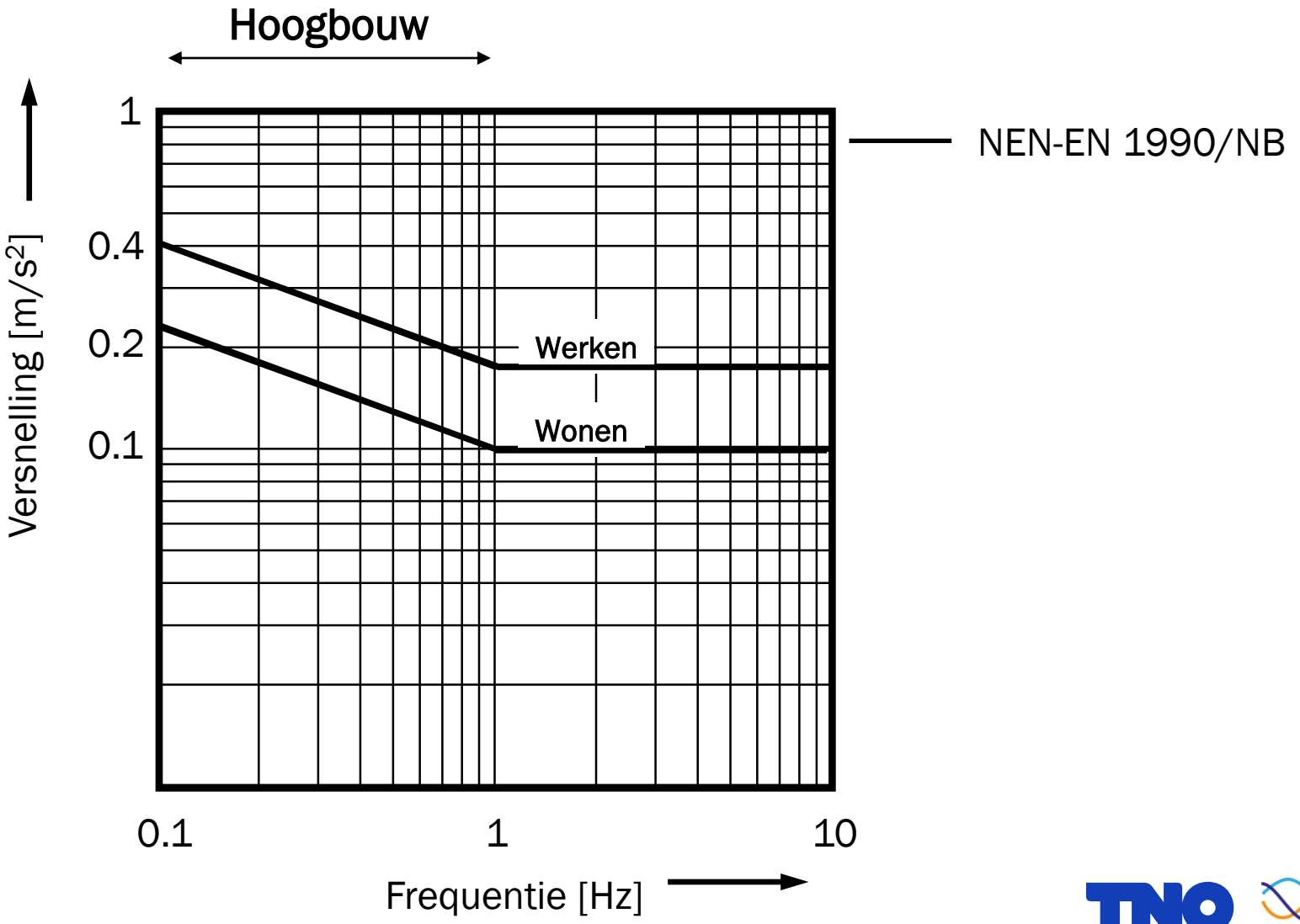
HiViBe

Voorspelling en beleving van windtrillingen in hoogbouw

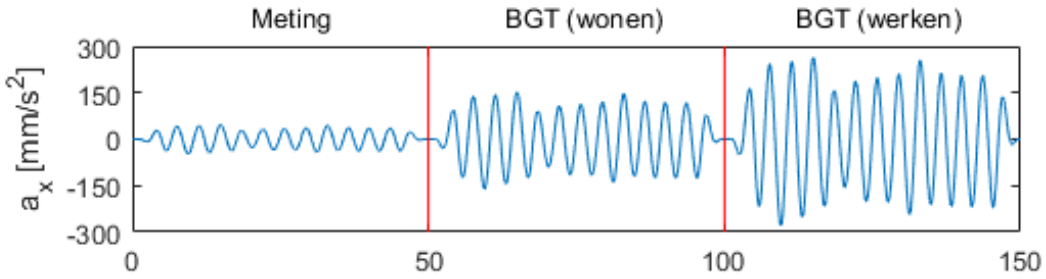
26 September 2023

Okke Bronkhorst, Davide Moretti, Chris Geurts, Joke Luyten, Thomas van Dijk en Jitse Pruiksma

Beoordeling windtrillingen Nederlandse hoogbouw



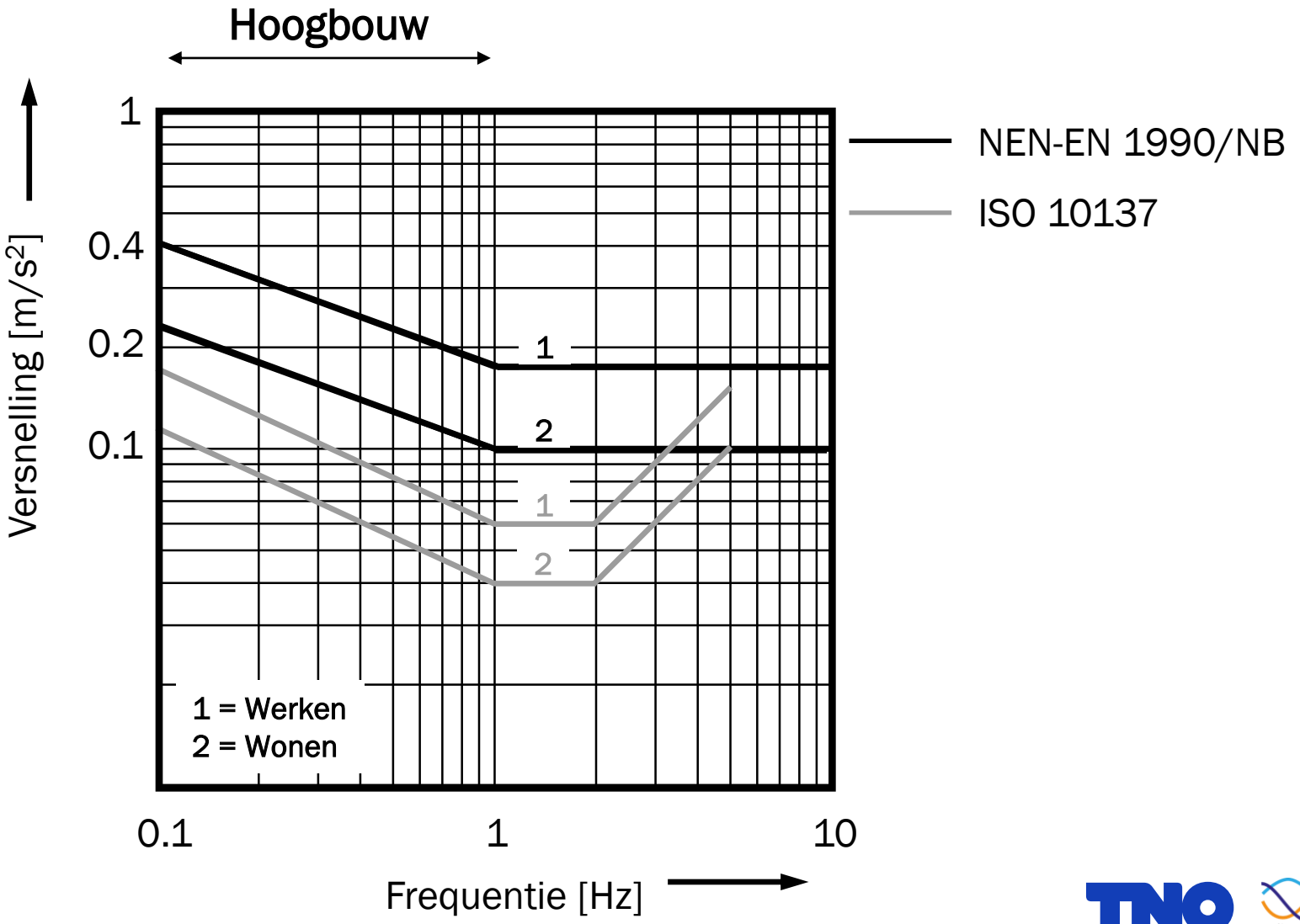
Beleving windtrillingen Nederlandse hoogbouw



