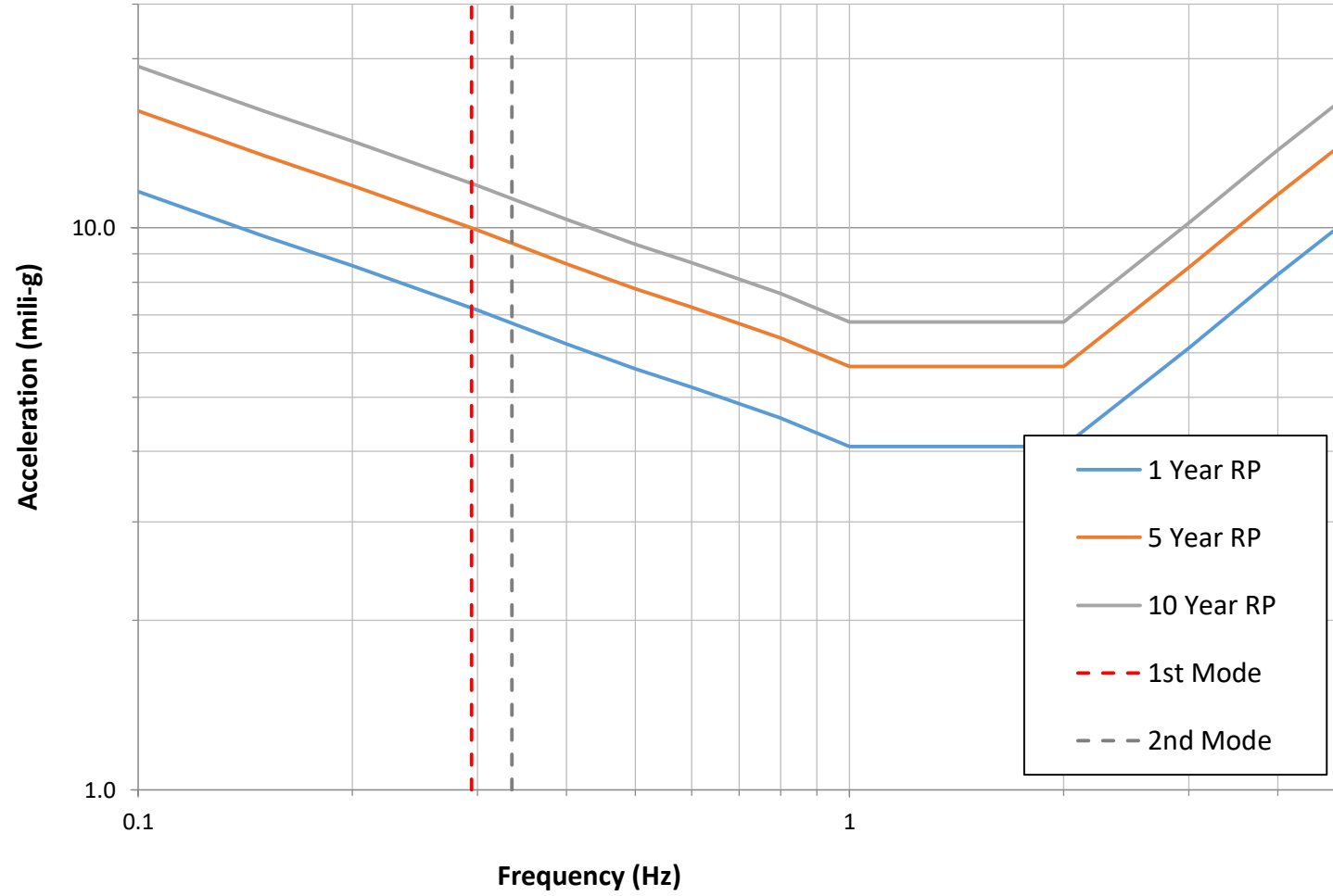
# Salınım ve İvmeler

$$a_w = f_{nW}^2 g_p \sqrt{w_d} \left( \frac{a_r}{\rho_B g \sqrt{\beta_w}} \right) \quad a_D = 4\pi^2 f_{nD}^2 g_p \sqrt{\frac{K_s F}{C_{eH} \beta_D}} \frac{\Delta}{C_g}$$

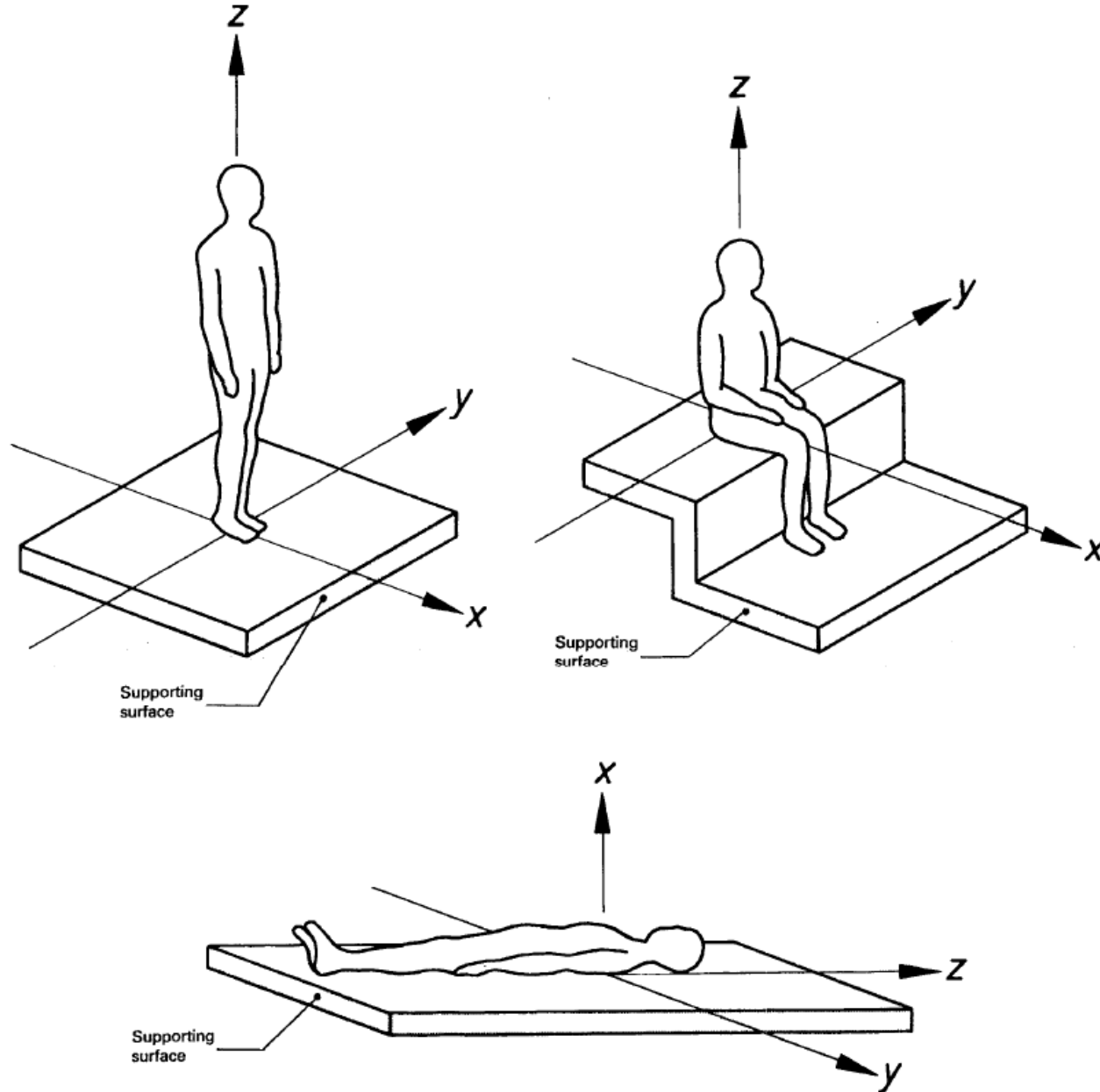
Historically, Equations (17) and (18) have been used with one-in-ten-year wind acceleration limits of 1% to 3% of  $g$  for the preliminary assessment of tall buildings. In North America in the period 1975 to 2000, many of the tall buildings that underwent detailed wind tunnel studies were designed for a peak one-in-ten-year acceleration in the range of 1.5% to 2.5% of  $g$ . The lower end of this range was generally applied to residential buildings and the upper end to office towers; their performance based on these criteria appears to have been generally satisfactory. Other criteria have been published that depend on the building's lowest natural frequency. The ISO criterion<sup>[31]</sup> can be expressed as a peak acceleration not exceeding  $0.928 f^{0.412}$  once every 5 years, where  $f$  is the lowest natural frequency in Hz. This results in a 5-year criterion of about 1.8% of  $g$  when  $f = 0.2$  Hz, and 2% of  $g$  when  $f = 0.1$  Hz.

