VIBRATIONS PROBLEMS

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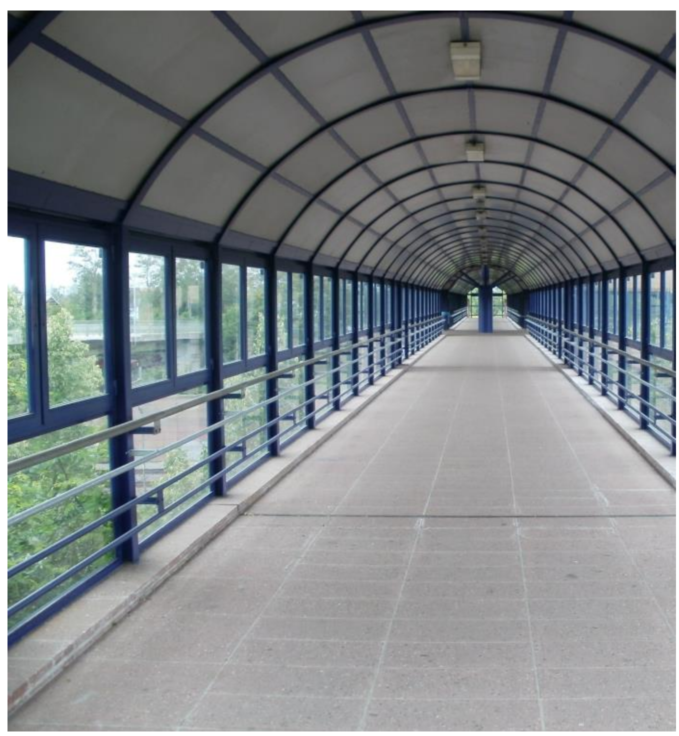
PEDESTRIAN BRIDGES



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Footbridge in Durbuy

From [Bureau Greisch, 2020]

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Vibration source

Representative types of activity		
Designation	Definition	Design activity rate [Hz]
"walking"	walking, continuous ground contact	1.6 – 2.4
"running"	running, discontinuous ground contact	2.0 – 3.5

Representative types of activity	Activity rate	[Hz]	Fourier coefficient and phase lag					
			α_1	ϕ_1	α_2	ϕ_2	α_3	ϕ_3
"walking"	vertical	2.0 2.4	0.4 0.5		0.1	$\pi/2$	0.1	$\pi/2$
	forward	2.0	$0.5(\alpha_{1/2}=0.1)$		0.2			
	lateral	2.0	$\alpha_{1/2} = 0.1$		$\alpha_{3/2} = 0.1$			
"running"	2.0 ..... 3.0		1.6		0.7		0.2	

From 'Vibration problems in structures', H. Bachman, 1995

→ Main frequencies of excitation from 1.5 to 3 Hz

! Harmonics !

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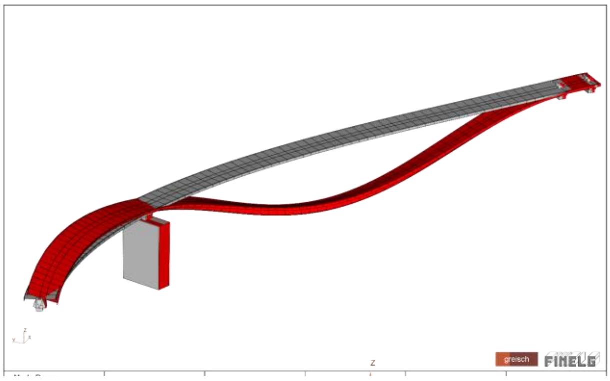
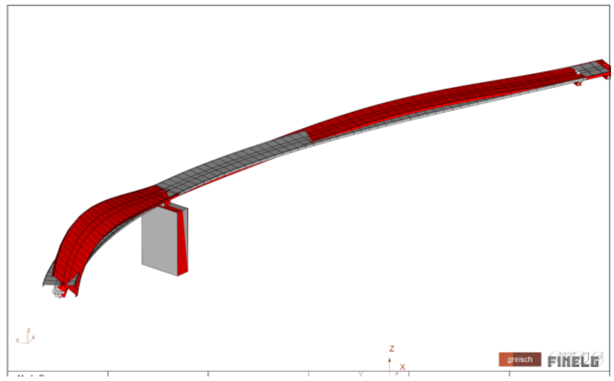
Footbridge in Durbuy

Mode 1 (2 Hz)

Mode 2 (4.16 Hz)





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Arch footbridge S8 expressway – Poland

