社團法人 俄羅斯國際工程院台灣分會
Taiwan Chapter of International Academy of Engineering
Тайваньское Отделение Международной Инженерной Академии

台俄科技移轉合作說明會
TAIWAN-RUSSIA Joint Technology Transfer Workshop

先進隔減震系統

俄羅斯國際工院台灣分會前理事長
台灣大學土木系 張國鎮教授

References

- Part I:

Seismic waves and seismic barriers

地震波分析與震波屏障技術

- Part II:

Ultimate Vibration Insulation

for earthquake engineering

隔震元件

Part I: Seismic waves and seismic barriers

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Russian Academy of Sciences

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Presidential Palace in Port-au-Prince, Haiti
Before Earthquake in January 2010
/The Palace was retrofitted with seismic isolators in 2004/

Building damages caused by some of the recent earthquakes

The trunk crack in the basement slab in **Fukushima I power plant**, Japan
March 2011, M_w=8.9-9.0

Destruction of the Presidential Palace in January 2010, M_w=7.3

Part I: Seismic waves and seismic barriers

Comparing two types of loadings:

A. Harmonic in time and uniformly distributed along base of the structure, as recommended by Codes of Practice

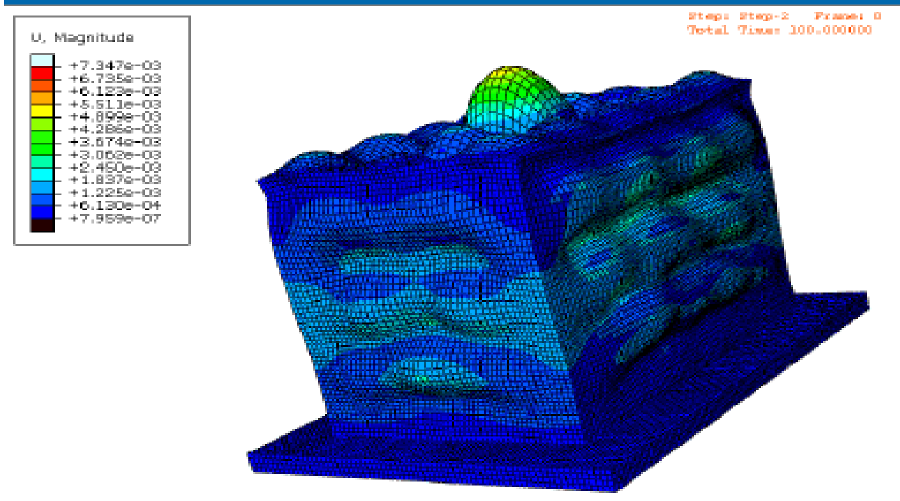
B. Wave load (the wave length is comparable with the spot of a building)

The finite element model of a building subjected to two types of seismic loads

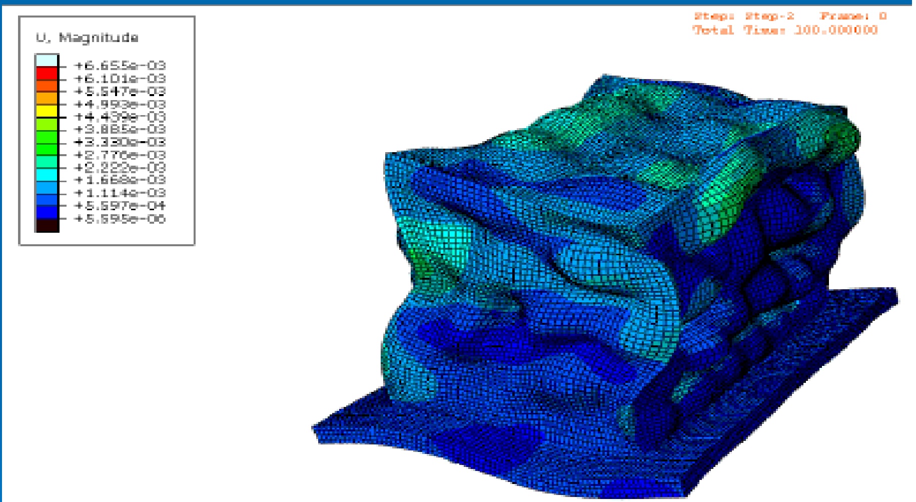
A. Harmonic in time and uniformly distributed load, as recommended by Codes of Practice

不同震波特性
存在分析差異

B. Wave load



以設計規範的地震波分析結構反應



以真實地震波(考慮波長效應)分析結構反應

Part I: Seismic waves and seismic barriers

Typical velocities of seismic waves

Type of Soil	Typical values according to [1 - 4]				Computed values
	Density, Mg/m^3	Poisson's ratio	V_S, m/s	V_P, m/s	V_R, m/s
Loose sand, saturated	**1.75**	**0.45**	**75**	**250**	70
Silt, including loess soils	**1.75**	**0.32**	**75**	**145**	70
Dense sand, unsaturated	**2.07**	**0.30**	**100**	**185**	95
Soft clay, saturated	**1.75**	**0.45**	**120**	**430**	110
Stiff clay, unsaturated	**2.00**	**0.20**	**290**	**325**	265
Gravel soil, unsaturated	2.07	0.25	540	935	500
Sandstone	2.25	0.25	1300	2250	1195
Limestone	2.55	0.30	2650	4960	2460
Granite	2.60	0.25	2900	5020	2670

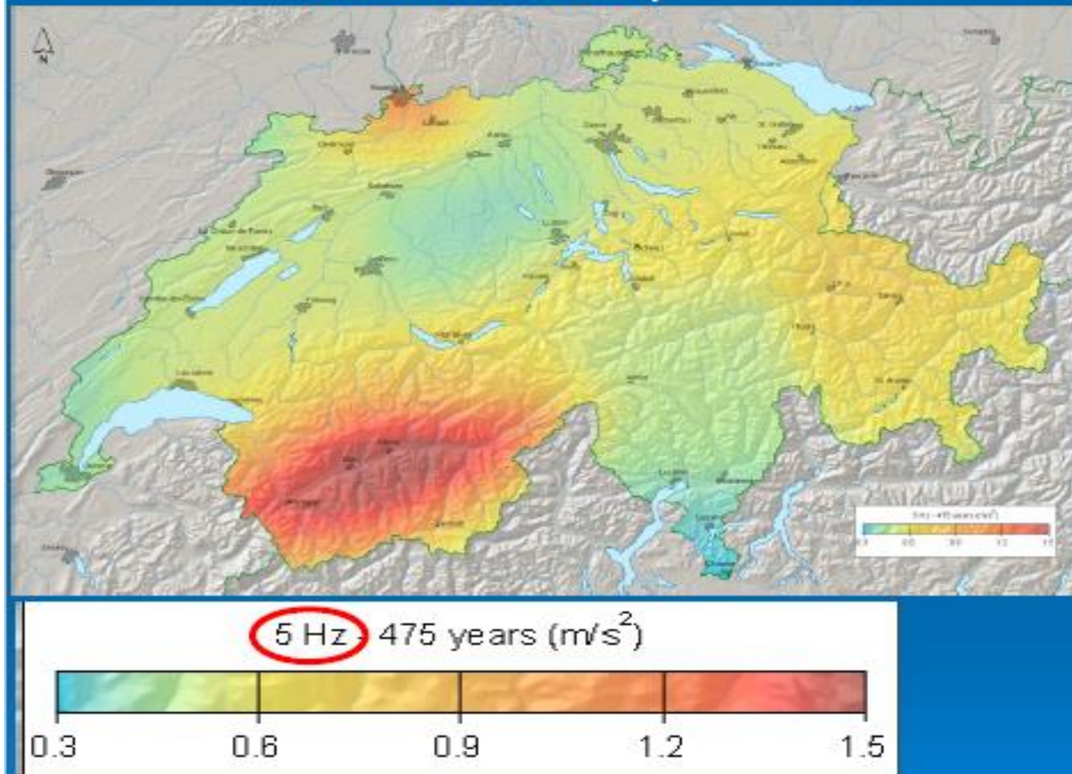
不同地盤土壤考量之地震波波速

$$V_P = V_S\sqrt{\frac{2(1-\nu)}{1-2\nu}} \qquad V_R \approx V_S\frac{0.87+1.12\nu}{1+\nu}$$

Part I: Seismic waves and seismic barriers

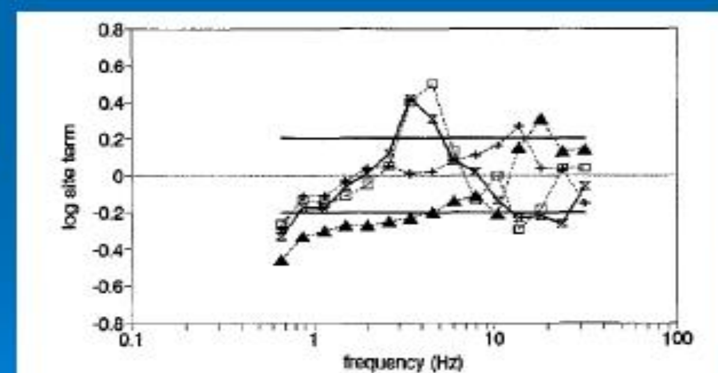
Peaks in the ground acceleration frequency spectra

Swiss hazard map



Ground acceleration peak at 5 Hz

Peaks at 12-15 Hz in acceleration spectra
Earthquakes in Eastern and Western Canada



Atkinson G.M. The High-Frequency Shape of the Source Spectrum for Earthquakes in Eastern and Western Canada, Bulletin of the Seismological Society of America, 1996, Vol. 86, No. 1A, 106-112.

地表加速度頻譜分布

Part I: Seismic waves and seismic barriers

The wavelengths of seismic waves corresponding to peaks in ground accelerations at f=5 Hz

