ETH zürich

IGT Professur für Geotechnik



The ETHZ Geotechnical Centrifuge Center (GCC)

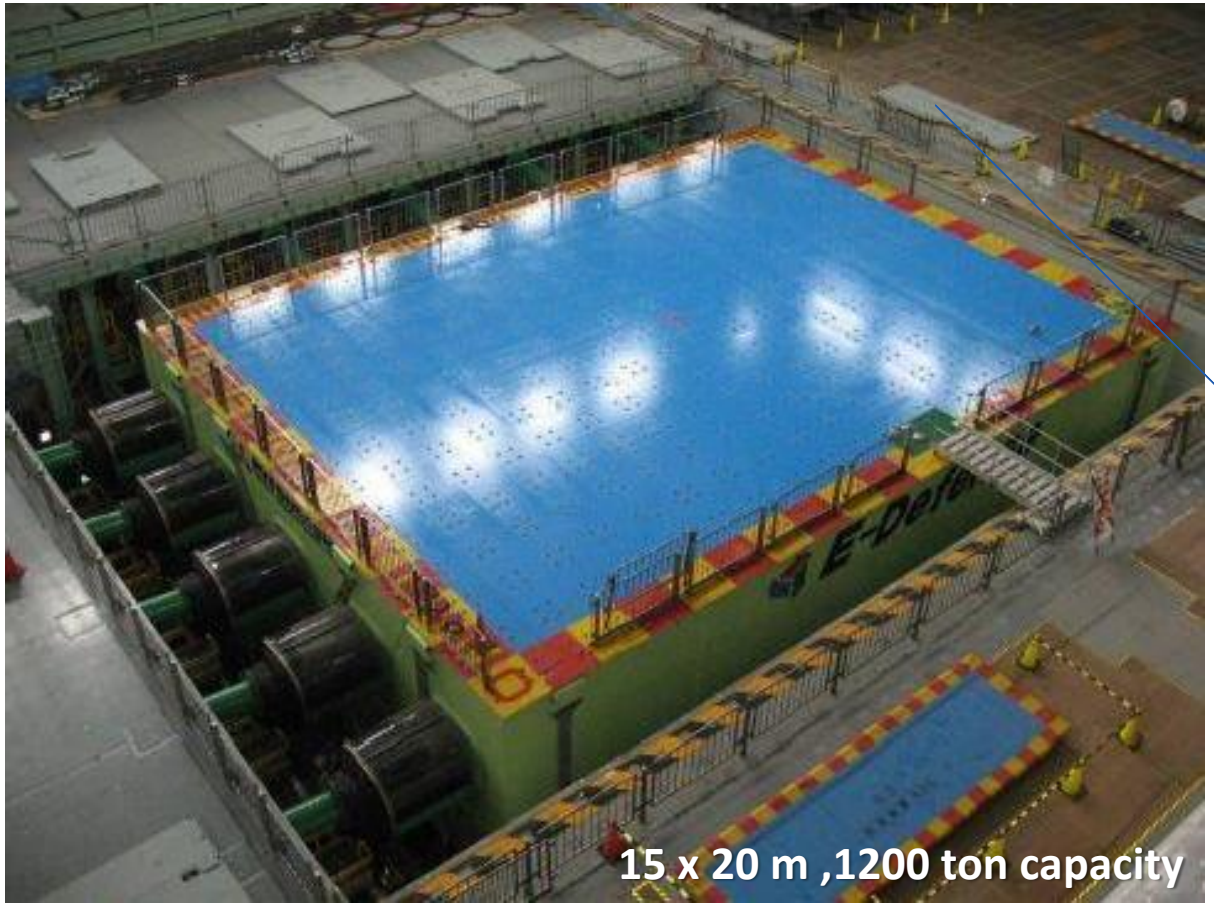
Prof. Dr. Ioannis Anastasopoulos
Chair of Geotechnical Engineering

SGEB General Assembly, 24.5.2024

Why Centrifuge Modelling?

Large–scale Testing

E-Defence, Japan: The largest shaking table

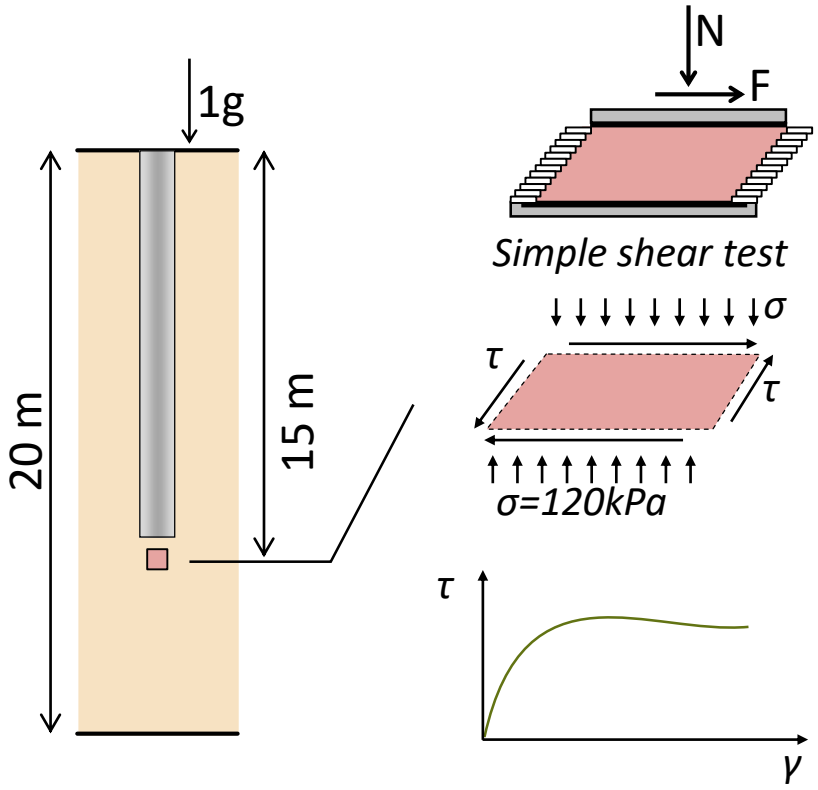


Real scale testing of school building

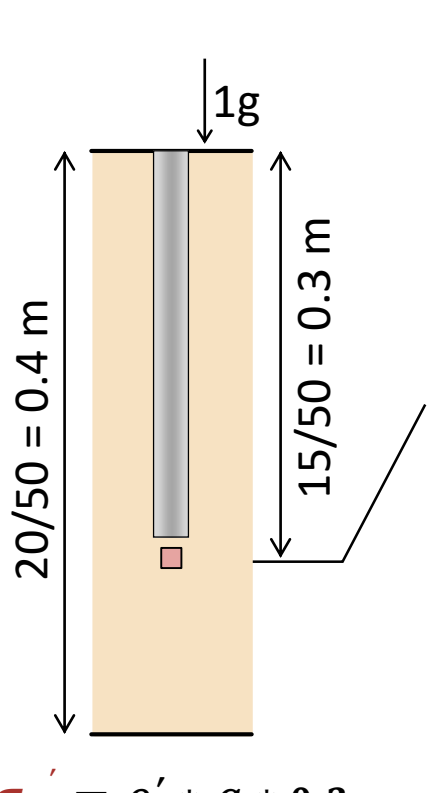


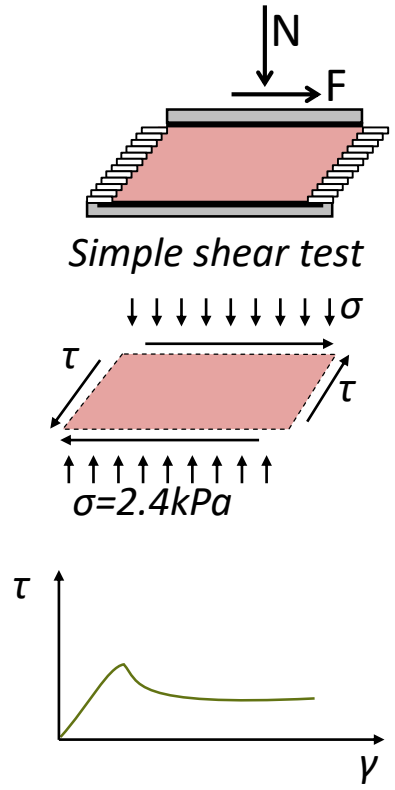
Why Centrifuge Modelling?

Field problem



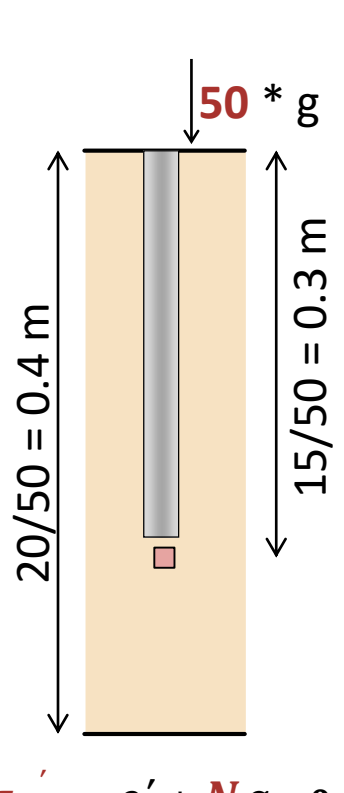
Scaled model (1:50)





$$\sigma_v' = \rho' * g * 0.3\,m = 2.4\,kPa$$

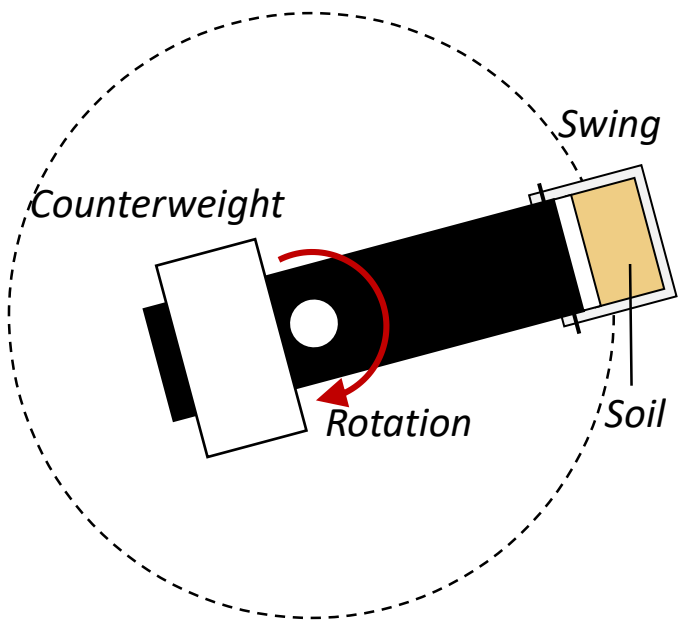
Centrifuge model (1:50)



