CIVIL 522: Seismic Engineering

Introduction

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EPFL, ENAC, Civil Engineering Institute

Objectives of today's lecture

To introduce:

- Course personnel
- Course logistics
- Performance of structures during earthquakes
- Seismic retrofitting of existing structures
- Learning objectives of the course
- Schedule

Course personnel: How to reach us?

Instructors

- Prof. Dr. Dimitrios Lignos (RESSLab, EPFL, GC B3 485) dimitrios.lignos@epfl.ch
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Teaching Assistants

- Ernesto Inzunza Araya (EESD, EPFL, GC, B2 464) Ernesto.inzunza@epfl.ch
- Jakov Oreb (EESD, EPFL, GC, B2 514) jacov.oreb@epfl.ch
- Selimcan Ozden (RESSLab, EPFL, GC B3 465) selimcan.ozden@epfl.ch
- Ce Wen (RESSLab, EPFL, GC B3 464) ce.wen@epfl.ch

Course evaluation methods

- Six take-home assignments (30%)
- Midterm examination (20%)
  - 2h written
- Final examination (50%)
  - 3h written

Resources and other information

- Lecture notes will be distributed through Moodle

- Reading material (articles, excerpts from books) will be provided through Moodle

- Suggested books

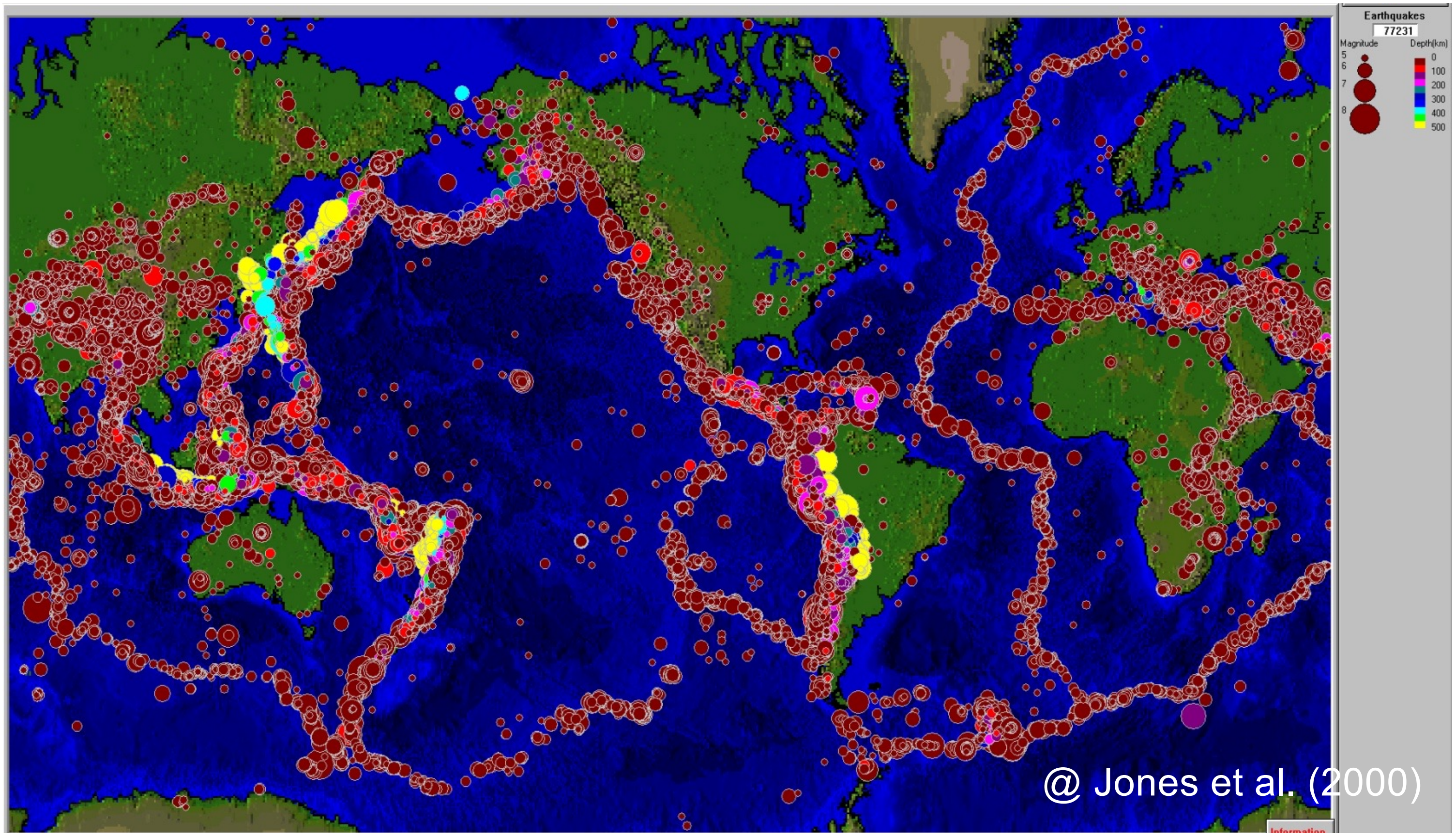
  - Bruneau, M., Uang, C-M., Sabelli, R. 2011, Ductile design of steel structures, McGraw-Hill Education.
  - Booth, E. 2014, Earthquake design practice for buildings, Thomas Telford, 3rd Edition
  - Lestuzzi, P., Badoux, M. 2008, Génie parasismique, Presses polytechniques et universitaires romandes.
  - Lestuzzi, P., Badoux, M. 2013, Evaluation parasismique des constructions existantes, Presses polytechniques et universitaires romandes.

Learning objectives

- Conceptual design
- Earthquakes and their effects on structures
- Capacity design of conventional structural systems
    - Reinforced concrete walls
    - Steel moment resisting frames, steel frames with bracings
- Seismic retrofitting of existing structures
- Assessment techniques
    - N2 method
    - SIA 269/8

Earthquakes

- ~80’000 earthquakes with $M > 5$ since 1960



Earthquakes

@the Guardian (Central Italy)

Key statistics worldwide

Human Casualties: 28’000 / year

Displaced Population: 317’500 / year

Source: UN Office for Disaster Risk Reduction

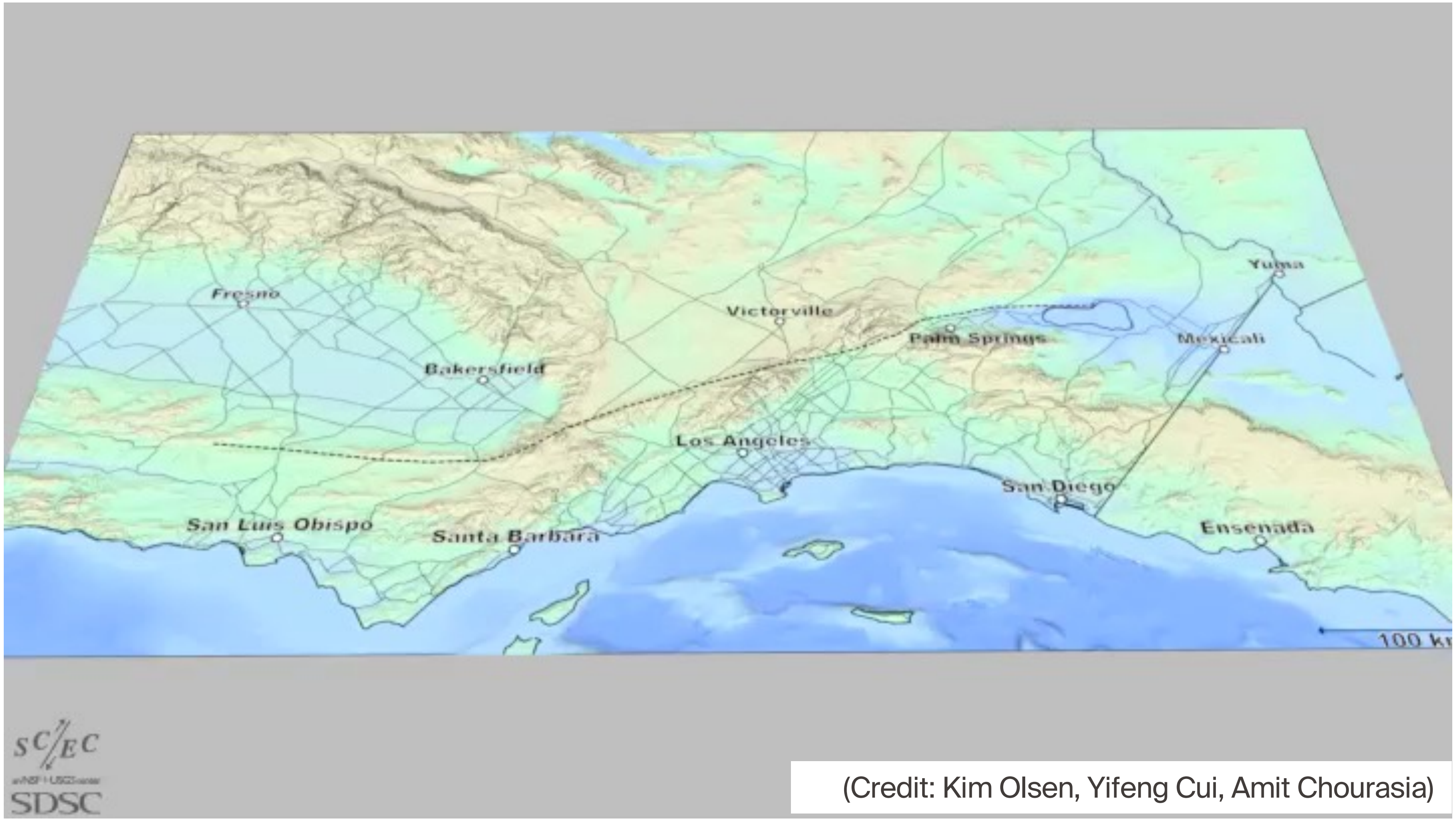
Types of earthquakes

- Tectonic: rupture of the earth crust
- Due to volcanic activity
- Due to the collapse of underground cavities
  - Natural cavities
  - Artificial cavities (mining)
- Earthquakes related to the filling of water basins (reduction of effective stresses can trigger earthquakes)
- Artificial
  - Large blasts
  - Induced seismicity due to geothermal activities or fracking