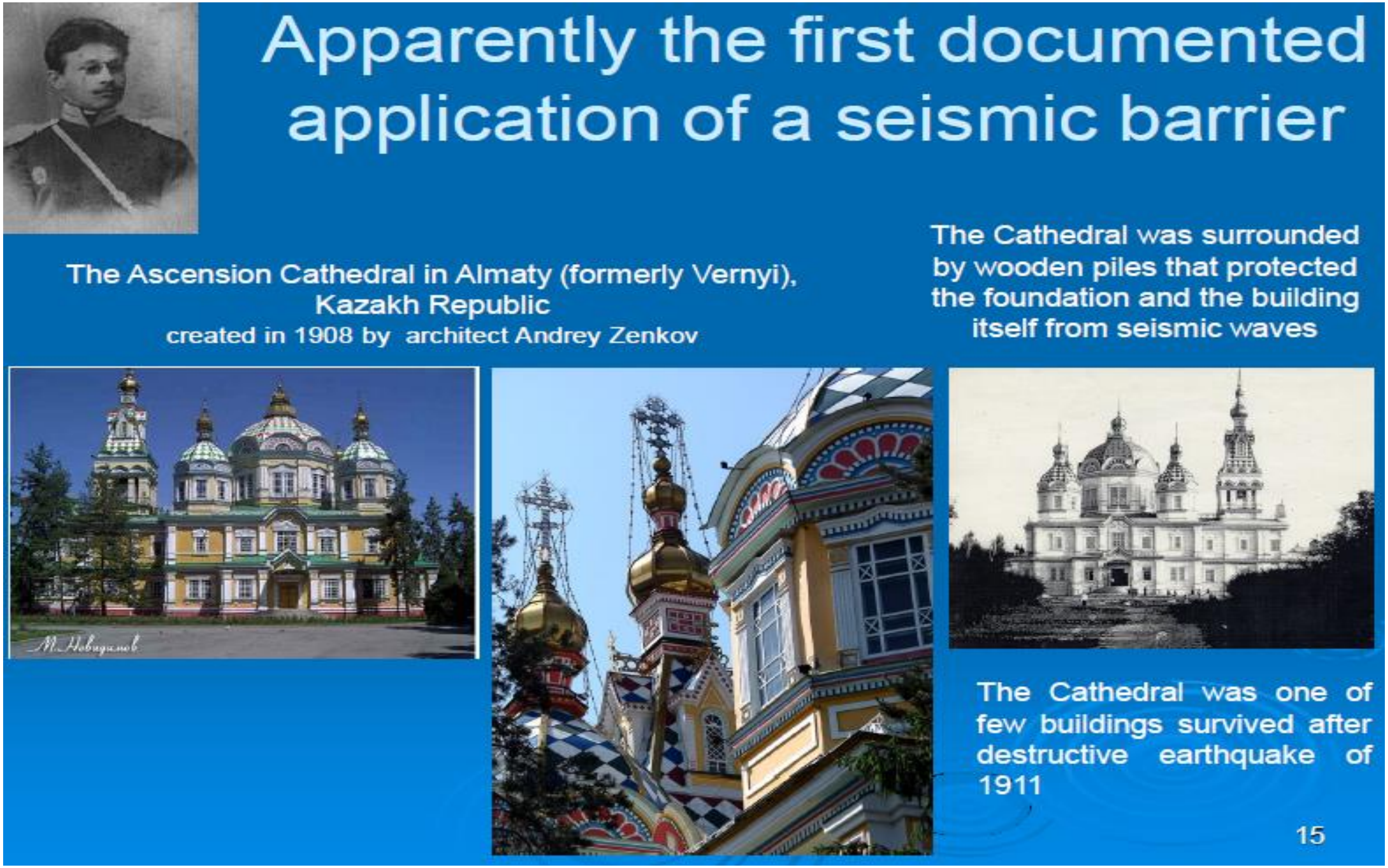
$$L = \frac{V_R}{f}$$

Type of Soil	V_R, m/s	L_R, m
Loose sand, saturated	70	14
Silt, including loess soils	70	14
Dense sand, unsaturated	95	19
Soft clay, saturated	110	22
Stiff clay	265	53
Gravel soil, unsaturated	500	100
Sandstone	1195	239
Limestone	2460	492
Granite	2670	534

綜合考量地盤特性與地表加速度，可得真實地震波(考慮波長效應)進行結構反應分析

Part I: Seismic waves and seismic barriers

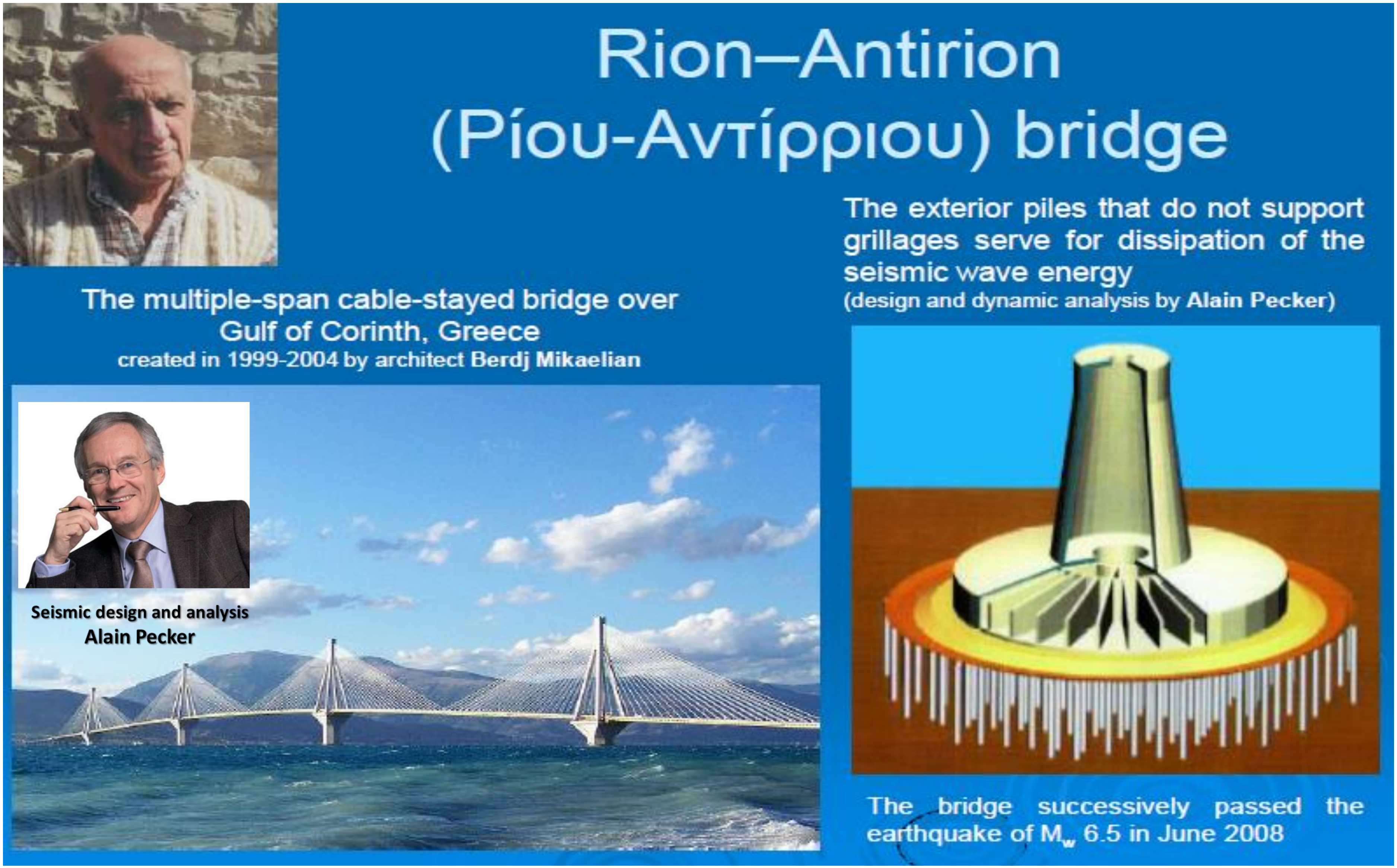
瞭解工址真實地震波(考慮波長效應)進行分析，進而可設計相應之震波屏障



最早的震波屏障技術應用案例(哈薩克)

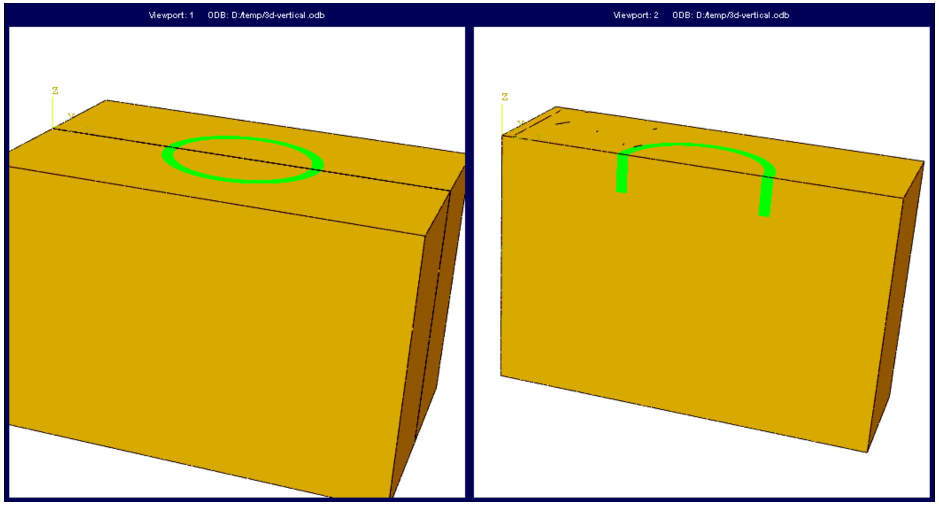
Part I: Seismic waves and seismic barriers

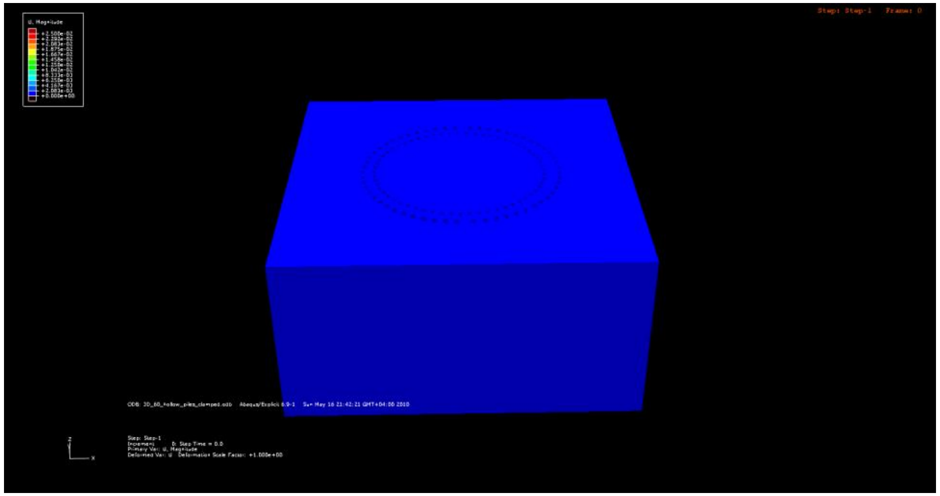
震波屏障技術應用案例



Territorial Seismic Protection against Seismic Waves (Seismic Barriers)

bulk waves, Rayleigh, Lamb, and Love waves





Beskos D.E., Dasgupta B., Vardoulakis I.G. Vibration isolation using open or filled trenches, Part1: 2-D homogeneous soil, Comput. Mech., **1986**, vol.1, pp. 43–63.

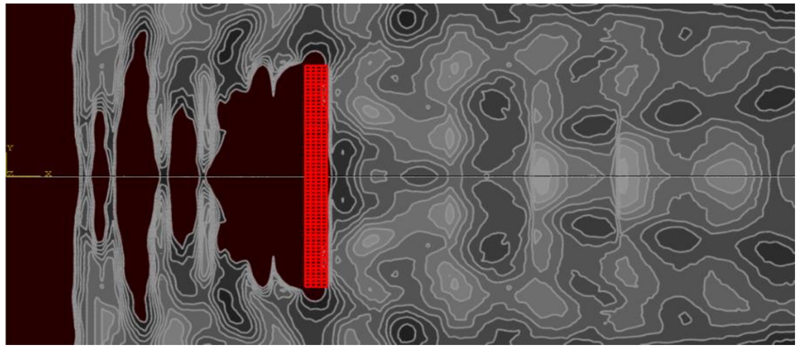
Adam, M., & Estorff, O. Reduction of train-induced building vibrations by using open and filled trenches. Computers and Structures, 2005, vol. 83, pp. 11 – 24.

Alzawi A., El Naggar M.H. Full scale experimental study on vibration scattering using open and in-filled (GeoFoam) wave barriers. Soil Dynamics and Earthquake Engineering, 2011, vol. 31, Issue 3, pp. 306–317.