$$\sigma_v' = \rho' * Ng * 0.3m = 120\,kPa$$

Principle of Centrifuge Operation

Beam Centrifuge

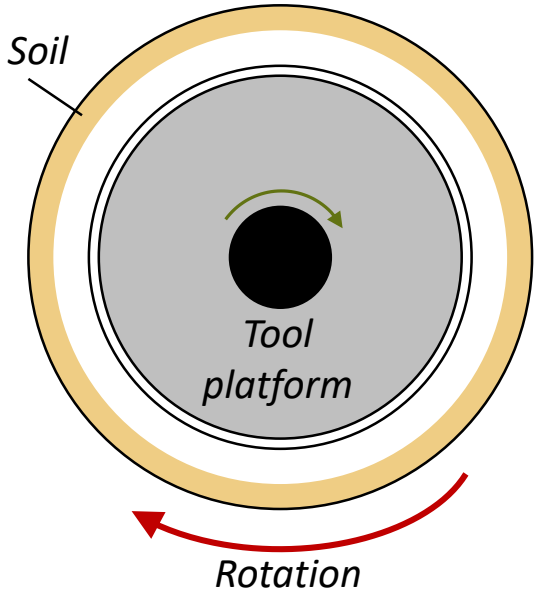




- Typically larger
- Larger payloads in general
- Slower spinning

Basic Principle: $N \times g = R \times \omega^2$

Drum Centrifuge



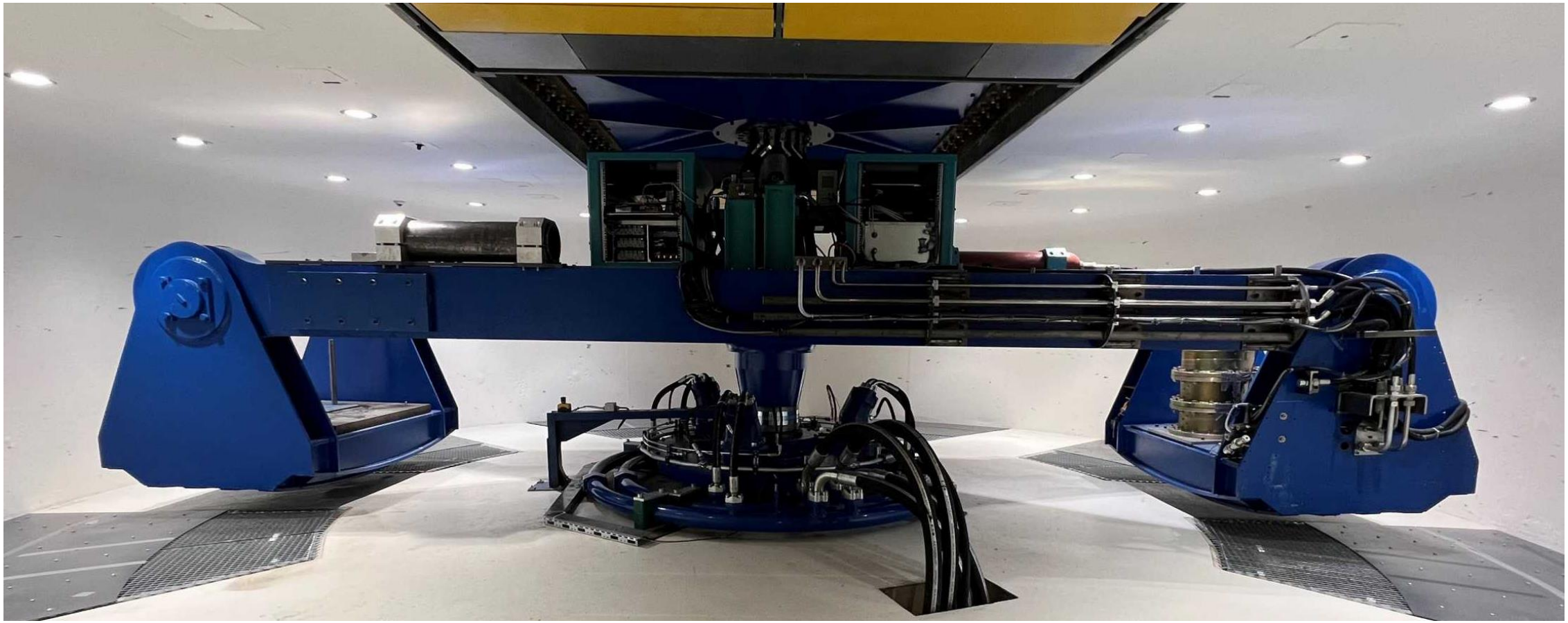
- Typically smaller
- For long problems
- Higher g level

The GCC

Ralf Herzog, Dr. Liam Jones, Markus Iten, Ernst Bleiker, Jürg Giger,
Andreas Kieper, Nicolas Germann, Dr. Lampros Sakellariadis,
Dr. Athanasios Agalianos, Dr. Kostas Kassas, Prof. Orestis Adamidis

The ETHZ Geotechnical Centrifuge Centre (GCC)

Beam Centrifuge



Manufcaturer: **Krupp (refurbished by Hagenbuch, IGT)**

Diameter: **9 m**

Established in: **2022**

Capacity: (5 tons @ 100 g) **500 gton**

The ETHZ Geotechnical Centrifuge Centre (GCC)

Shaking Table



- Simulation of any real or synthetic motion
- Free edges to allow for mounting of long models of up to 2 m length

Capacity

Payload: 700 kg @ 100 g

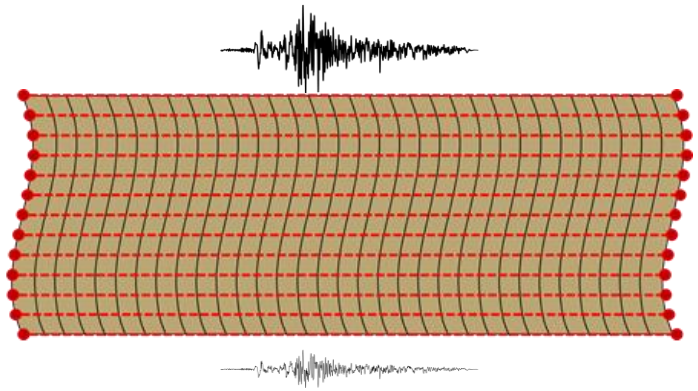
(1700 kg @ 50 g)

Frequency: 0 to 350 Hz

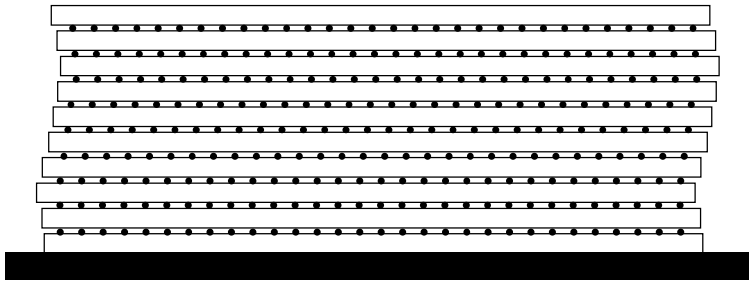
Amplitude: 16 g (700 kg)

The ETHZ Geotechnical Centrifuge Centre (GCC)

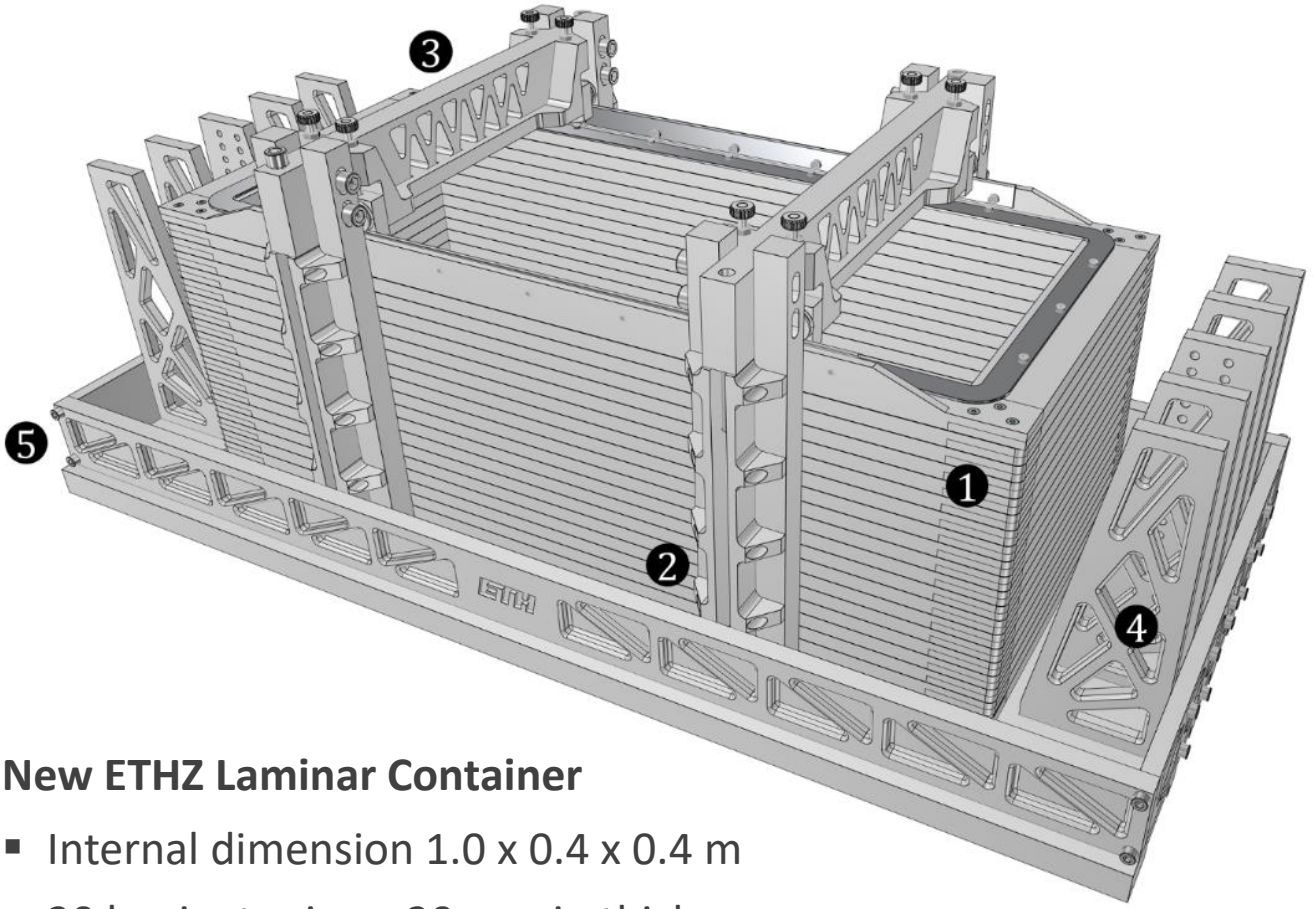
Laminar Container



FE: Multi Point Constraints (MPCs)



Lab: Laminates connected with sliders

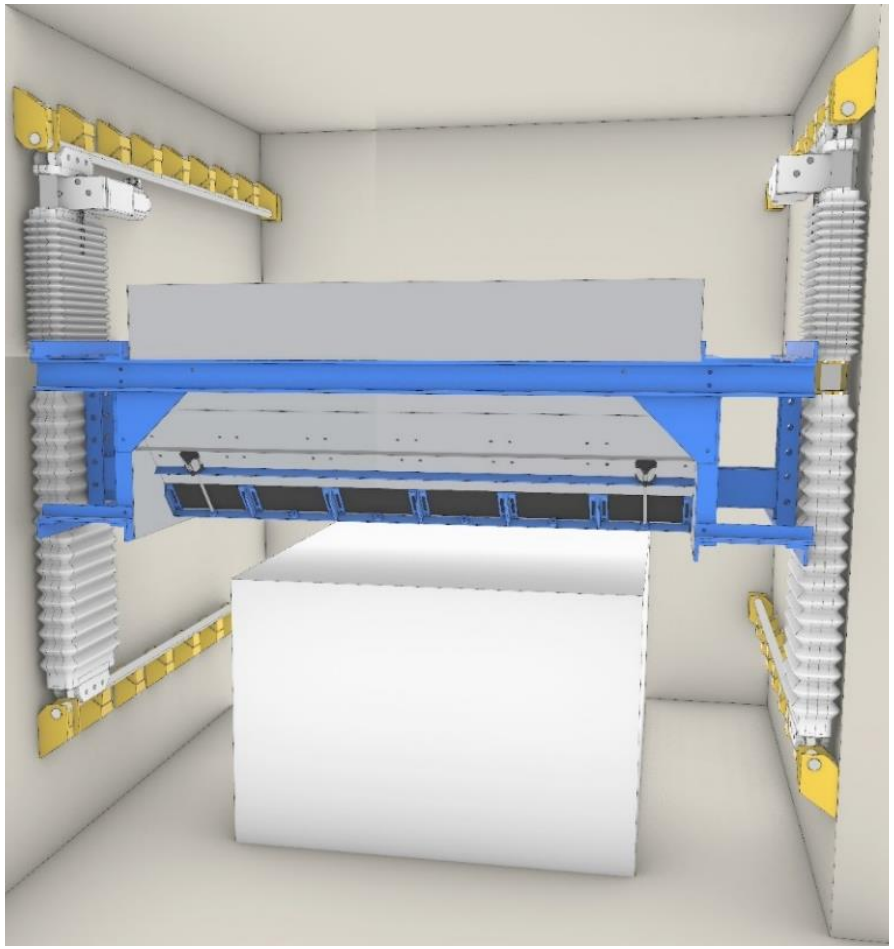


New ETHZ Laminar Container

- Internal dimension 1.0 x 0.4 x 0.4 m
- 20 laminate rings, 20 mm in thickness

The ETHZ Geotechnical Centrifuge Centre (GCC)