[A. Banas, R. Jankowski *Experimental and Numerical Study on Dynamics of Two Footbridges with Different Shapes of Girders,* Appl. Sci. 2020, 10, 4505; doi:10.3390/app10134505]

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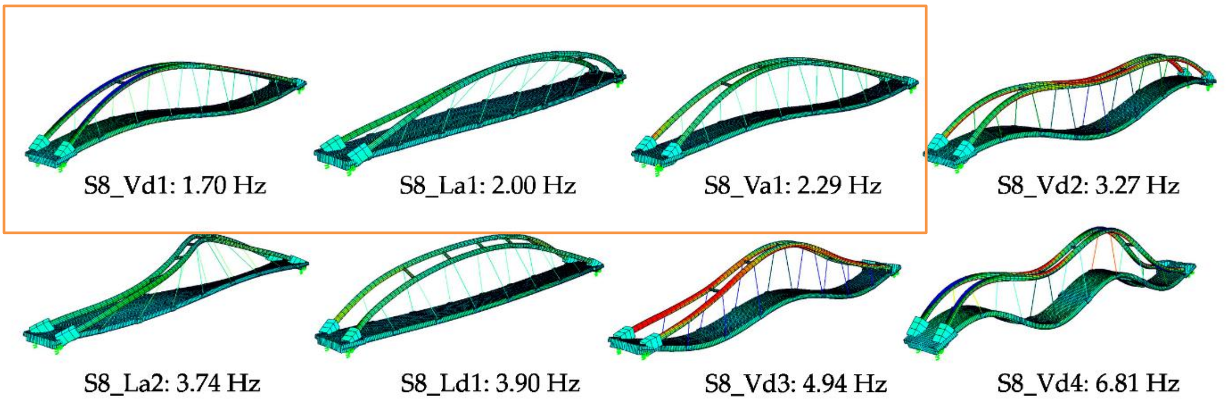
Mode shapes

Potential resonance (first harmonic)



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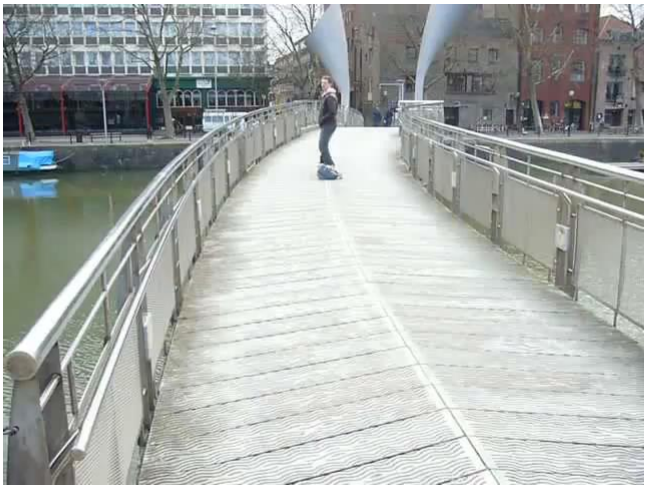
Pedestrian induced vibrations



https://www.youtube.com/watch?v=zpGZN8r2QxY

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Pedestrian induced vibrations

https://www.youtube.com/watch?v=gQK21572oSU

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HIGH-RISE BUILDINGS

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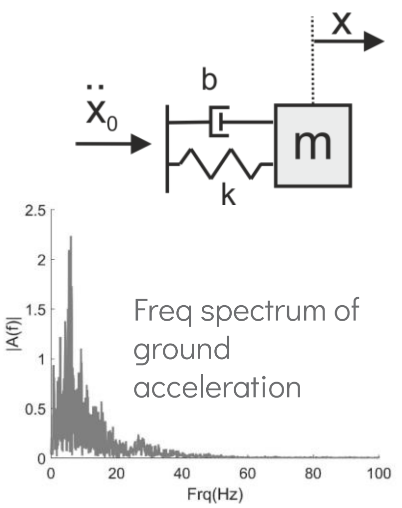
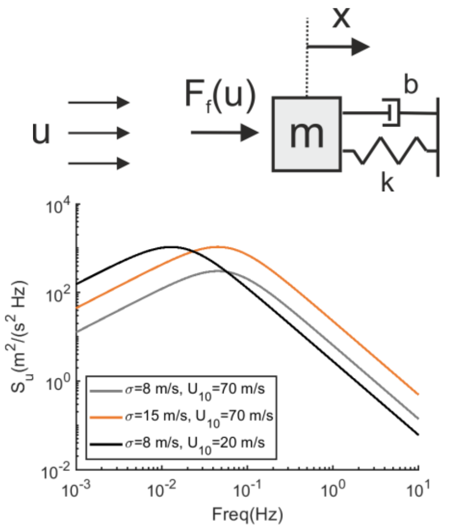
Wind and earthquake excitations