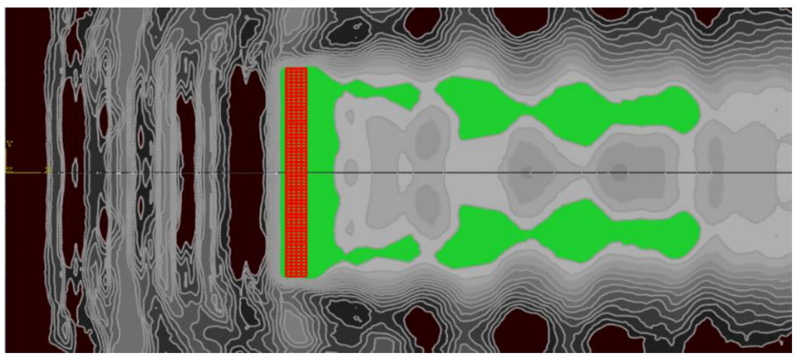
Jesmani, M., Fallahil, M.A. & Kashani, H.F. Effects of geometrical properties of rectangular trenches intended for passive isolation in sandy soils. Earth Science Research, 2012, vol. 1, No. 2, pp. 137 – 151.

Qiu Bo, Limam A., Djeran-Maigre I. Numerical study of wave barrier and its optimization design. Finite Elements in Analysis and Design, 2014, vol. 84, pp. 1–13.

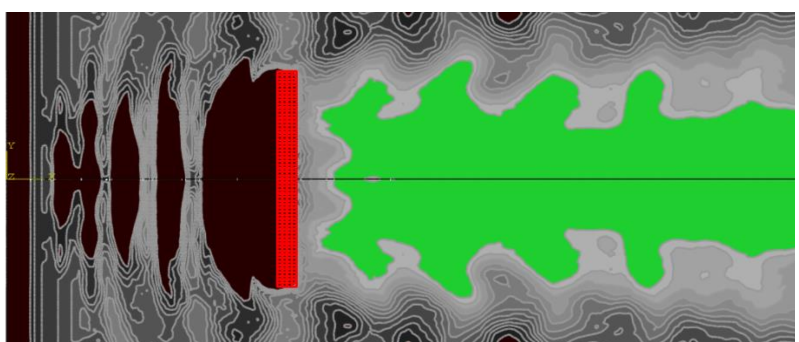
Infilling Seismic Barriers with Acoustic Metamaterials Resembling Broadband Phononic Crystals



Geofoam



Concrete



Metamaterial

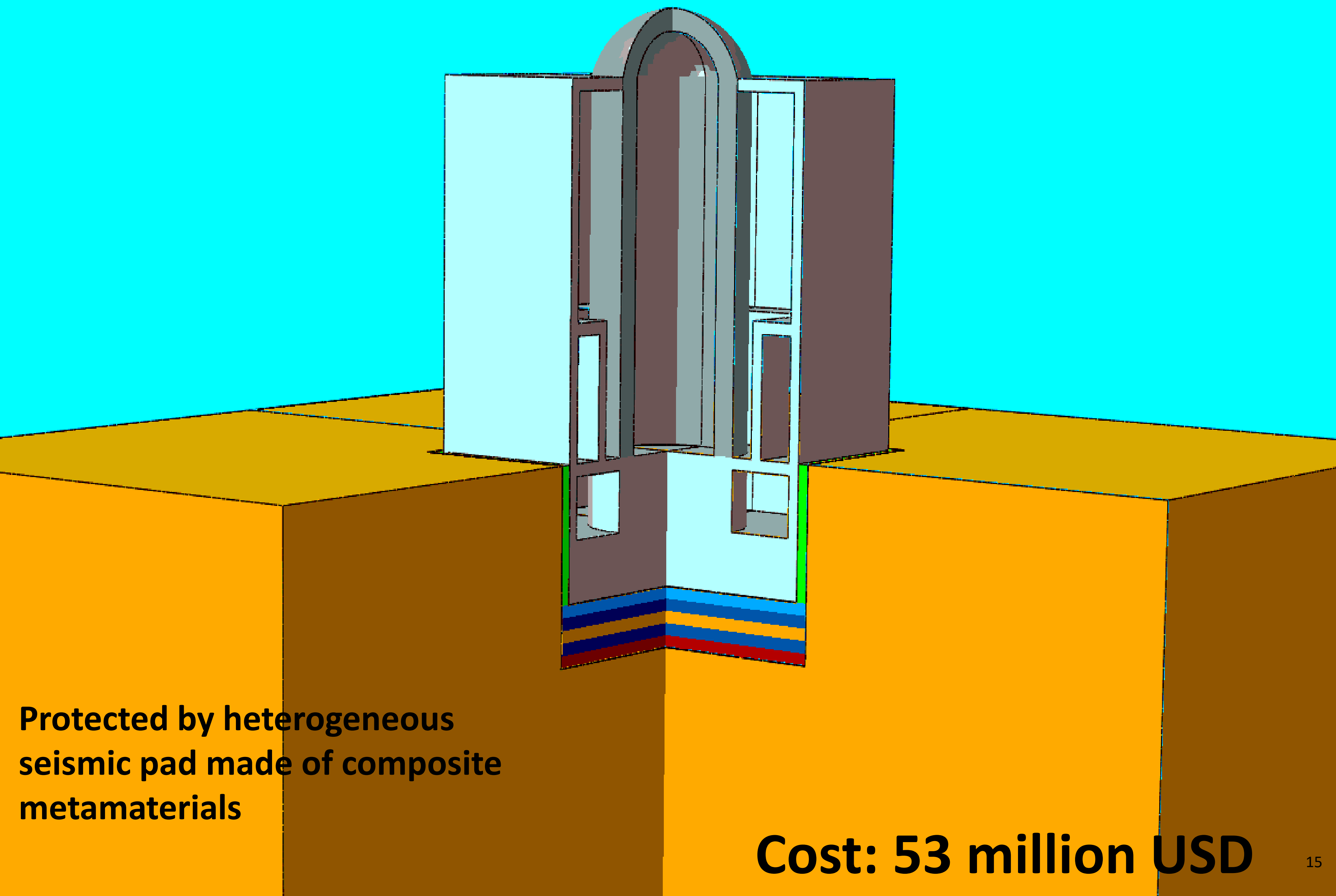
Relevant Research Topics Are Being Carried Out by

- United States: Stanford University (professors D.Barentt, T.C.T.Ting), Northwestern University (professor S.Goshal)
- France: Ecole nationale des ponts et chaussées (Professor R.Frank), University Joseph Fourier, Grenoble (Professors C.Vigginani, D.Dias), INSA de Lyon (Professors I.Djeran-Maigre, A.Limam), Ecole Normale Superieure, Paris (Professor R.Madariaga)
- Japan: University of Tokyo (Professor I.Towhata), Chuo University (Professor T.Kokusho), Tsukuba University (Professors K.Ishihara, T.Taeda)
- Greece: Aristotle University of Thessaloniki (Professor K.Pitalakis)
- Spain: Technical University of Catalonia (Professor A.Gens)
- Uzbekistan: Institute of Earthquake Engineering Academy Ouse. (Prof. T.R.Rashidov)


Airport Runways/Taxiways
Cairns, Australia
Direction of Rayleigh Waves
Seismic Barriers
Cost: 66,7 million USD

Seismic barriers around the tower and seismic pads underneath the base

NPP Reactor Building



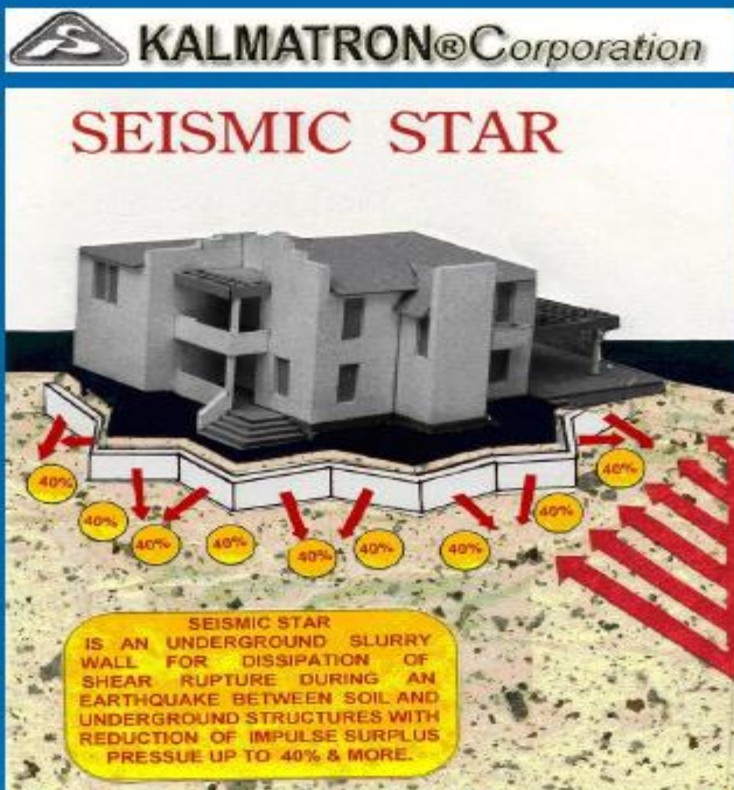
Protected by heterogeneous seismic pad made of composite metamaterials

Cost: 53 million USD

Part I: Seismic waves and seismic barriers

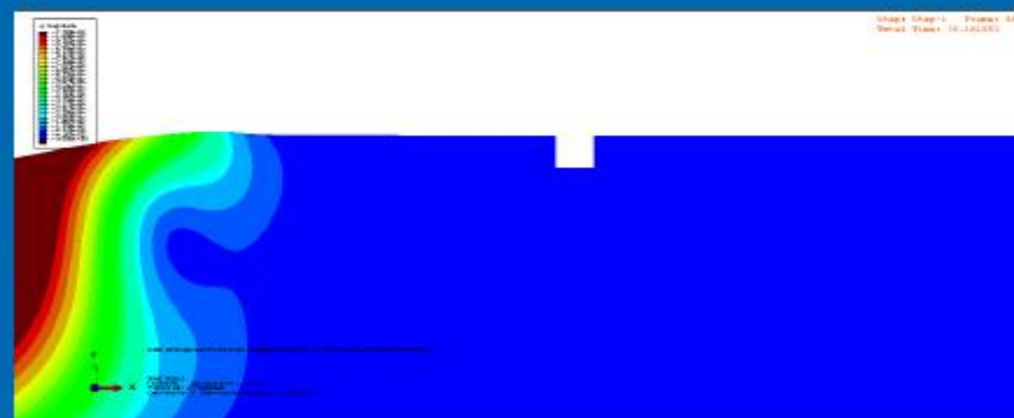
震波屏障技術應用分析

A shallow wall around a building



"The depth of placement is 1 m and thickness of the screen (wall) could be any. The trench is filled in with soft material…"