Automated Pluviation System (APS)





- Preparation of controllable and repeatable models
- Control of sand relative density by mass flow rate
- Fully-automated control of lateral and vertical motion
- Sand raining along the entire container width
- Equipped with laser sensors for automatic adjustment of drop height
- 6 independent hopper openings offering adjustable raining width

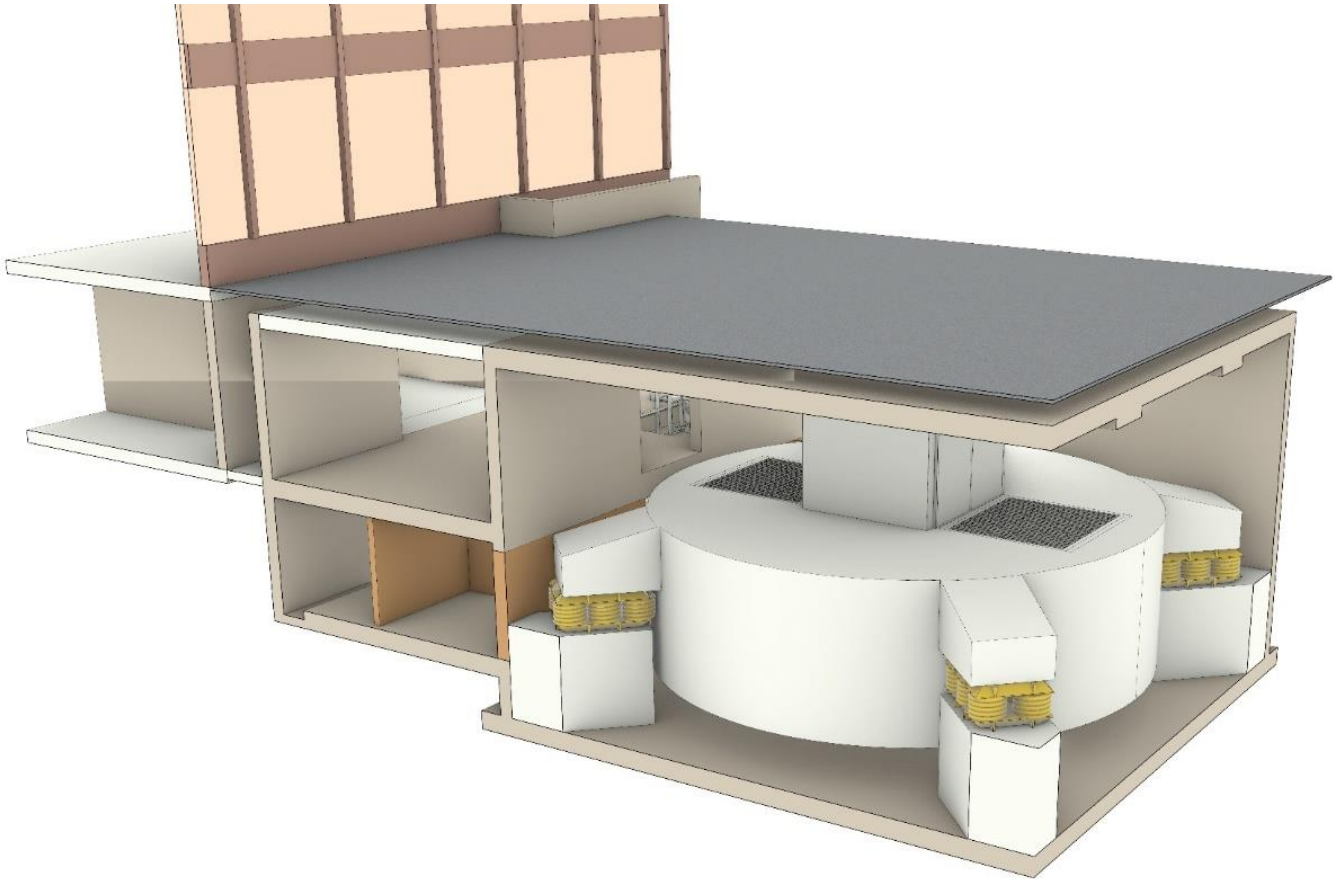
The ETHZ Geotechnical Centrifuge Centre (GCC)

New HPQ building–DPHYS: extremely sensitive to vibrations



The ETHZ Geotechnical Centrifuge Centre (GCC)

Vibration Isolation





Research Examples

Retrofit of Existing Bridges

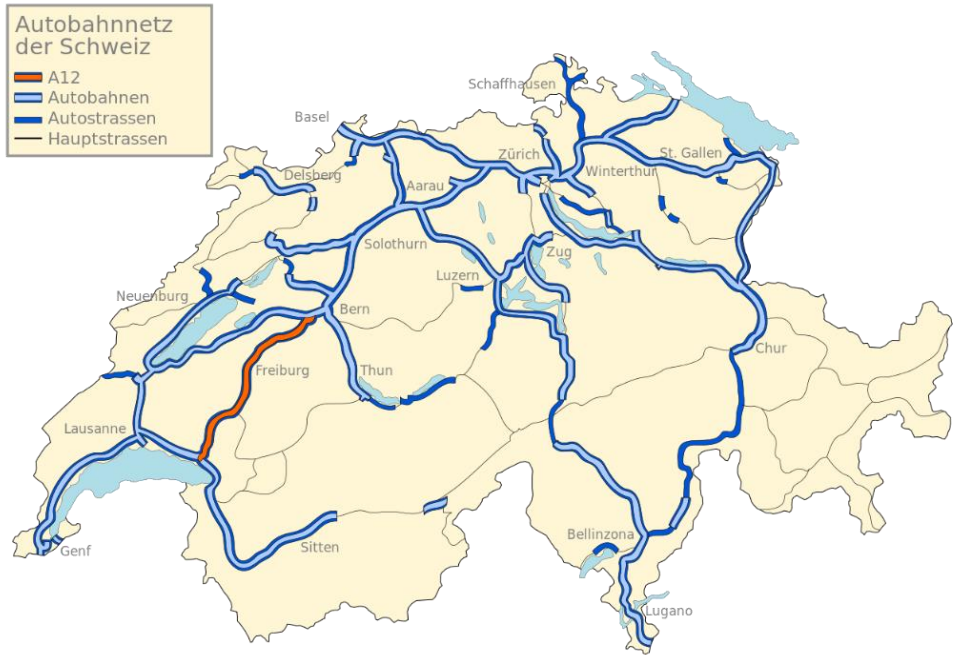
Dr. Lampros Sakellariadis
Dr. Alexandru Marin

Retrofit of Existing Bridges

Motivation

- Increased traffic demand
- Infrastructure optimization (ASTRA, 2008)

  Addition of lanes → Widening of existing bridges
- Seismic retrofit

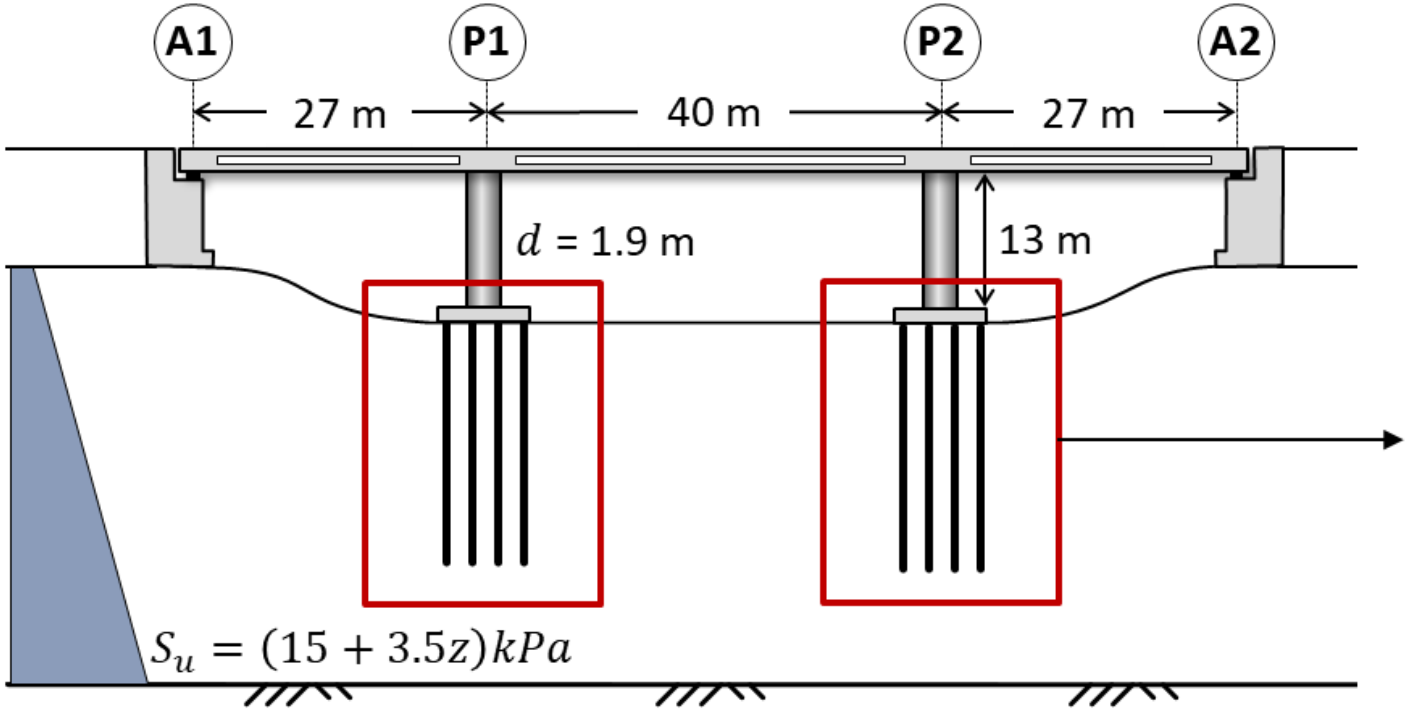


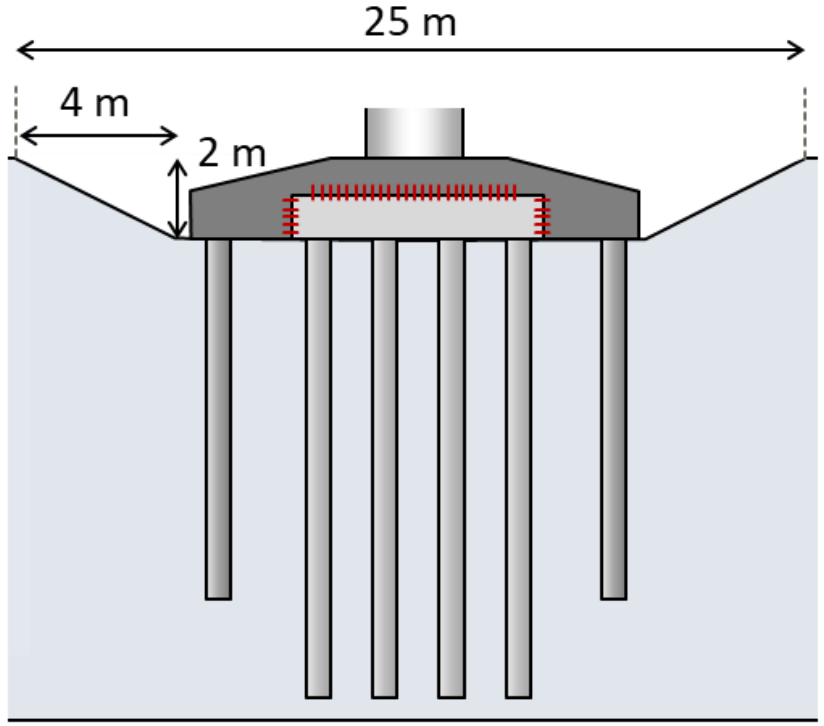
Example: Aare Bridges at Ruppoldingen (Dauner et al. 2000)