Santa Cruz Earthquake



Davenport spectrum

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Wind excitation

303 m high-rise building, Guangzhou China

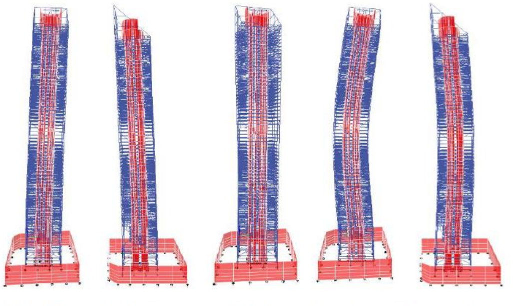

Figure 16. Mode shapes for the first five orders from simulation via finite element method.

Table 6. Results of natural frequencies of Leatop Plaza.

Mode No.	Measurement (Hz)	Simulation (Hz)	Difference (%)	Mode Type
1	0.183	0.164	10.4	1st mode in X direction (sway)
2	0.182	0.167	8.24	1st mode in Y direction (sway)
3	0.429	0.388	9.56	1st mode in Z direction (torsion)
4	0.683	0.592	13.3	2nd mode in X direction (sway)
5	0.656	0.612	6.71	2nd mode in Y direction (sway)

Zhi Li, J. Fu, Y. He, Z. Liu, J. Wu, R. Rao and C.T. Ng, *Structural Responses of a Supertall Building Subjected to a Severe Typhoon at Landfall,* Appl. Sci. 2020, 10, 2965

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Building swaying in the wind

https://www.youtube.com/watch?v=i1sHJRCJPS4 13

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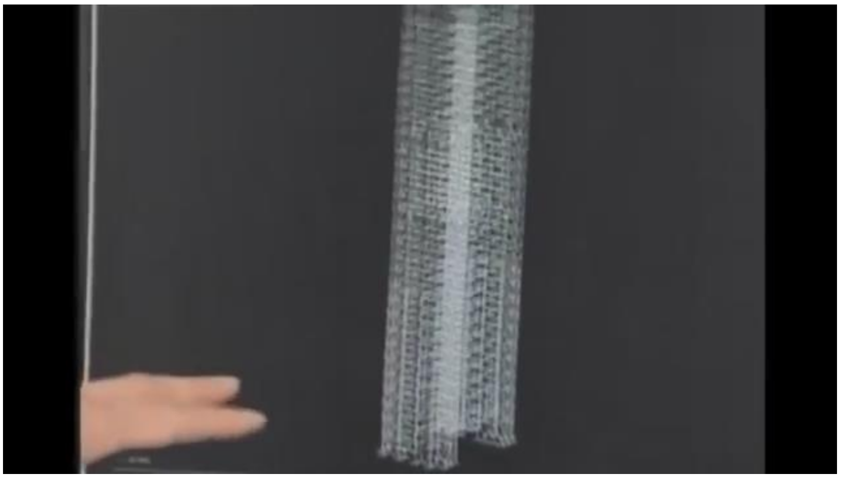
Building swaying after earthquake



https://www.youtube.com/watch?v=2t2xxKMN-Ic&t=230s 14

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MACHINE INDUCED VIBRATIONS

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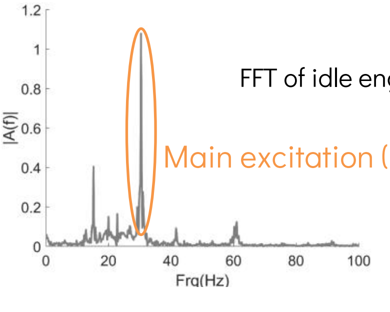
Machine induced vibrations

Force transmitted to the surroundings



FFT of idle engine acceleration

Main excitation (30 Hz)

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Washing machines

https://www.youtube.com/watch?v=SRbFxgezAX0

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Harvester

[Romaric BIAOU OLAYE]