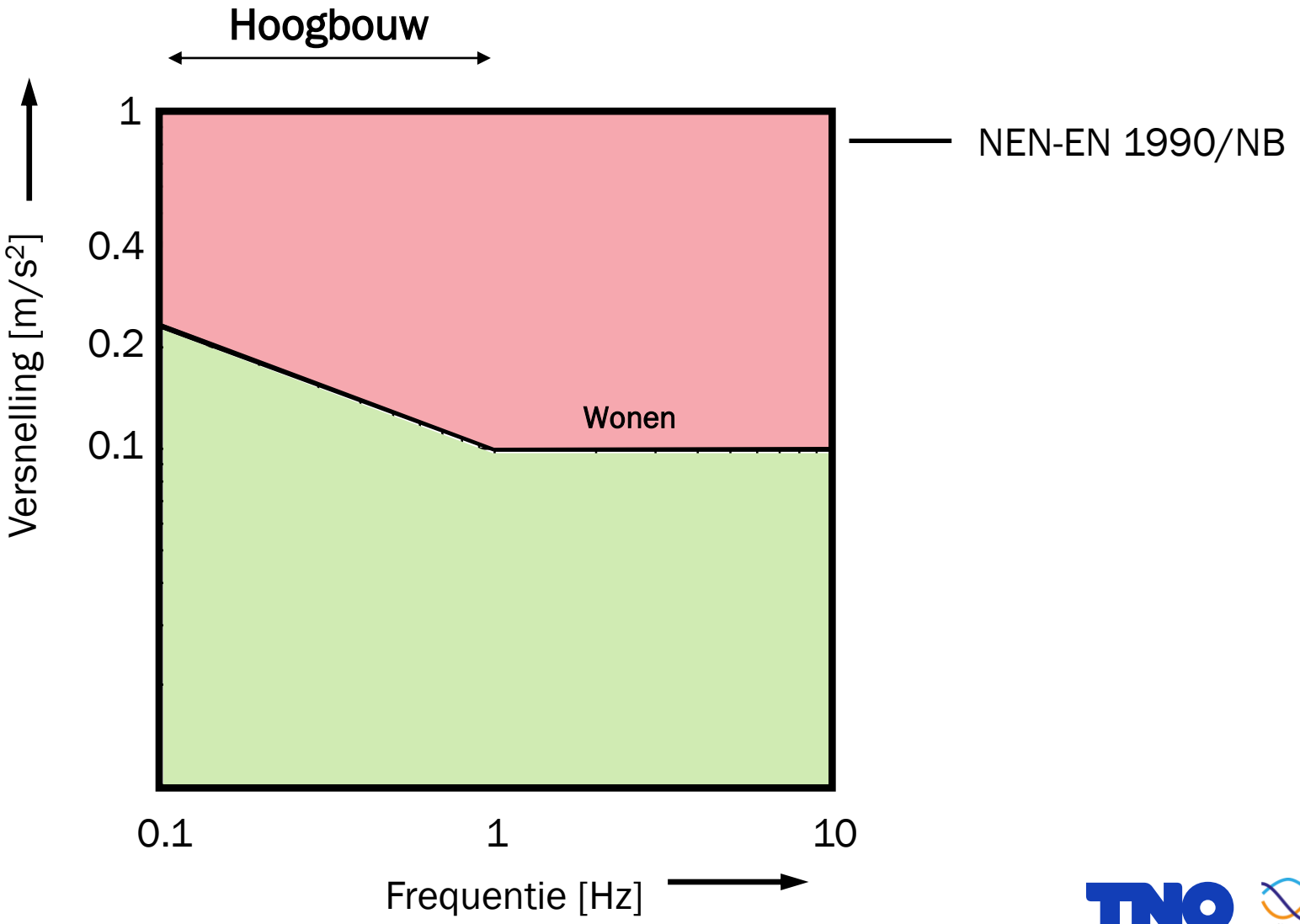
Waarneming	Meting	Wonen	Werken
Niets gemerkt	2 personen		
Gevoeld	32 personen	14 personen	3 personen
Beetje hinderlijk		18 personen	15 personen
Hinderlijk		2 personen	9 personen
Zeer hinderlijk			6 personen
Beangstigend			2 personen

C.P.W. Geurts, *Gevoelig voor trilling?*, Bouwen met Staal, 266, 2018.
C.P.W. Geurts, *Beleving van trillingen in hoogbouw*, GTL Hoevelaken, 2019.

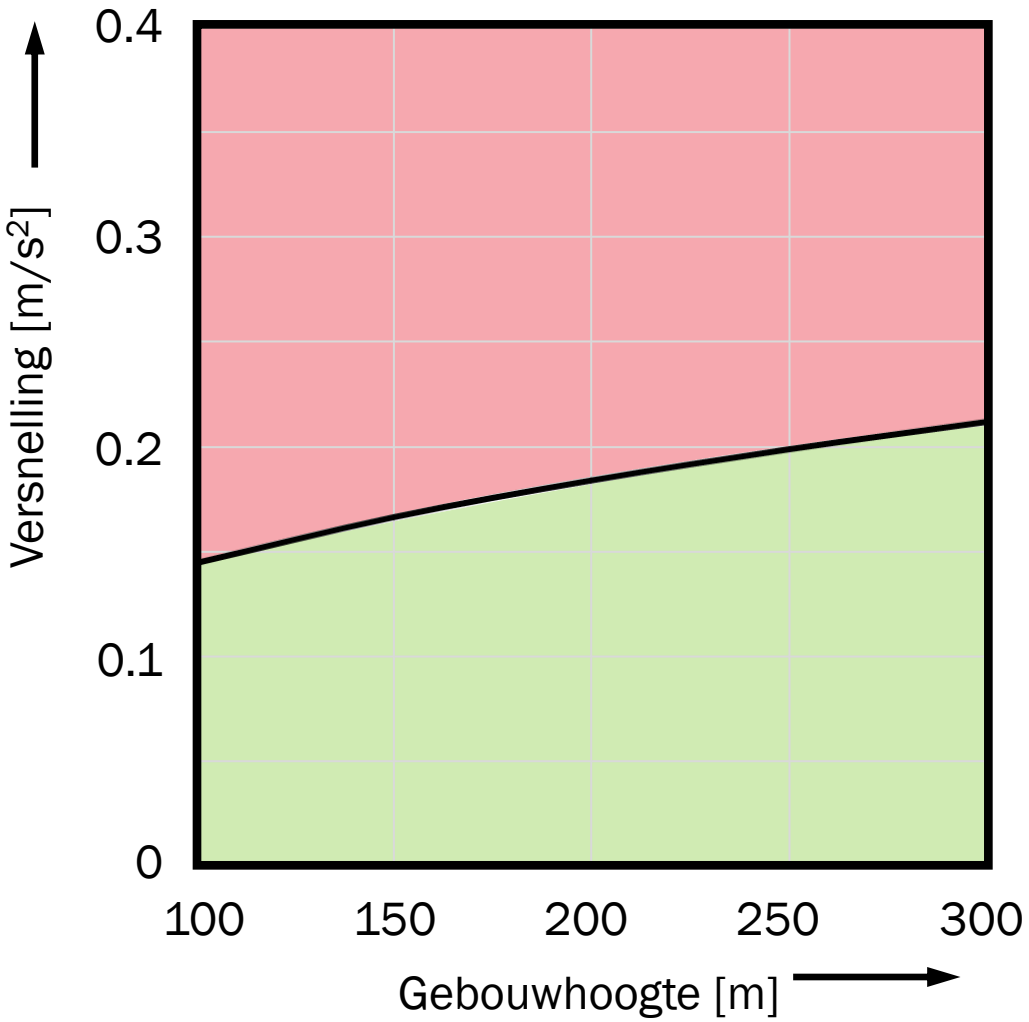
Beoordeling windtrillingen hoogbouw



Beoordeling windtrillingen hoogbouw

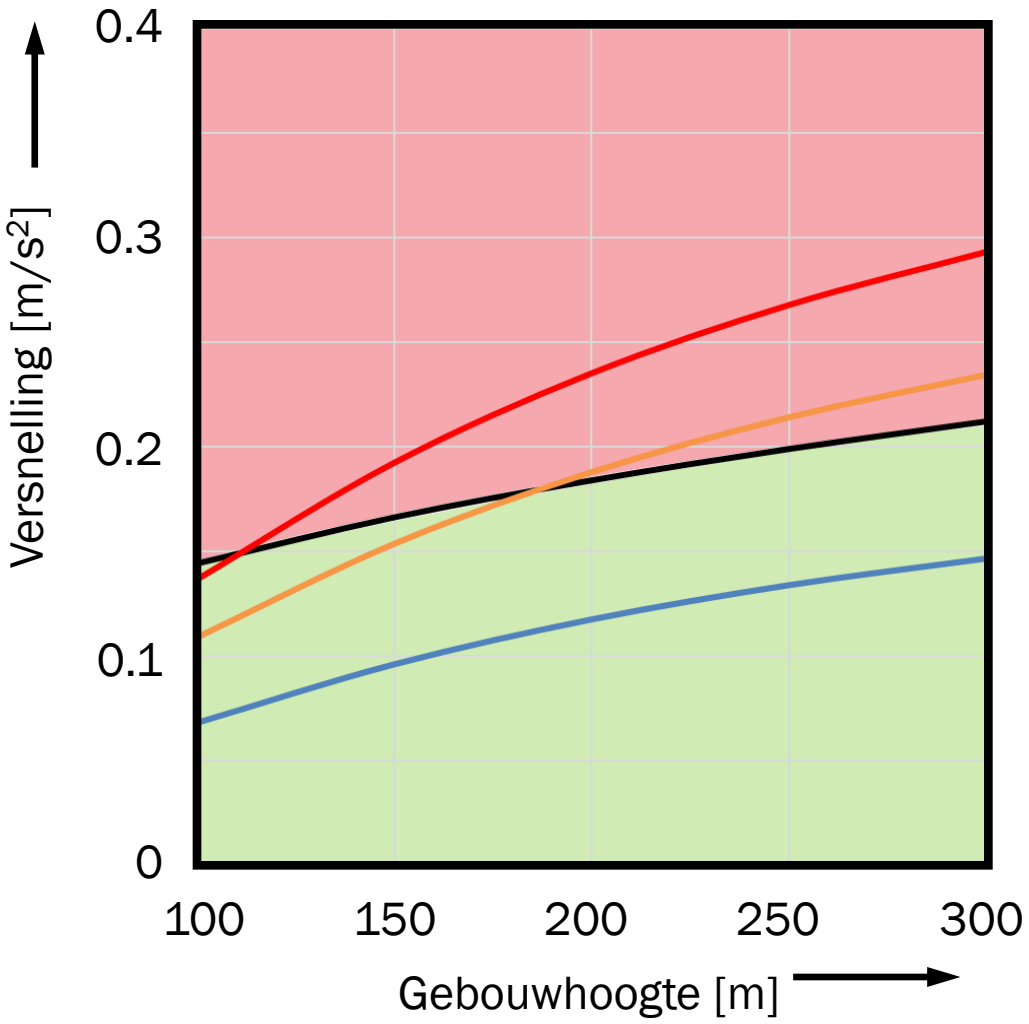


Grenswaarde versus gebouwhoogte



NEN-EN 1990/NB (wonen)