Retrofit of Existing Bridges

Foundation retrofit can be challenging



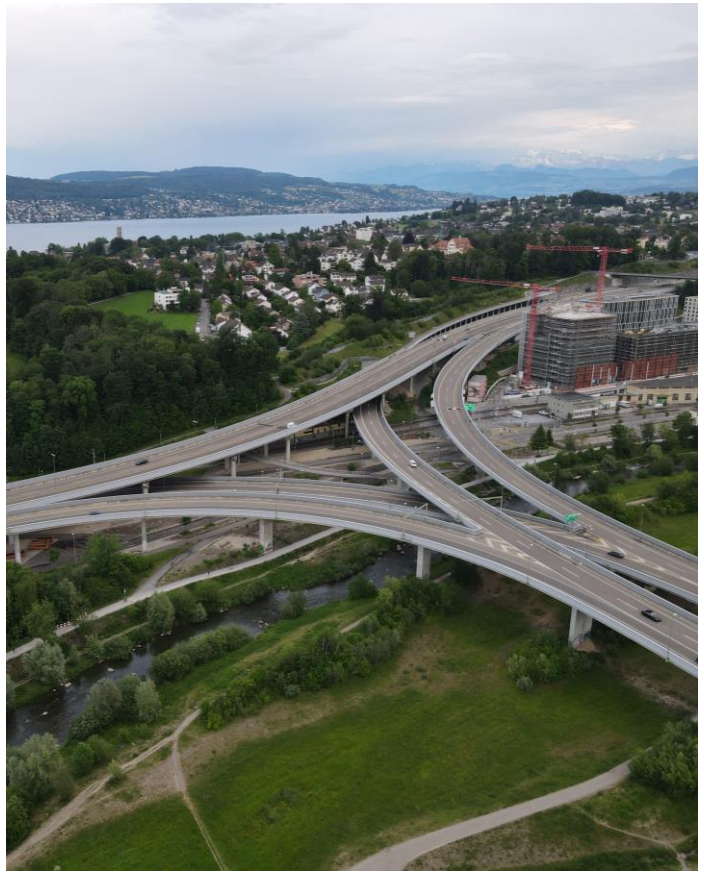


Foundation retrofit ?