# Salınım Algısı

ISO 10137 Residential

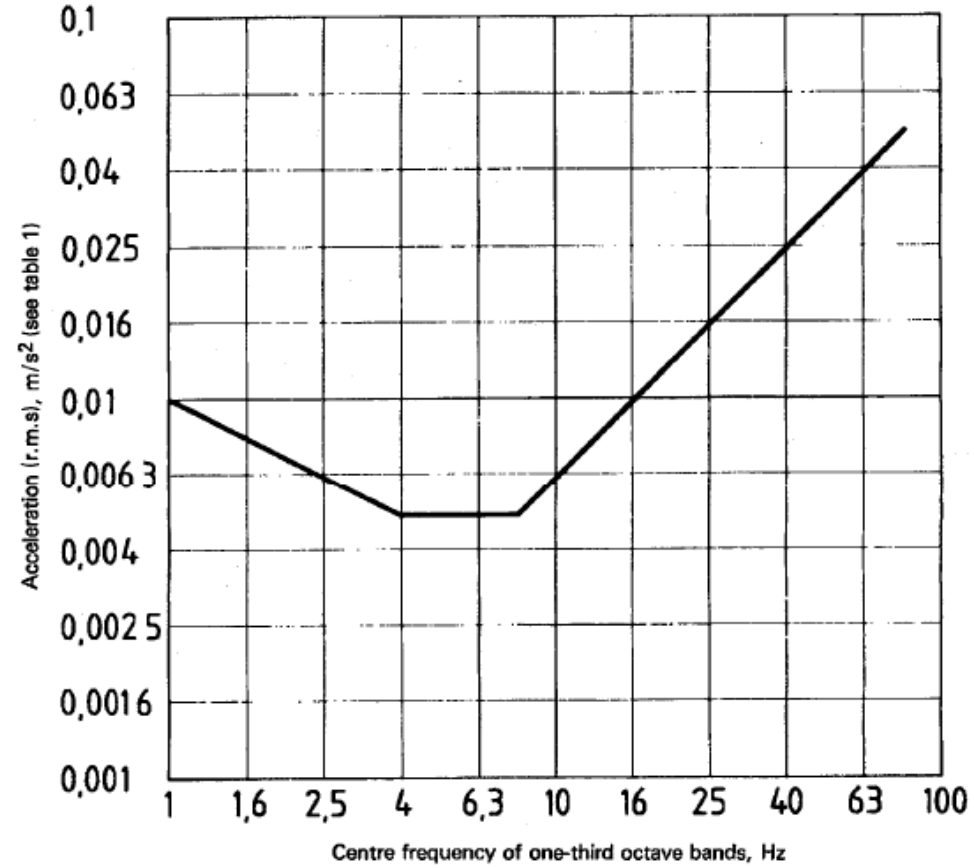


# Salınım Algısı

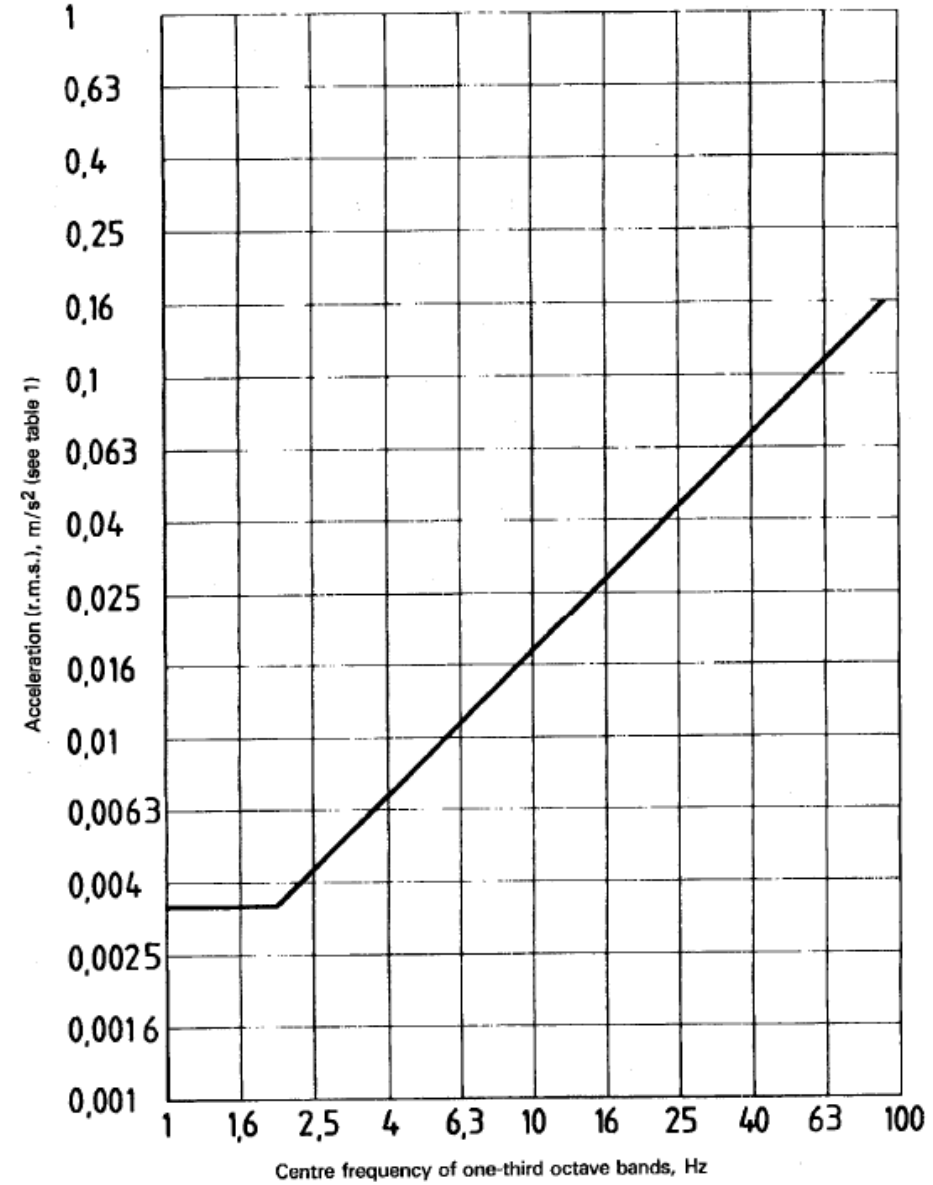




# Salınım Algısı

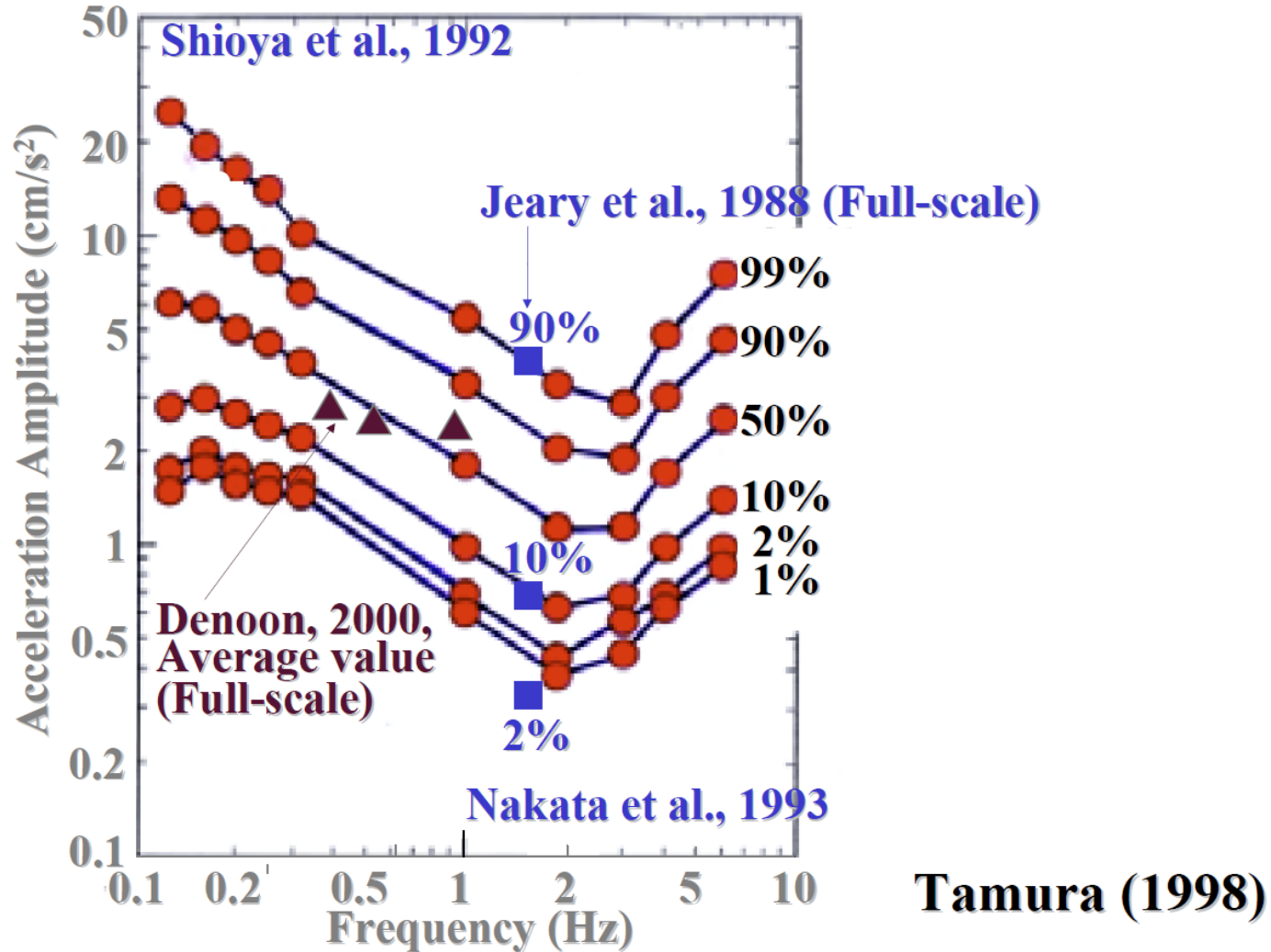


# Salınım Algısı

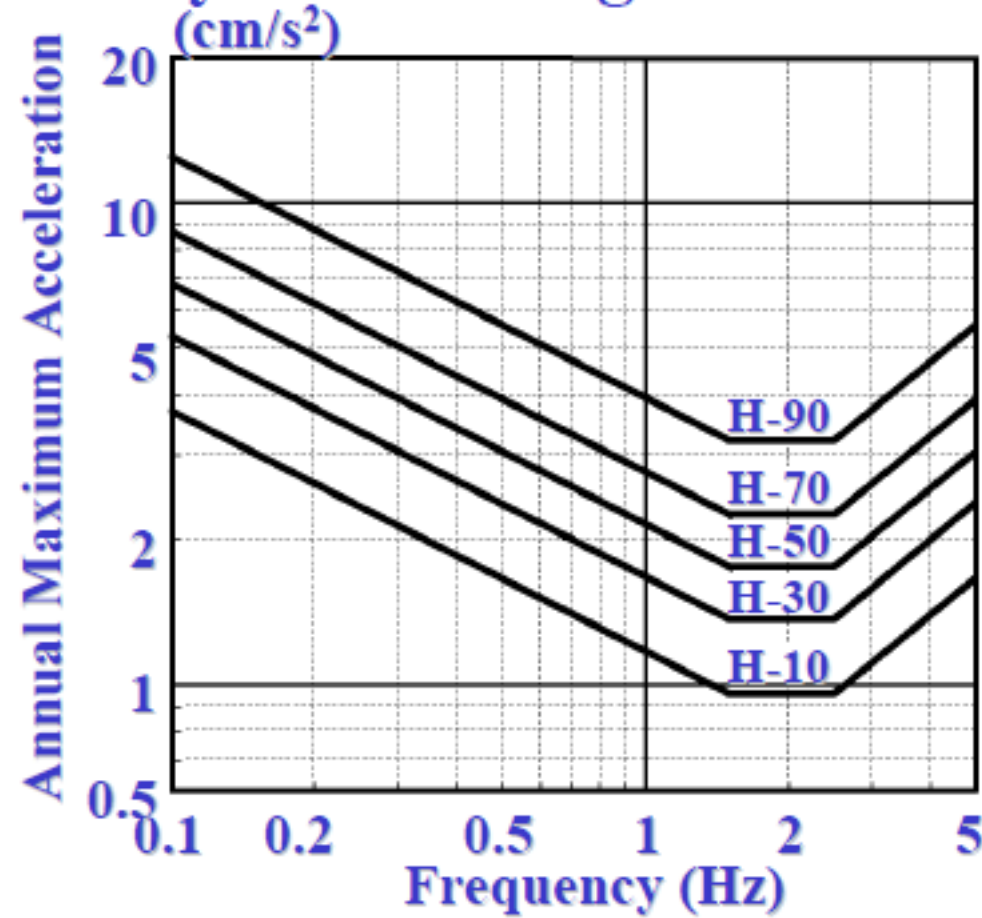