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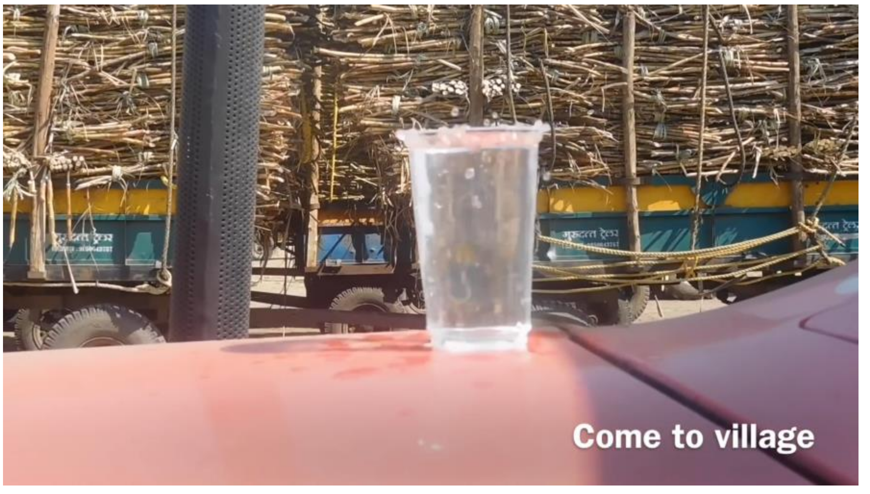
Tractor engine



https://www.youtube.com/watch?v=7tJkI7dygfU

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Helicopter ground resonance

https://www.youtube.com/watch?v=ZcdYIkrQVzA

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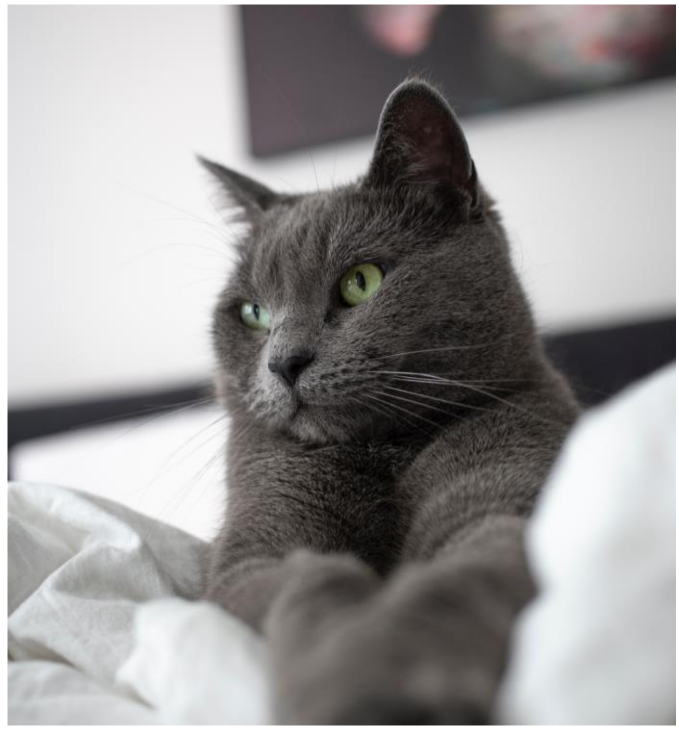
PRECISION EQUIPMENT AND COMFORT



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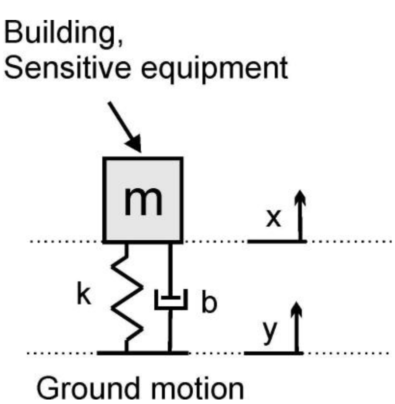
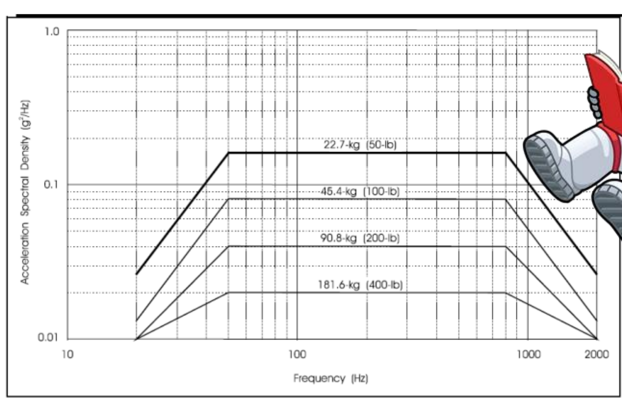
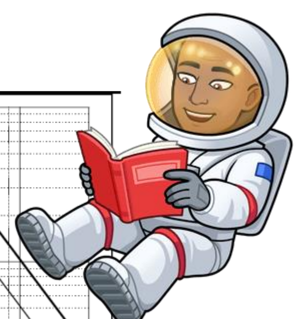
Vibrations caused by the surroundings







GSFC Standard (Nasa)