FEM modeling of a shallow trench interacting with Rayleigh wave



http://www.seismicstar.com/SCREENS.html

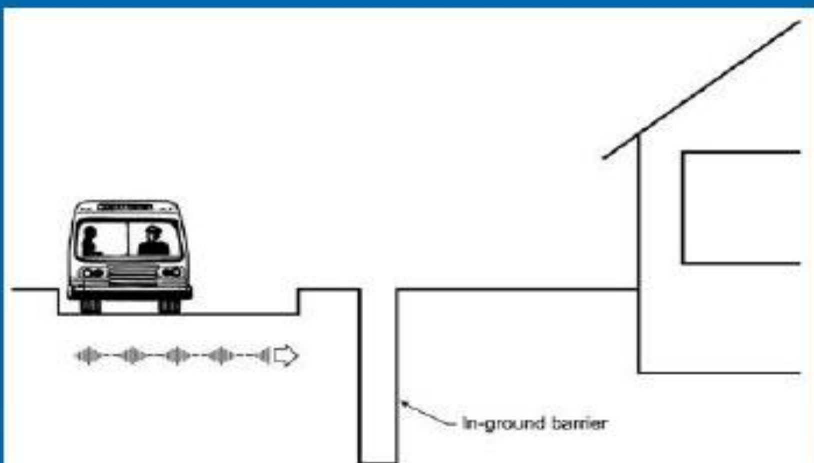
Part I: Seismic waves and seismic barriers

震波屏障技術應用分析

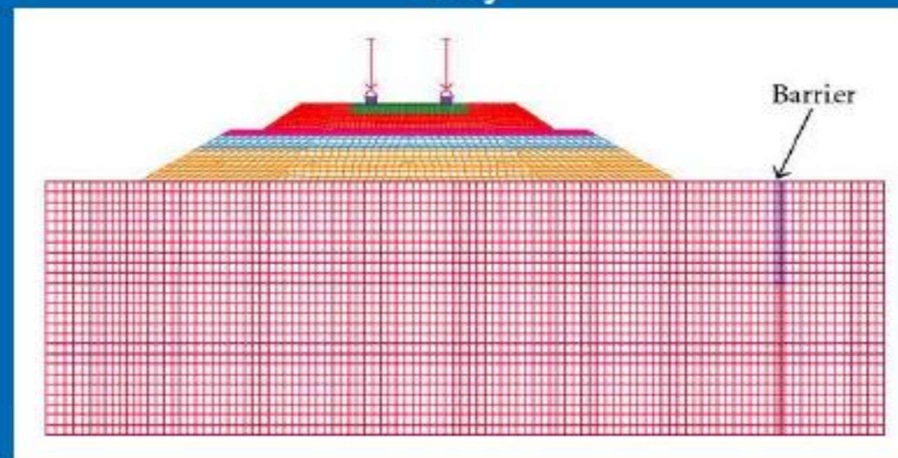
Barriers for vibration protection

Dr. O. Hunaidi,
The National Research Council Institute of Canada

Buonsanti M., Cirianni F., Leonardi G., Santini A., and Scopelliti F.
Mediterranean University of Reggio Calabria, Italy



Trench that protects from Rayleigh waves. The trench is filled in with lime or cement



The FEM model for analyzing interaction of Rayleigh waves with vertical barrier. The barrier is made of either *concrete*; or *polyurethane*; or *rubber*. *Verdict*: concrete barrier appears superior.

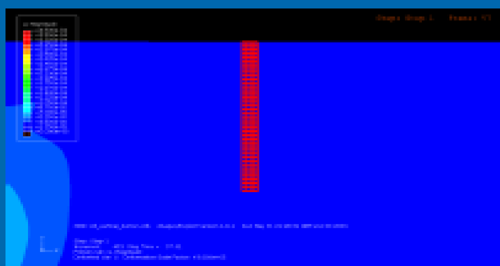
Hunaidi O. Traffic vibrations in buildings, Construction Technology Updates, 2000, N.39, National Research Council of Canada, ISSN 1206-1220

Buonsanti M., Cirianni F., Leonardi G., Santini A., and Scopelliti F., "The influence of dynamic soil-structure interaction on traffic induced vibrations in buildings," Soil Dynamics and Earthquake Engineering, vol. 27, no. 7, pp. 655–674, 2007.

Part I: Seismic waves and seismic barriers

震波屏障技術基本概念

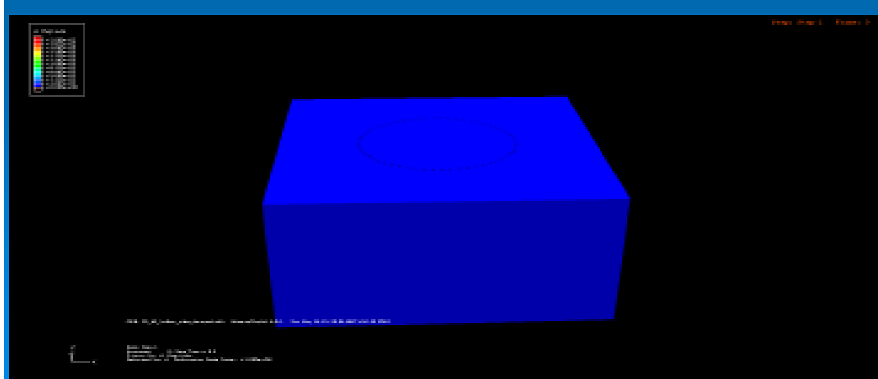
Three types of seismic barriers



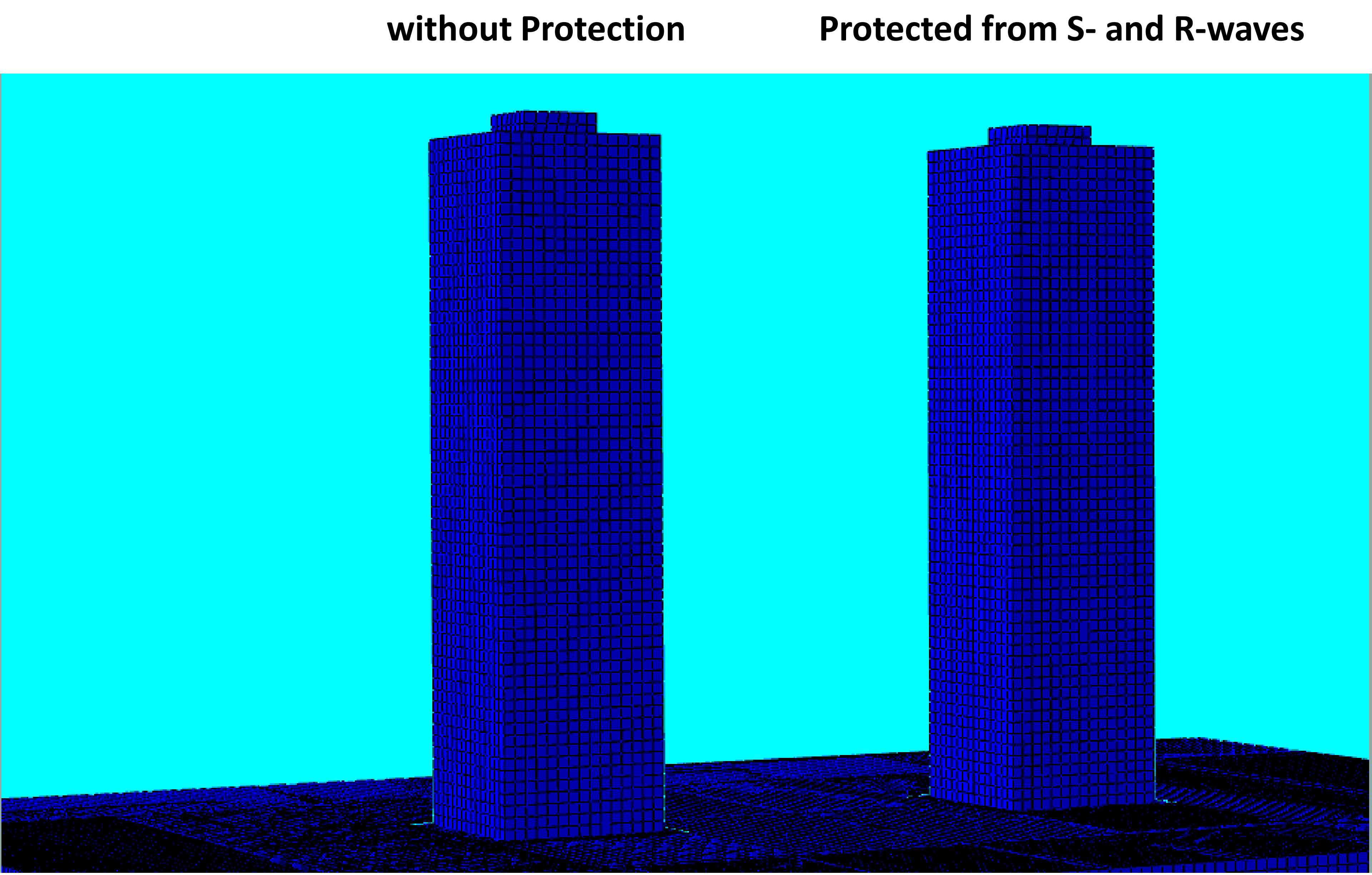
Vertical barrier

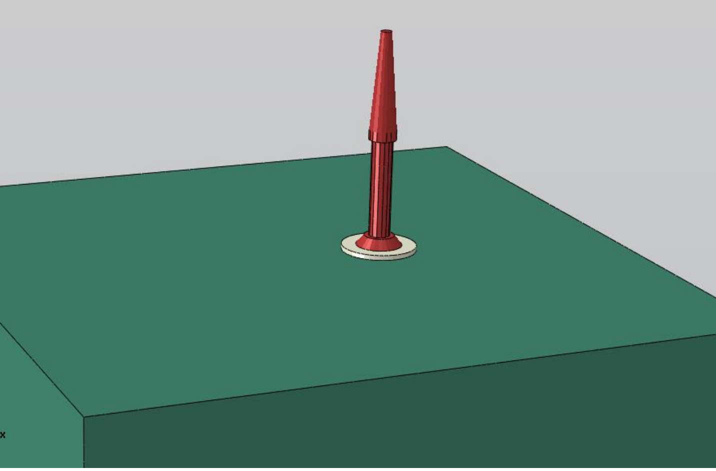
/ click on a picture to animate /

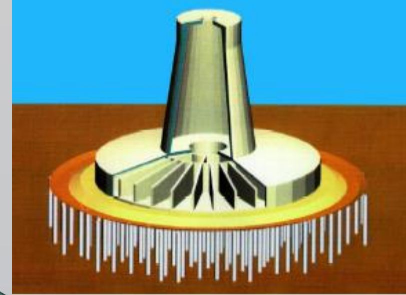
Horizontal barrier
/ click on a picture to animate /

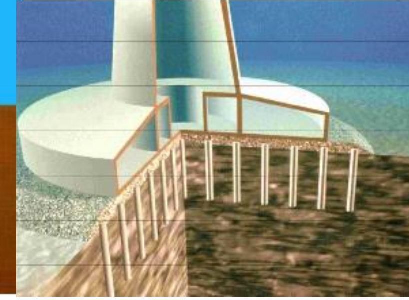


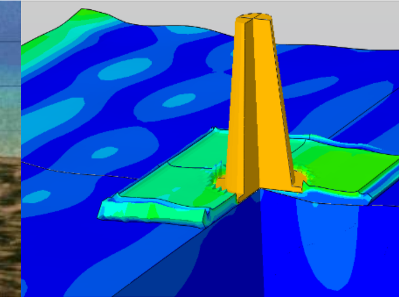
The pile field surrounding the protected region
/ click on a picture to animate /