Fault rupture and wave propagation

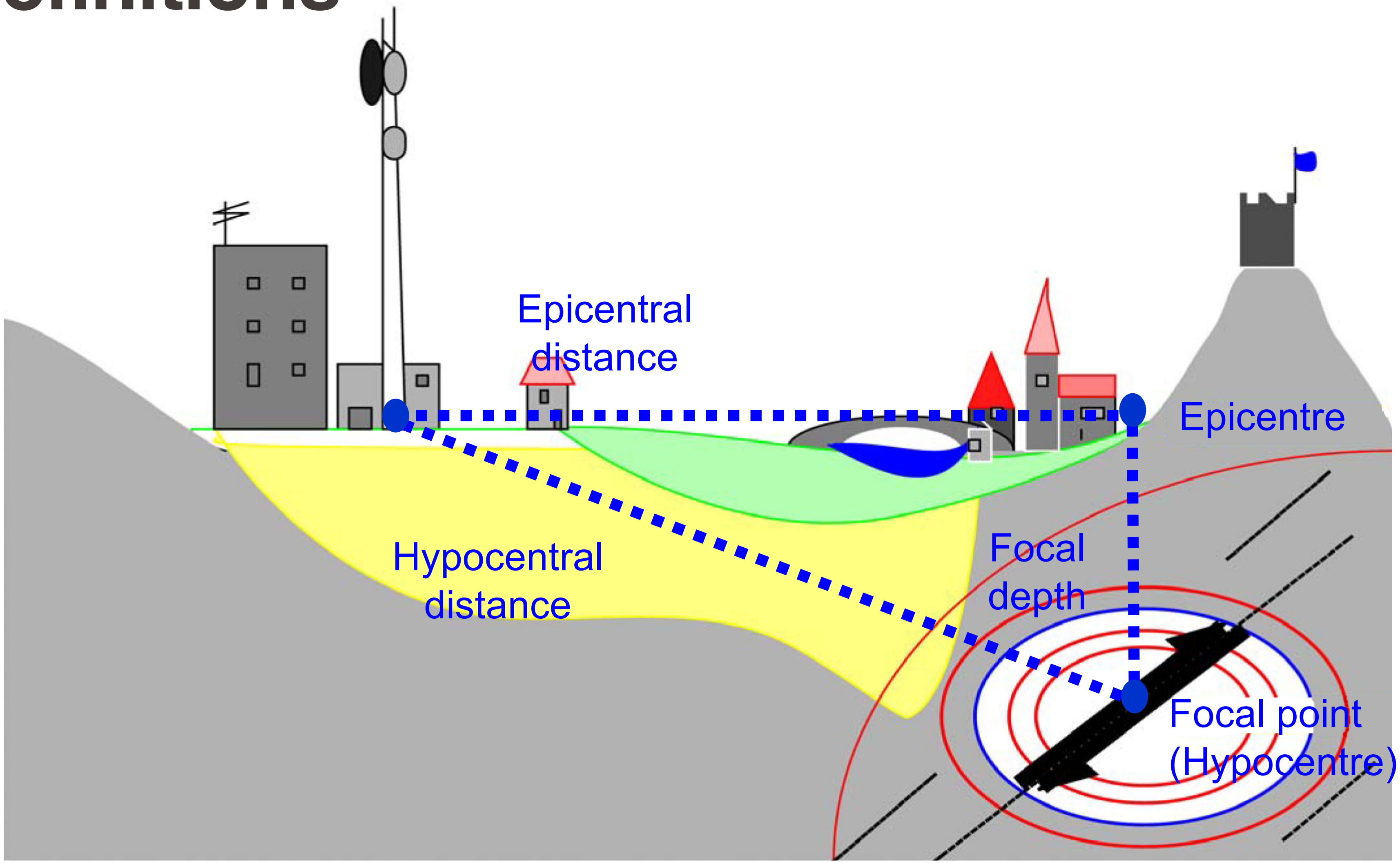
Source: USGS (Computer Simulation of a Magnitude 6.5 Earthquake on the Seattle Fault)

Fault rupture and wave propagation (2)



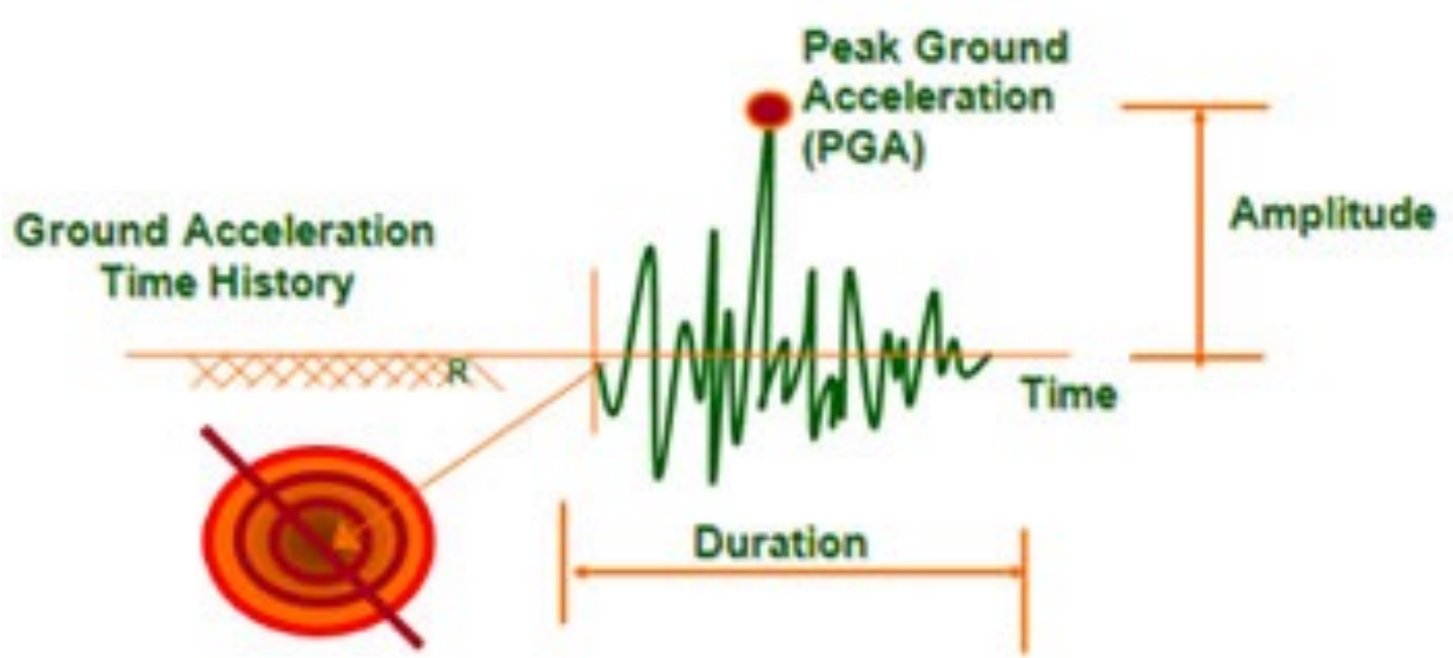
(Credit: Kim Olsen, Yifeng Cui, Amit Chourasia)

Definitions



Definition of seismic actions

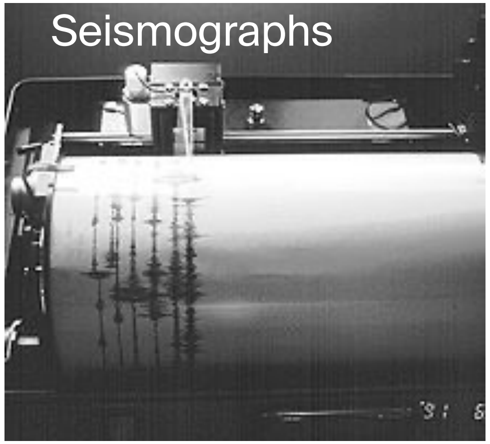
Reference Horizontal Peak Ground Acceleration α_{gR}