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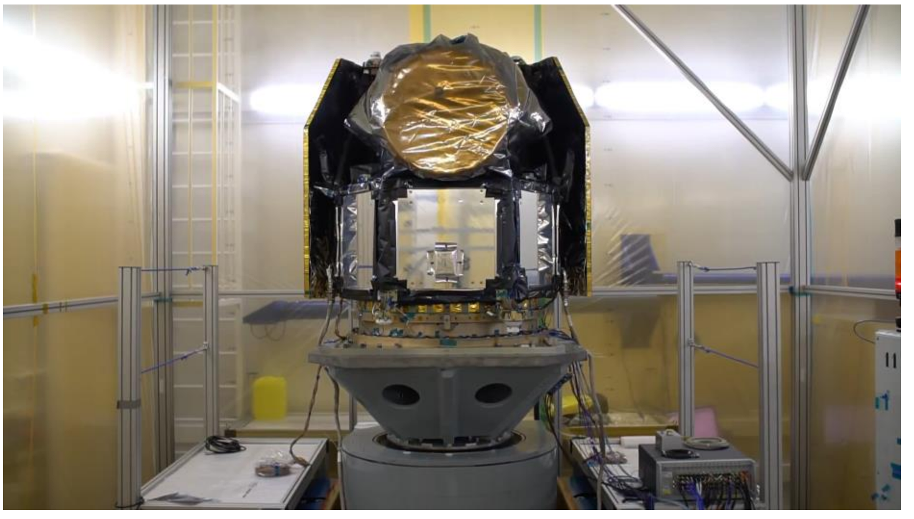
Payload comfort in space launchers (satellites)



https://www.youtube.com/watch?v=1O4PEqeXk5M

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Comfort in sports cars

https://www.youtube.com/watch?v=5bsuar1vo2g

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Precision microscope vibration

https://www.youtube.com/watch?v=9MFsymYmwLo

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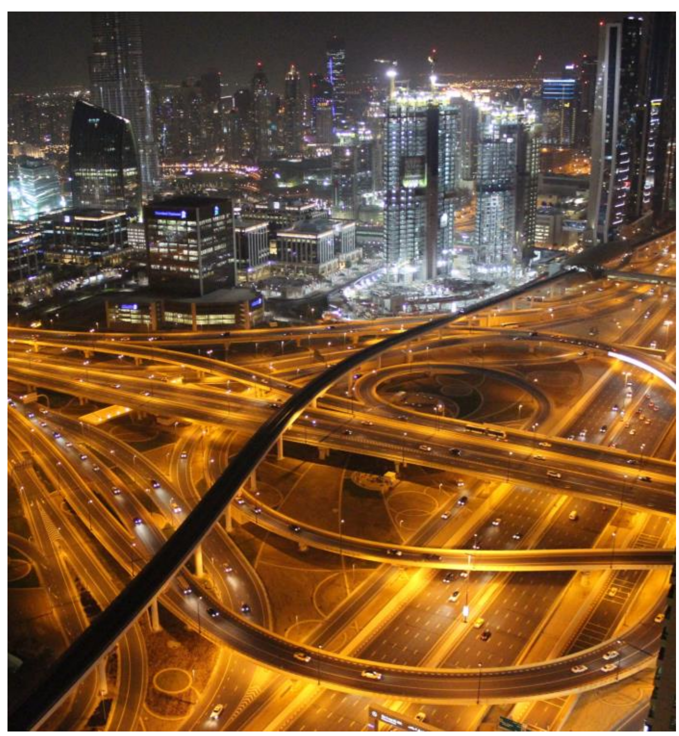
VIBRATIONS CAUSED BY TRAFFIC



