Dynamics of structures

1. Vibrations : Introduction

Arnaud Deraemaeker (aderaema@ulb.ac.be)

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Definition and mechanism of vibrations

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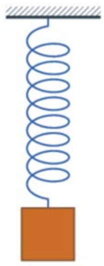
Vibrations : definition

Vibration refers to mechanical oscillations about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road. (from wikipedia)

pendulum



Mass on a spring

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Vibrations are all around us

Vibrator in cell phone

Tools

Rotating machines

Sound

Shaver

Tram

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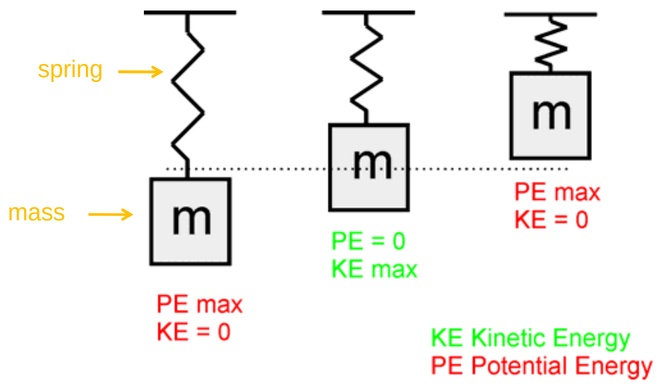
Mechanism of vibrations

Transfer between kinetic energy and potential energy



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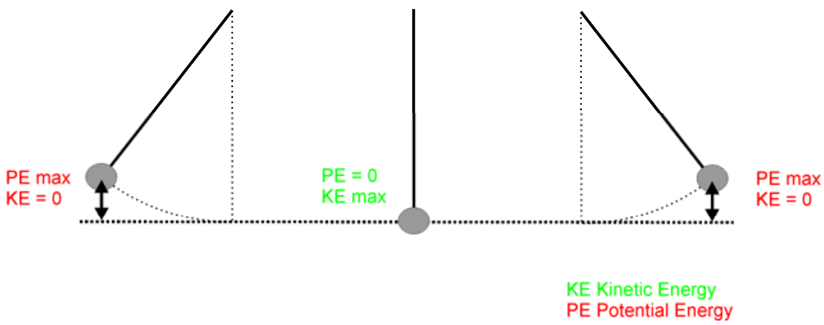
Mechanism of vibrations

Transfer between kinetic energy and potential energy



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Vibrations in civil engineering structures

Traditionnally, vibrations have not been a big concern in civil engineering, except for high levels of vibrations due to earthquakes

But …..

- Vibration sources are increasing
- Comfort demands are increasing
- Health issues are appearing
- In some cases, high precision technologies require very low vibration levels
- New designs make some structures more susceptible to vibrations

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Vibrations in civil engineering structures

Civil engineering structures have evolved towards <u>slender structures</u> with low level of damping, where vibrations become an issue

An old arch bridge

The Millau viaduct

This trend is also visible in other areas (automotive, aerospace) : reduction of weigth for optimal use of material results in higher levels of vibrations

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Vibrations in civil engineering structures

A first example : the Millenium bridge in London

Tate modern musuem of Art

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Vibrations in civil engineering structures

Opening june 10, 2000

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Vibrations in civil engineering structures

A second example : Dongting cable-stayed bridge (China)

Cables vibrations (wind)

cables

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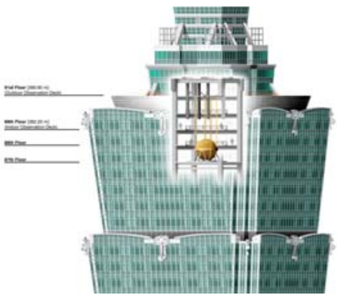
Vibrations in civil engineering structures

A third example : high rise buildings



Tuned mass damper
to reduce motion

Oscillatory motion due to strong winds
-> Problems of safety and comfort

Taipei 101 (509 m), Tapei, Taiwan

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Vibrations in civil engineering structures

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Vibrations in civil engineering structures

A fourth (catastrophic) example: Takoma Narrows bridge, USA, 1940

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Vibrations in civil engineering structures

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Vibrations sources in civil engineering

EXTERNAL SOURCES
Seismic activity
Subway, road and rail systems, airplanes
Construction equipment
Wind, Waves
Pedestrians

INTERNAL SOURCES
Ventilation systems
Elevator and conveyance systems
Fluid pumping equipment
Machines and generators
Aerobics and exercise rooms – human activity