Ontwerpgrenzen in zicht



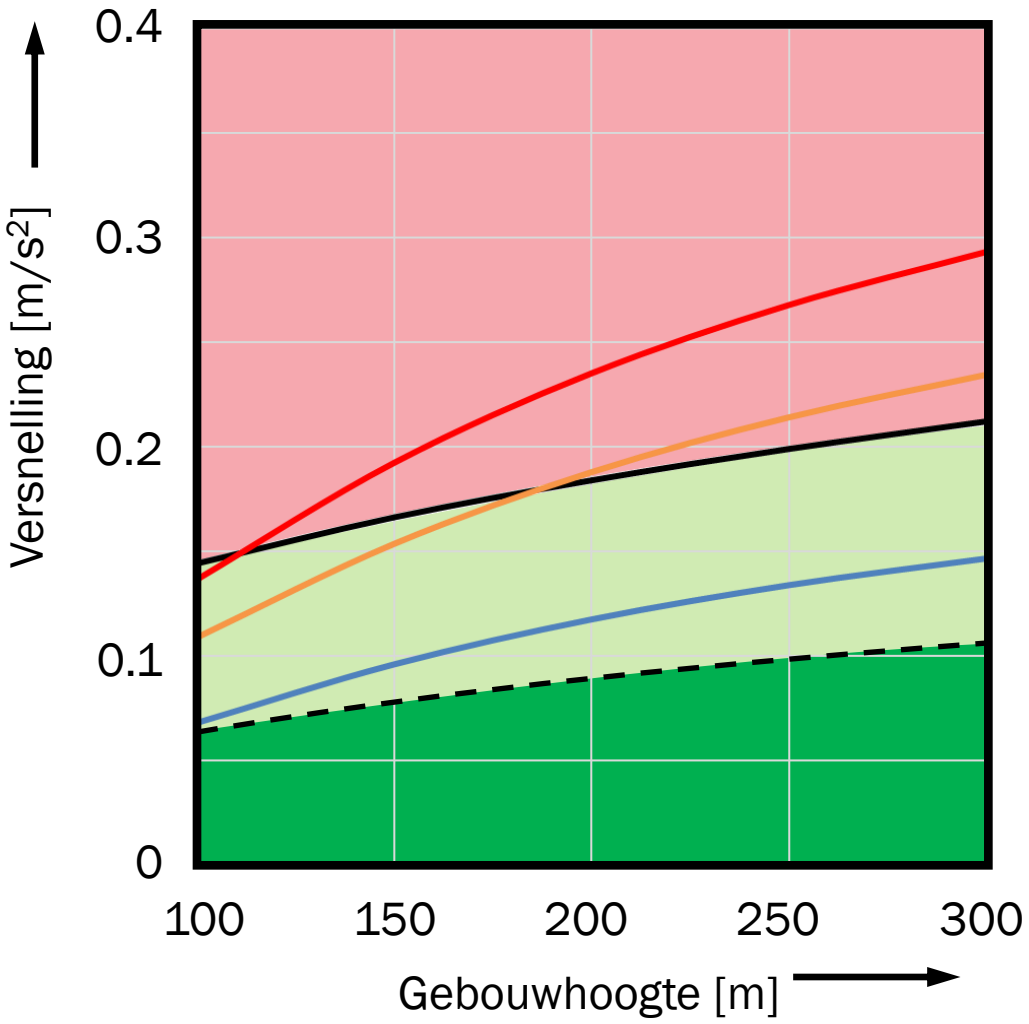
Licht stalen gebouw

Licht betonnen gebouw

NEN-EN 1990/NB (wonen)

Zwaar betonnen gebouw

Ontwerpgrenzen in zicht



Licht stalen gebouw

Licht betonnen gebouw

NEN-EN 1990/NB (wonen)

Zwaar betonnen gebouw

ISO 10137 (wonen)

Eigenfrequentie onderschat





	Montevideo	JuBi	NEMC	Oval tower	New Orleans
Meting	0.41 Hz	0.46 Hz	0.54 Hz	0.40 Hz	0.28 Hz
Ontwerp (NEN 6702)	0.19 Hz	0.27 Hz	0.27 Hz	0.33 Hz	0.19 Hz

Demping onderschat en overschat





	Montevideo	JuBi	NEMC	Oval tower	New Orleans
Meting	1.4 %	1.0 %	1.7 %	1.4 %	0.8 %
Ontwerp (NEN 6702)	1.0 %	1.0 %	1.0 %	1.0 %	1.0 %

Demping onderschat en overschat

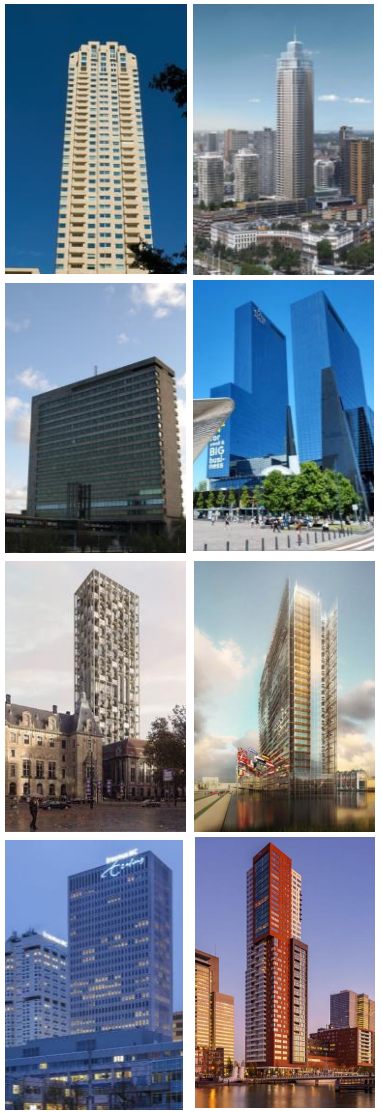




	Montevideo	JuBi	NEMC	Oval tower	New Orleans
Meting	1.4 %	1.0 %	1.7 %	1.4 %	0.8 %
Ontwerp (NEN 6702)	1.0 %	1.0 %	1.0 %	1.0 %	1.0 %
NEN-EN 1991-1-4	1.2 %	1.6 %	1.6 %	1.6 %	1.6 %

HiViBe

- Doel
  - Betrouwbare voorspelling windtrillingen hoogbouw
- Beoogde resultaten
  - Rekenmethodes voor de dynamische respons
  - Monitoring programma hoge gebouwen



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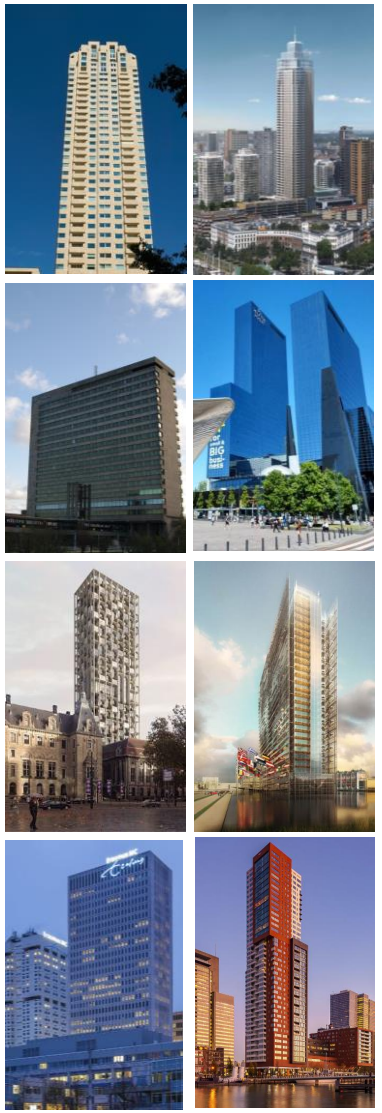
HiViBe

- Nieuwe Eurocode windbelasting
- Onderschatting eigenfrequentie
- Invloed fundering op demping
- Invloed trillingsamplitude en duur
- Invloed nabijgelegen gebouwen