Retrofit of Existing Bridges

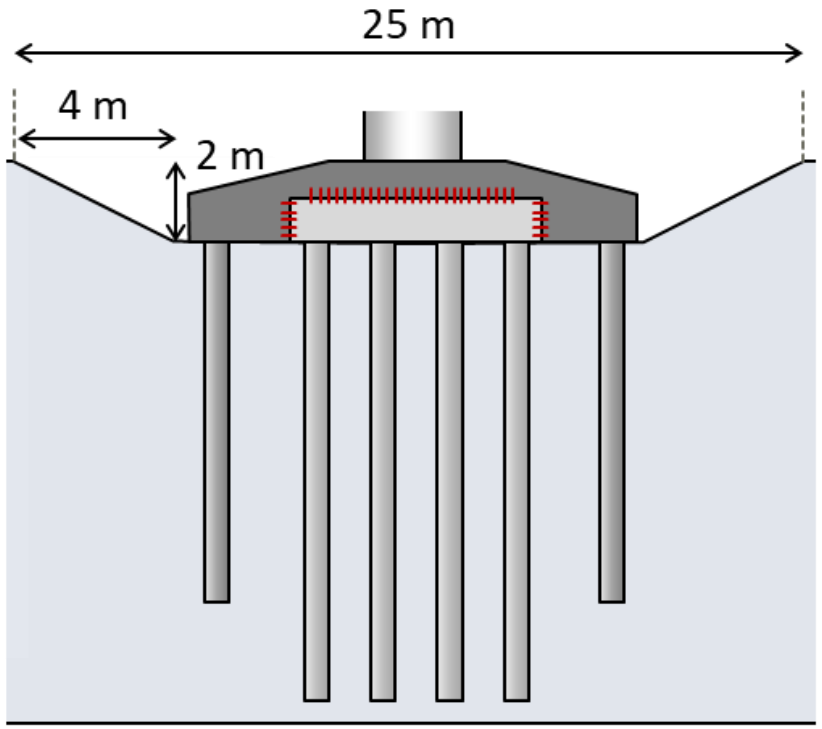
Foundation retrofit can be challenging

Space limitations



Heavy machinery





Retrofit of Existing Bridges

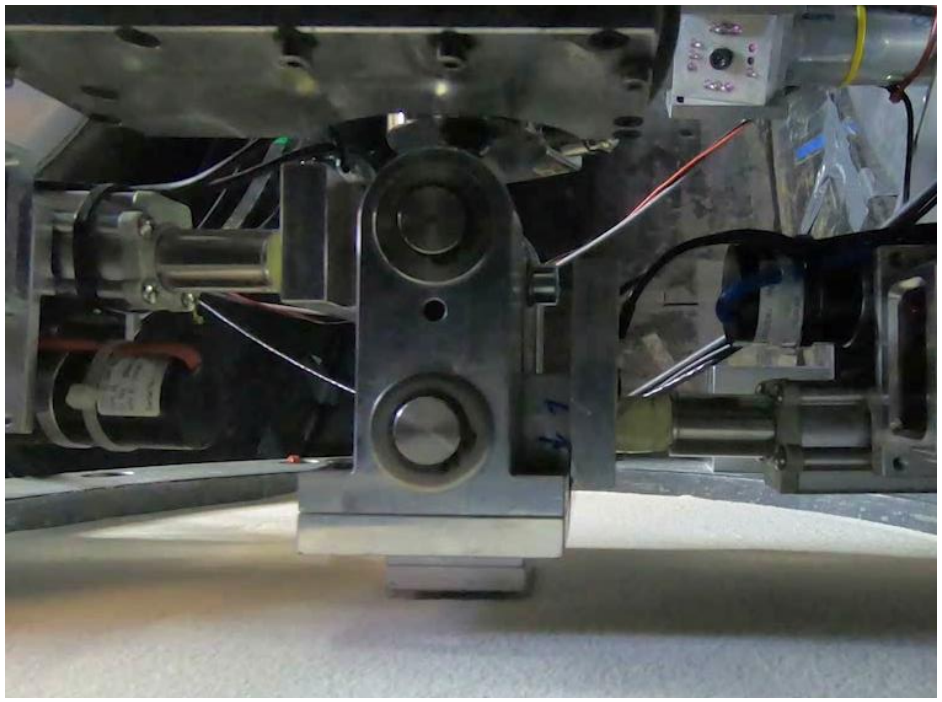
Lampros Sakellariadis PHD

Need for improved foundation design

Axial loading



Combined loading

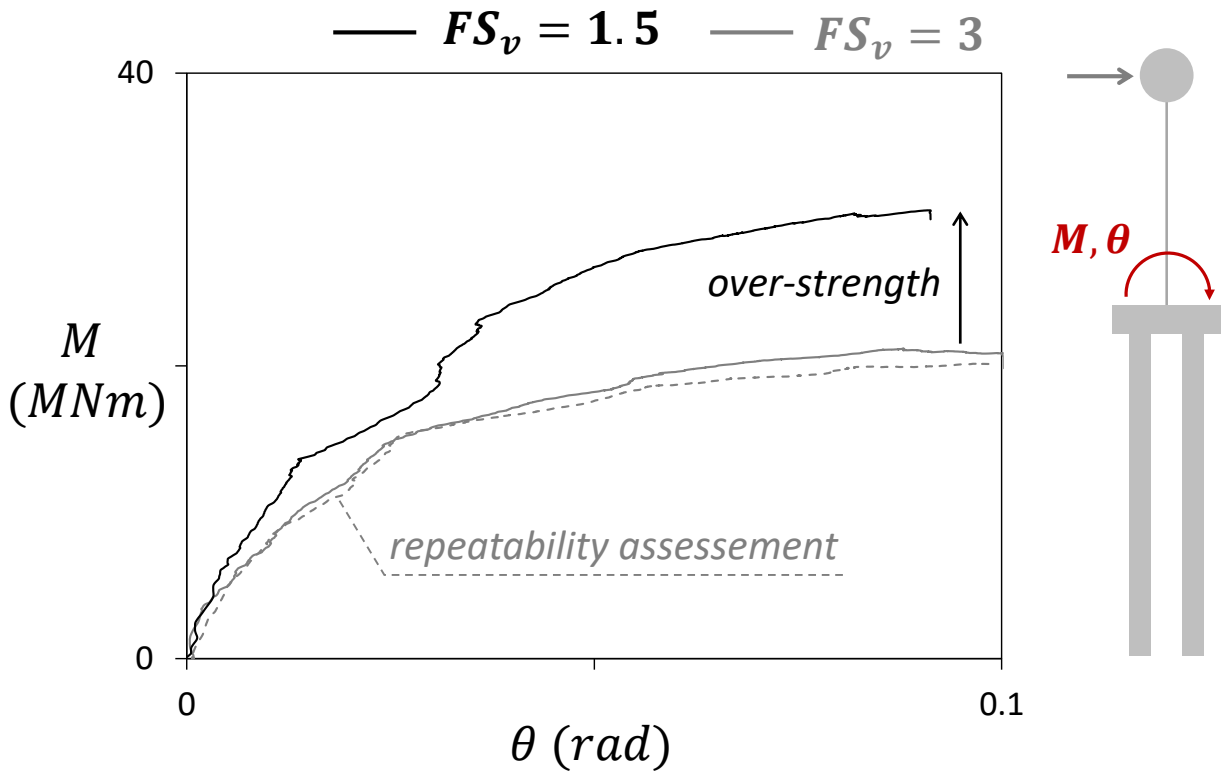


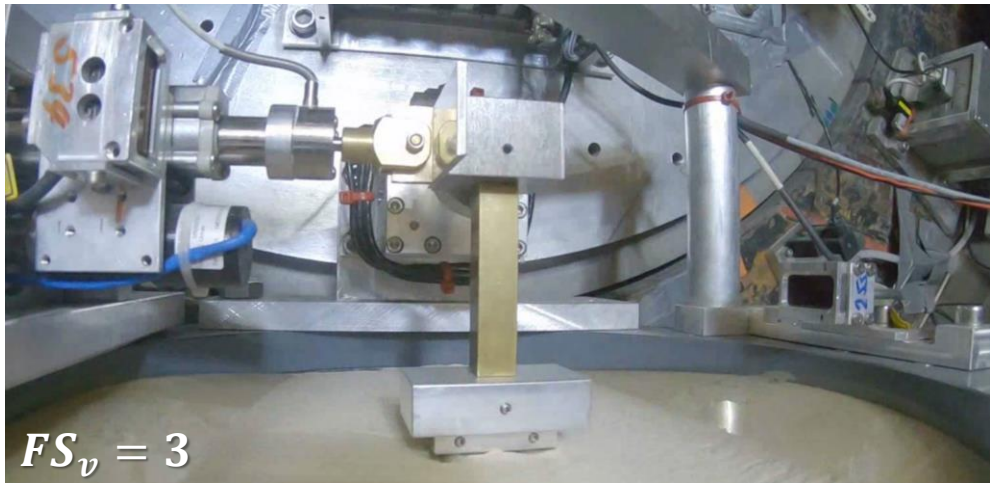
Vibration testing

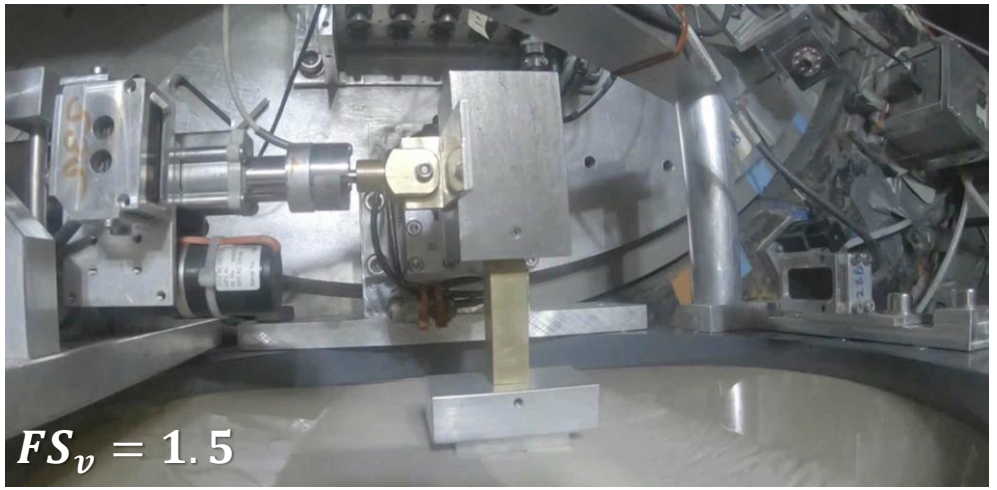


Retrofit of Existing Bridges

Horizontal pushover: moment capacity



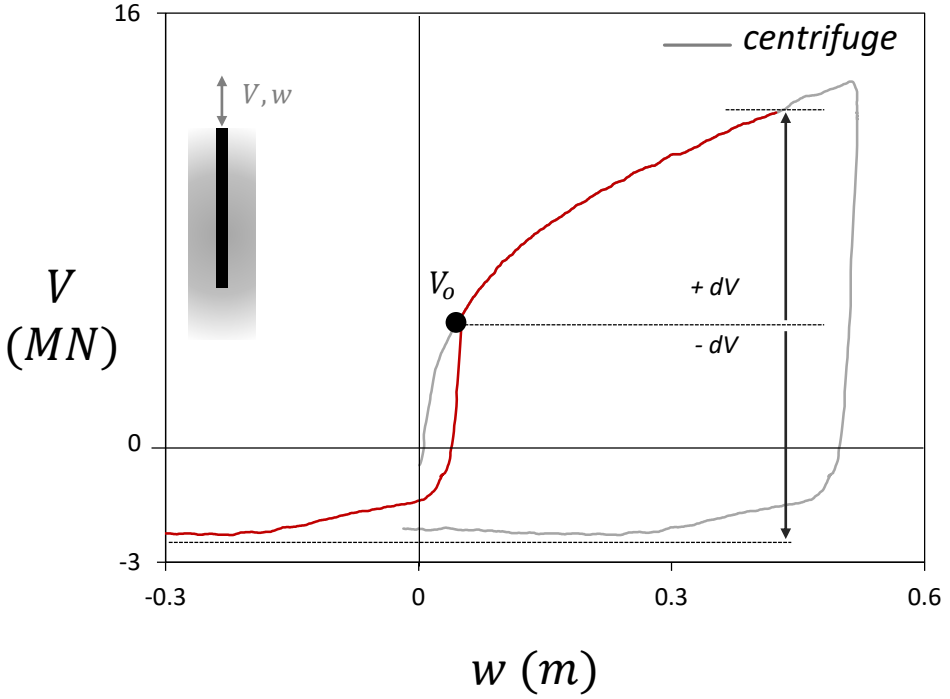




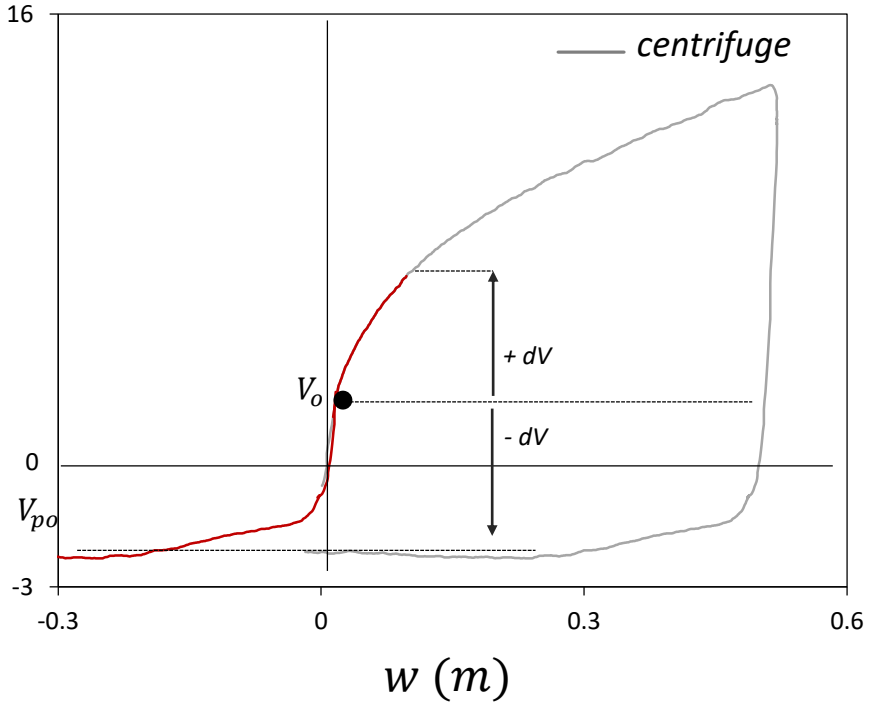
Retrofit of Existing Bridges

Horizontal pushover: moment capacity

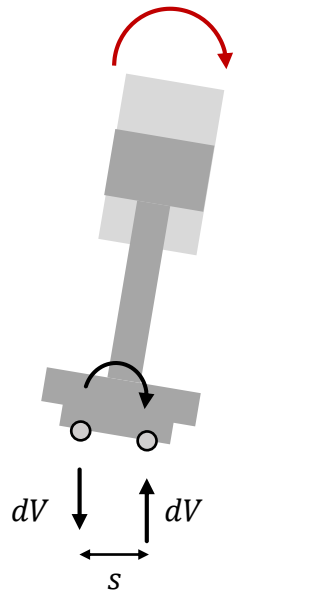
Heavily loaded (FS_v = 1.5)



Lightly loaded (FS_v = 3)



$$M_{ult} = |dV| * s$$



Research Examples

Seismic Assessment of Existing Dams

Dr. Kostas Kassas

Hydropower Dams

682 Hydropower Dams produce 60% of Electricity of Switzerland

Grande Dixence Dam
Europe's tallest Dam (285 m)



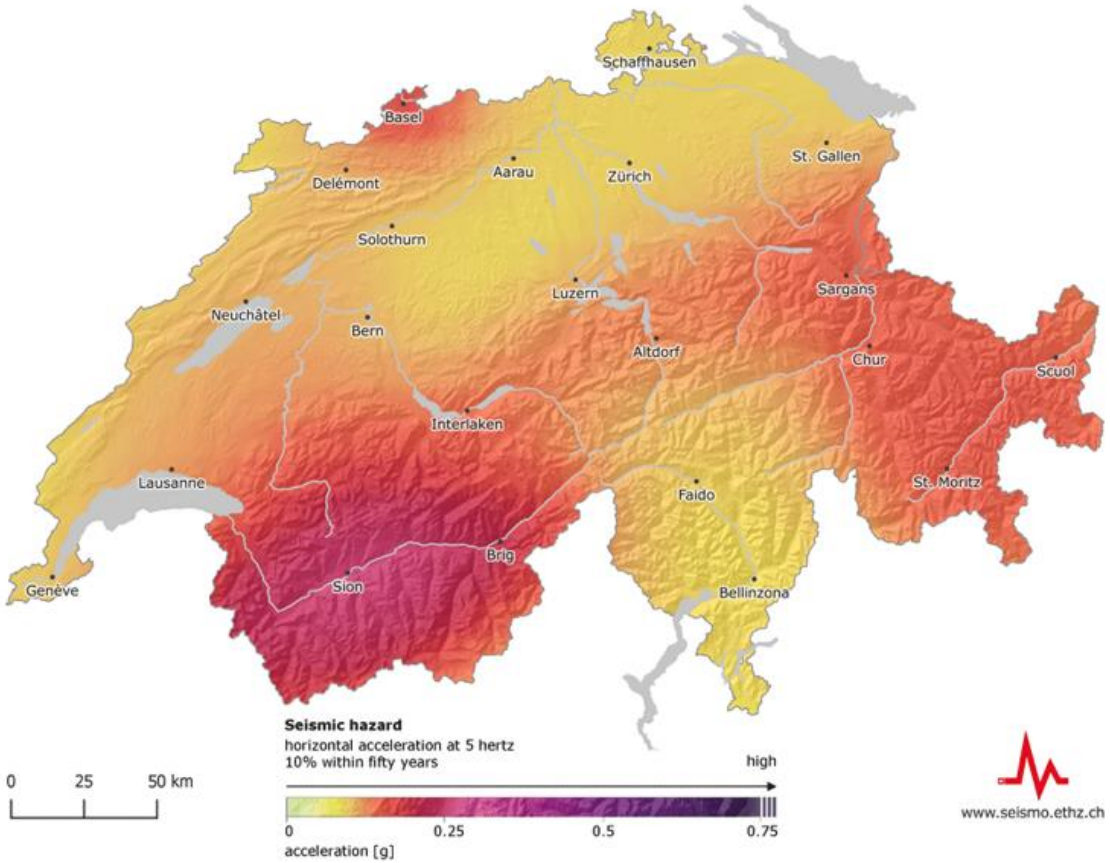
2'000 GWh yearly production:
Covering the energy needs of 500'000 homes