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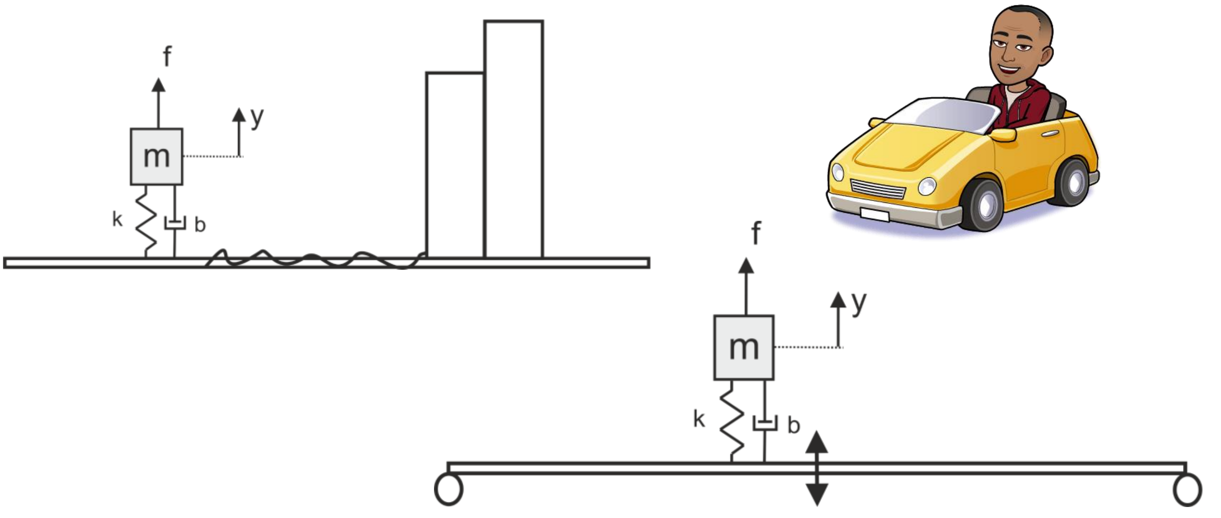
Vibrations caused by traffic



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Vibrations caused by traffic

https://www.youtube.com/watch?v=ZAa6ehyIZ94

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Vibrations caused by traffic

https://www.youtube.com/watch?v=ioSyeKusvE8

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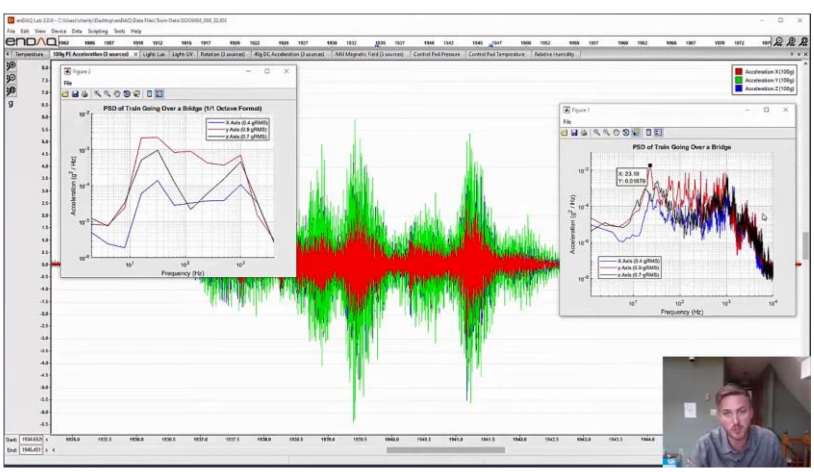
Vibrations caused by traffic



https://www.youtube.com/watch?v=ioSyeKusvE8

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VORTEX INDUCED VIBRATIONS

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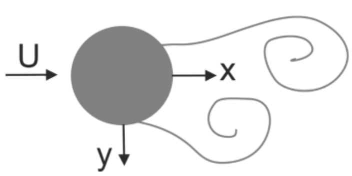
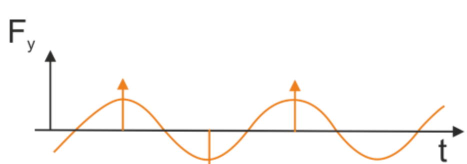
Vortex Induced Vibrations





$$f_v = \frac{S_t}{D} U$$

Resonance $f_v = f_n$

Critical wind speed $$U_c = \frac{D}{S_t} f_n$$

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Vortex Induced Vibrations

https://www.youtube.com/watch?v=YbZE_dgAqkc

https://www.youtube.com/watch?v=-JA6EfdDeck

https://www.youtube.com/watch?v=8OExYy28moc

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Vortex Induced Vibrations

https://www.youtube.com/watch?v=rlpUhgfEZPU

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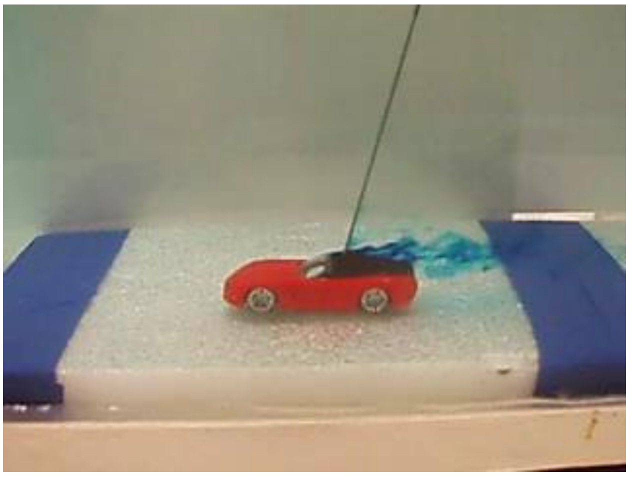
Vortex Induced Vibrations