**Figure 3a — Building vibration x- and y-axis base curve for acceleration**  
(this represents the side-to-side and back-to-chest vibration base curve, see 4.2.2)

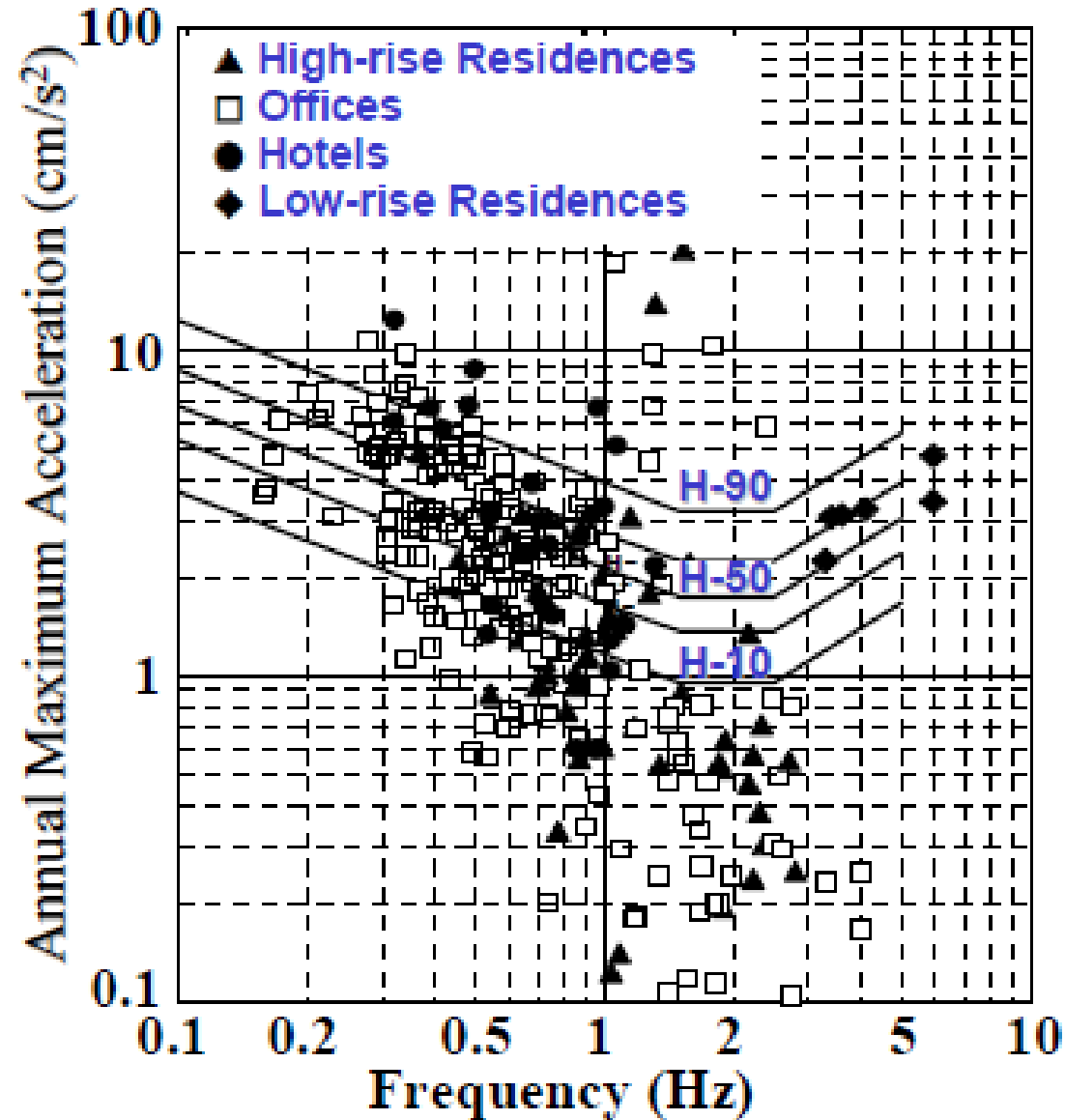
## Probabilistic Human Perception Threshold