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HiViBe

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- **Onderschatting eigenfrequentie**
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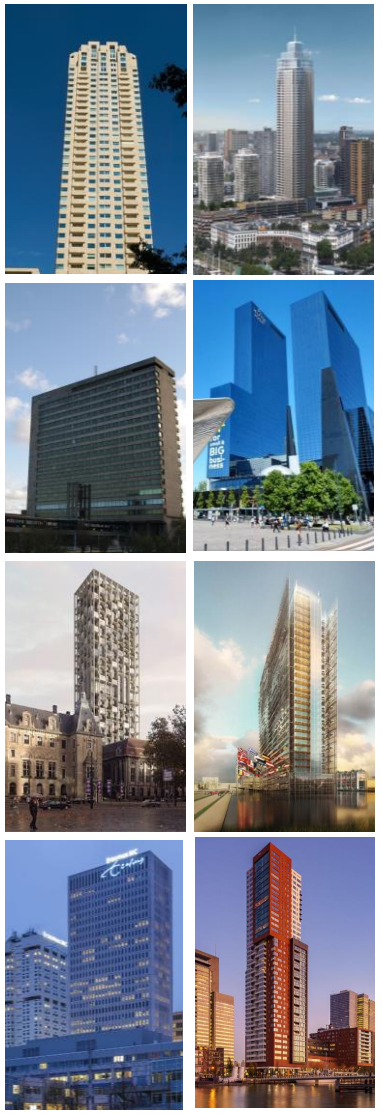
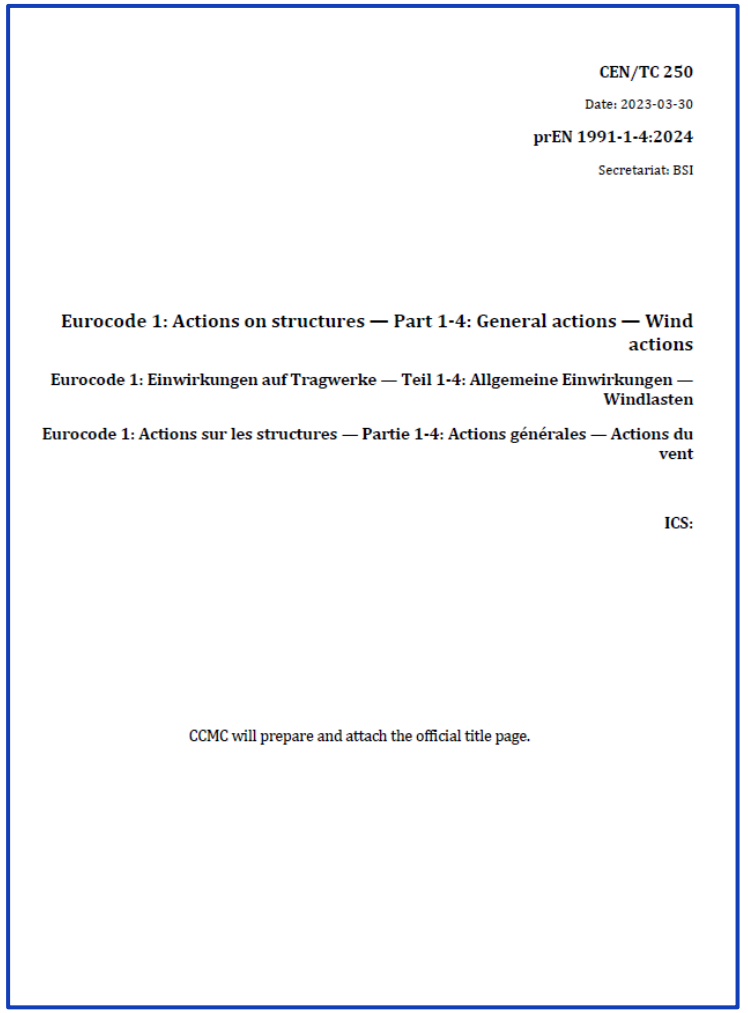


A.J. Bronkhorst, C.P.W. Geurts, Long-term vibration and wind load monitoring on a high-rise building, Proceedings ISMA, Leuven, 2020.

Nieuwe Eurocode windbelasting

- 2005: EN 1991-1-4 publicatie
- 2015: Start ontwikkeling 2e generatie
- 2023: prEN 1991-1-4 klaar (enquiry versie)
- 2028: Terugtrekken eerste generatie



CEN/TC 250

Date: 2023-03-30

prEN 1991-1-4:2024

Secretariat: BSI

Eurocode 1: Actions on structures — Part 1-4: General actions — Wind actions

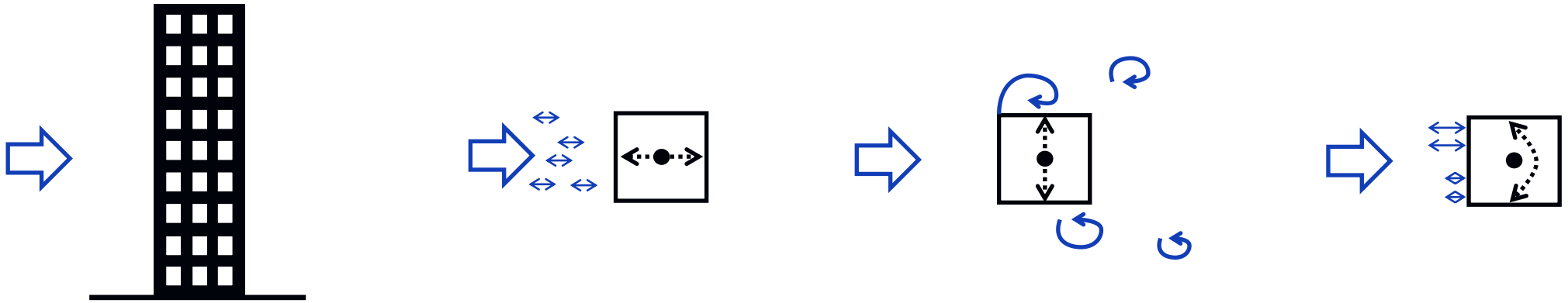
Eurocode 1: Einwirkungen auf Tragwerke — Teil 1-4: Allgemeine Einwirkungen — Windlasten

Eurocode 1: Actions sur les structures — Partie 1-4: Actions générales — Actions du vent

ICS:

CCMC will prepare and attach the official title page.

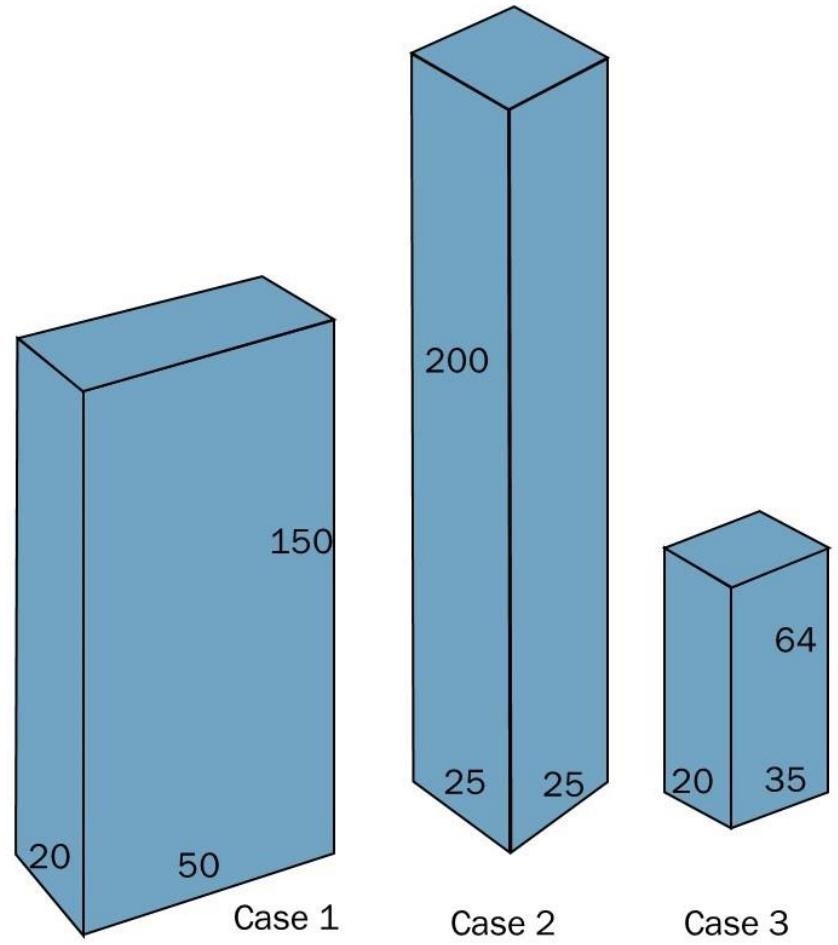
Windtrillingen: langs, dwars en torsie



	Langstrillingen	Dwarstrillingen	Torsietrillingen
EN 1991-1-4:2012	Hst. 6 + Bijlage B/C	-	-
prEN 1991-1-4:2024	Bijlage F	Bijlage G (Bijlage H)	Bijlage G

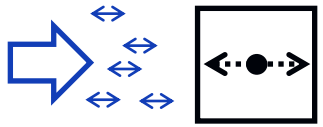
Benchmark studie prEN 1991-1-4:2024

- Berekeningen door 7 partijen
- Drie hoogbouw cases
- Resultaten gedeeld
- Gezamenlijke controle