Source: Earthquake Disaster Management

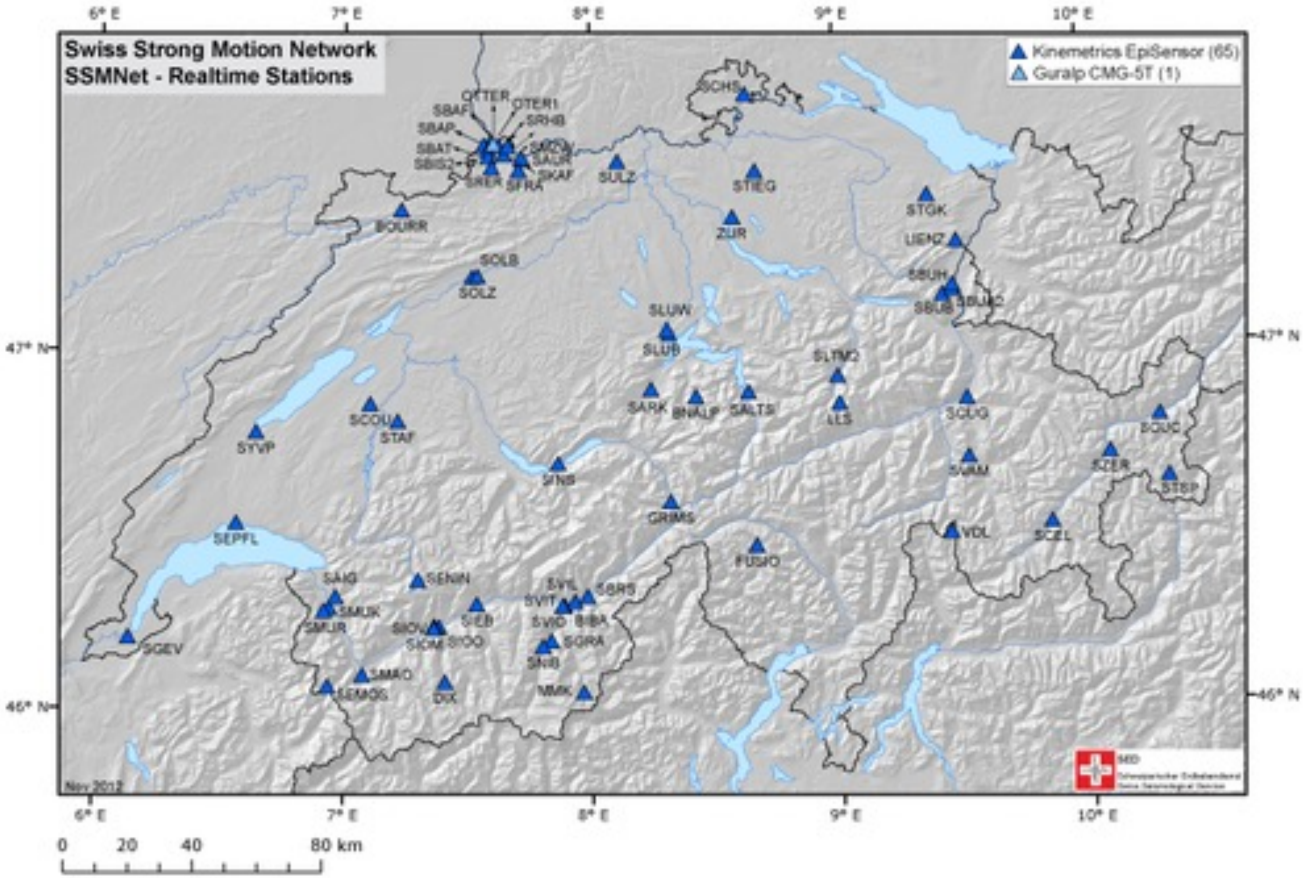
EPFL

Accelerometers



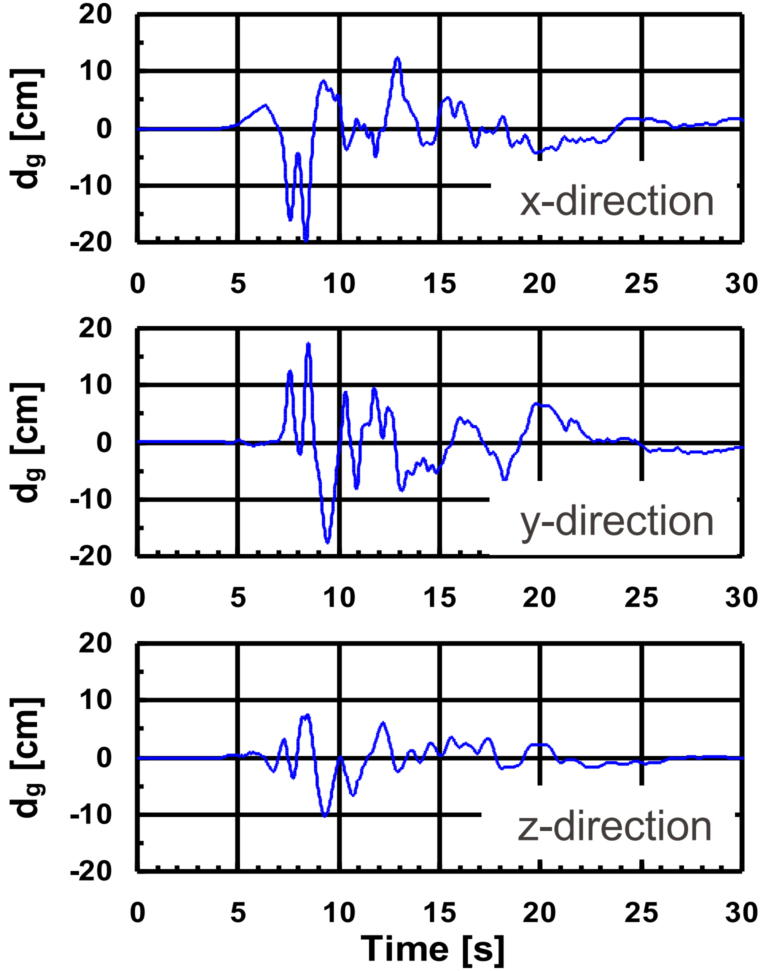
http://de.wikipedia.org/wiki/Seismograph

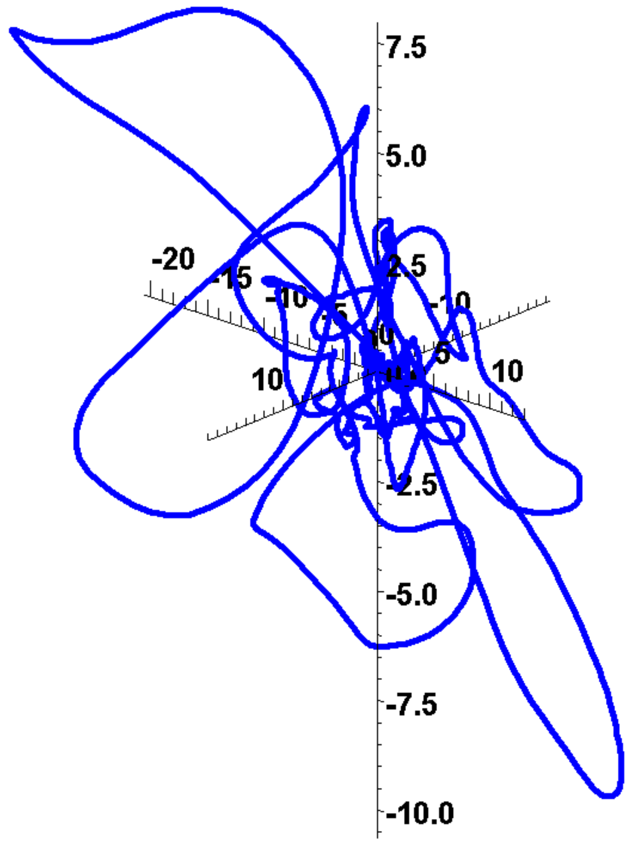
Network of Seismographs in Switzerland



3-dimensional ground movement

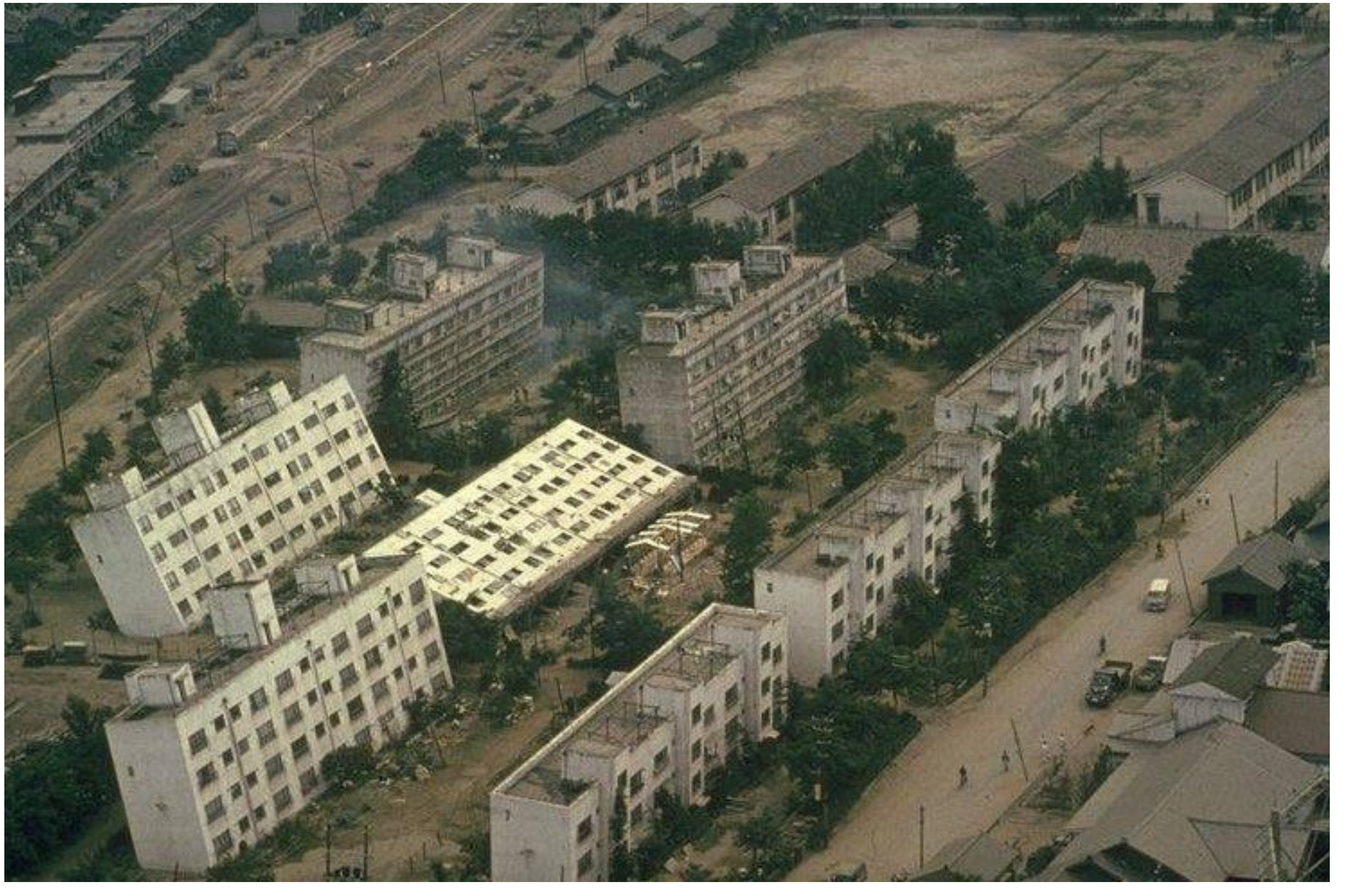
1995 Kobe Earthquake, $M_w = 6.9$, JMA Station, d_{epi}=18km