https://www.youtube.com/watch?v=oYegGVgvDb4

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Vortex Induced Vibrations

https://www.youtube.com/watch?v=qROefSbKcms

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Vortex Induced Vibrations

https://www.youtube.com/watch?v=J21uZjFVPak

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GALOPPING AND DIVERGENCE

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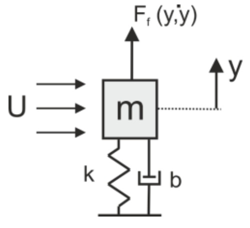
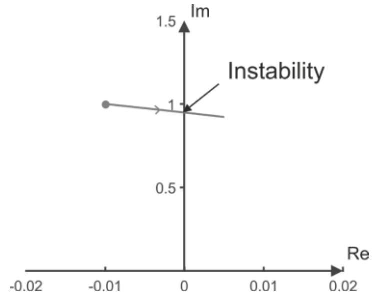
Galopping and divergence



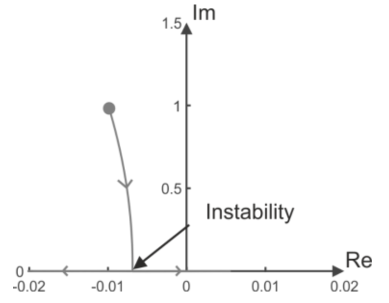
$$\ddot{\eta} + [2\xi - \beta_1(U_r)]\,\dot{\eta} + [1 - \gamma_1(U_r)]\,\eta = 0$$

Variable damping   Variable stiffness

Galopping (oscillatory)



Divergence (static)



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Galopping

https://www.youtube.com/watch?v=GEGbYRii1d4

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Divergence

[From Vincent Denoël, ULiège]

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FLUTTER

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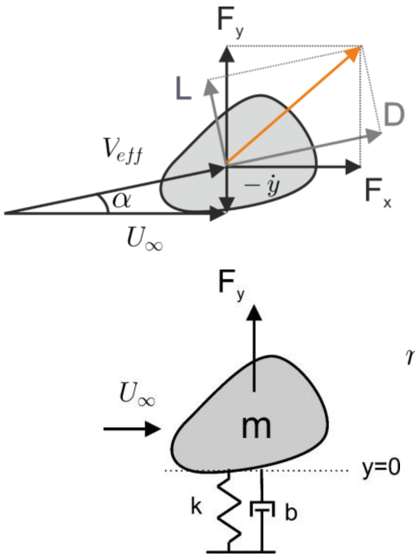
Single mode flutter



$$F_y = Lcos\alpha + Dsin\alpha$$

$$tan\alpha = \frac{-\dot{y}}{U_\infty}$$

$$m\ddot{y} + b\dot{y} + ky = F_y$$

$$= Lcos\alpha + Dsin\alpha$$

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Single mode flutter

$$\boxed{m\ddot{y} + b\dot{y} + ky = Lcos\alpha + Dsin\alpha}$$

$$\simeq L + D\alpha$$

$$\simeq (L_0 + \frac{dL}{d\alpha}\alpha) + (D_0 + \frac{dD}{d\alpha}\alpha)\alpha$$

$$\simeq L_0 + (\frac{dL}{d\alpha} + D_0)\alpha$$

$$\simeq L_0 + (\frac{dL}{d\alpha} + D_0)\frac{-\dot{y}}{U_\infty}$$

$$m\ddot{y} + \left(b + \frac{1}{U_\infty}(\frac{dL}{d\alpha} + D_0)\right)\dot{y} + ky = 0$$

$$L = \frac{1}{2}tC_L\rho U_\infty^2$$

$$D = \frac{1}{2}tC_D\rho U_\infty^2$$

$$m\ddot{y} + \left(b + \frac{1}{2}t\rho\boxed{(\frac{dC_L}{d\alpha} + C_D)}U_\infty\right)\dot{y} + ky = 0$$

Can be negative and lead to zero damping at critical speed

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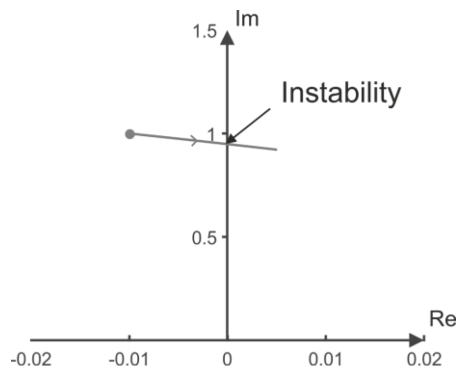
Single mode flutter

$$m\ddot{y} + \left(b + \frac{1}{2}t\rho\left(\frac{dC_L}{d\alpha} + C_D\right)U_\infty\right)\dot{y} + ky = 0$$