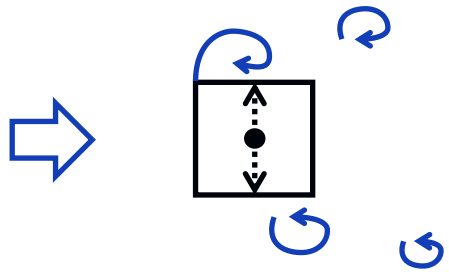


Benchmark studie prEN 1991-1-4:2024

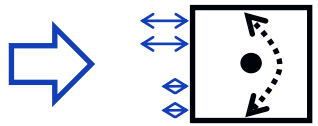
- Langstrillingen
  - c_{sd}, $a_{peak,x}$

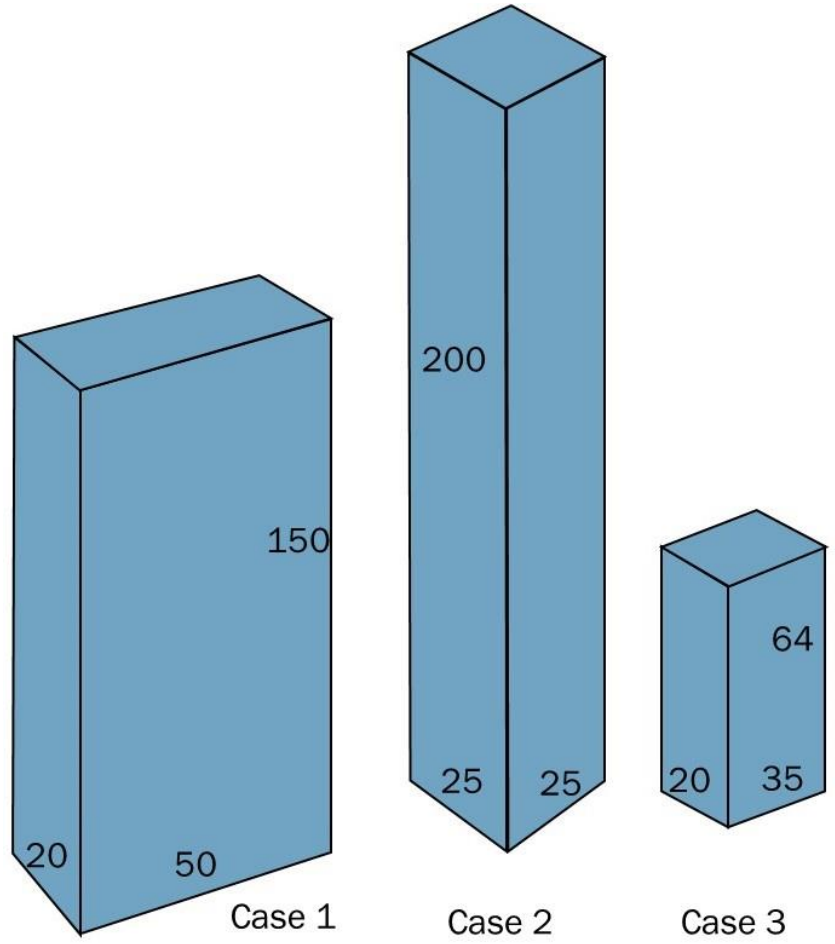


- Dwarstrillingen
  - $f_L(h)$, $a_{peak,y}$

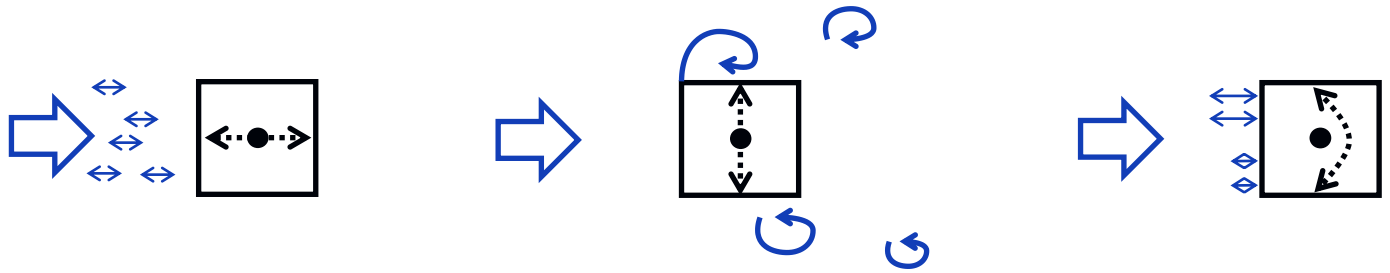


- Torsional vibrations
  - $m_M(h)$, $a_{peak,M}$



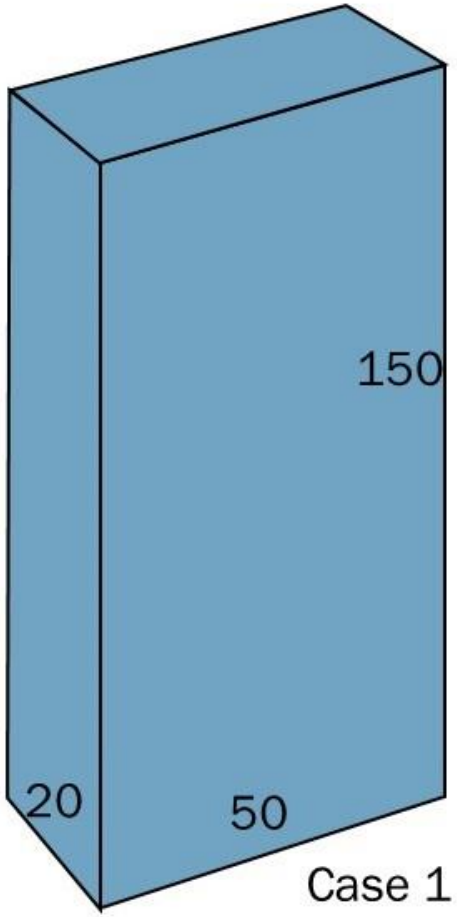


Benchmark studie: resultaten Case 1



Resultaat	c_{sd}	$a_{peak,x}$	$f_L(h)$	$a_{peak,y}$	$m_M(h)$	$a_{peak,M}$ *
laagst	0,88	0,022	19741	0,005	227178	0,012
hoogst	0,94	0,065	75246	0,069	532363	0,187
correct	0,88	0,037	65112	0,038	532363	0,032

* a_{peak} in m/s^2; $a_{peak,M}$ follows from $a_{peak,M}$ in rad/s x 1/2 diagonal



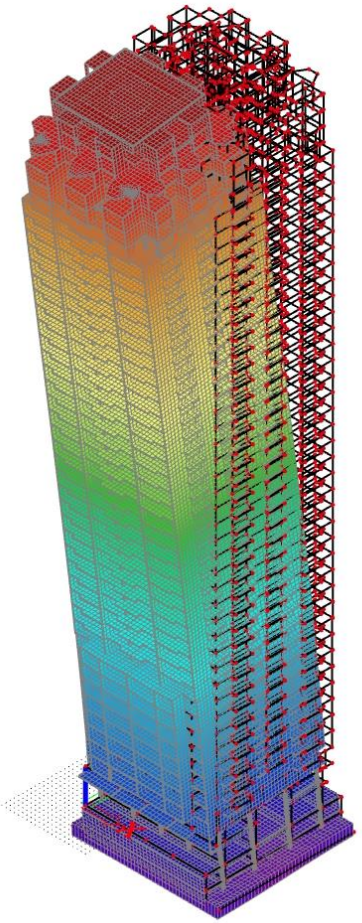
Benchmark studie prEN 1991-1-4:2024

- Evaluatie deelnemers
  - Inzicht oorzaken verschillen
  - Overeenstemming input parameters
  - Correcties rekenregels prEN 1991-1-4

- Externe communicatie
  - Terugkoppeling CEN werkgroep
  - Kennisoverdracht Nederlandse ontwerppraktijk

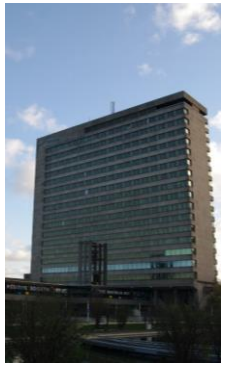
In-situ metingen versus FEM berekeningen