## AIJ Guidelines for the Evaluation of Habitability to Building Vibration (2004)

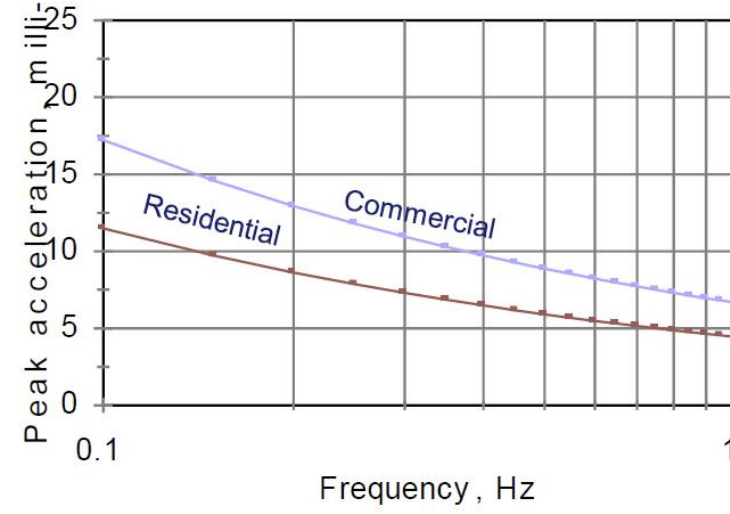


## AIJ Guidelines 2004



# Salınım Algısı

ISO Criteria for single frequency



Moving room simulations of multiple frequencies

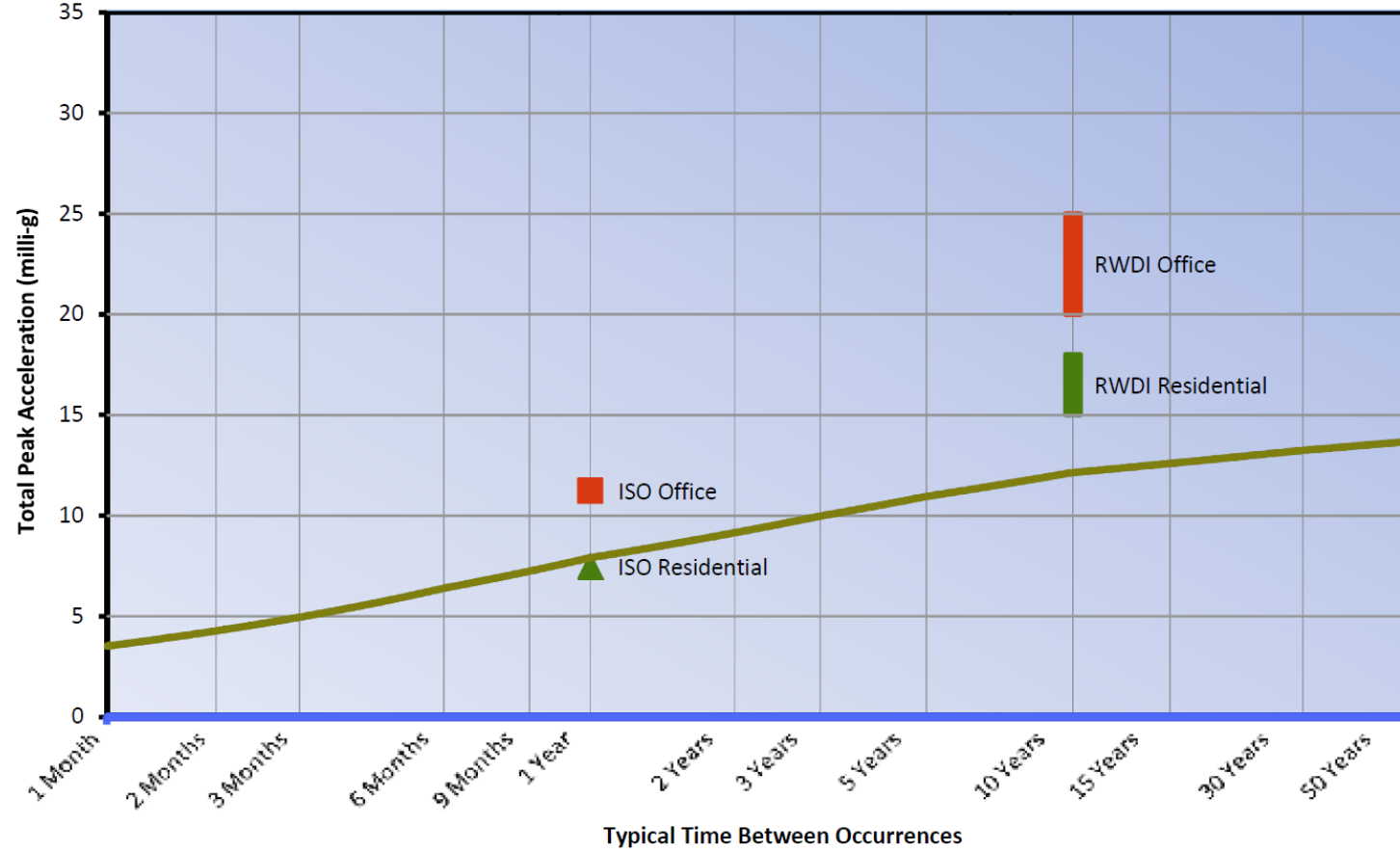




# Salınım Algısı



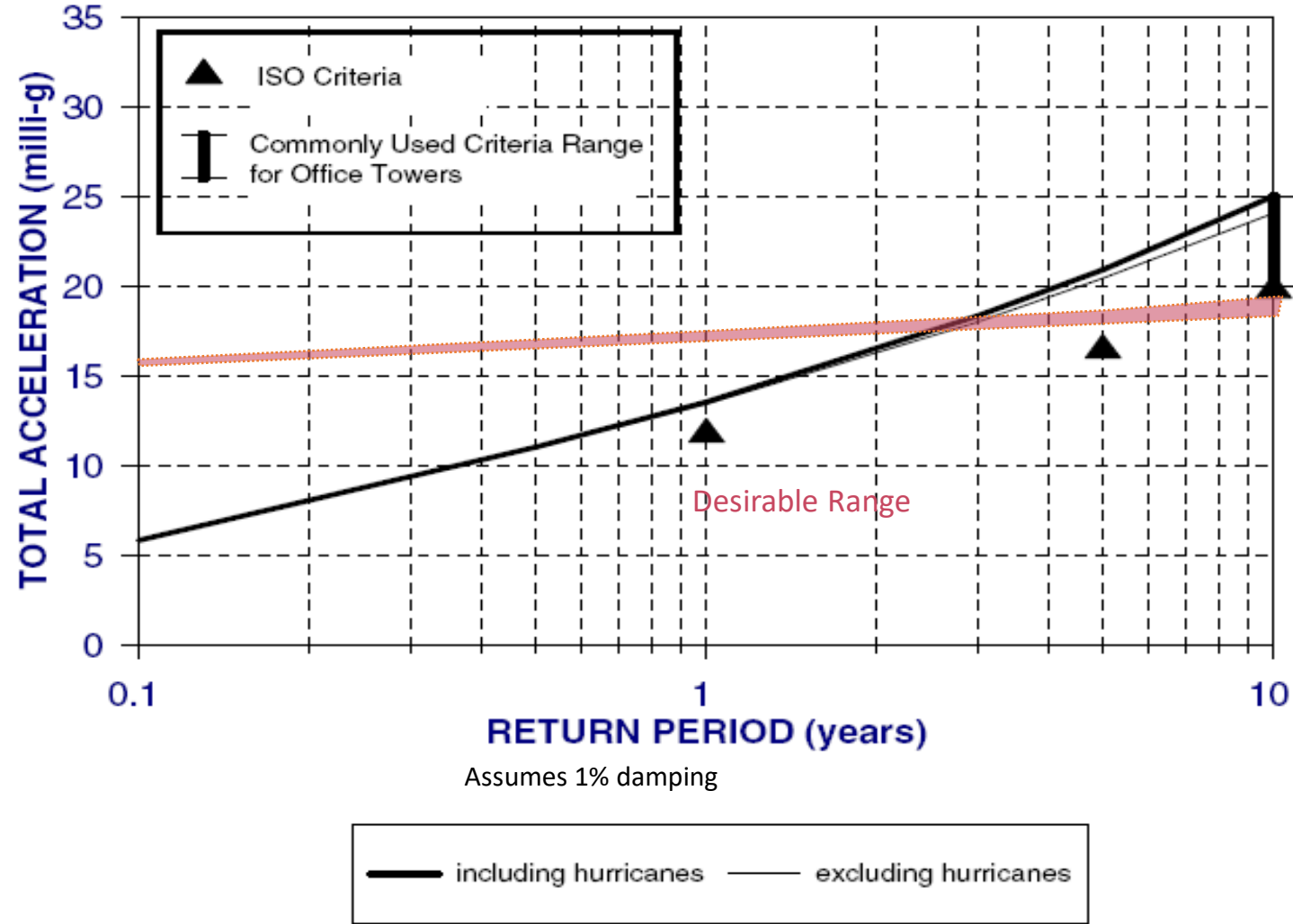
# Salınım Algısı



Return Period (Years)	Peak Accelerations <sup>(2)</sup> Total - [X, Y and torsional components] (milli-g)	Peak Torsional Velocities (milli-rads/sec)	
		Predicted	CTBUH <sup>(5)</sup> Criteria
1	7.9 - [4.6, 4.8, 4.7]	1.0	1.5
5	11 - [6.2, 6.5, 6.9]	1.4	-
10	12 - [6.9, 7.2, 7.6]	1.5	3