@ Dr. A. Dazio

Effects of earthquakes: Liquefaction



Nigata earthquake 1964, Japan

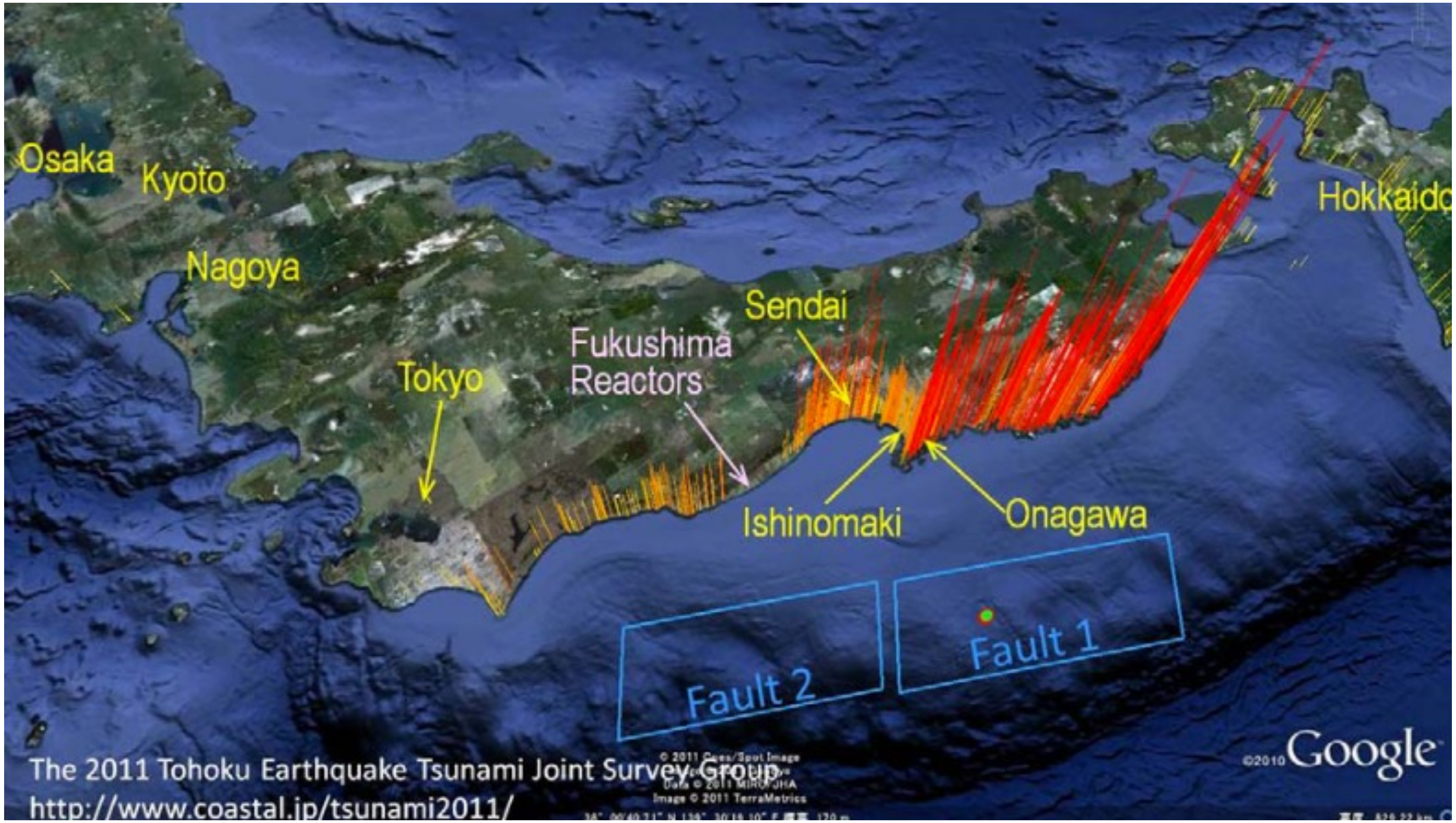
Effects of earthquakes: Landslides, rockfalls

@ Dr. T. Wenk

Effects of earthquakes: Tsunami

@ Prof. Dr. K. Beyer

Effects of earthquakes: Tsunami



@ Prof. Dr. D. Lignos

Effects of earthquakes: Tsunami

@ Prof. Dr. D. Lignos

Damage to unreinforced masonry buildings

@ Prof. Dr. K. Beyer

Damage to reinforced concrete buildings

Olive View Medical Center, San Fernando 1971 earthquake (Photos @PEER)

Damage to steel frame buildings

@Prof. Dr. R. Tremblay

@AIJ, 1995 Kobe earthquake, Japan

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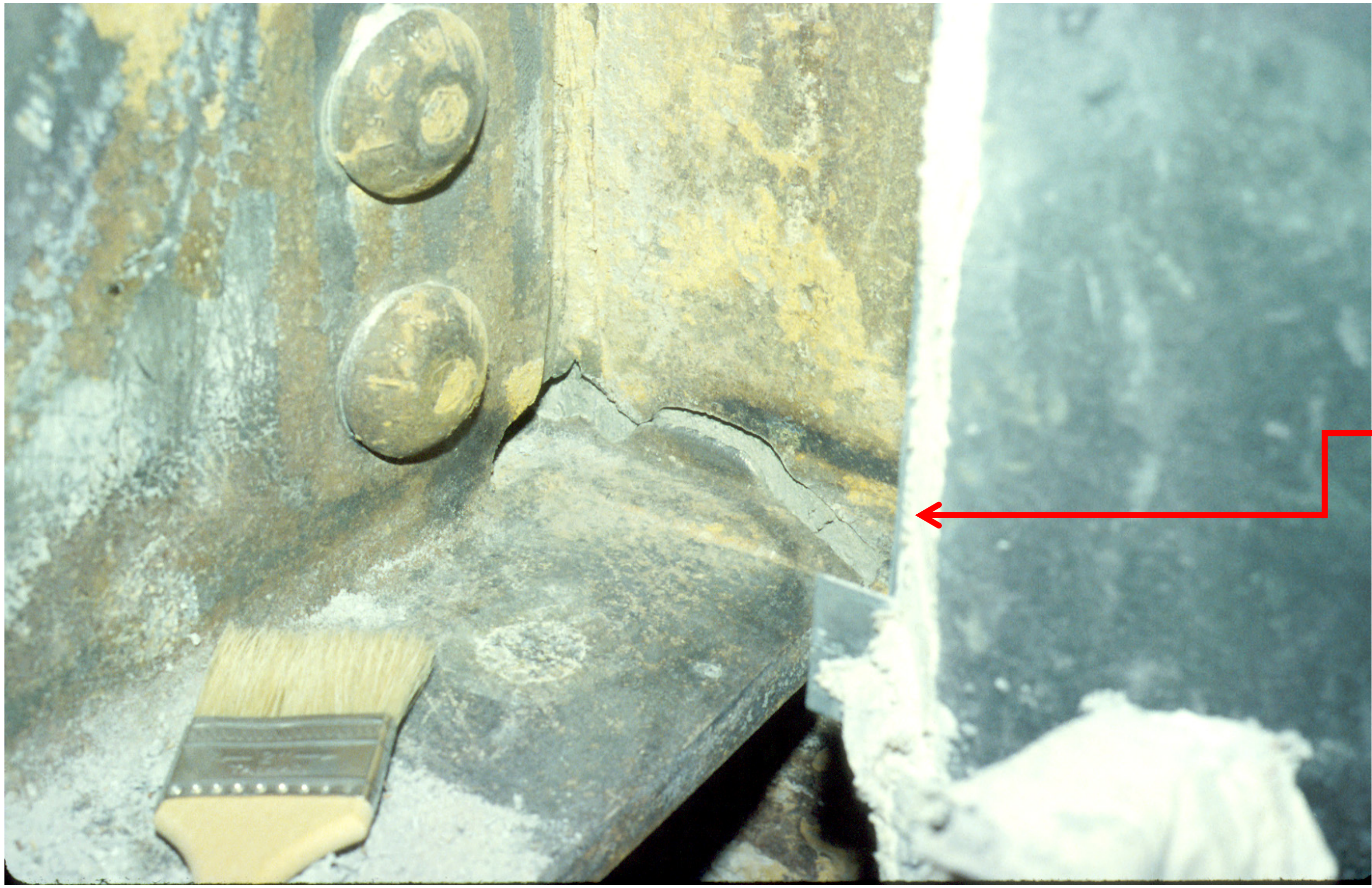
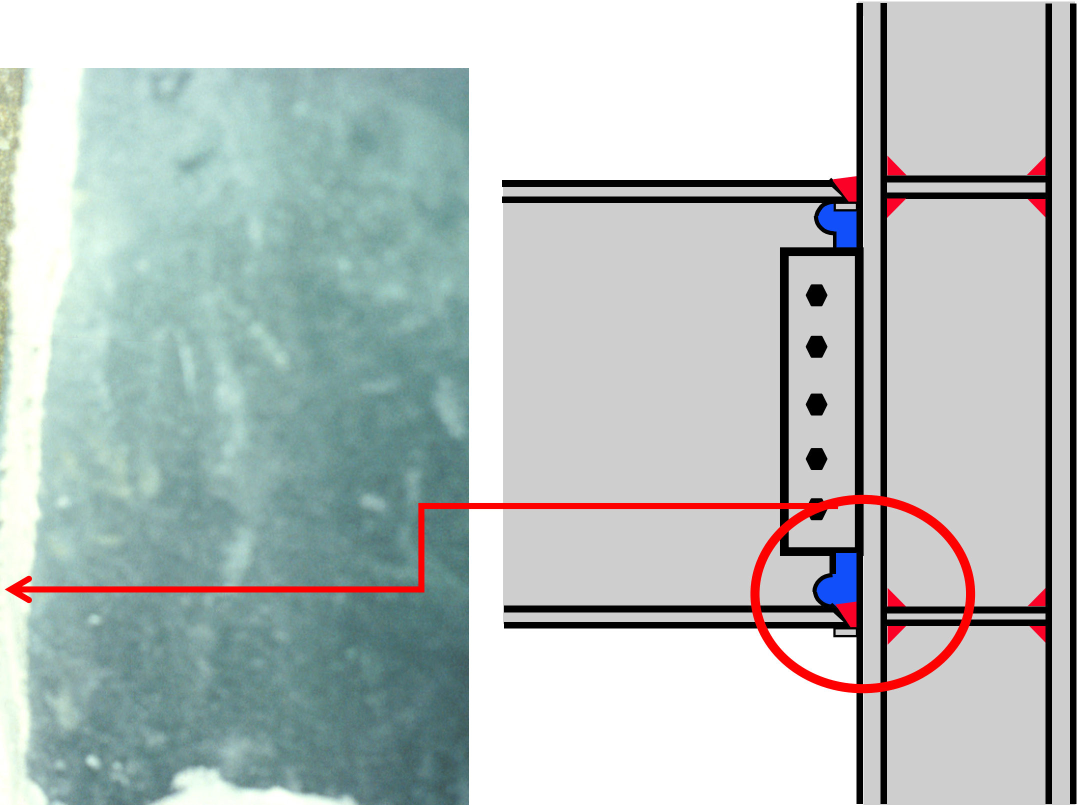
Damage to steel frame buildings (2)