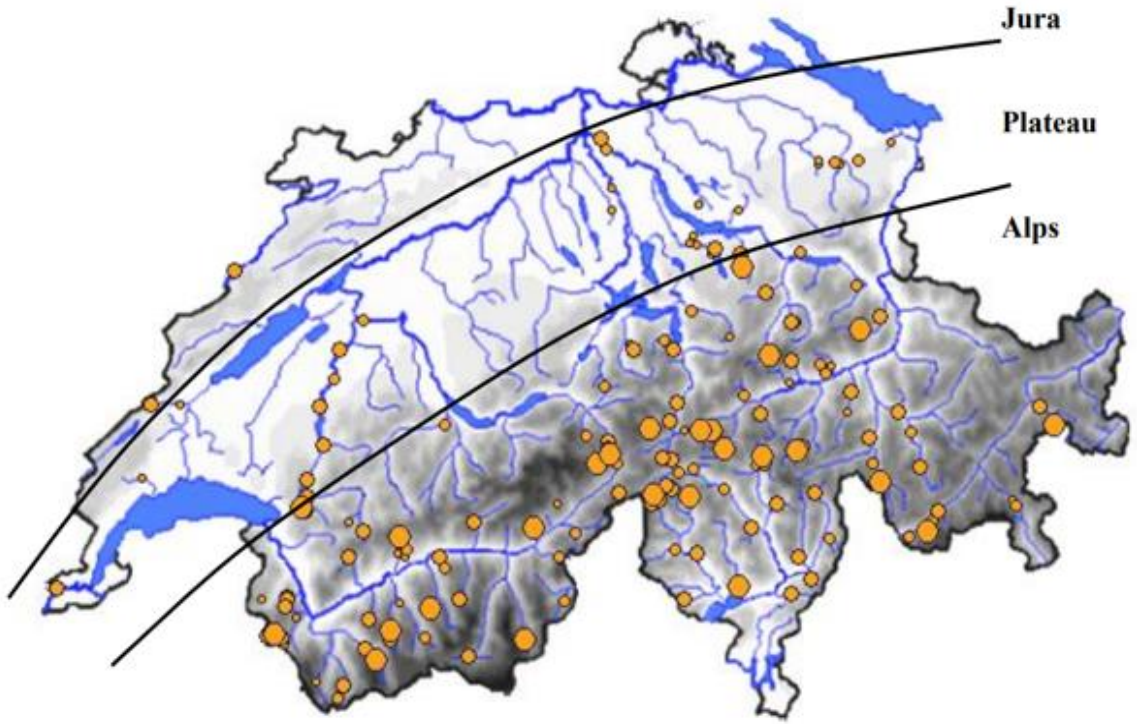
Hydropower Dams

Darbre et al. (2021)

Seismic hazard



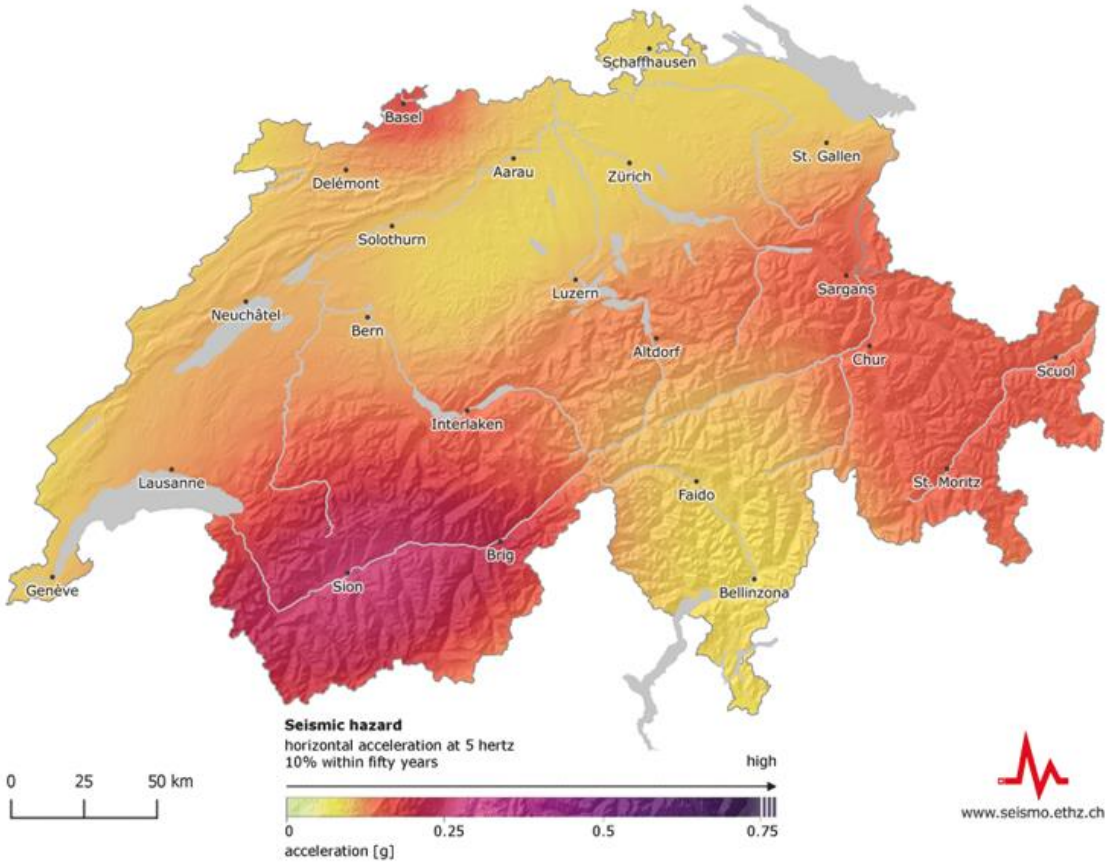
Large dams



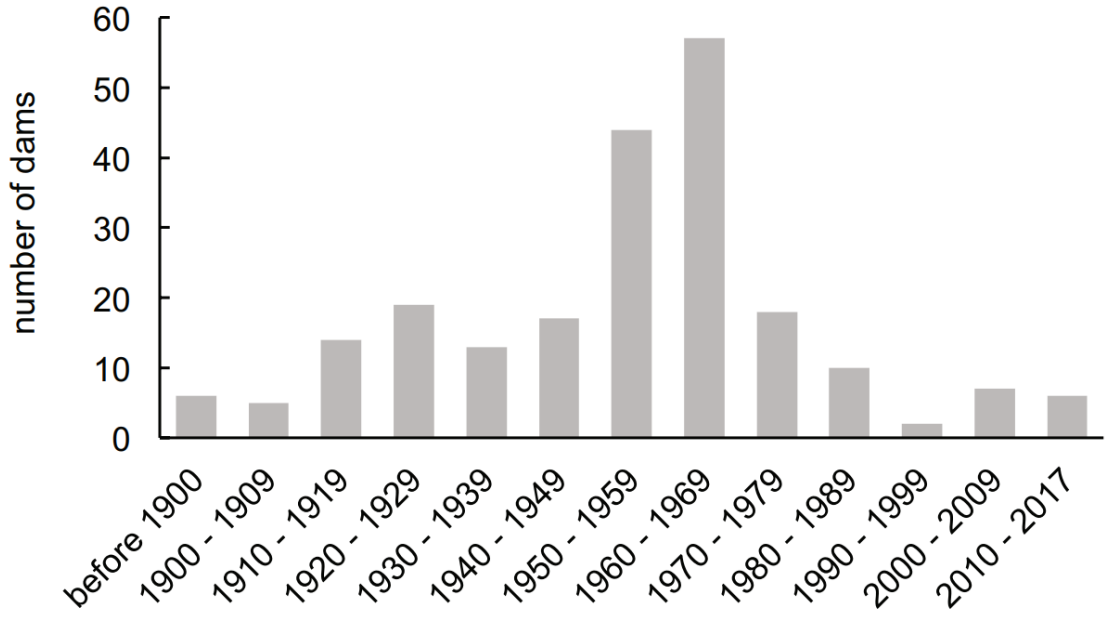
Hydropower Dams

Darbre et al. (2021)

Seismic hazard



Large dam construction time



The vast majority of existing dams:

- ✓ Built before the 90's
- ✓ No or transitional seismic design

Urgent Need for Seismic Re–Assessment

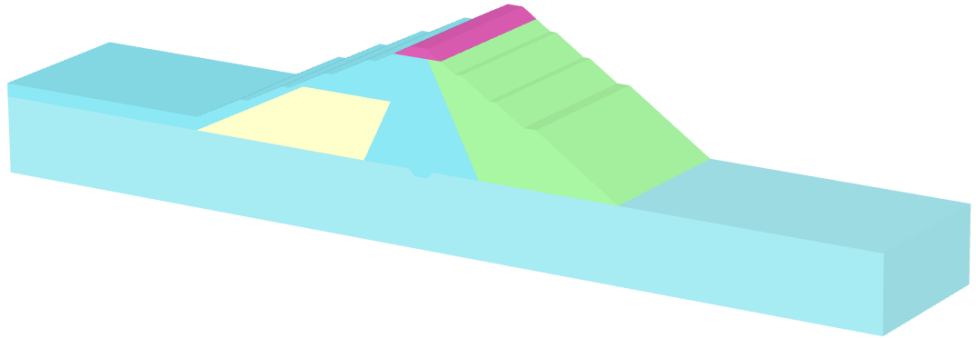
Failure of the San Fernando Dam (CA): 1971 San Fernando Earthquake



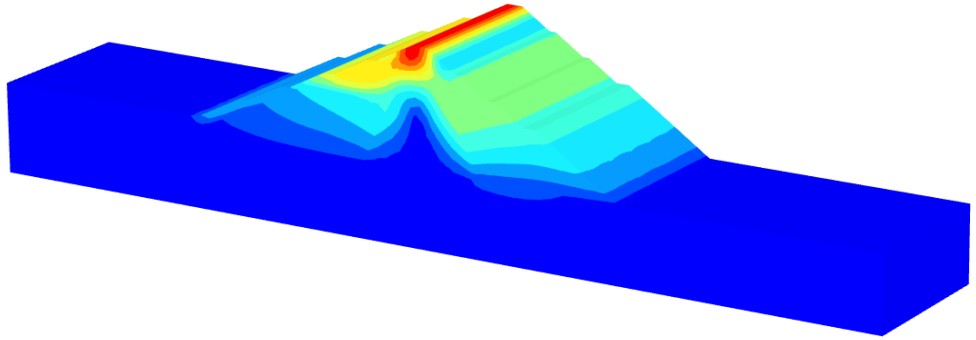
Urgent Need for Seismic Re–Assessment

Numerical Analysis

3D FE model of a dam



Contours of displacement



Numerical code	Constitutive model
PLAXIS 2D/3D	UBCSAND (1997)
FLAC 2D/3D	Hypoplastic model (1997)
ABAQUS	PDMY (2000)
OPENSEES	DM04 (2004)
LS-DYNA	Ta-Ger (2016)
Real-ESSI	P2PSand (2021)
Cyclic 1D	PM4sand (2017)

Research Examples

Soil liquefaction and ist effcets on Structures

Dr. Kostas Kassas

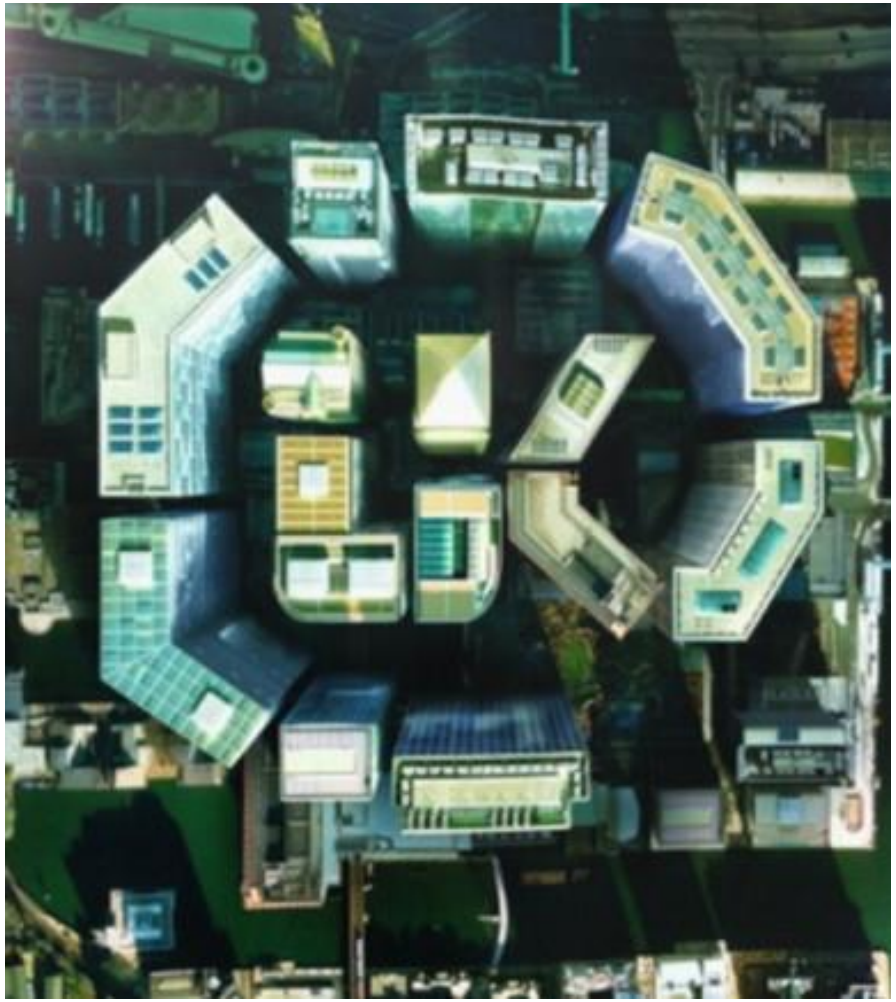
Recent Case-histories of Liquefaction

Maduo, China (2021): G0613 Xining–Lijiang Expressway



Recent Case-histories of Liquefaction

Structure–Soil–Structure Interaction (SSSI)