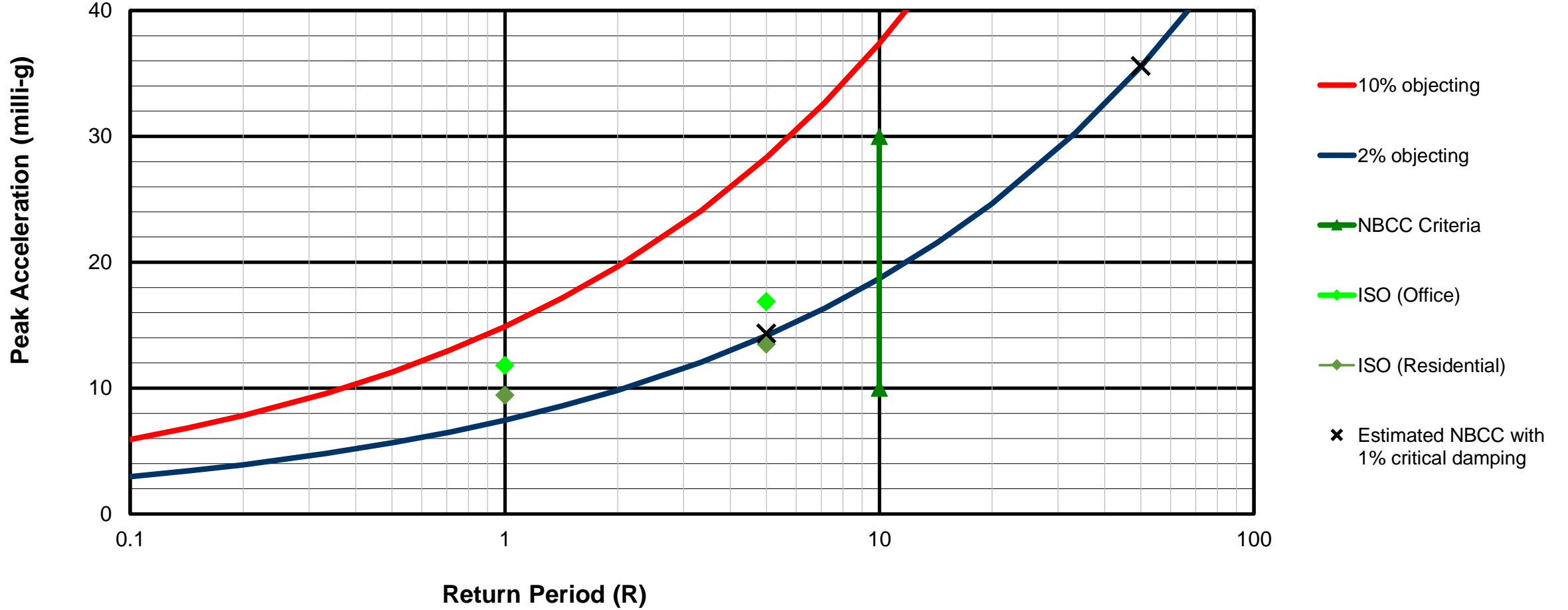


# Salınım Algısı

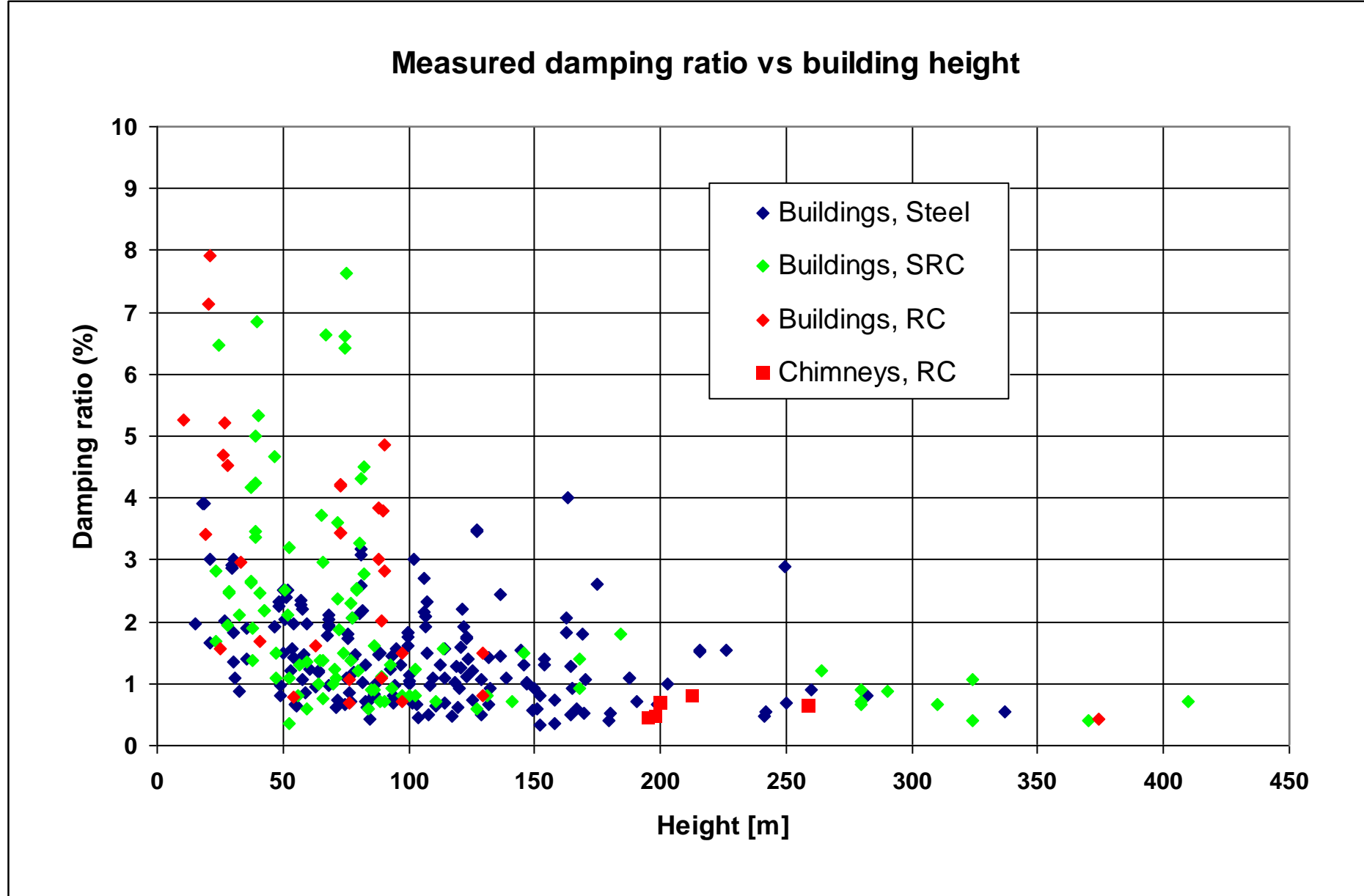


# Salınım Algısı

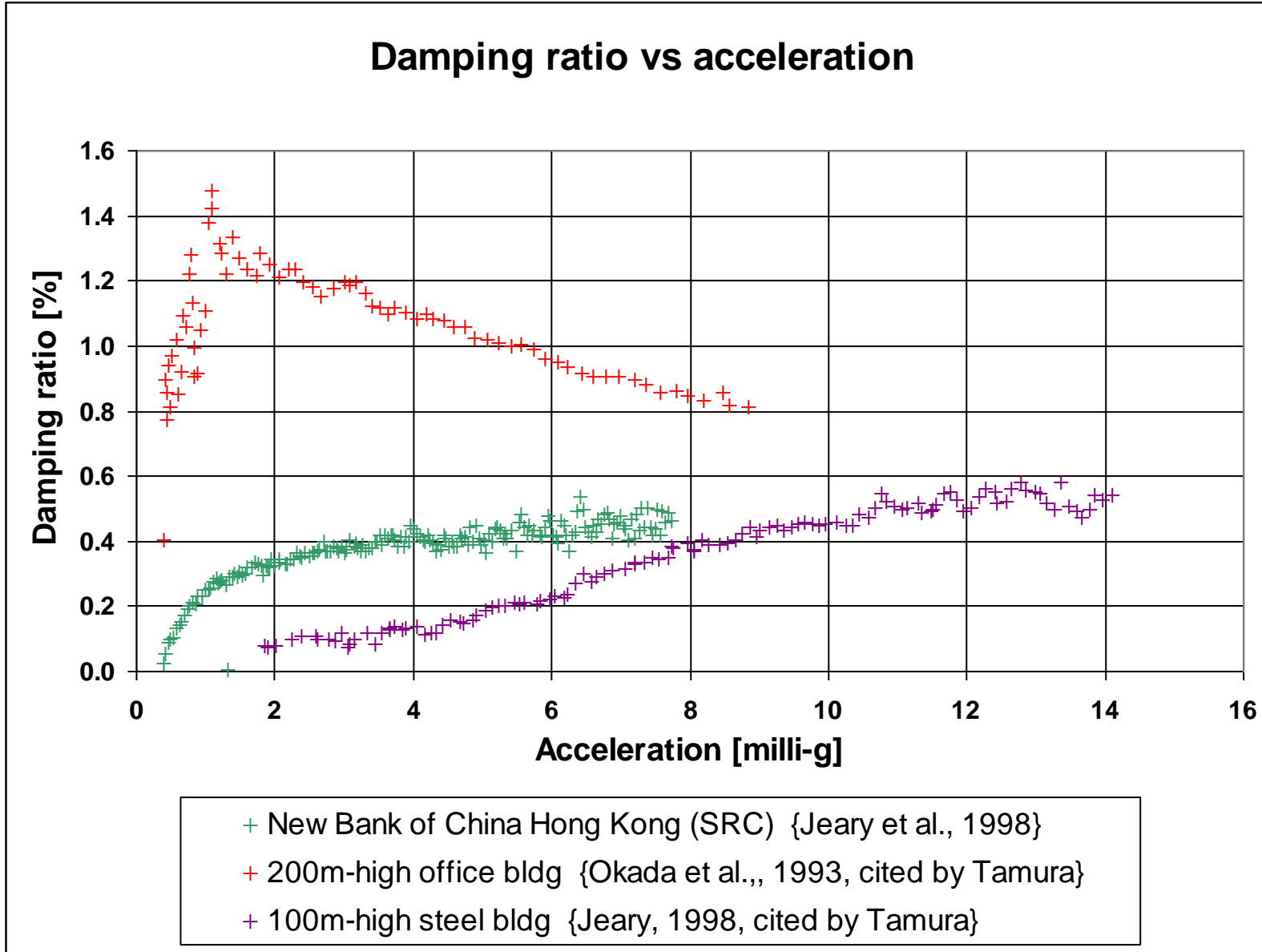
Acceptability Criteria for sway of building of 4.88sec period