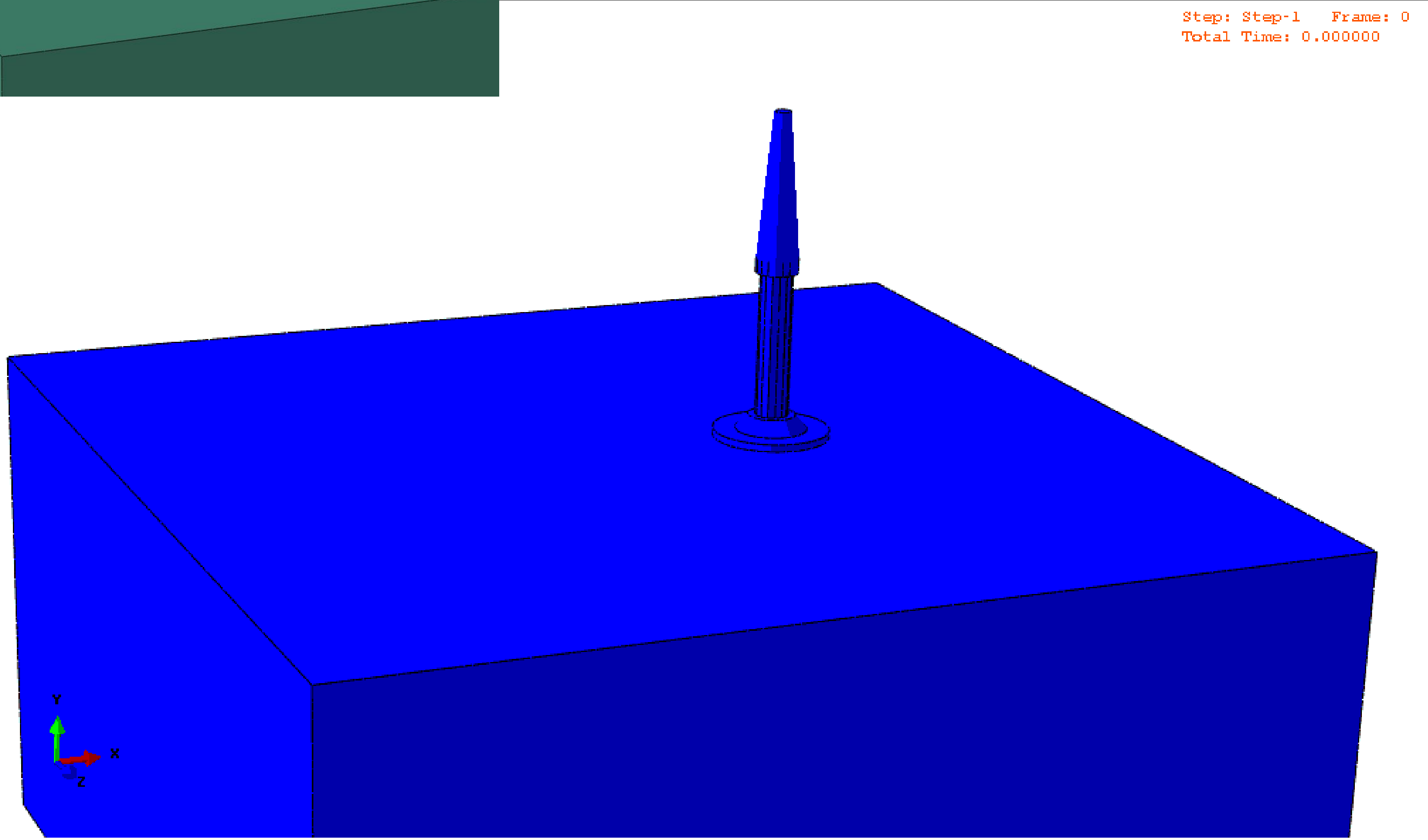

without Protection
Protected from S- and R-waves










Step: Step-1 Frame: 0
Total Time: 0.000000
Y
X
Z

Part II:

Ultimate Vibration Insulation for earthquake engineering

B. von Bernstorff and I. Emri
Karlsruhe Institute of Technology, Faculty of Mechanical Engineering, Germany
Center for Experimental Mechanics, Faculty of Mechanical Engineering, University of Ljubljana, Ljubljana, Slovenia

- New damping elements that exhibit orders of magnitude higher energy absorption than existing dampers will be presented.

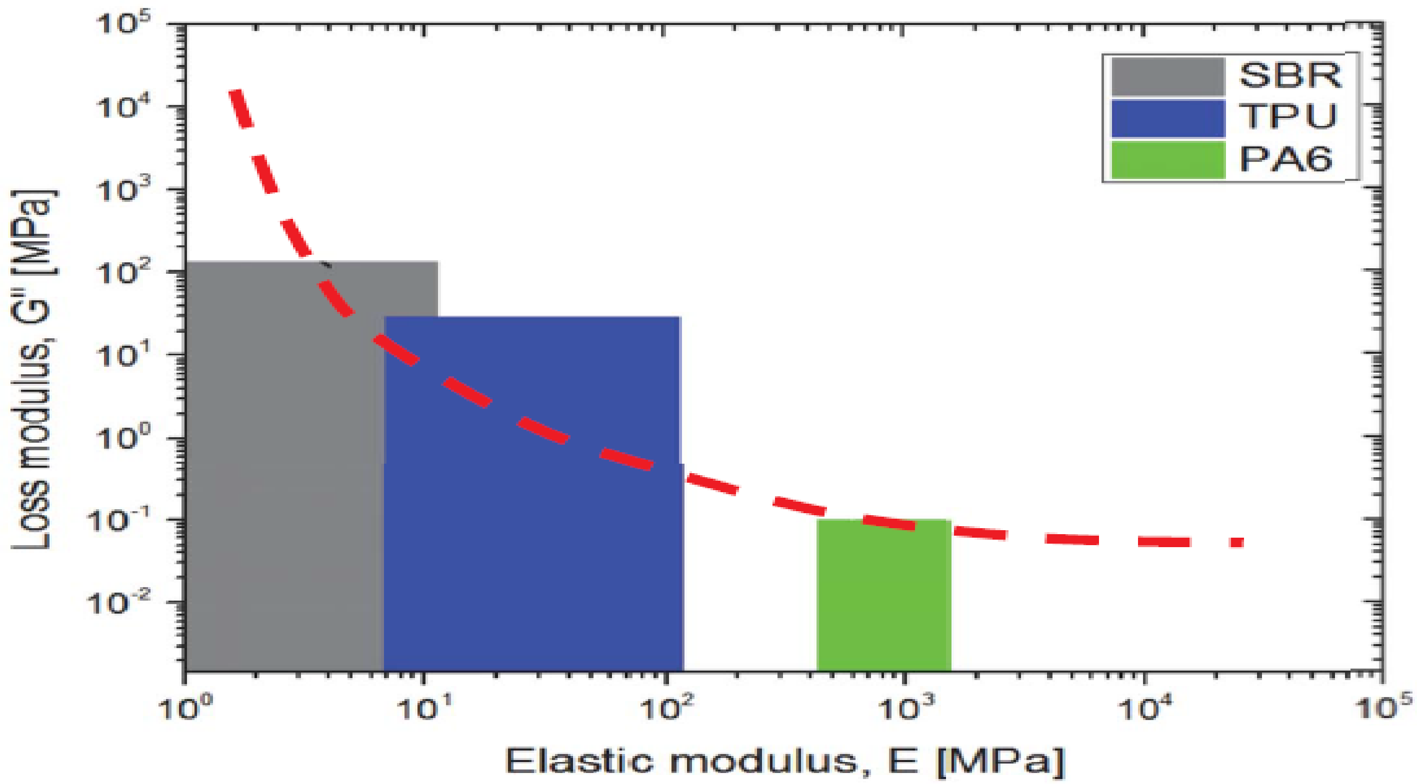
- Energy dissipation is a characteristic of the involved underlying damping processes.
- In our invention we achieved orders of magnitude higher damping by:
  - ...modifying the existing dissipative process, and
  - ...introducing additional dissipative mechanisms, which together improve the energy absorption of a damping element.

Part II: Ultimate Vibration Insulation for earthquake engineering

Limitation of the existing materials for dampers

既有材料對隔震/阻尼器之限制

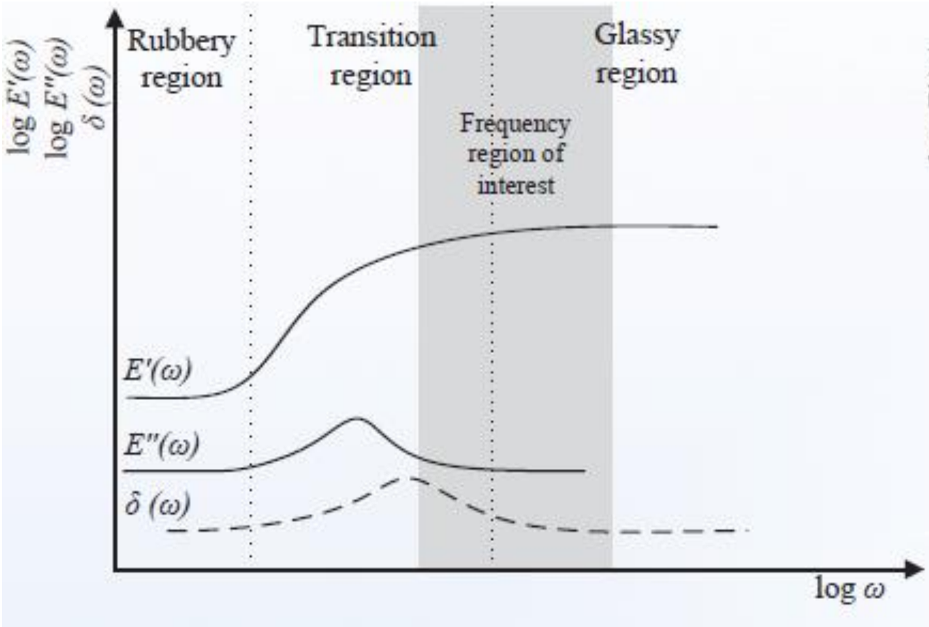
Application of the existing materials with high energy absorption is limited by their low modulus and consequently low stiffness.