- 7 gebouwen
- FEM berekeningen
- Trillingsmetingen



Onderschatting eigenfrequentie

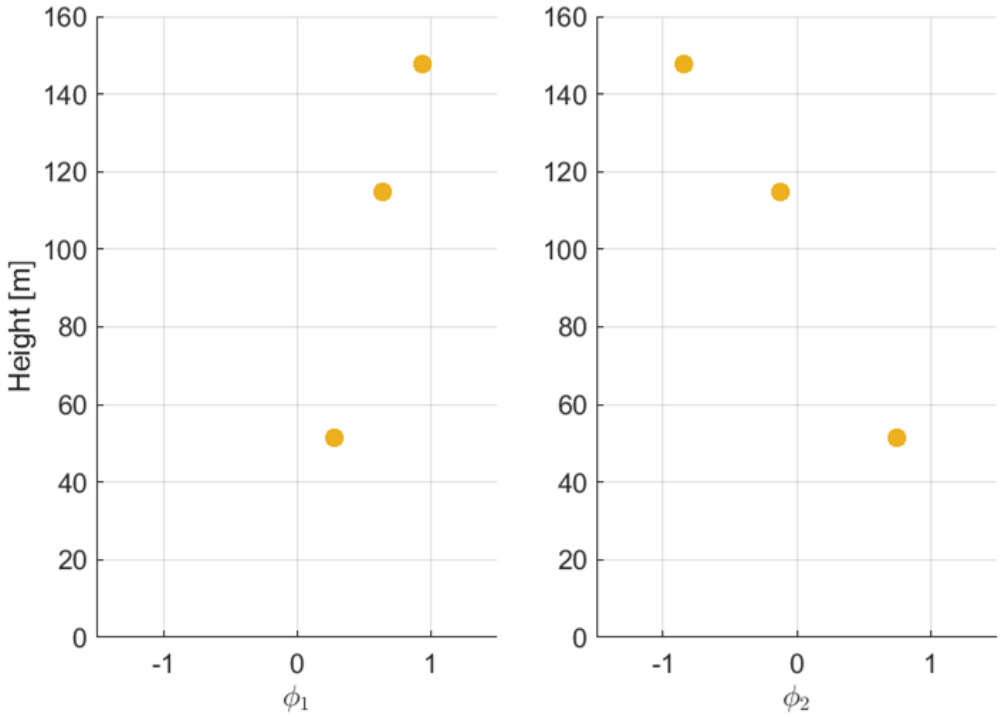


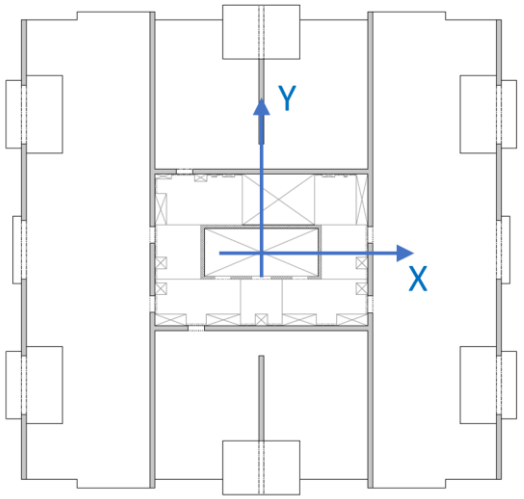


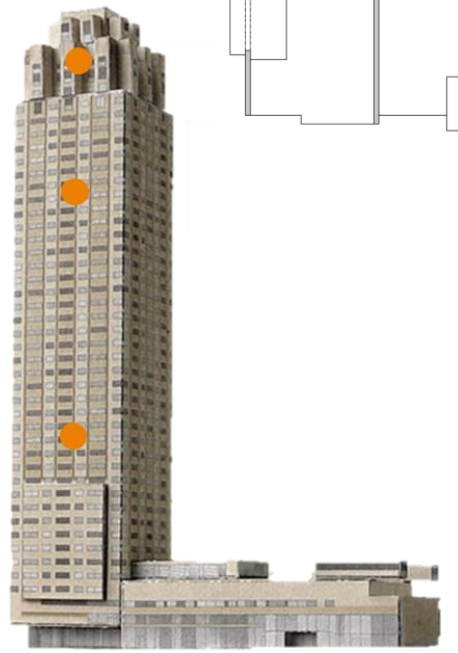


	New Orleans	Zalmhaven	Tinbergen	JuBi toren	Erasmus MC	Montevideo	EPO
Meting	0.28 Hz	0.34 Hz	0.67 Hz	0.46 Hz	0.54 Hz	0.44 Hz	0.44 Hz
Berekening	0.23 Hz	0.24 Hz	0.32 Hz	0.34 Hz	0.27 Hz	0.33 Hz	0.29 Hz

Gemeten trilvormen New Orleans

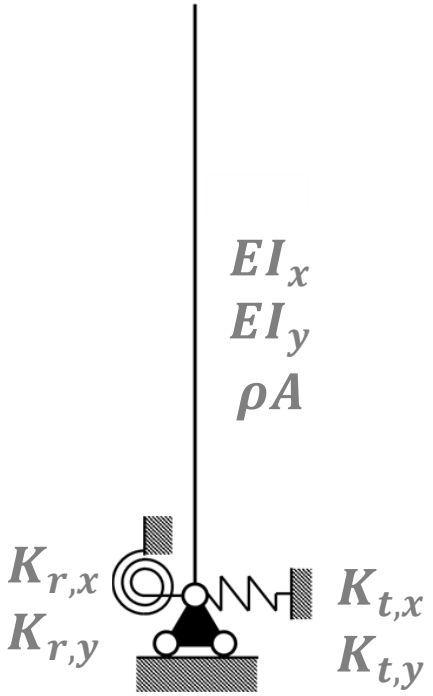


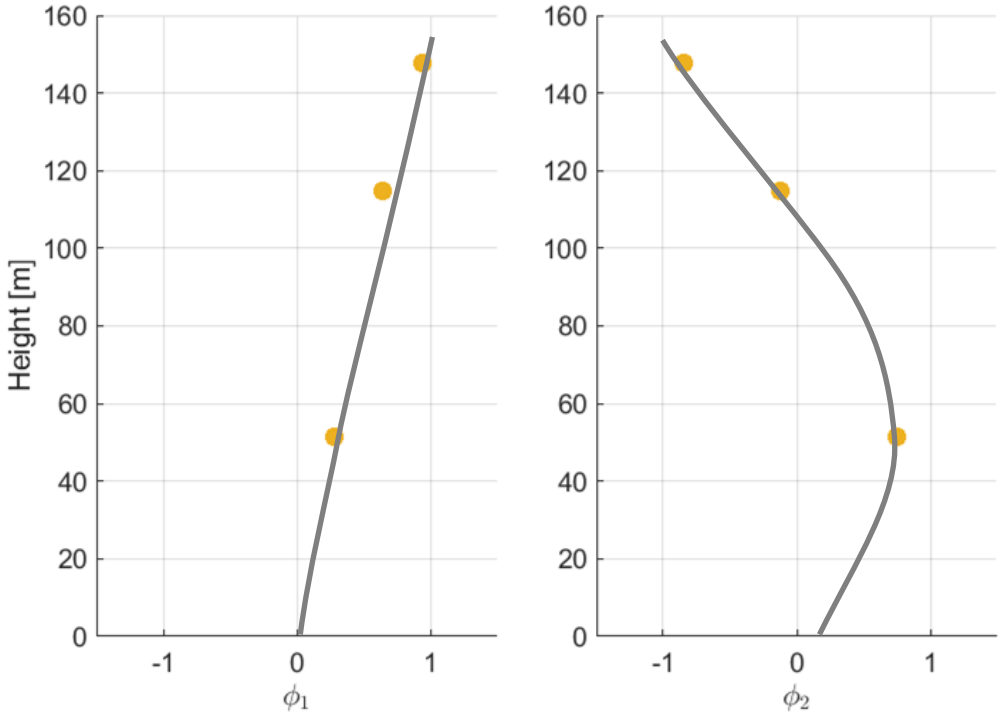


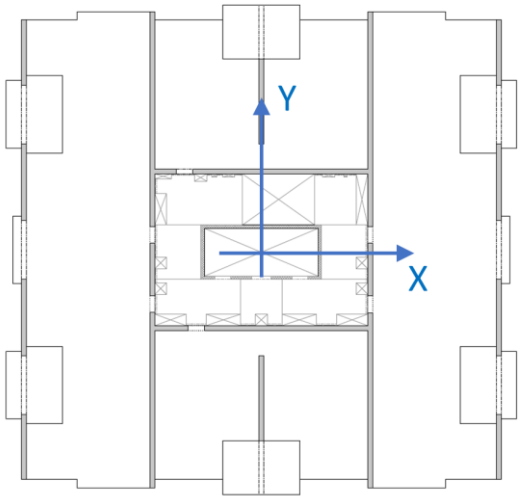


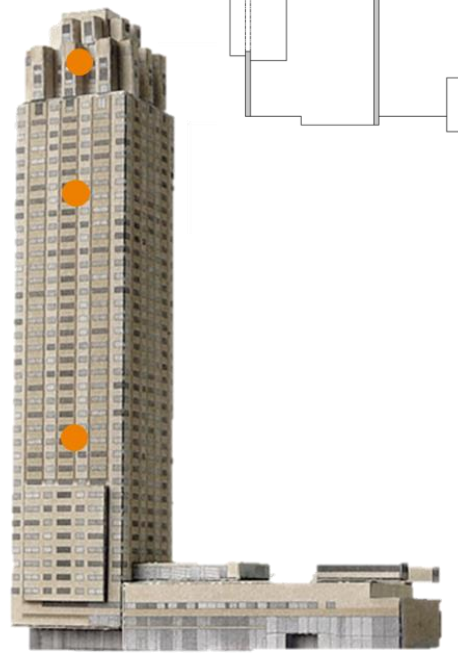
	$f_{y,1}$	$f_{y,2}$
Meting	0.28 Hz	1.53 Hz