# Salınım Azaltma Yöntemleri



# Salınım Azaltma Yöntemleri



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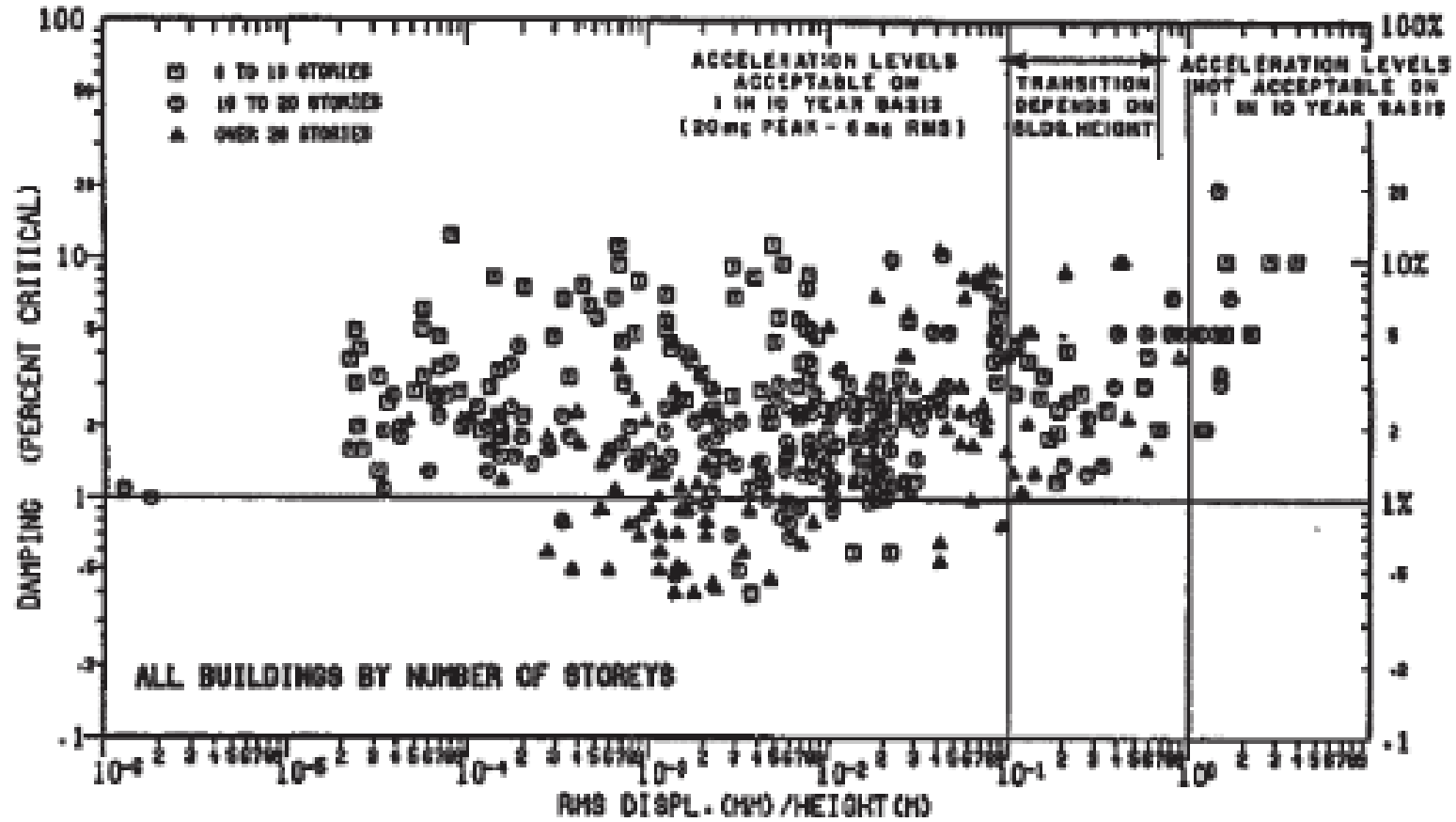


Figure 17 — Summary of damping estimates by amplitude of vibration by Davenport and Hill-Carroll (1986).