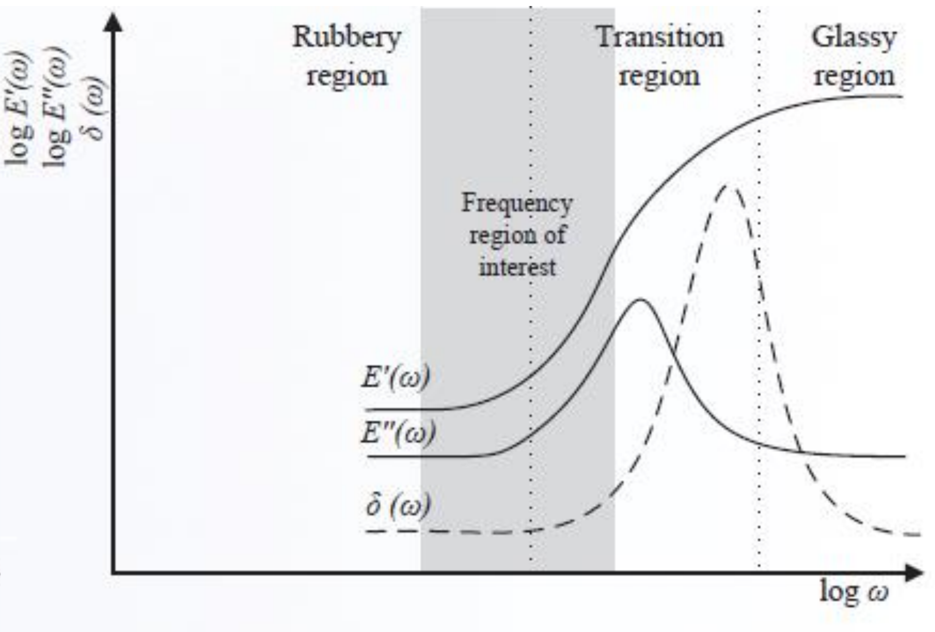
TPU: Thermoplastic Polyurethane Elastollan

Part II: Ultimate Vibration Insulation for earthquake engineering

Theromoplastic Polymer

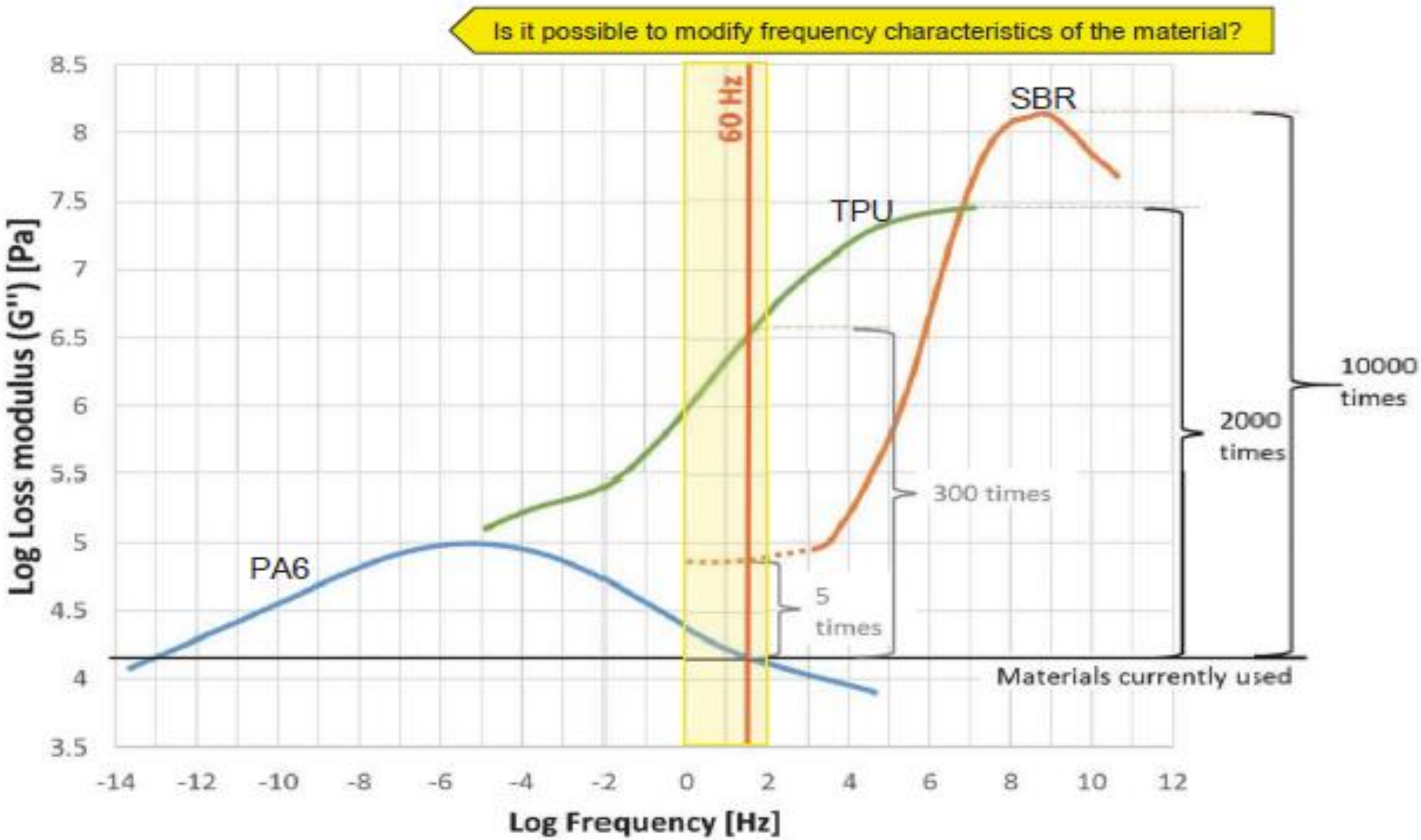


Elastomeric Polymer



Part II: Ultimate Vibration Insulation for earthquake engineering

Existing technology does not allow utilization of the "full potential" of the materials used in vibration insulation. G'' is a measure of dissipated energy $W_{diss} = \pi\varepsilon_0^2 G''(\omega)$.

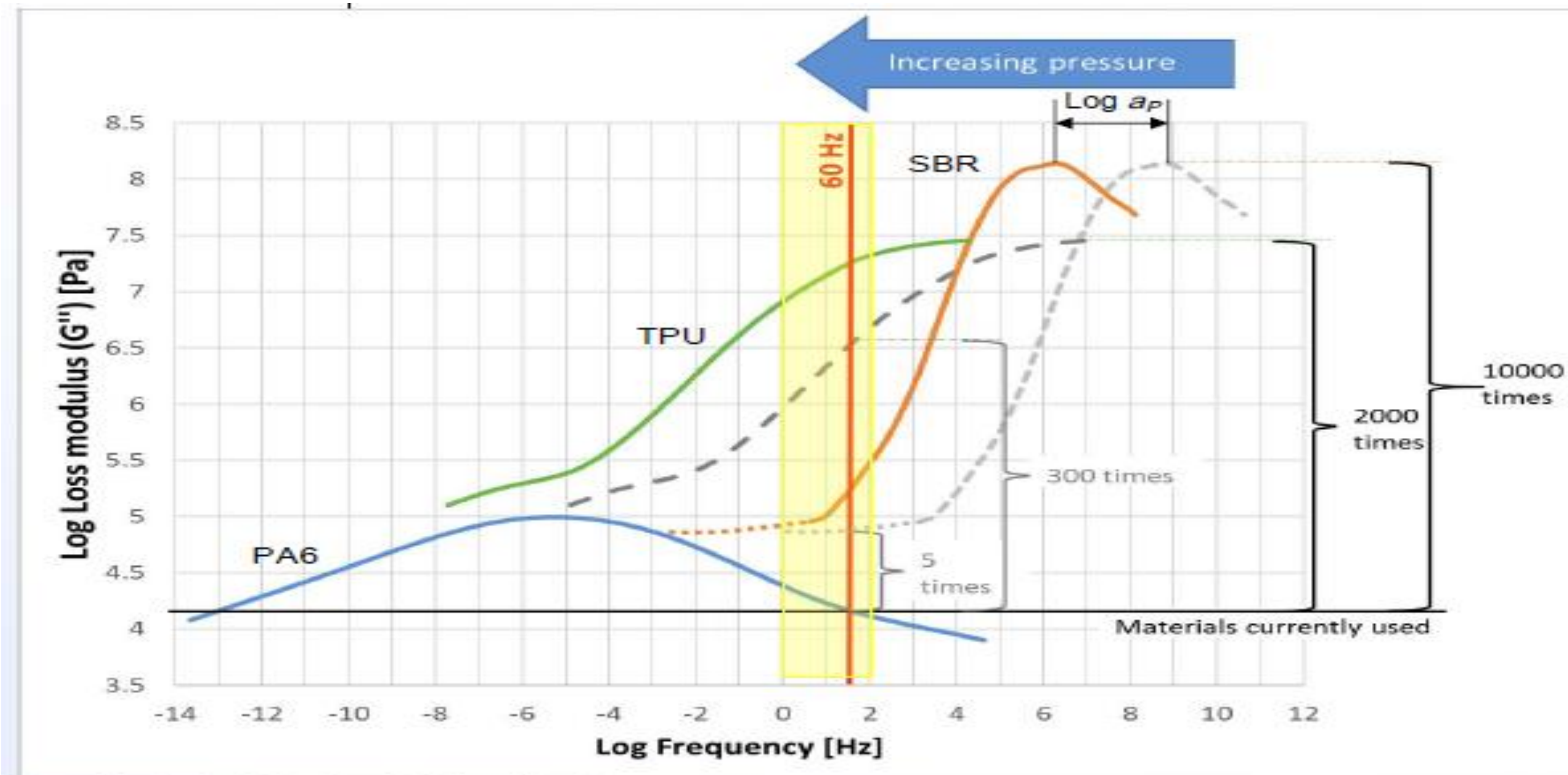


Part II: Ultimate Vibration Insulation for earthquake engineering

Innovative solution to

Full potential of the materials for vibration insolation

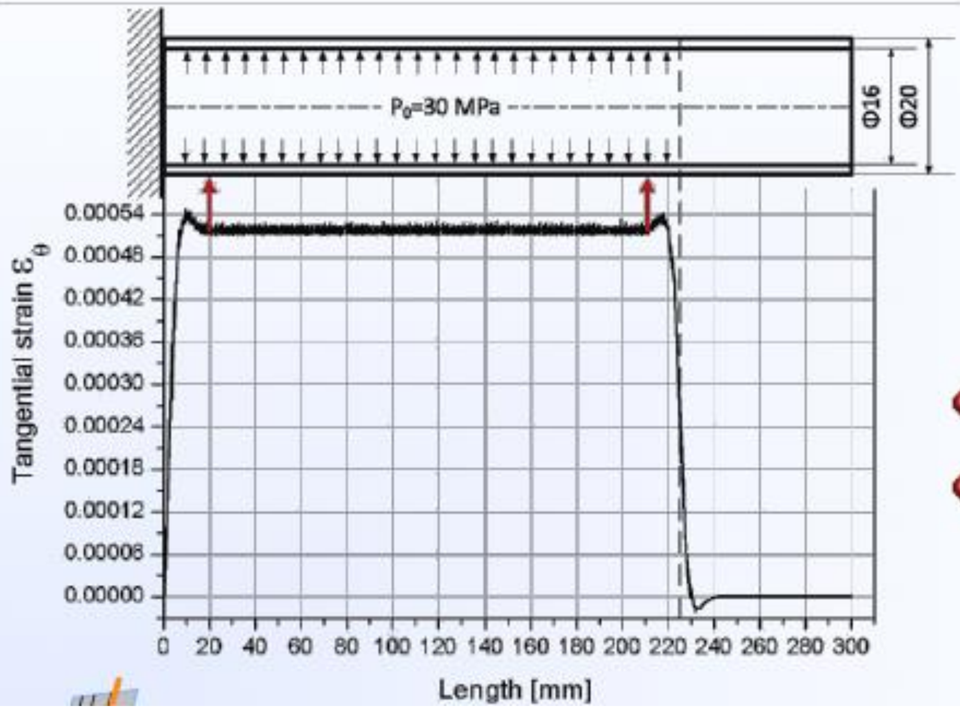
By exposing the same material to hydrostatic pressure one can improve its damping properties by orders of magnitude.