Can be negative and lead to zero damping at critical speed



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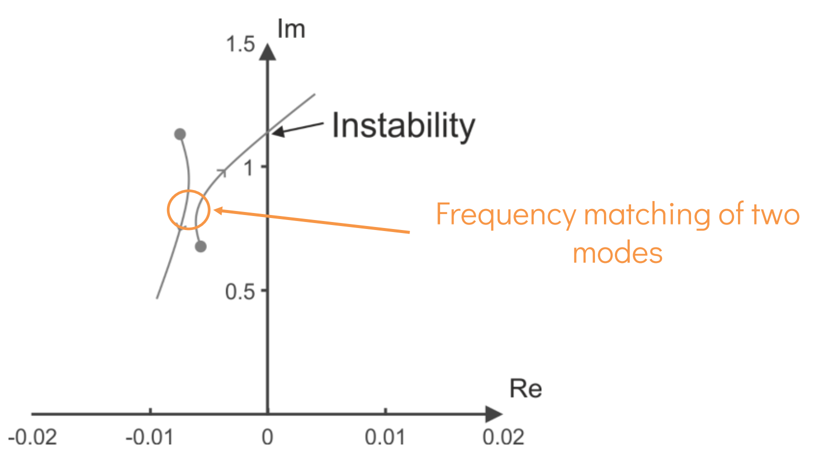
Stability for MDOF systems

- Single mode flutter (galopping)
- Coupled mode flutter



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Flutter in Tacoma Narrows bridge

https://www.youtube.com/watch?v=XggxeuFDaDU

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Aeroelastic flutter in aircrafts

Aeroelastic flutter in aircrafts

https://www.youtube.com/watch?v=pEOmCkZyXzk

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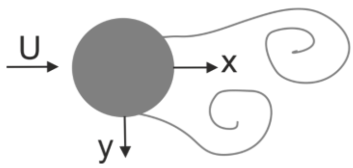
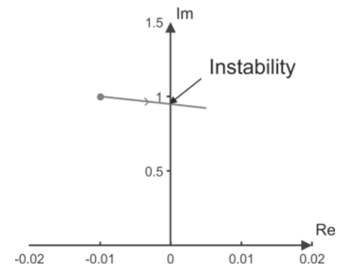
VIV vs instabilities

VIV



Galopping, flutter



- Resonance
- Amplitude limited by damping

- Instability of a pole
- Unlimited amplitude (zero damping)

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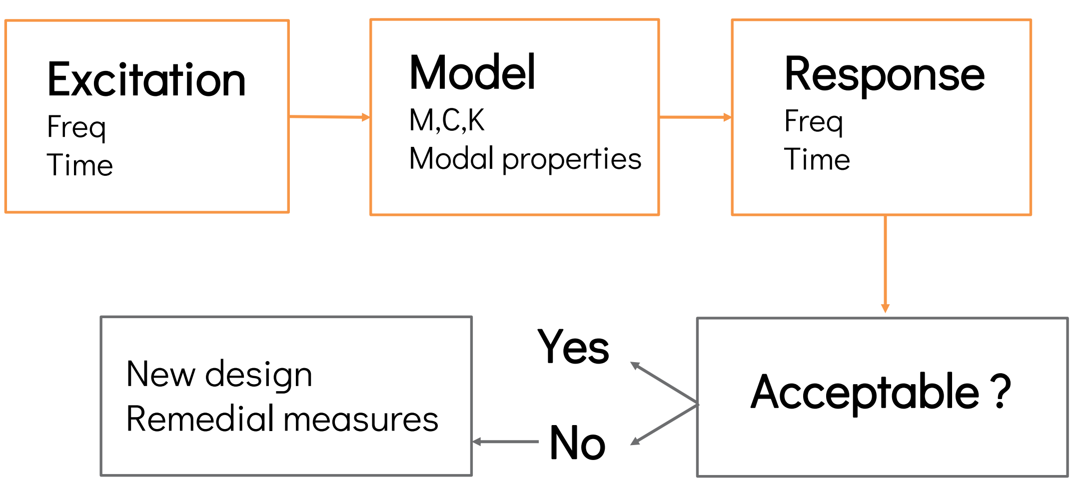
Summary



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