1. Vibrations: Introduction

Arnaud Deraemaeker (aderaema@ulb.ac.be)

Definition and mechanism of vibrations
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)

Vibrations are all around us

- Vibrator in cell phone
- Tools
- Rotating machines
- Sound
- Shaver
- Tram
Mechanism of vibrations

Transfer between kinetic energy and potential energy

spring → mass

PE max
KE = 0

PE max
KE = 0

KE Kinetic Energy
PE Potential Energy
Traditionally, 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

Civil engineering structures have evolved towards slender structures 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 weigh for optimal use of material results in higher levels of vibrations.
1. Vibrations: Introduction

Vibrations in civil engineering structures

A first example: the Millennium bridge in London

Tate modern museum of Art

Opening June 10, 2000
Vibrations in civil engineering structures

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

Cables vibrations (wind)

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), Taipei, Taiwan
A fourth (catastrophic) example: Takoma Narrows bridge, USA, 1940
Vibrations in civil engineering structures

1. Vibrations in civil engineering structures:

**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
1. Vibrations: Introduction

## Types of excitation

**Free vibrations**
- Initial displacement
- Shock

**Forced Vibrations**
- Continuous excitation
Forced vibrations: types of input forces

**Harmonic force signal**

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

**Periodic force signal**

- Rigid rotating machine:
  - $F_x = me\omega^2 \cos(\omega t)$
  - $F_y = me\omega^2 \sin(\omega t)$

**Random force signal**

- Mobile phone vibrator

Harmonic excitation

The signal is in the form of a sine or/and cosine function.
1. Vibrations: Introduction

**Periodic excitation**

The signal repeats itself

![Power generator](image)

**Random excitation**

No structure in the signal

- Wind
- Traffic
- Waves
- Earthquakes

![Building and ground motion](image)
1. Vibrations: Introduction

Undesirable effects of vibrations

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

Positive effects of vibrations

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

[Image of high frequency vibrations in engines]

[Image of electric tooth brush, sander, and musical instrument, loudspeaker, vibrating seats]
Case studies

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
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

Case study 3: Machinery induced vibrations in a building

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