# Salınım Azaltma Yöntemleri

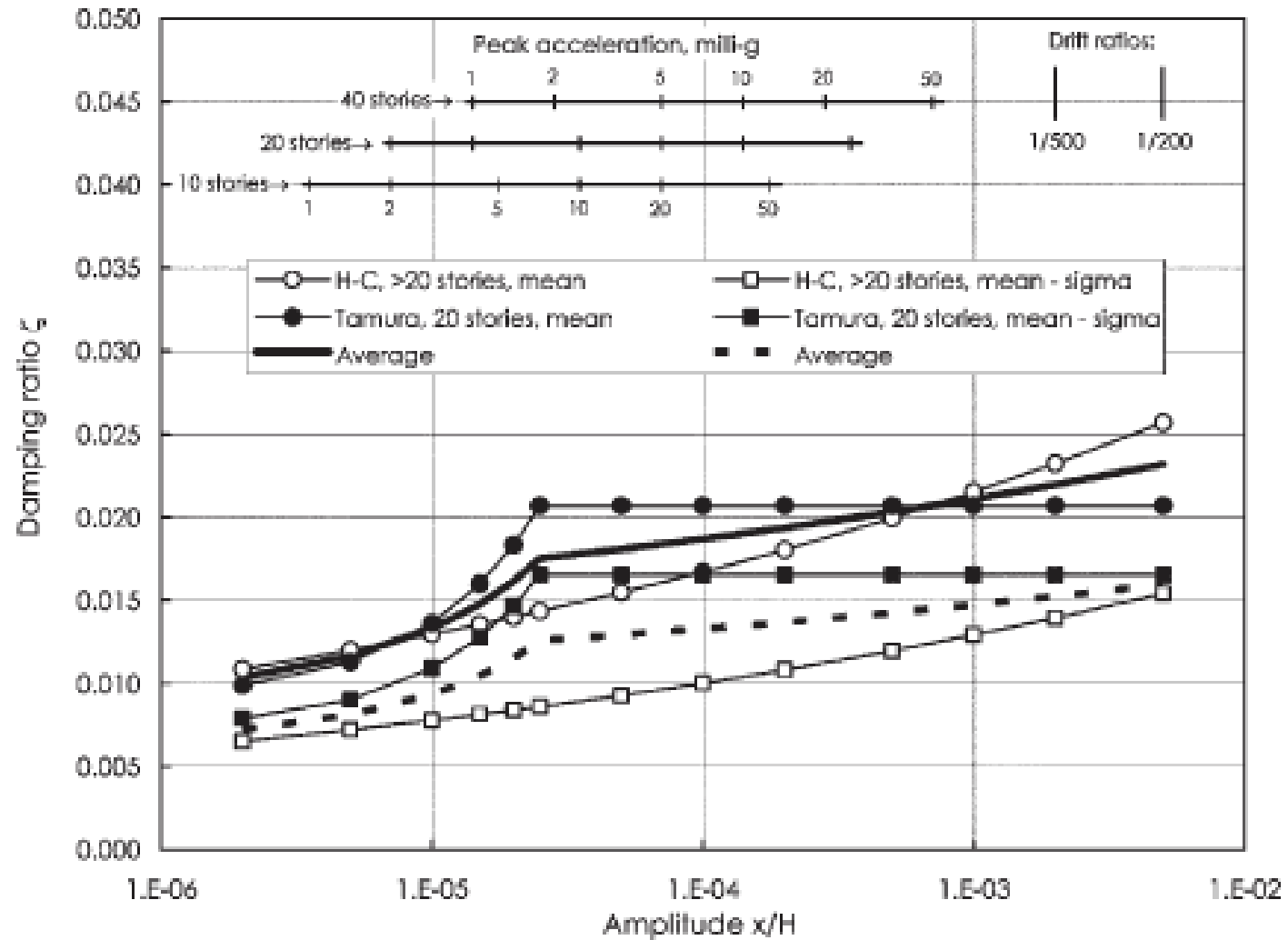
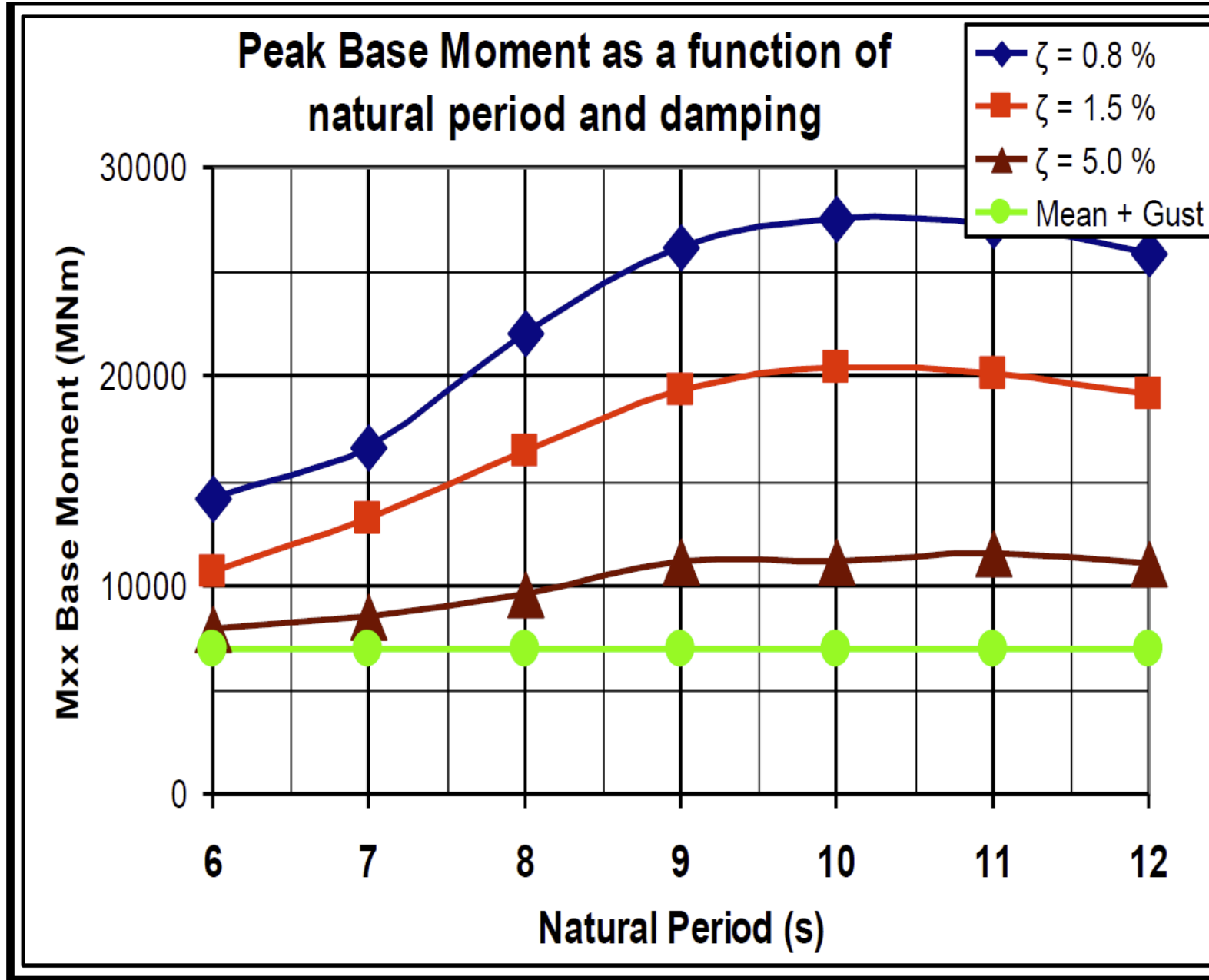
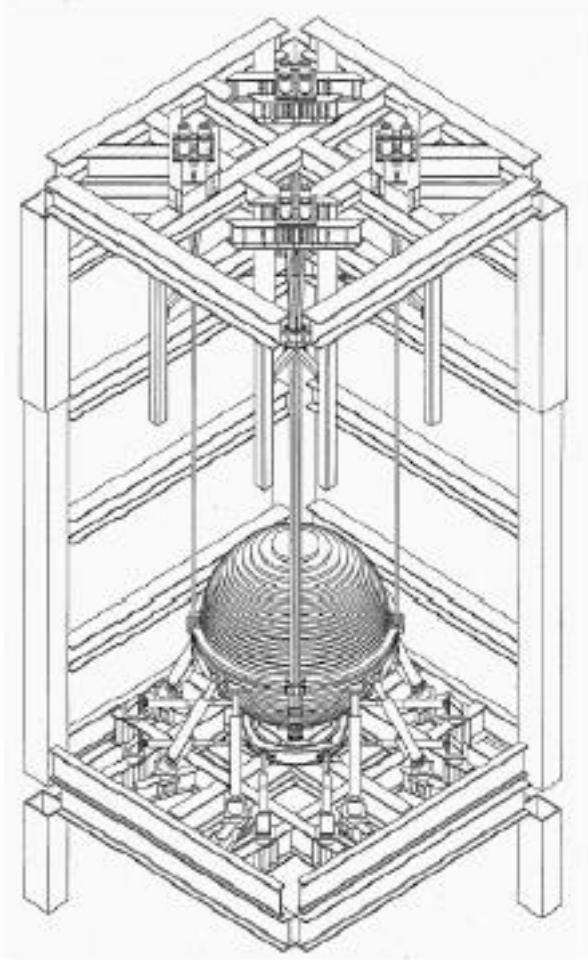