Berekende trilvormen New Orleans



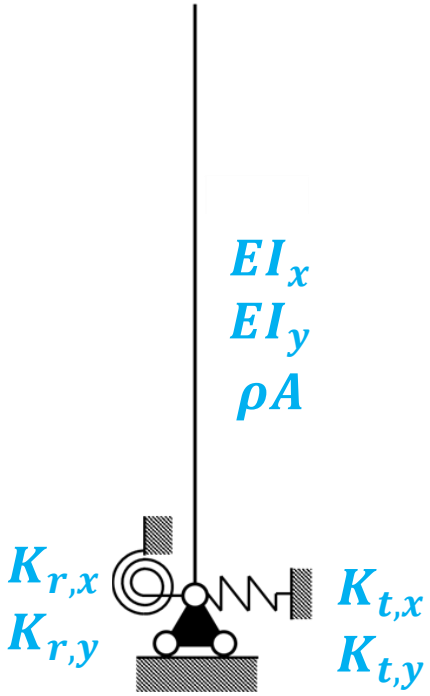


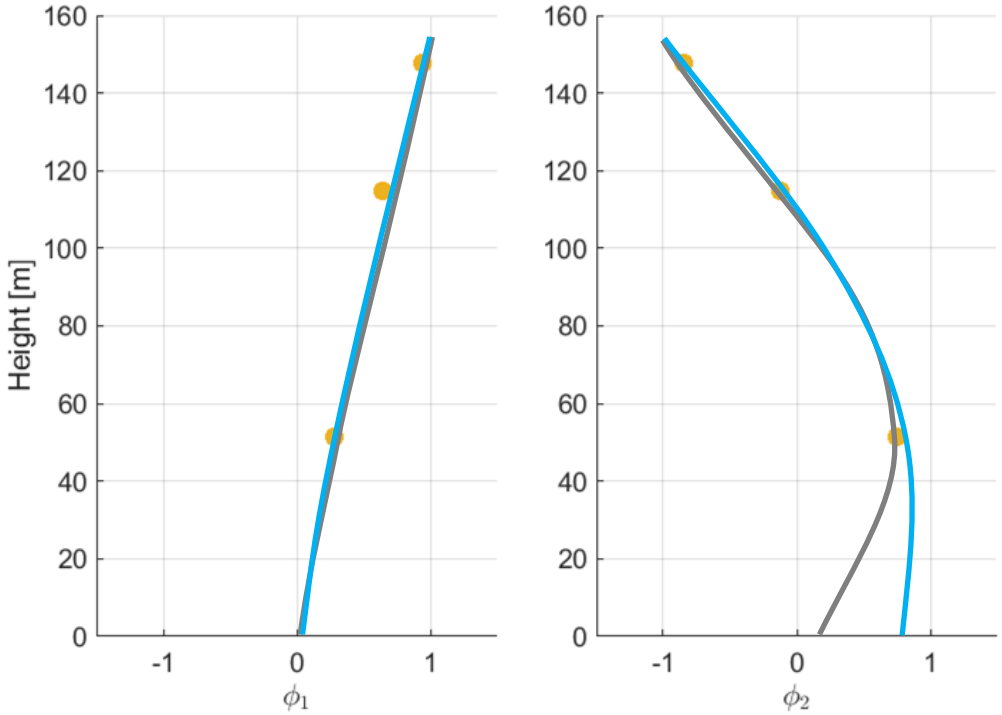


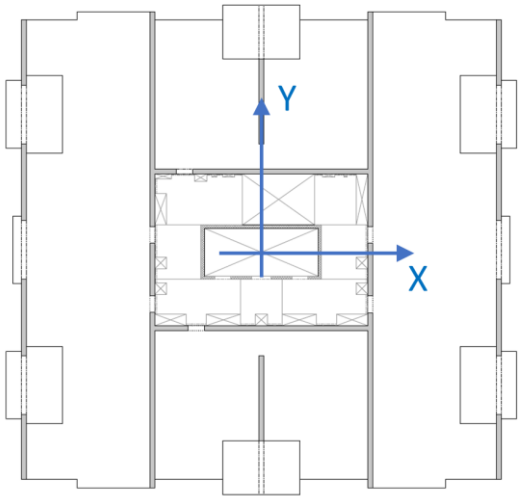


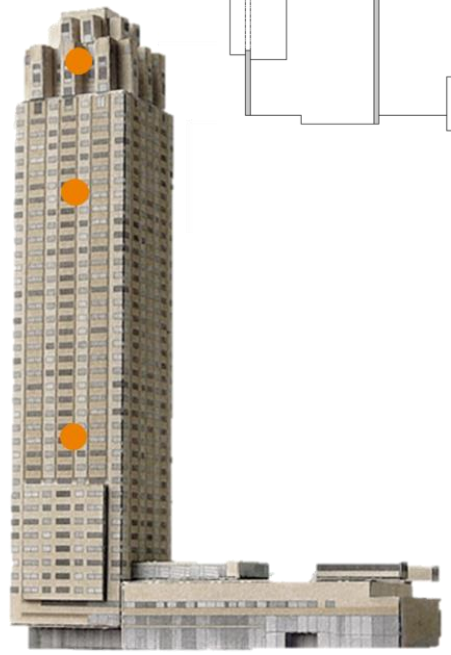
	$f_{y,1}$	$f_{y,2}$
Meting	0.28 Hz	1.53 Hz
Berekening	0.23 Hz	1.25 Hz

Optimalisatie model op metingen



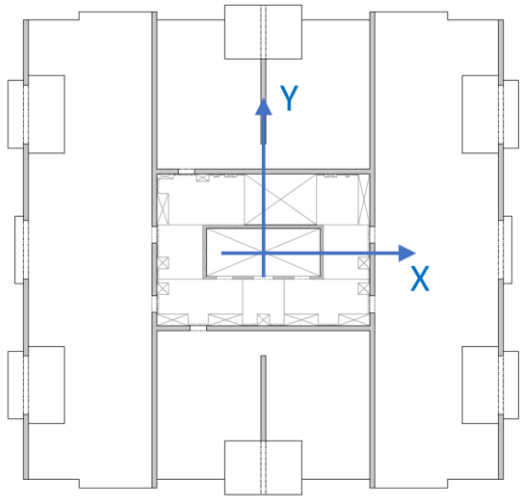




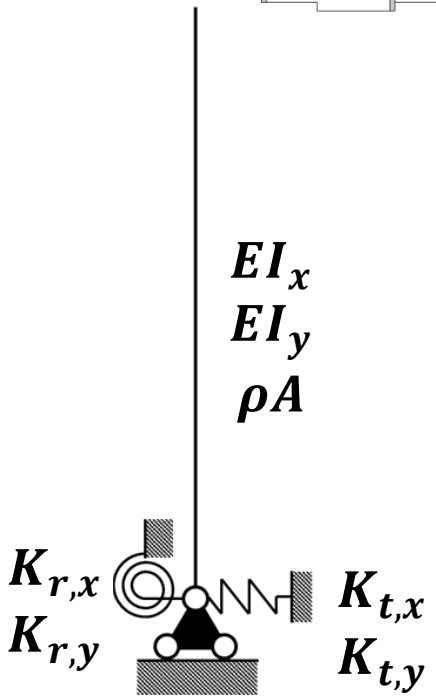


	$f_{y,1}$	$f_{y,2}$
Meting	0.28 Hz	1.53 Hz
Berekening	0.23 Hz	1.25 Hz
Optimalisatie	0.28 Hz	1.53 Hz

Constructieve eigenschappen



Eigenschap	Optimalisatie	Berekening	Verhouding
ρ [kg/m^3]	477	477	1
EI_{xx} [Nm^2]	13.1x10^{13}	7.12x10^{13}	0.54
EI_{yy} [Nm^2]	11.5x10^{13}	5.39x10^{13}	0.47
K_{rxrx} [Nm/rad]	2.74x10^{12}	2.38x10^{12}	0.87
K_{ryry} [Nm/rad]	3.86x10^{12}	2.63x10^{12}	0.68
$K_{t,x}$ [N/m]	2.45x10^{9}	3.11x10^{9}	1.27
$K_{t,y}$ [N/m]	1.66x10^{9}	3.15x10^{9}	1.90



A.J. Bronkhorst, D. Moretti, C.P.W. Geurts, Identification of the dynamic properties of the residential tower New Orleans, EVACES Tokyo, 2021.
D. Moretti, A.J. Bronkhorst, C.P.W. Geurts, Identification of the structural properties of a high-rise building, ISMA Leuven, 2022.

Kalibratieberekeningen

Model	Eigenfrequentie			Paalstijfheid	E-moduli				Toelichting
	1e mode X [Hz]	2e mode Y [Hz]	3e mode T [Hz]	[MN/m]	lateien	wanden bg-5e	wanden 5e-59e	vloeren	
0	0,24	0,25	0,52	500	E_{cm}	$0,45*E_{cm}$	E_{cm}	$0,03*E_{cm}$	**Origineel**
A	0,26	0,26	0,50	500	$0,5*E_{cm}$	E_{cm}	E_{cm}	$0,03*E_{cm}$	$E_{lateien}$↓ E_{wanden}↑
B	0,26	0,26	0,52	500	E_{cm}	E_{cm}	E_{cm}	$0,03*E_{cm}$	$E_{lateien}$↑
C	0,27	0,27	0,56	500	E_{cm}	E_{cm}	E_{cm}	E_{cm}	$E_{vloeren}$↑
D	0,29	0,29	0,64	500	$1,3*E_{cm}$	$1,3*E_{cm}$	$1,3*E_{cm}$	$1,3*E_{cm}$	E↑
E	0,31	0,31	0,64	1000	$1,3*E_{cm}$	$1,3*E_{cm}$	$1,3*E_{cm}$	$1,3*E_{cm}$	Paalstijfheid↑
F	0,33	0,33	0,67	1000	$1,3*E_{cm}$	$1,3*E_{cm}$	$1,3*E_{cm}$	$1,3*E_{cm}$	Massa↓[1]

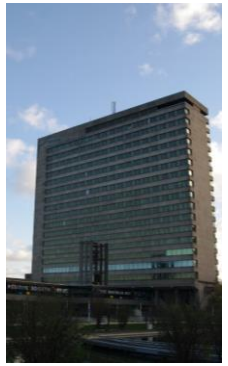
[1] *1.0G, andere modellen zijn inclusief momentaan veranderlijk (1.0G+1.0Q $_{phi}$)*