@Prof. Dr. M. Engelhardt

Damage to steel frame buildings (3)





@Prof. Dr. M. Engelhardt

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Damage to steel frame buildings (4)

@Prof. Dr. D. Lignos

Damage to bridges

@Dr. T. Wenk

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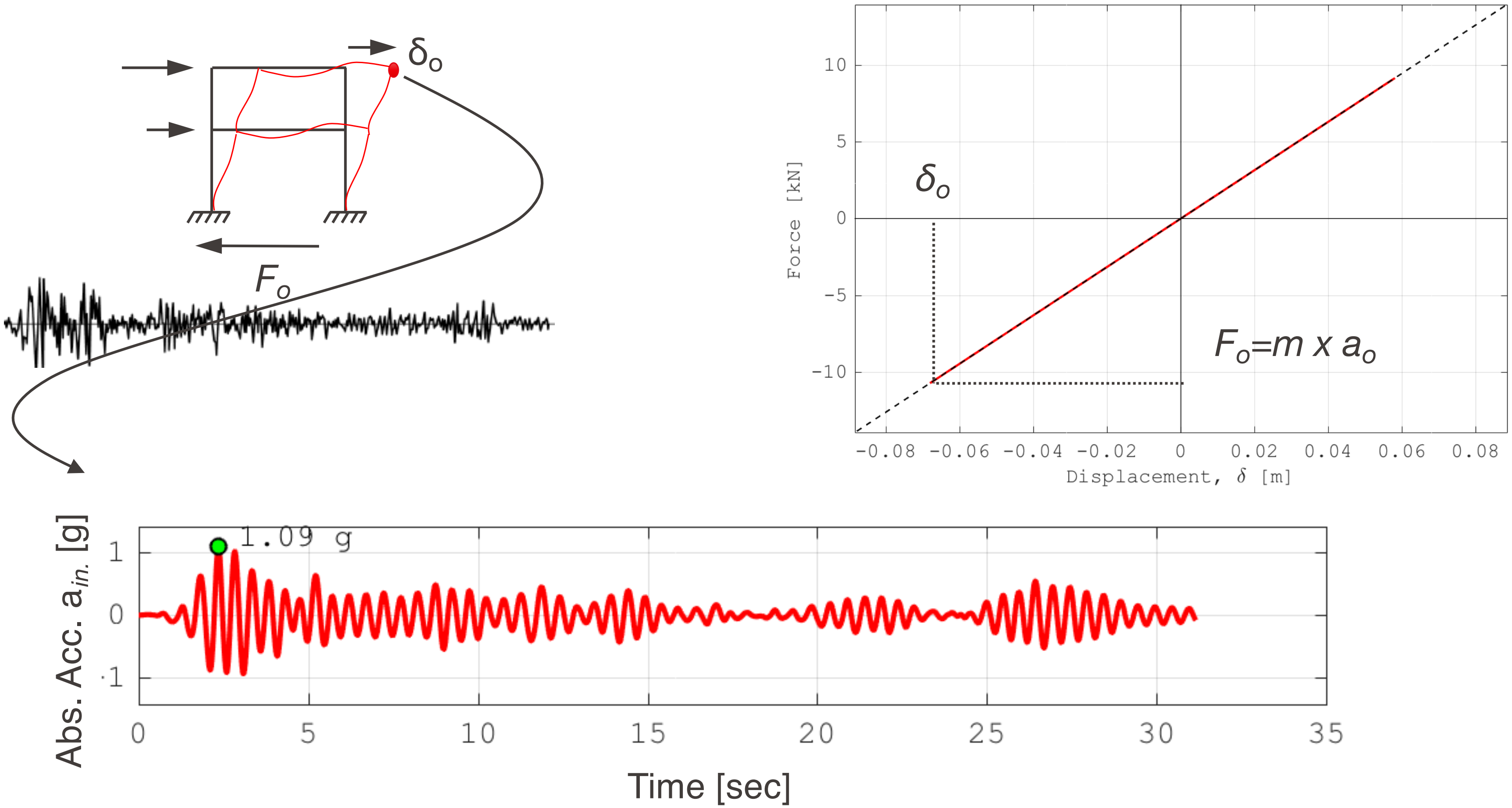
Damage to bridges

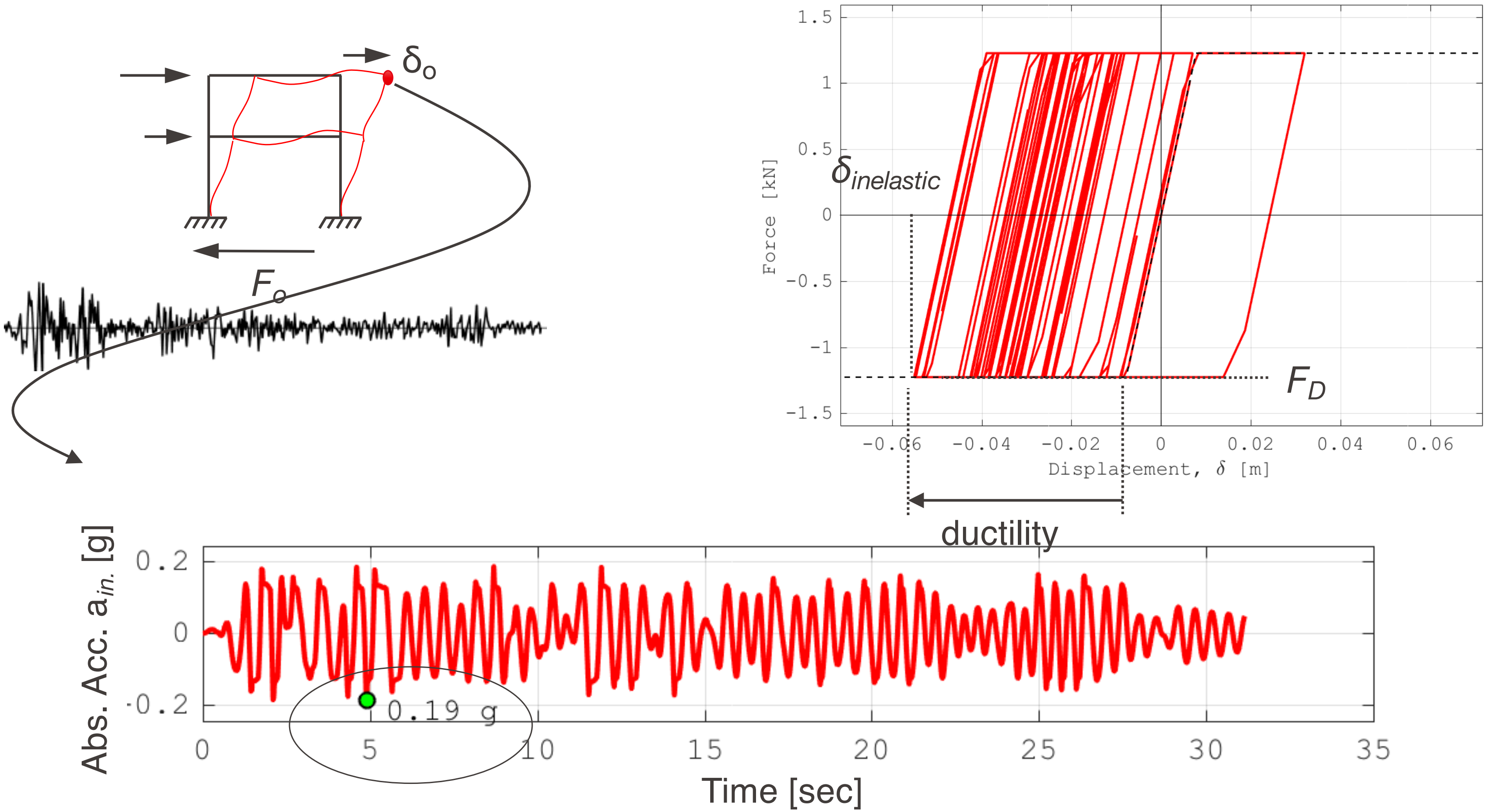
Damage to bridges

Overturned Hanshin Expressway, 1995 Kobe Earthquake, Japan (images courtesy of AIJ)

Elastic versus inelastic response of structures during earthquakes (from Dynamics of structures)