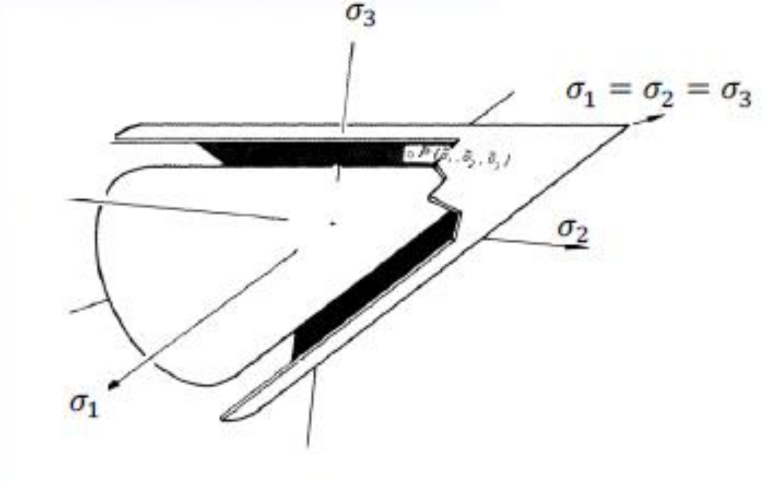


Part II: Ultimate Vibration Insulation for earthquake engineering

Characteristics of the prototype

- Pure hydrostatic pressure cannot be applied through uniaxial loading
- Uniaxial compressive stress destroys the material





- Granular system may behave as a fluid
- Proper particles size distribution leads to fluid-like behavior

Part II: Ultimate Vibration Insulation for earthquake engineering

Theoretical Background | **Behavior of granular materials**

- Conditions at which granular material exhibits fluid-like behavior depends on:
  - Particle size
  - Particle size distribution
  - Particle shape
  - External factors (humidity and temperature)
  - Driving force (gravity, shear, **pressure**)

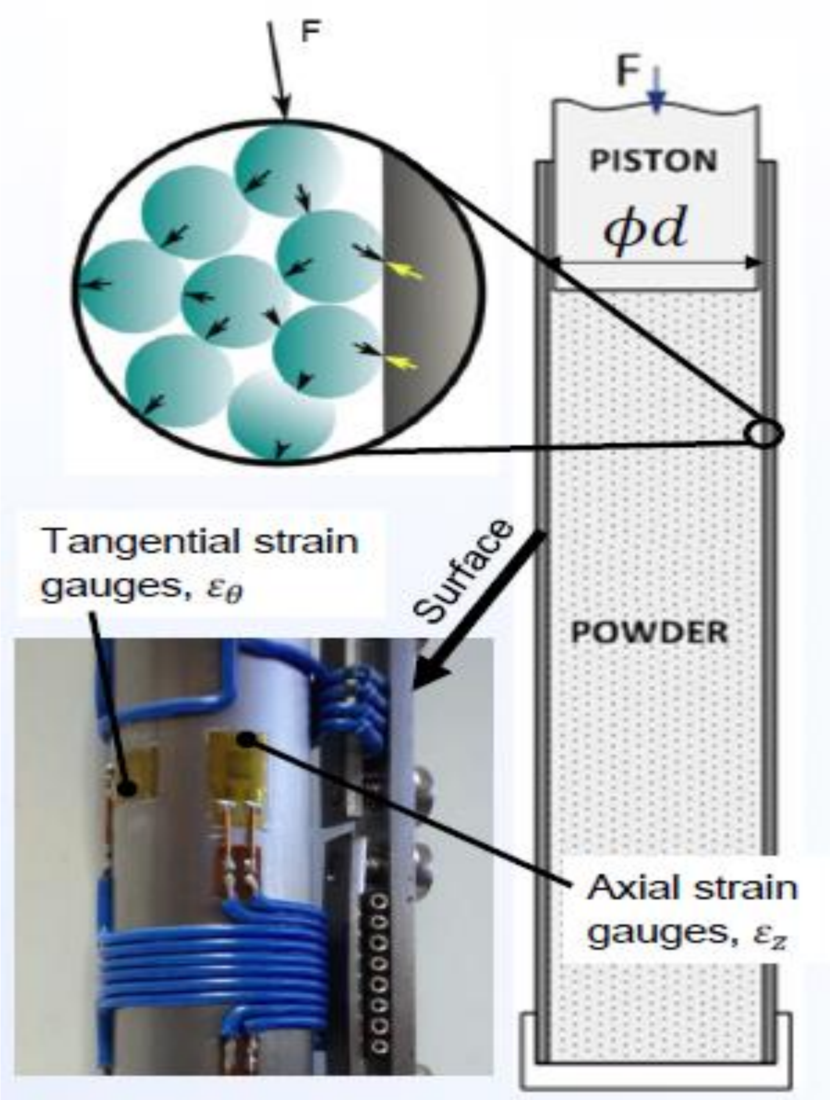
↓

In our case we need to understand the fluid-like behavior of granular systems at high pressure.

Currently there are no commercial apparatuses that allow such analysis.

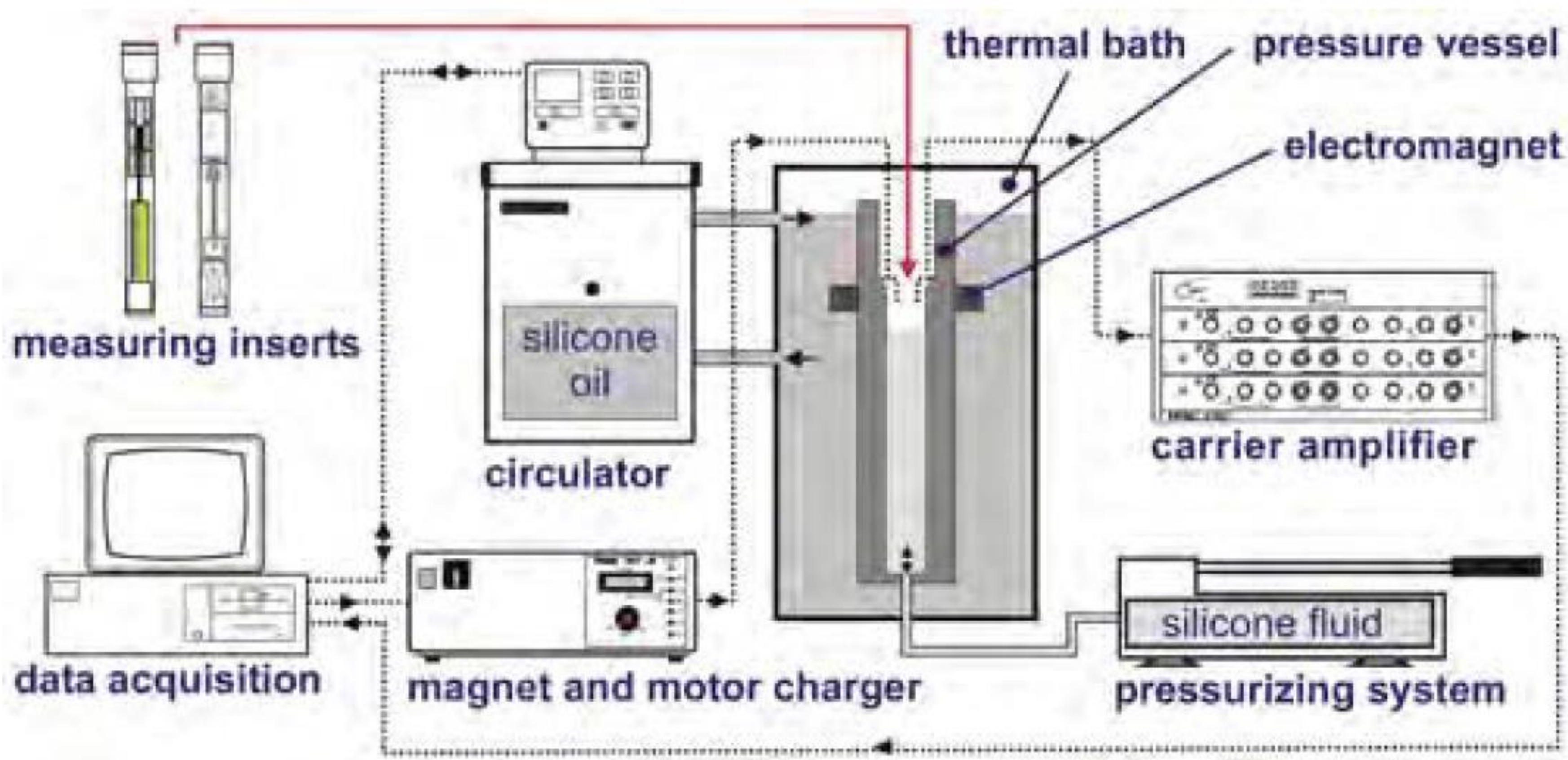
Part II: Ultimate Vibration Insulation for earthquake engineering

Concept of the Granulate Flow Analyzer (GFA) apparatus

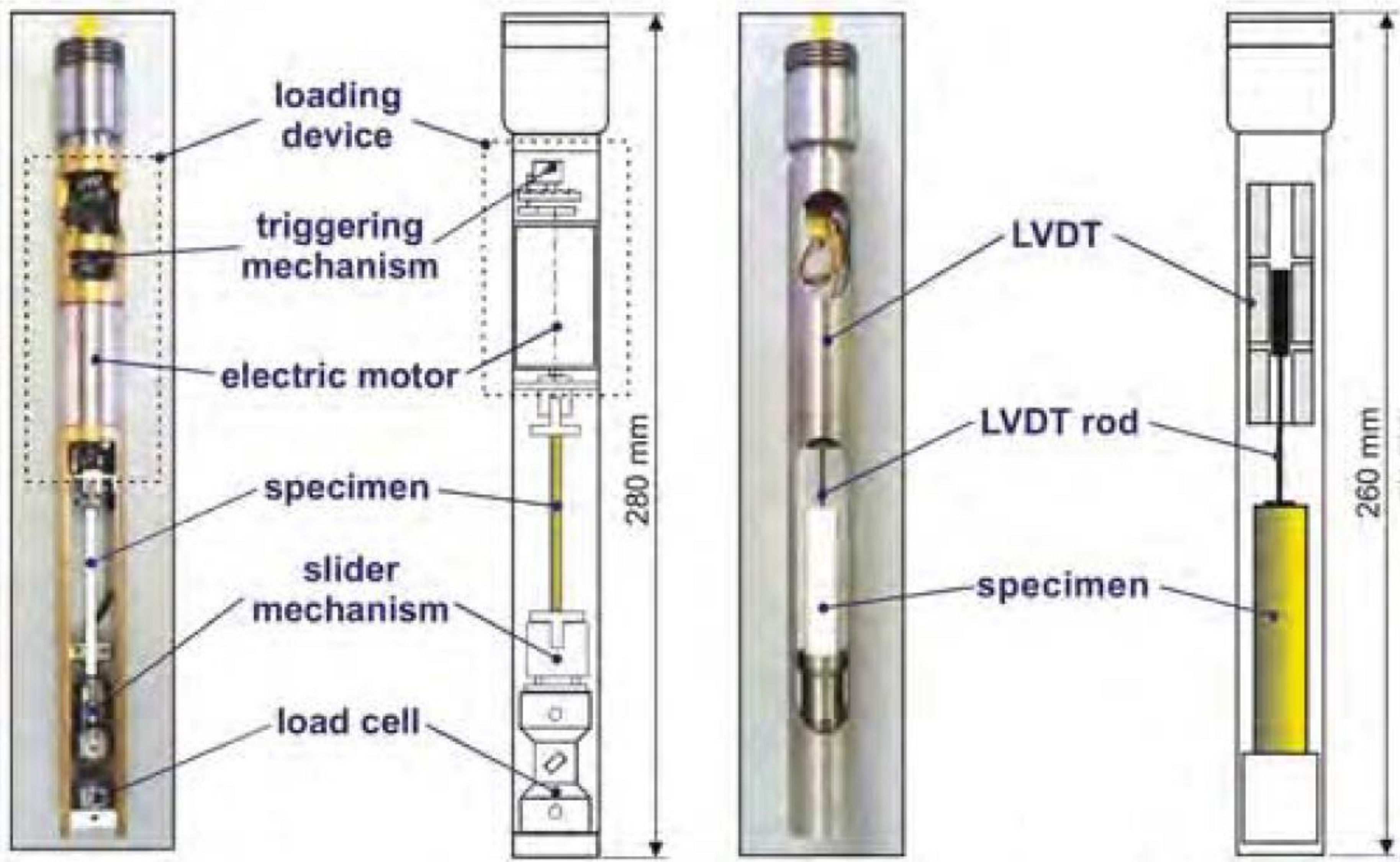


- Cylinder - filled with granular material - force applied on top by piston
- Confined compression of granular material inside a cylinder leads to an elastic deformation of cylinder
- **Strains** are measured by strain gages on the surface of the cylinder
- Strain gauges in axial ε_z and tangential directions ε_θ