Zalmhaven

Mode	Richting	Meting	Berekening	Verhouding
f_1	X	0,34 Hz	0,24 Hz	0,71
f_2	Y	0,34 Hz	0,25 Hz	0,74
f_3	θ	0,63 Hz	0,52 Hz	0,83

Demping

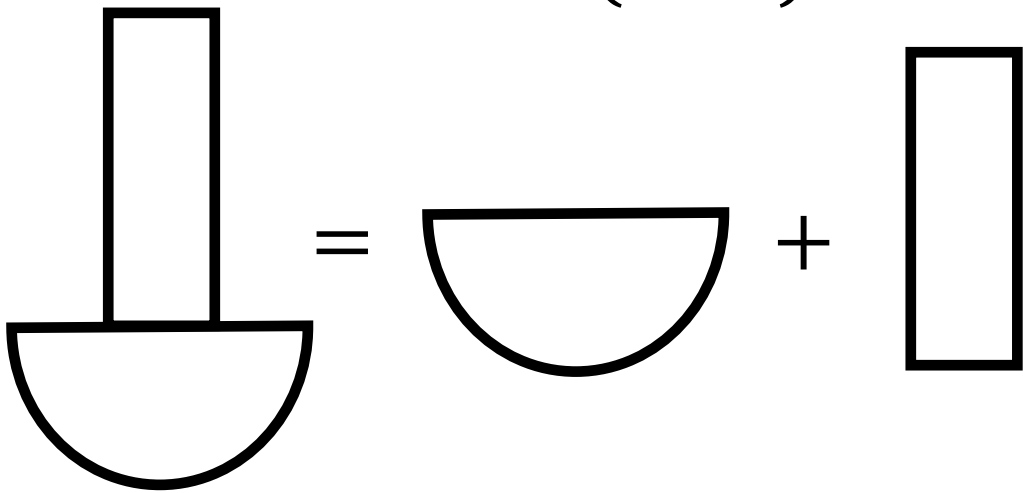





	New Orleans	Zalmhaven	Tinbergen	JuBi toren	Erasmus MC	Montevideo
Meting	0.8 %	1.0 %	1.0 %	1.0 %	1.7 %	1.4 %
EN 1991-1-4	1.6 %	1.6 %	1.6 %	1.6 %	1.6 %	1.2 %

Invloed fundering op demping

$$D_t = D_f + \frac{1}{\left(\tilde{T}/T\right)^3} D_g$$



A.J. Bronkhorst, C.A. van Bentum, S. Sanchez Gomez, Wind-induced vibrations and damping in high-rise buildings, TNO 2018 R10644, 2018.
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C. Cruz, E. Miranda, Insights into damping ratios in buildings, Earthq. Engng. Struct. Dyn., p. 1-19, 2020.
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Invloed fundering op demping - voorbeeld

- Woontoren New Orleans (D_t = 0.8%)
  - H x b x d: 155 m x 29 m x 29 m
  - ρ_b : 500 kg/m^3
  - ρ_s : 1955 kg/m^3
  - V_s : 325 m/s

Parameter	$f_e = 0{,}19$ Hz
$D_g/(\tilde{T}/T)^3$	0,28 %
D_f	0,07 %
D_t	0,35 %

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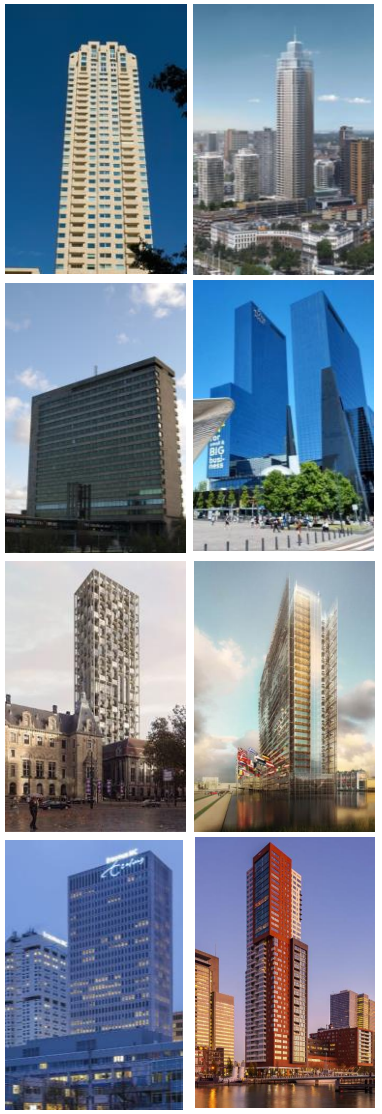
  - V_s : 325 m/s

Parameter	$f_e = 0{,}19$ Hz	$f_e = 0{,}28$ Hz
$D_g/(\tilde{T}/T)^3$	0,28 %	0,28 %
D_f	0,07 %	0,32 %
D_t	0,35 %	0,60 %

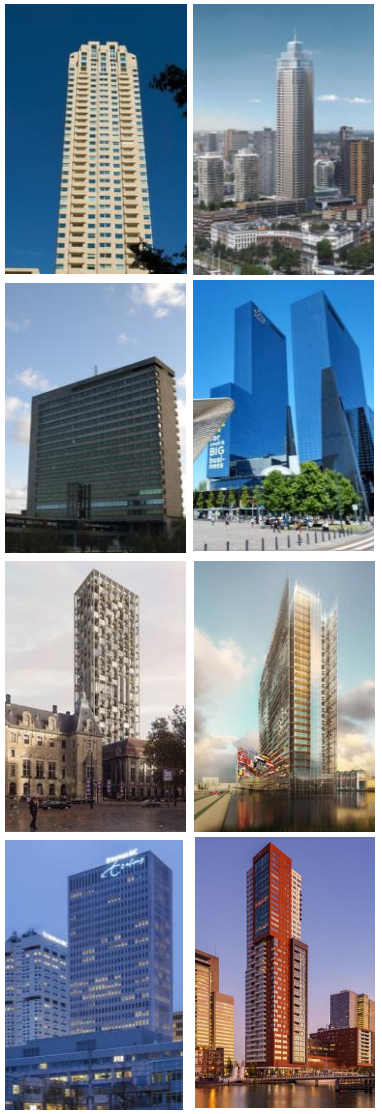
Afsluiting

- Betrouwbare voorspelling windtrillingen



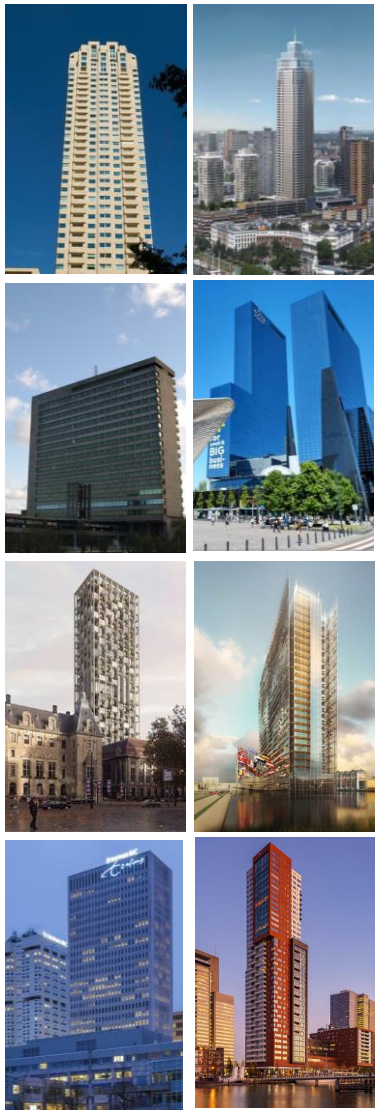
Afsluiting

- Betrouwbare voorspelling windtrillingen
- Nieuwe Eurocode windbelastingen



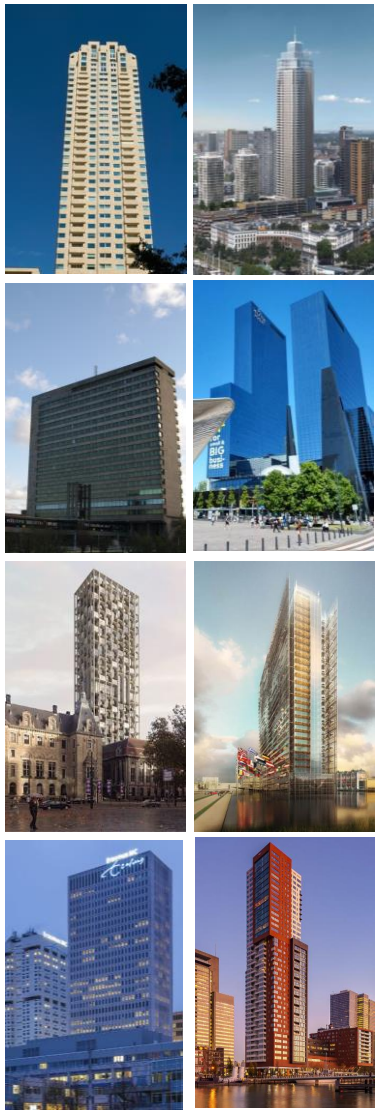
Afsluiting

- Betrouwbare voorspelling windtrillingen
- Nieuwe Eurocode windbelastingen
- Inzicht in onderschatting eigenfrequentie



Afsluiting

- Betrouwbare voorspelling windtrillingen
- Nieuwe Eurocode windbelastingen
- Inzicht in onderschatting eigenfrequentie
- Dempingsmodel inclusief invloed fundering



Bedankt

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