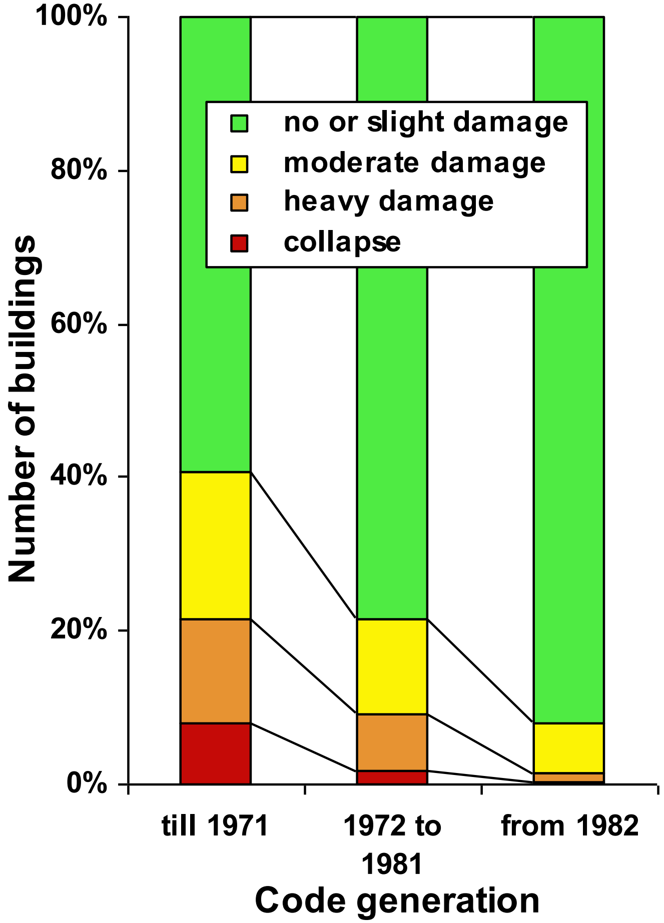
Elastic versus inelastic response of structures during earthquakes (from Dynamics of structures)



Seismic design specifications in SIA standards

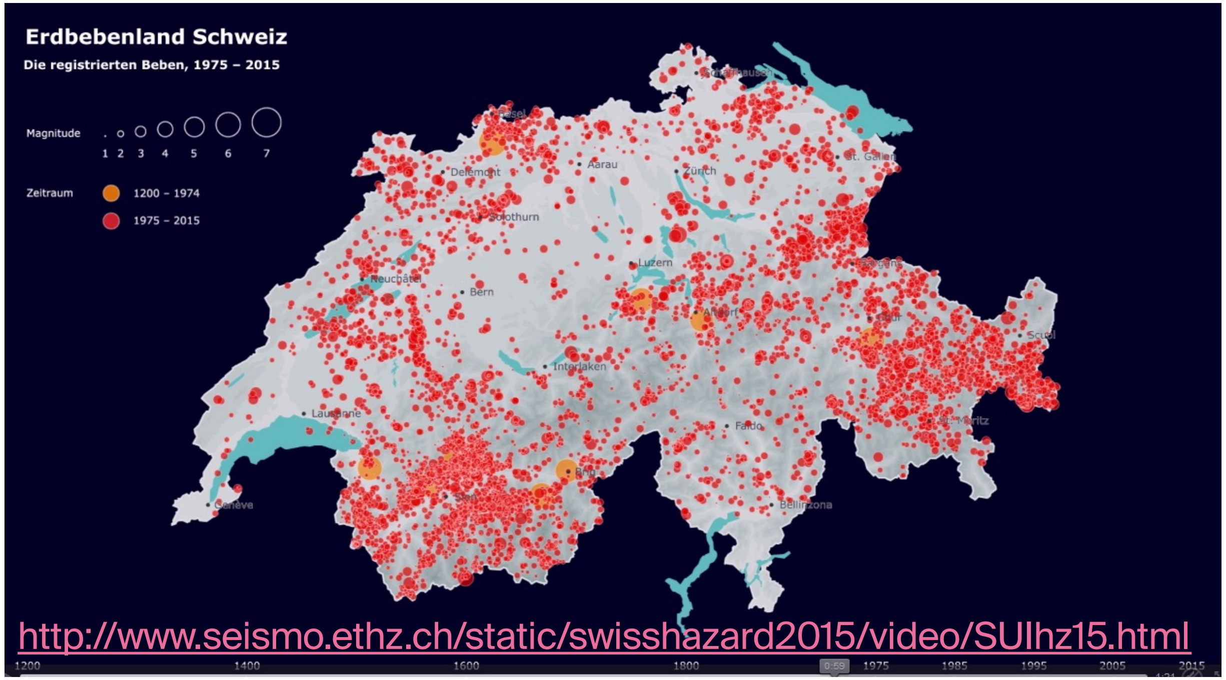
Year	Seismic design specifications
Before 1970	nothing
1970	Very general (2% or 5% of the self weight)
1989	Conventional design (Definition of seismic hazard zones, response spectra)
2003	Introduction of capacity design in Swiss building codes
2004	SIA 2018 «Verification of the seismic safety of existing buildings»
2013	Partial revision of SIA 262 (including revision of seismic design provisions)
2013	Eurocode 8 (2012: Determination of national determined parameters (NDPs) for Switzerland)
2017	Introduction of the new code SIA 269/8 for the seismic evaluation of existing structures
2025	New generation of Eurocodes; revision of Eurocode 8 currently under way

Impact of seismic design standards on type of damage



[Architectural Institute of Japan, 1995]

Seismic hazard in Switzerland



http://www.seismo.ethz.ch/static/swisshazard2015/video/SUIhz15.html

- Largest documented earthquake: 1356 earthquake in Basel (M=6.6).
- An event of this magnitude is expected to occur in Switzerland in average once in 1500 years.
- On average,
  - 10 earthquakes with M=3-4 per year in Switzerland.
  - One earthquake with M>5 every 8-15 years
  - Earthquakes with M>6 every 50-150 years.

Historical earthquakes in Switzerland

Earthquakes in Switzerland with an Intensity VIII or larger ('Significant damage') or M_w>6.0

Year	Place	Epicentral intensity	Magnitude M_w	Depth [km]
1295	Churwalden GR	8	6.5	12
1356	Basel BS	7.5	6.2	-
1356	Basel BS	9	6.9	12
1524	Ardon VS	8	6.4	12
1584	Aigle VD	7	6.4	12
1601	Unterwalden	7	6.2	12
1685	Oberwallis	6	6.1	12
1755	Brig, Naters VS	8	6.1	12
1855	Törbel VS	8	6.4	12
1946	Ayent VS	7	6.0	12
1946	Ayent VS	8	6.1	12
1960	Brig	8	5.3	12

SED: http://histserver.ethz.ch

Return period of earthquakes

Return period of an earthquake:

= Mean time between two earthquakes with $M_w \geq m$

$$T = \frac{1}{p}$$

p = Mean frequency of earthquakes with $M_w \geq m$ (per year)

Most design standards around the world consider the following for standard buildings:

- The seismic design action is based on a horizontal acceleration with a probability of exceedance 10% in 50 years (design basis earthquake)
- Probability that there is an earthquake with $M_w \geq m$ in n years:

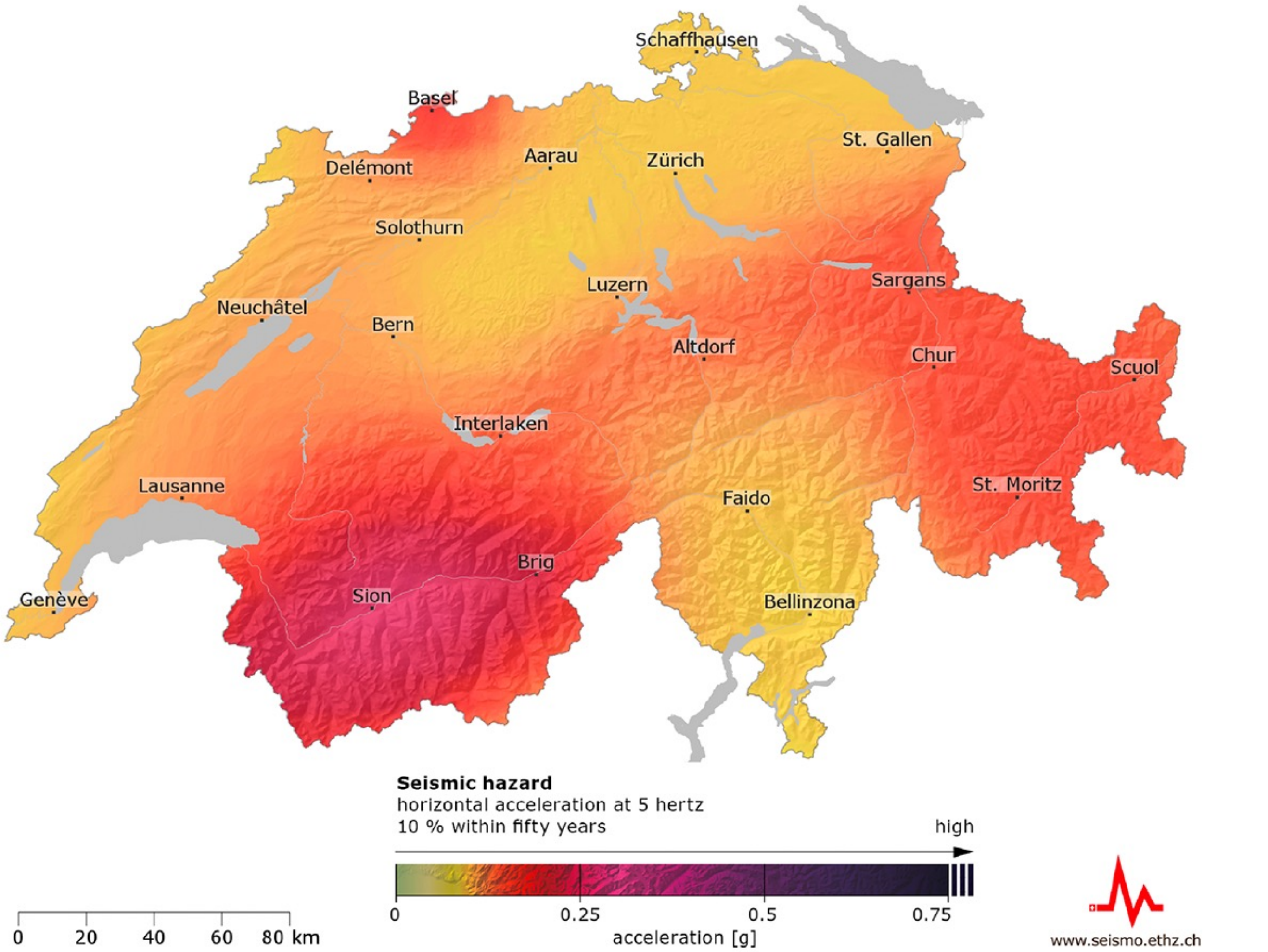
$$P_n = 1 - (1-p)^n$$

- Return period of earthquake that is expected to be exceeded with a probability of 10% in 50 years:

$$P_n = 1 - (1-p)^{50} = 0.1 \quad \rightarrow \quad p = 0.002105 \frac{1}{year} \quad \rightarrow \quad T = \frac{1}{p} = 475 \; years$$