Recent Case-histories of Liquefaction

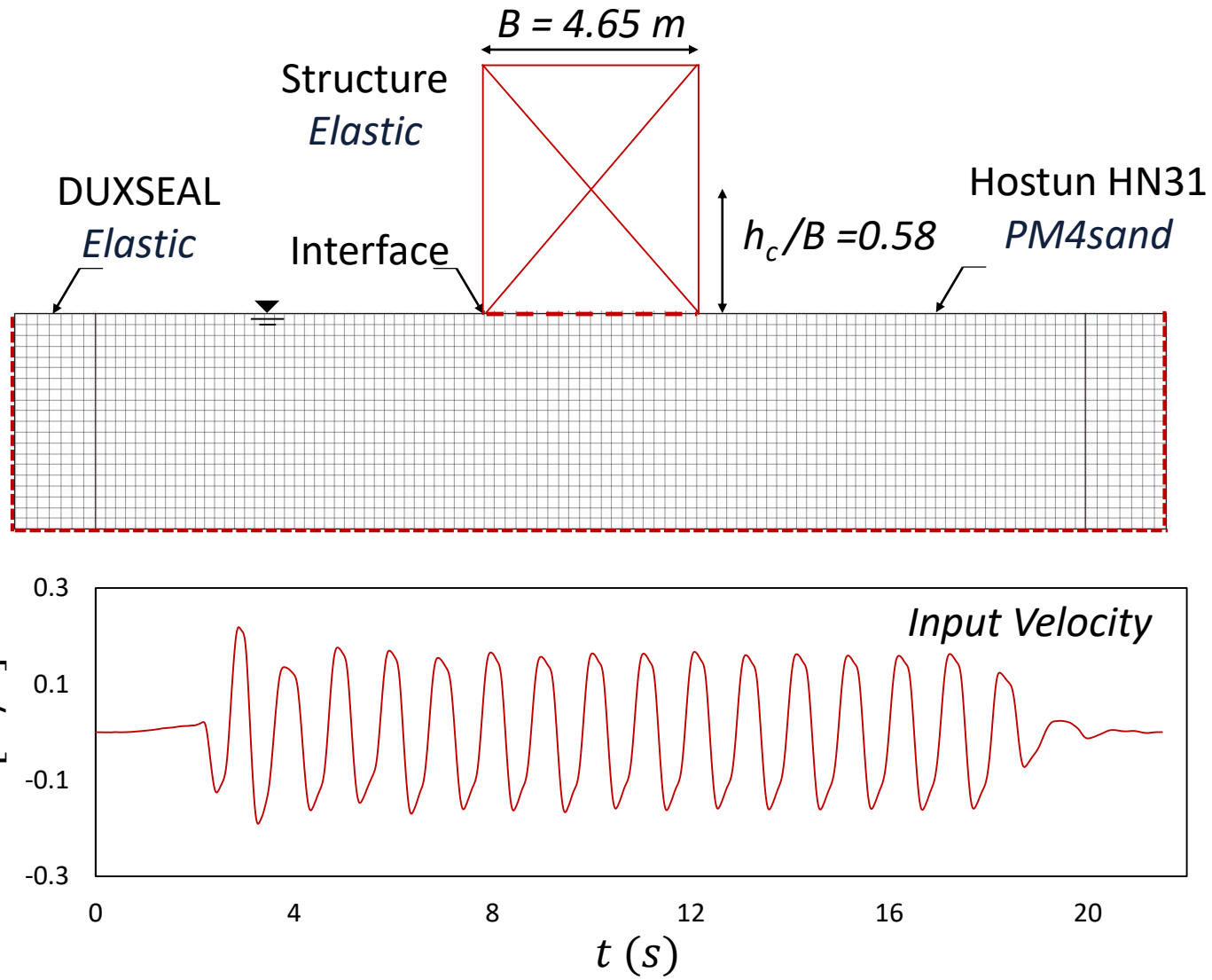
Adapazari, Kocaeli, Turkey (1999)



Kahramanmaras, Turkey (2023)



Numerical Modelling: FLAC2D



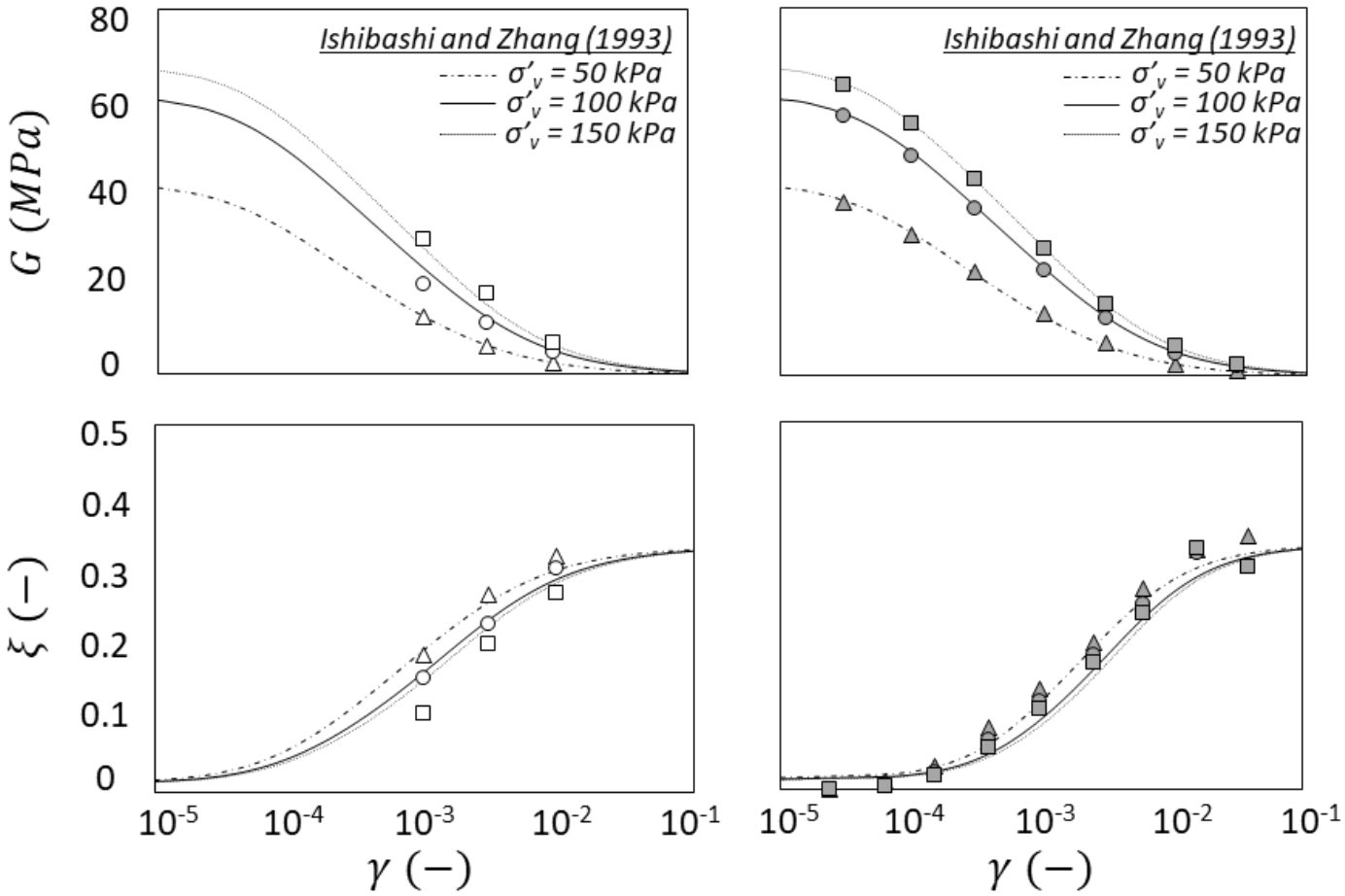
- ✓ *Fully-coupled analysis*
- ✓ *Effective stress analysis*
- ✓ *PM4Sand Calibration* $f(e)$
- ✓ *Duxseal elastic response [*Popescu & Prevost *1993]*
- ✓ *Automated parametric construction of the numerical model with FISH*