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Types of excitation

Free vibrations

Short initial excitation

Forced Vibrations

Continuous excitation

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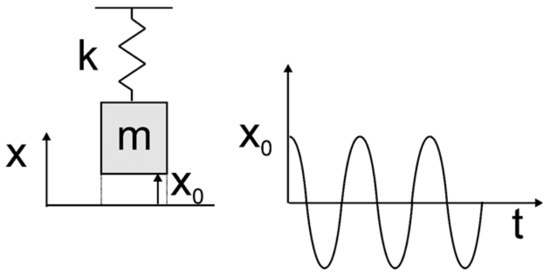
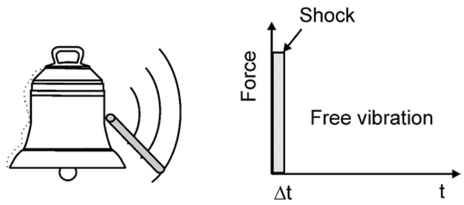
Free vibrations

Initial displacement



Shock



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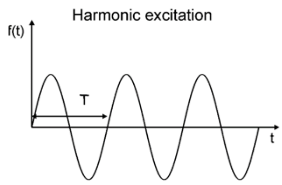
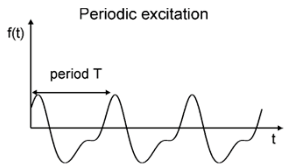
Forced vibrations : types of input forces

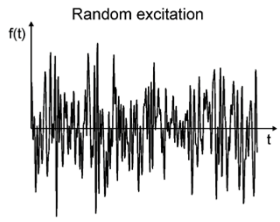
Harmonic force signal



Periodic force signal



Random force signal



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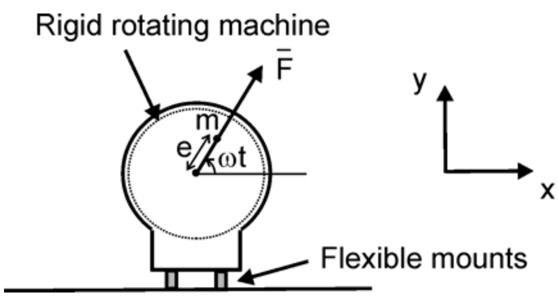
Harmonic excitation

The signal is in the form of a sine or/and cosine function



$$F_x = me\omega^2 \cos(\omega t)$$
$$F_y = me\omega^2 \sin(\omega t)$$

Mobile phone vibrator

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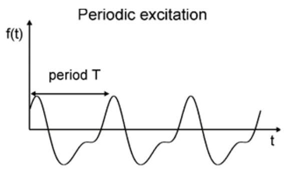
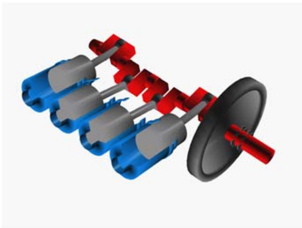
Periodic excitation

The signal repeats itself



Power generator



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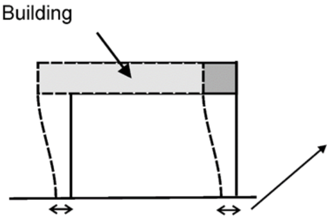
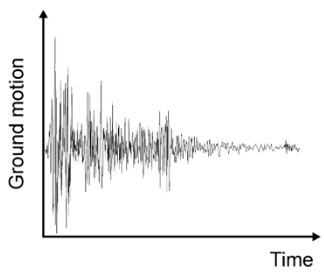
Random excitation

No structure in the signal

- Wind
- Traffic
- Waves
- Earthquakes





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Undesirable effects of vibrations

- Fatigue
- Noise
- Comfort
- Health
- Performances
- …
- (collapse)

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Positive effects of vibrations

- High frequency vibrations to decrease friction in engines (formula 1)
- Electric tooth brush, sander
- Musical instrument, loudspeaker
- Vibrating seats
- …

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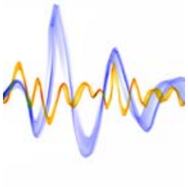

Case studies

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A test-case based learning of vibrations in civil engineering

Case study 1 : pedestrian induced vibrations of a footbridge

- Source of excitation
- Effects
- Design methodology
- Remedial measures

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A test-case based learning of vibrations in civil engineering

Case study 2 : Vibrations of high-rise buildings

- Source of excitation
- Effects
- Design methodology
- Remedial measures

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A test-case based learning of vibrations in civil engineering

Case study 3 : Machinery induced vibrations in a building

- Source of excitation
- Effects
- Design methodology
- Remedial measures

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A test-case based learning of vibrations in civil engineering

Case study 4 : Vibrations caused by traffic

- Source of excitation
- Effects
- Design methodology
- Remedial measures

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