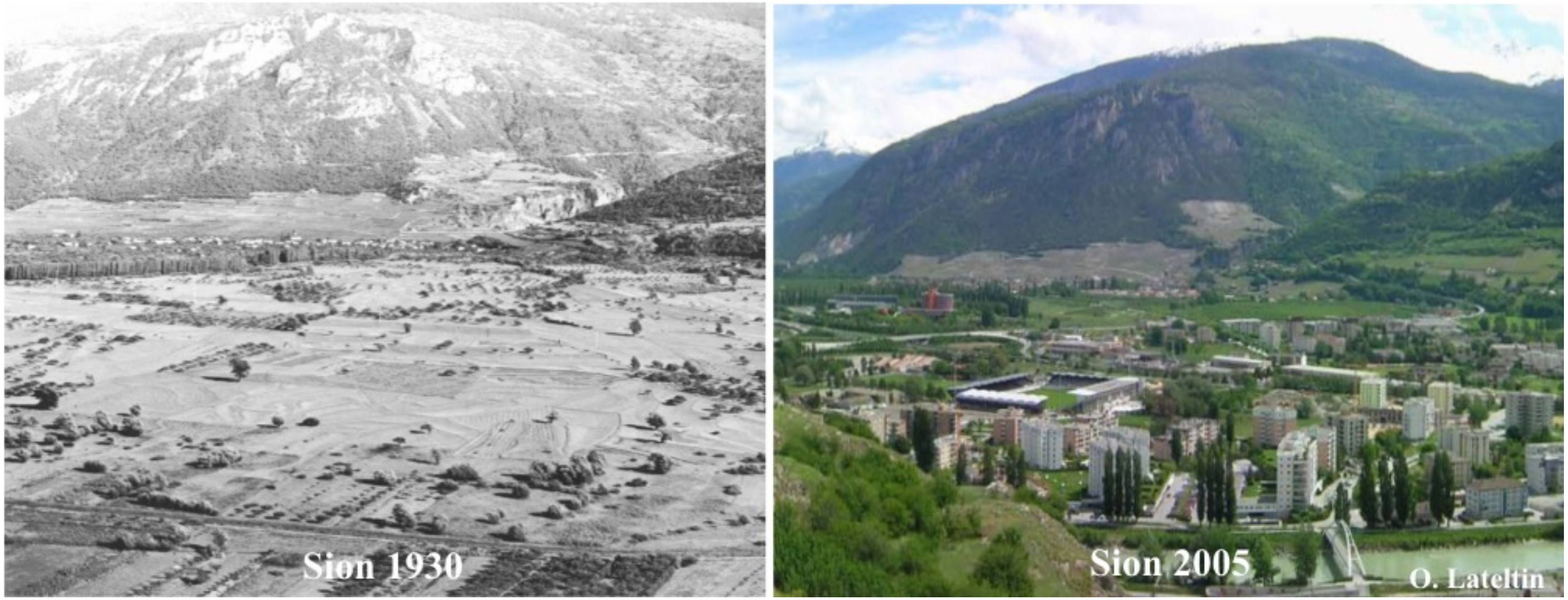
A probability of exceedance of 10% in 50 years corresponds to a return period of 475 years

Seismic hazard in Switzerland



http://www.seismo.ethz.ch/en/home/

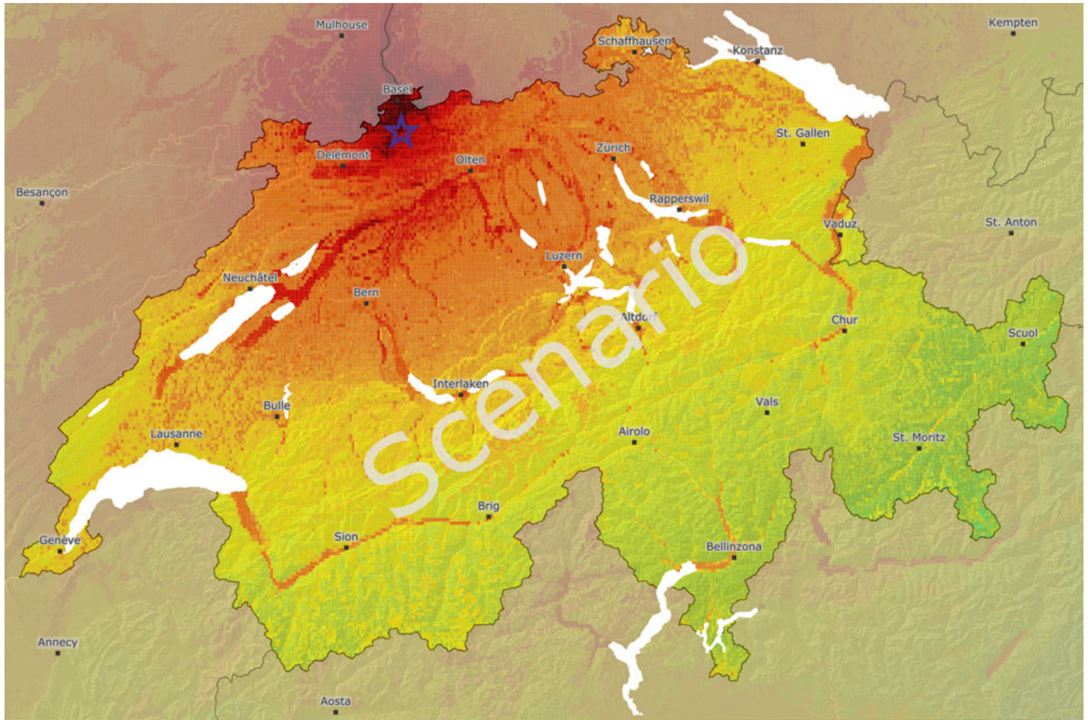
Evolution of the seismic risk in Switzerland



Seismic risk = Seismic hazard x vulnerability x value

The seismic hazard is ~constant in time, but the seismic risk is not!

The earthquake of Basel



Intensity	II	III	IV	V	VI	VII	VIII	IX
Impact	scarcely felt	weak	largely observed	strong	slightly damaging	damaging	heavily damaging	destructive

Map of the possible impacts of an earthquake with a magnitude of 6.6 near Basel.

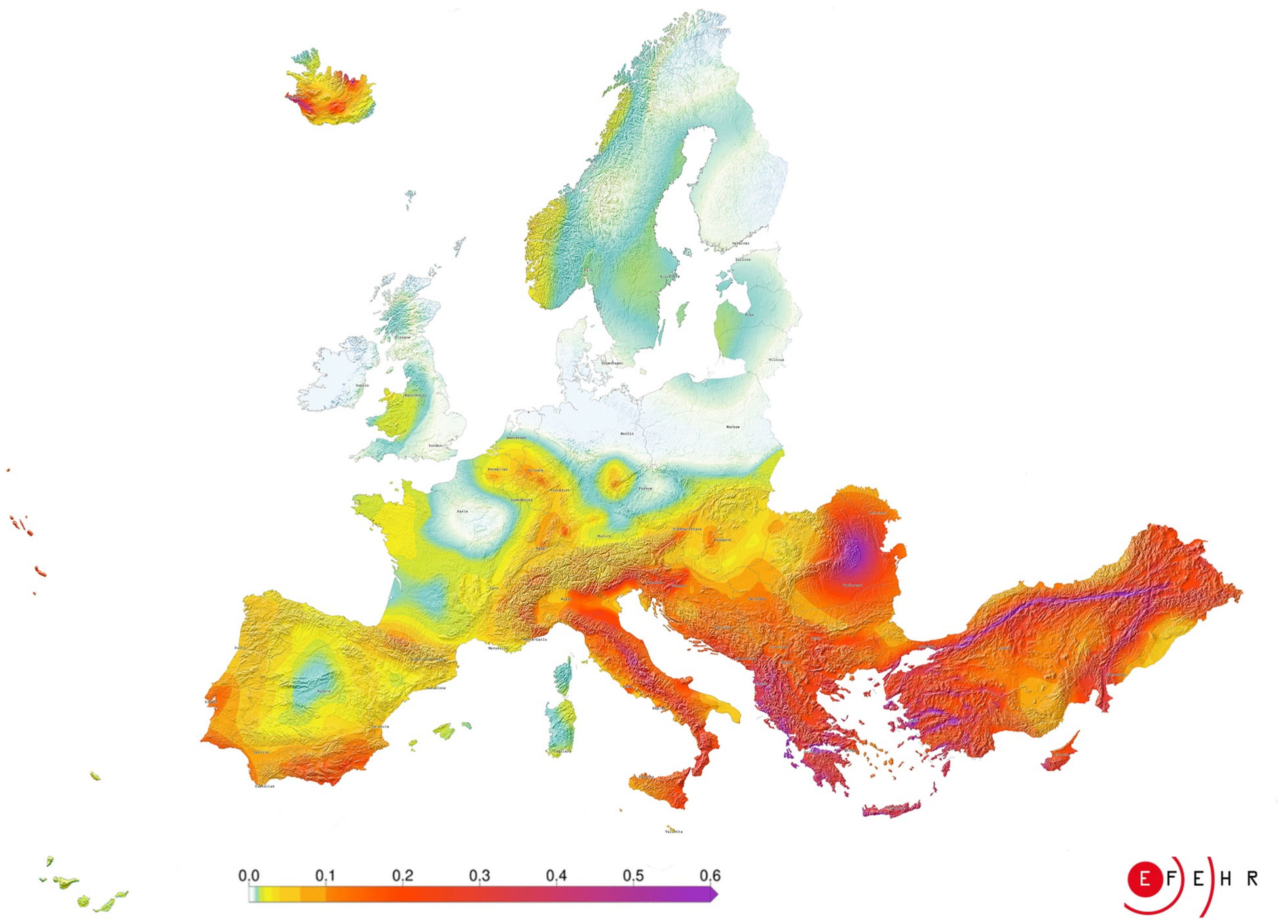
Scenario: A repetition of the 1356 earthquake of Basel from 1356 today (estimated return period 2000-2500 years)