Figure 19 — Summary of damping prediction curves by Hill-Carroll (H-C) and Tamura.

# Sönümleyiciler

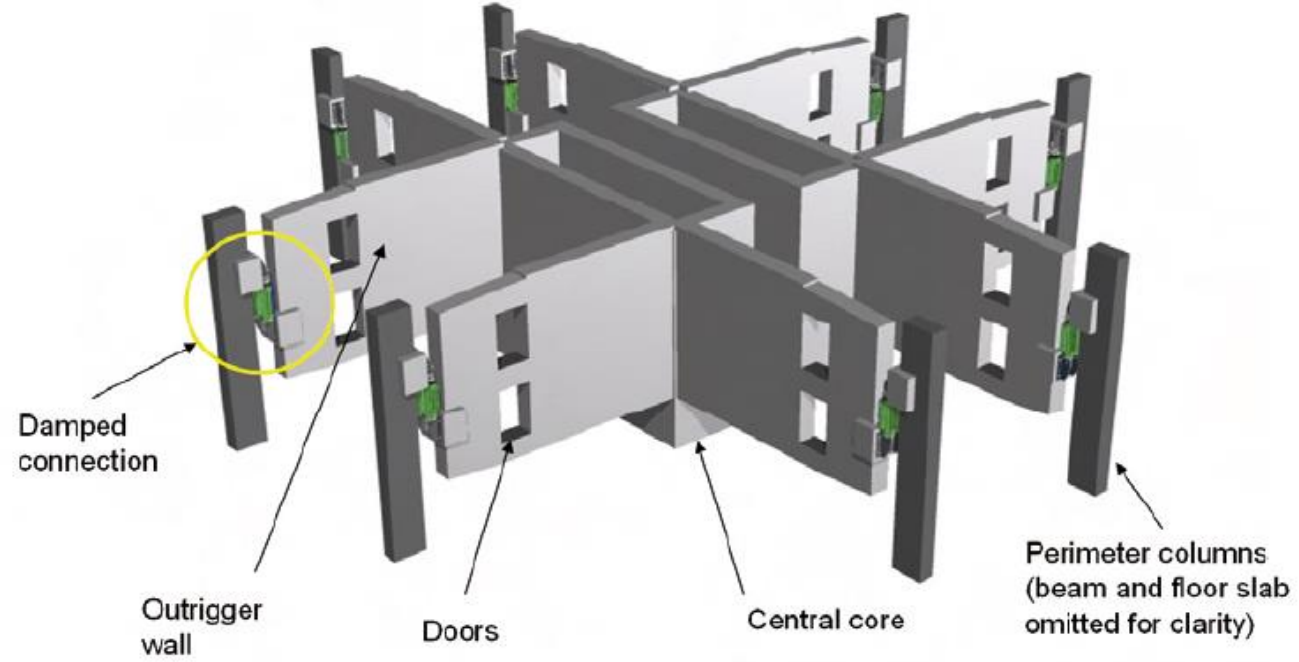


# Ayarlı Kütle Sönümleyiciler



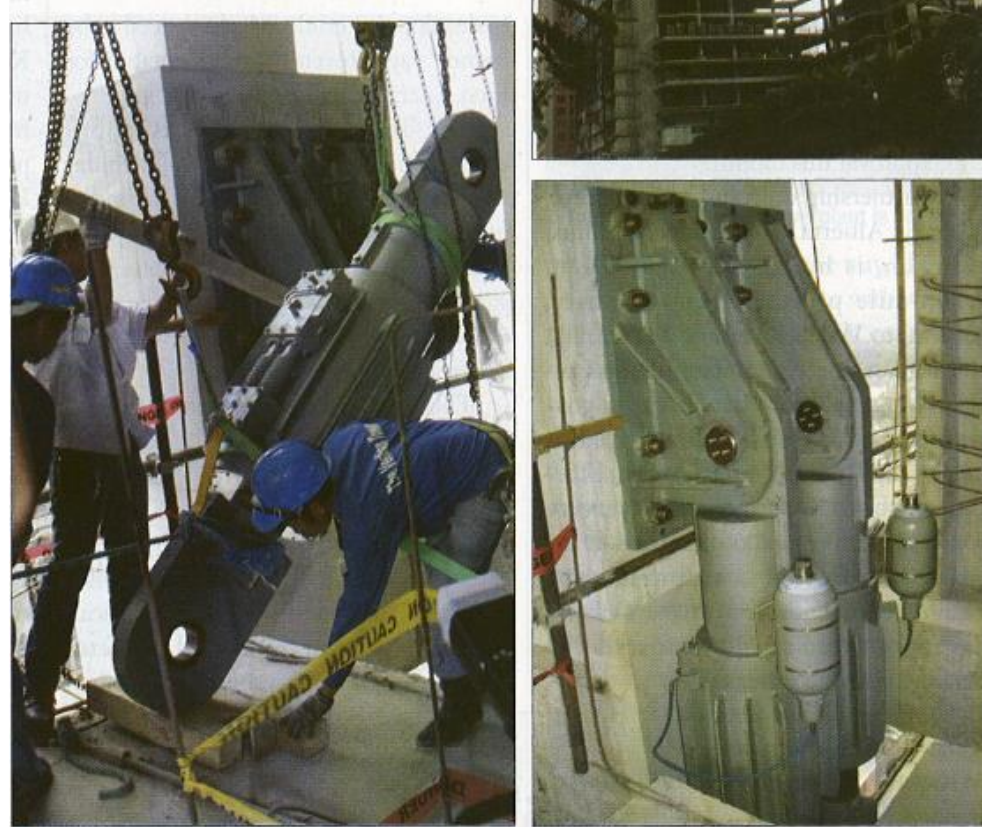


# Sönümleyicili Dışdestek Sistemi



Arup Damped Outrigger System

# Sönümleyicili Dışdestek Sistemi



▲ **Weight Reducers.** Dampers on 60-story towers reduced concrete needed by 20%, saving \$4 million.



St Francis Towers, Manila – 5-7%  
Sönümleme



Los Faros de Panama – 2-4%  
Sönümleme