Carefull Calibration: Soil Element Tests



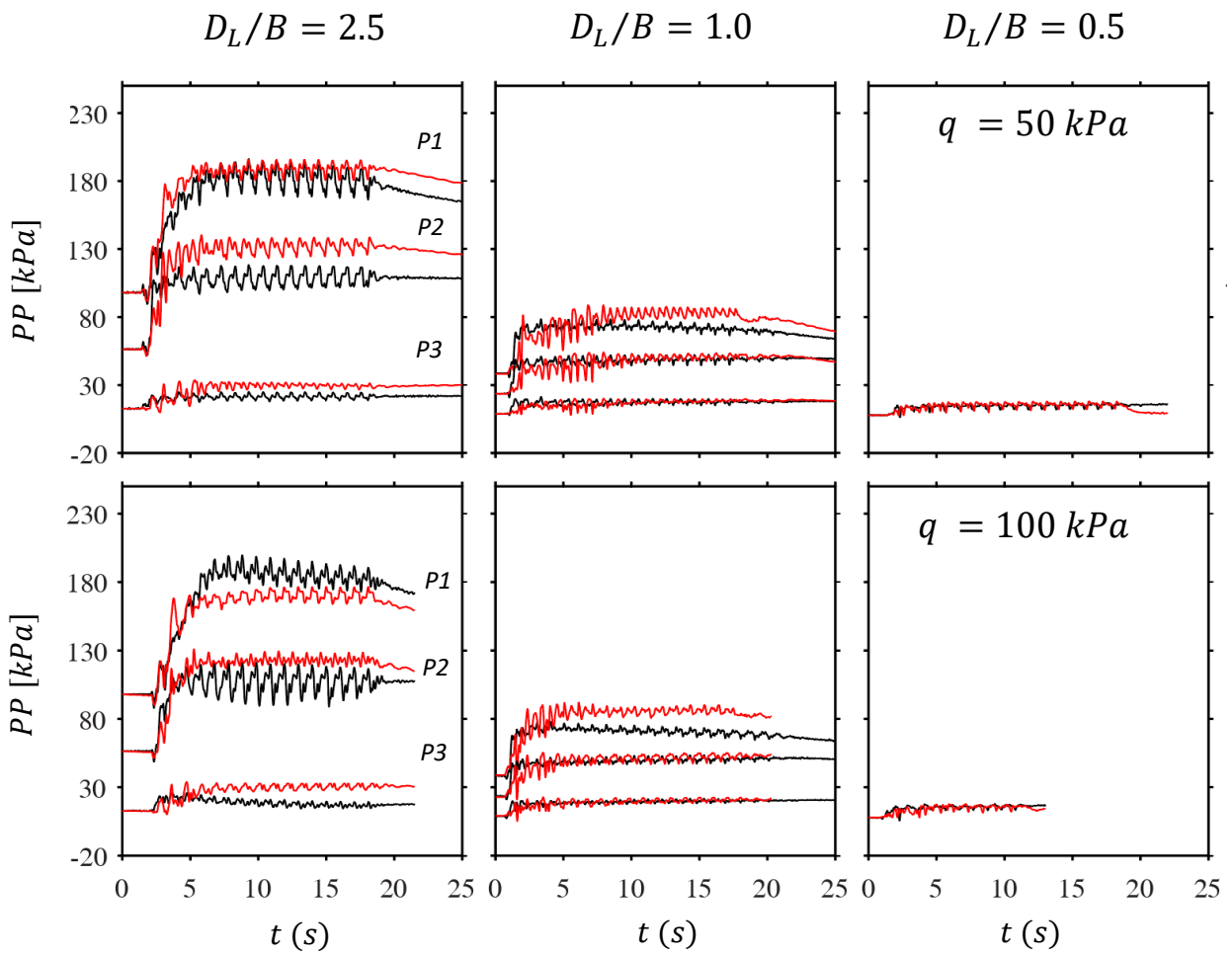
△ ○ □ Drained DSS Tests

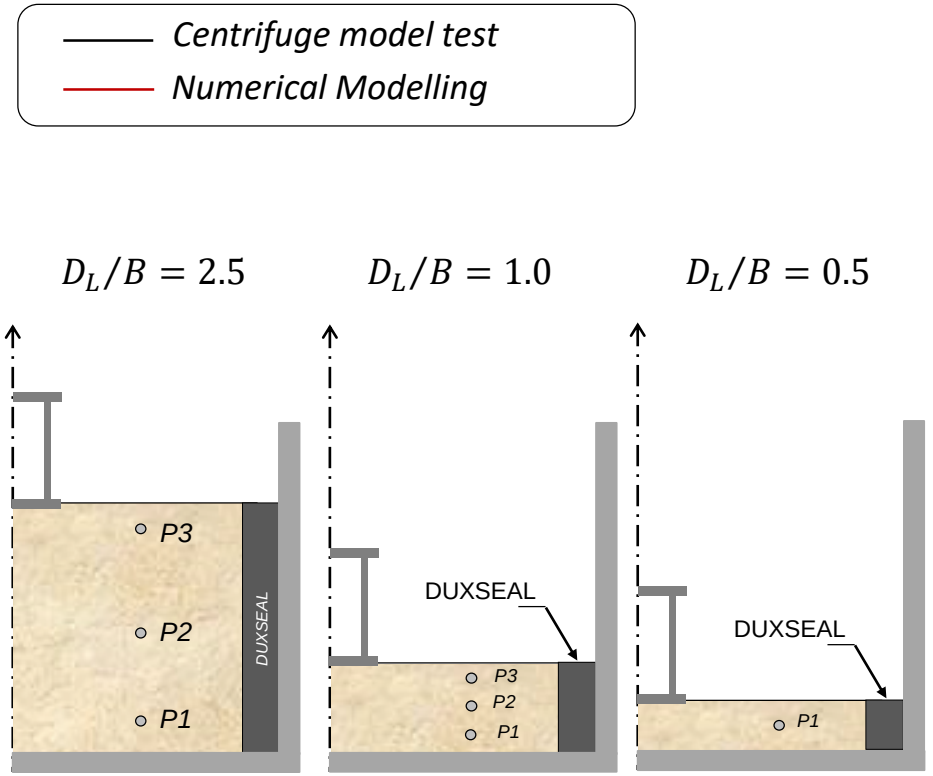
△ ● ■ PM4Sand



Validation against Centrifuge Tests

Pore pressures (free field)





Adapazari Case Histories

Building Clusters Response (SSSI)

Isolated tall building



2 tall buildings (Terveler buildings)

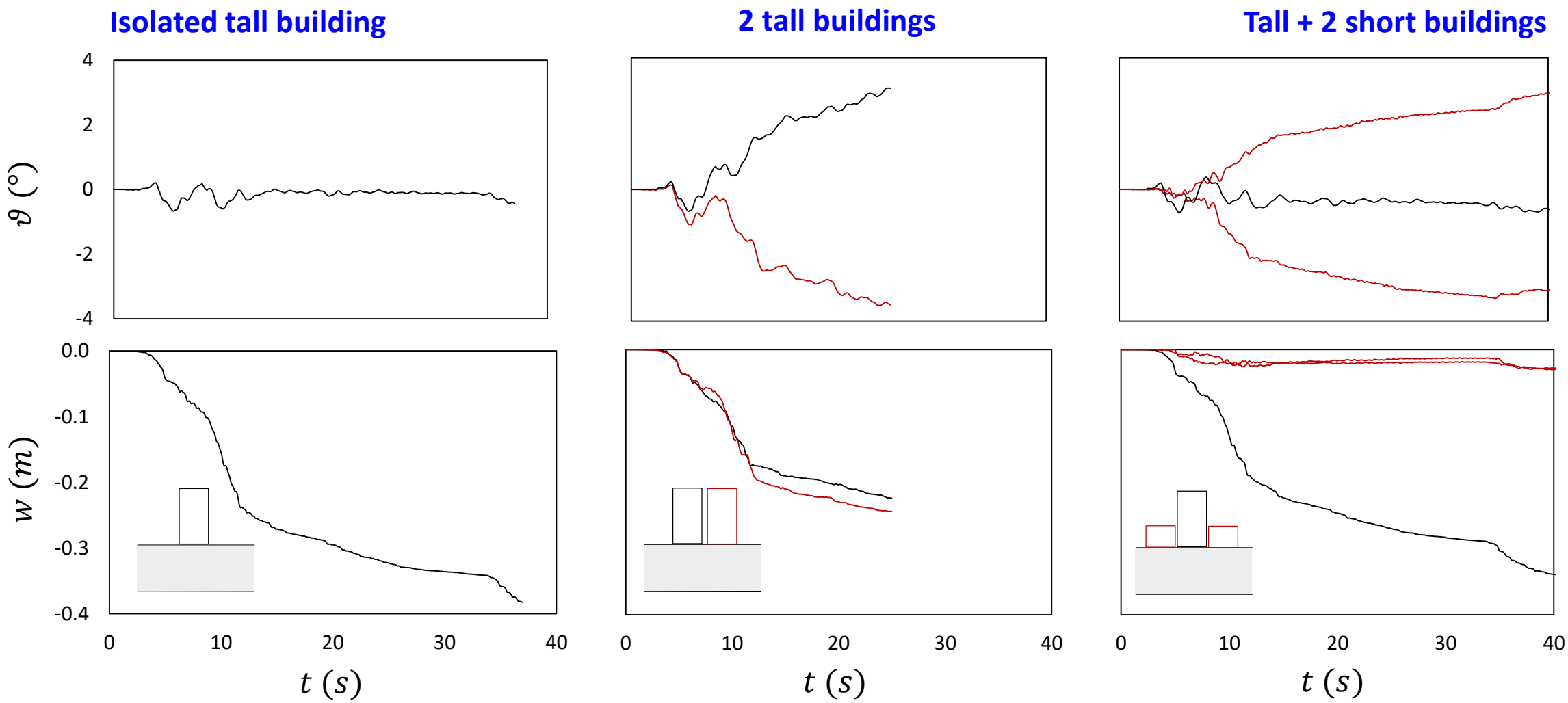


Tall + 2 short buildings



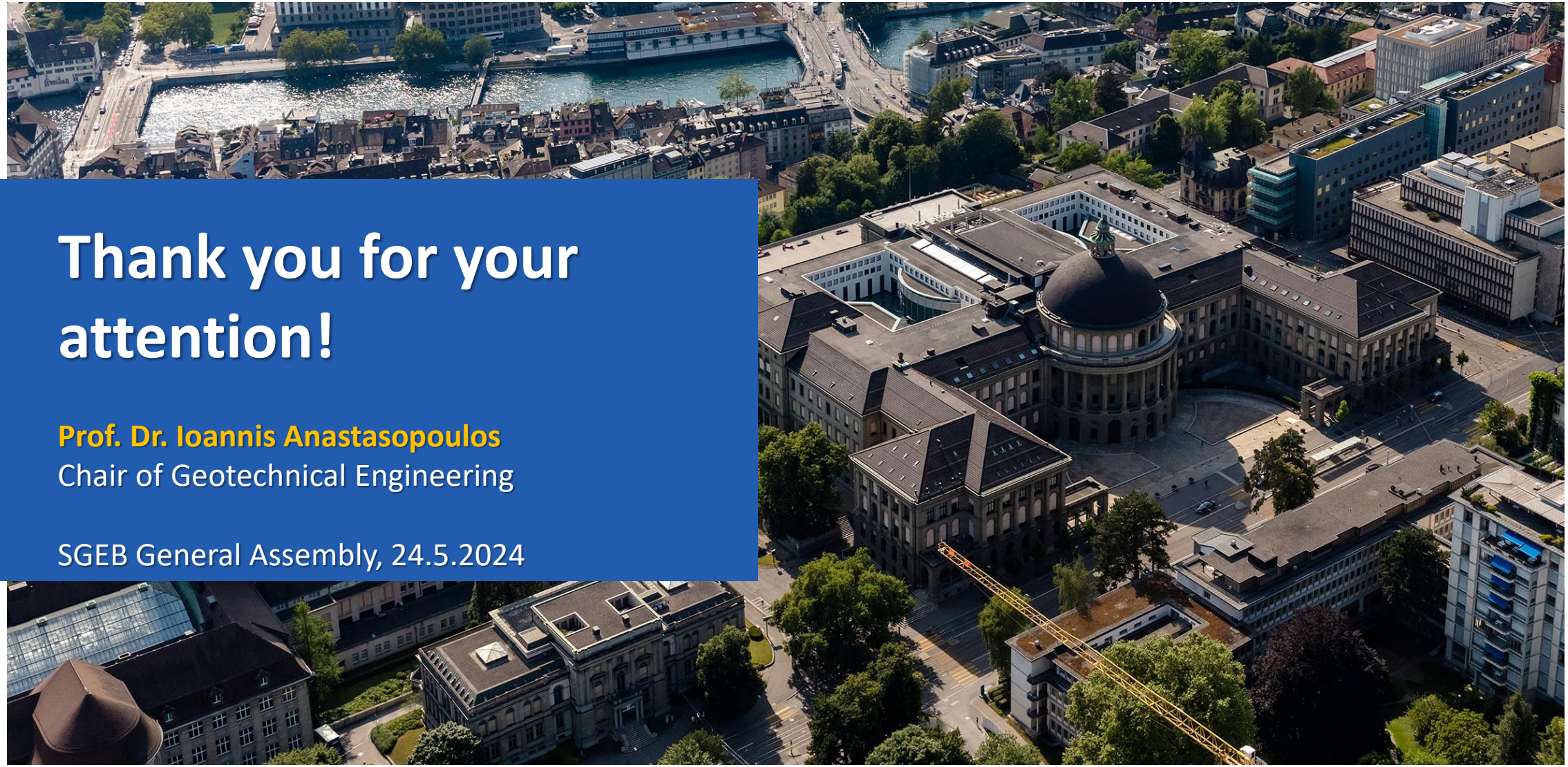
Adapazari Case Histories

Building Clusters Response (SSSI)



ETH zürich

IGT Professur für Geotechnik



Thank you for your attention!

Prof. Dr. Ioannis Anastasopoulos
Chair of Geotechnical Engineering

SGEB General Assembly, 24.5.2024