Expected outcomes:

- ~ 77,000 buildings across Switzerland would suffer moderate to severe damage. In the hardest-hit cantons, this would mean up to 70% of the building stock. ~ 3,000 fatalities
- CHF ~ 45 billion of building damage
- Costs due to business downtime have not been included

Source: Swiss Seismological Service http://seismo.ethz.ch/en/home/

Seismic hazard in Europe



http://www.efehr.org/earthquake-hazard/What-is-earthquake-hazard/

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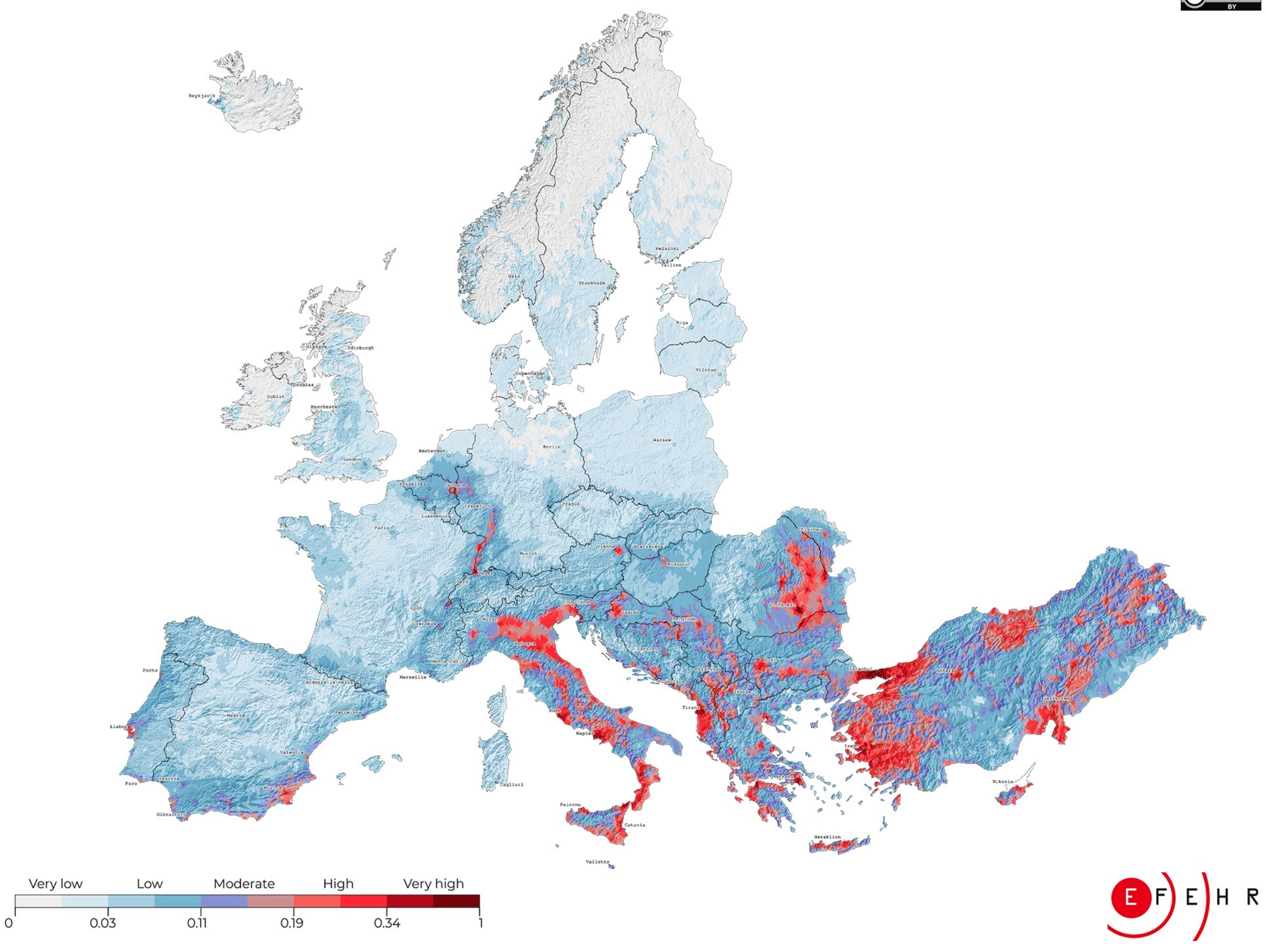
Seismic hazard in Europe



http://www.efehr.org/earthquake-risk/What-is-earthquake-risk/

Seismic retrofitting of existing structures

Université de Laval – Pavillon Alexandre Vachon, Quebec, Canada

https://www.quaketek.com/applications/

Seismic retrofitting of existing structures

https://www.quaketek.com/applications/

Seismic retrofitting/extensions of existing structures

Why Seismic Engineering (CIVIL 522)

- Seismic force demands depend on the dynamic behavior of a structure
  - Stiffness, mass, strength characteristics of a structure, soil conditions, etc

- Large earthquakes are rare events
  - We accept that built infrastructure will likely be damaged (inelastic response)

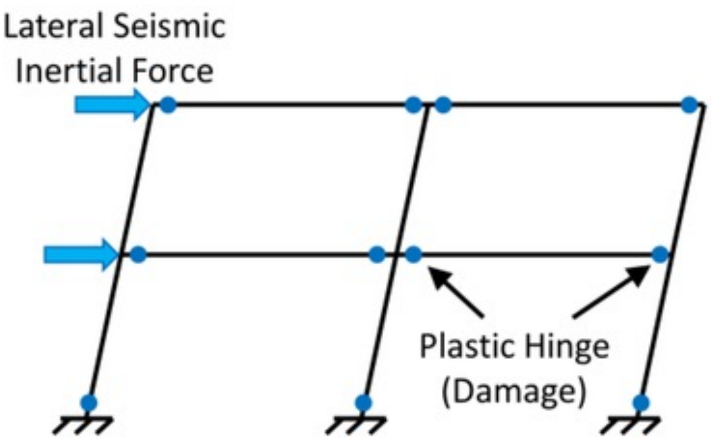
- Structures exhibiting inelastic behavior shall be designed for adequate ductility

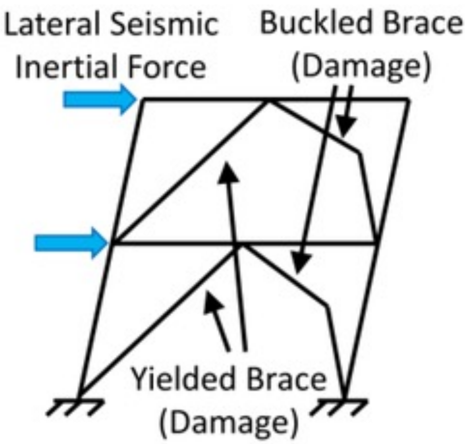
Course objectives

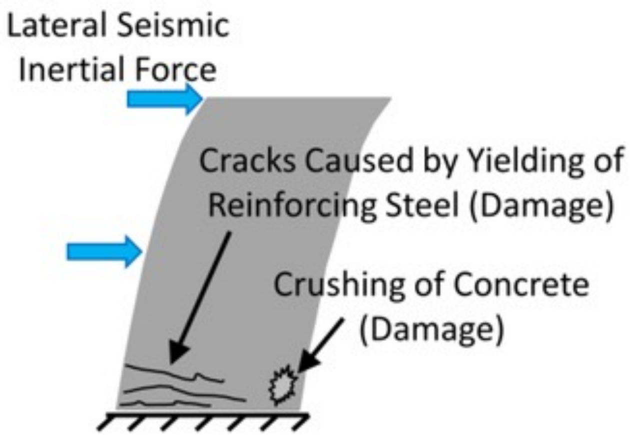
- **New buildings**
  - Conceptual design
  - Design of structural members, their connections
  - Structural detailing
  - Choice of materials

- **Existing buildings**
  - Assessment methods
  - Design of alternative retrofitting schemes

Course objectives (2)

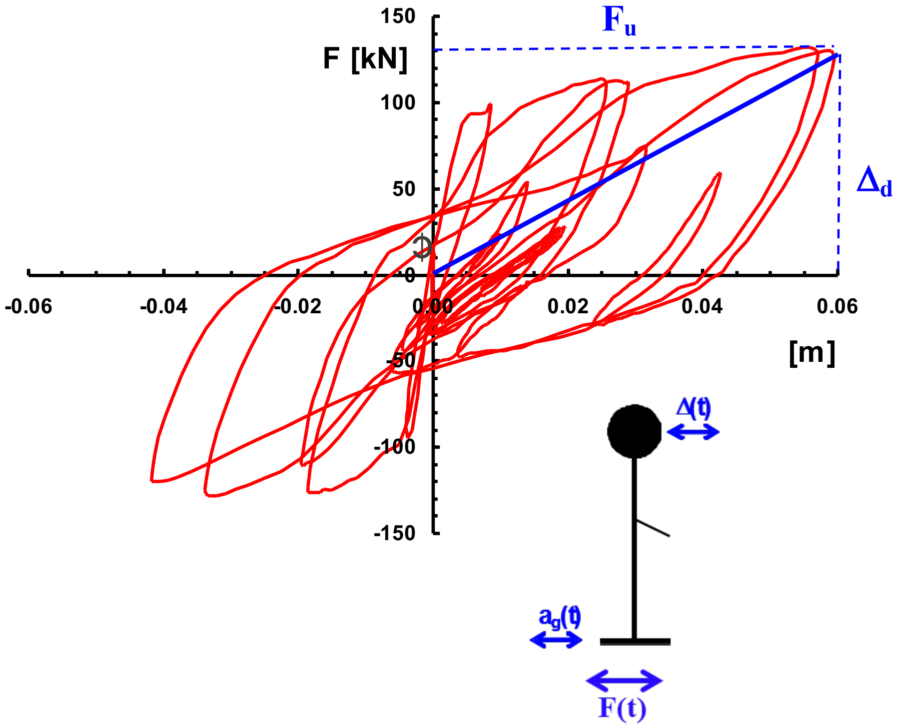






Course objectives

Peak force and displacement estimation of structures subjected to earthquakes



Basic elements of displacement-based evaluation of existing structures