High-pressure Apparatus CMS
Granular Friction Analyzer (GFA) Apparatus



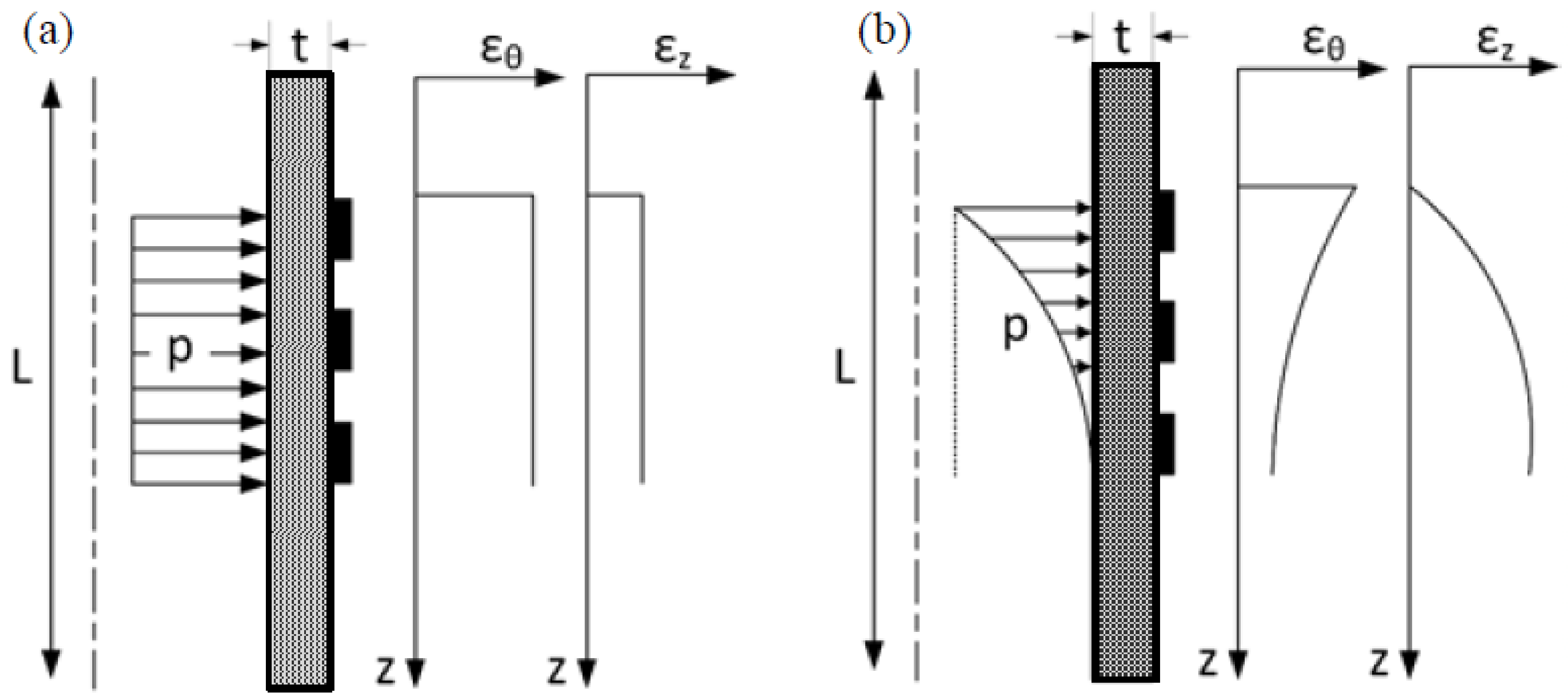
I Emri, T Prodan. Experimental mechanics 2006; 46:429 (2006).


loading
device
triggering
mechanism
electric motor
specimen
slider
mechanism
load cell
280 mm
LVDT
LVDT rod
specimen
260 mm

Part II: Ultimate Vibration Insulation for earthquake engineering

How to generate hydrostatic pressure?

Stress distribution in an uniaxial loaded cylinder

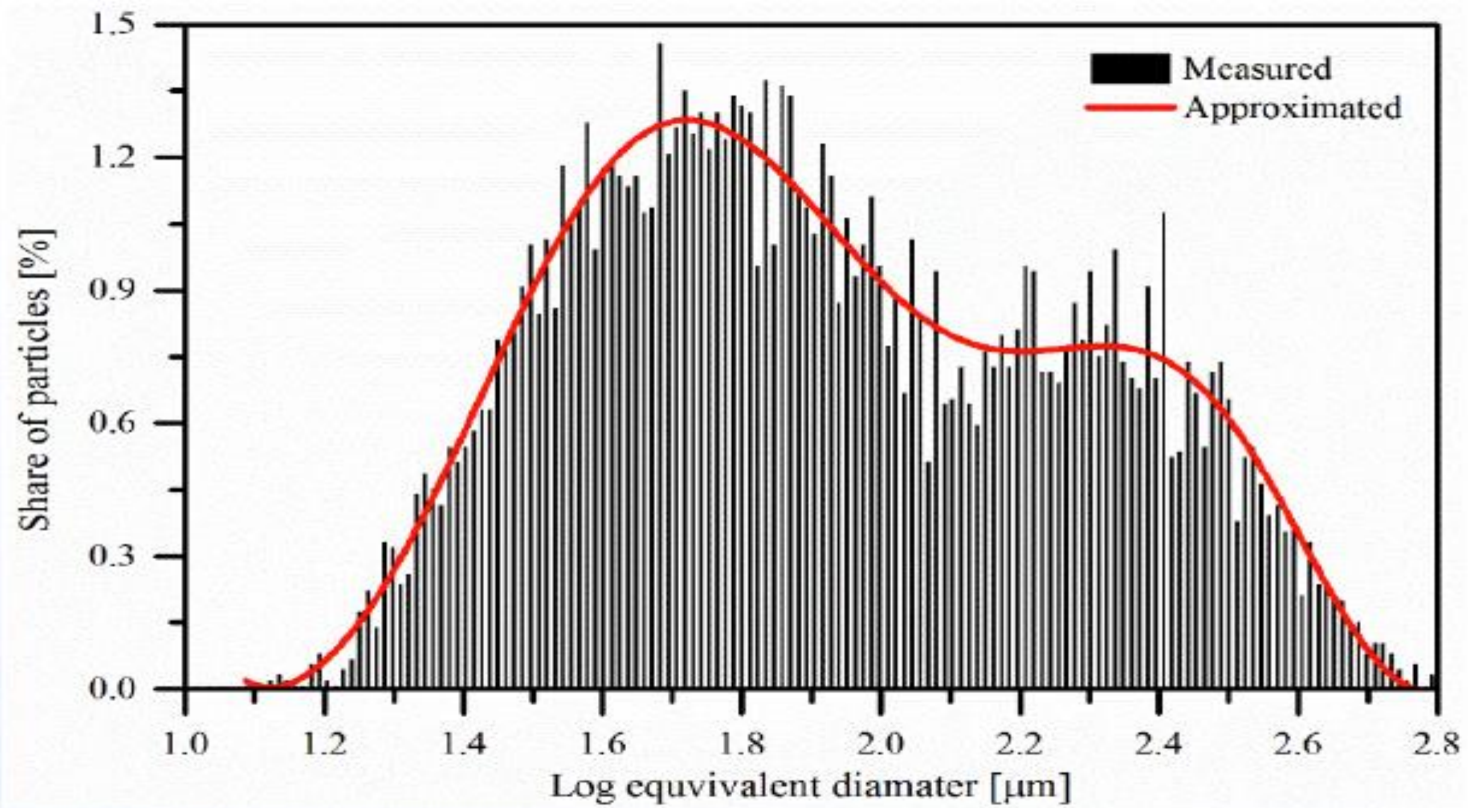


- Expected results for tangential and axial strain along the length of a cylinder (a) for a fluid, and (b) for a powder

Part II: Ultimate Vibration Insulation for earthquake engineering

Optimized particles distribution for fluidlike hydrostatic pressure

Application in a Granular Damping Element



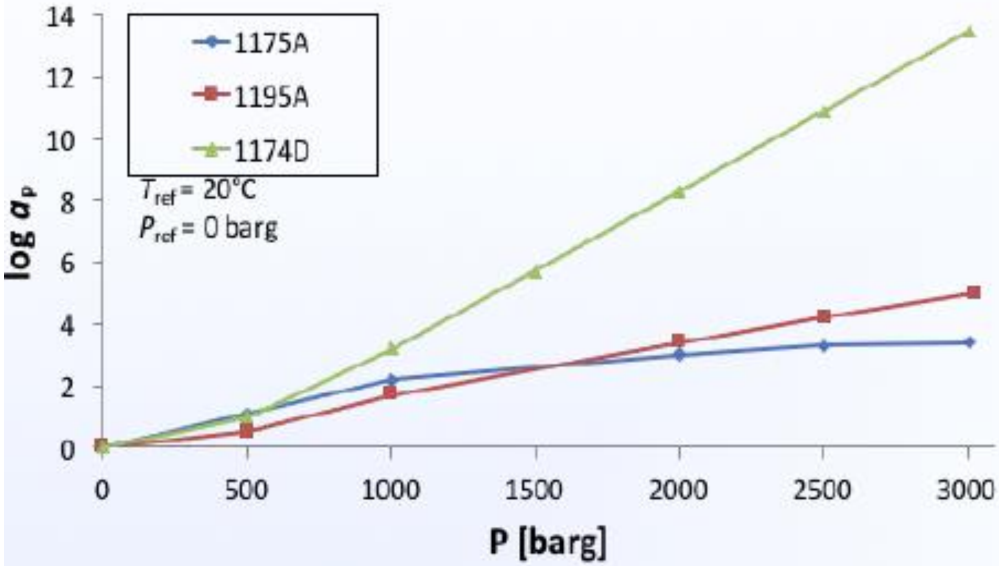
- M. Bizjak: The Effect of Granular Rubber Size Distribution On Acoustical Properties of Sound Insulation Plates. Master Thesis, Faculty of Mechanical Engineering, University of Ljubljana, 2013

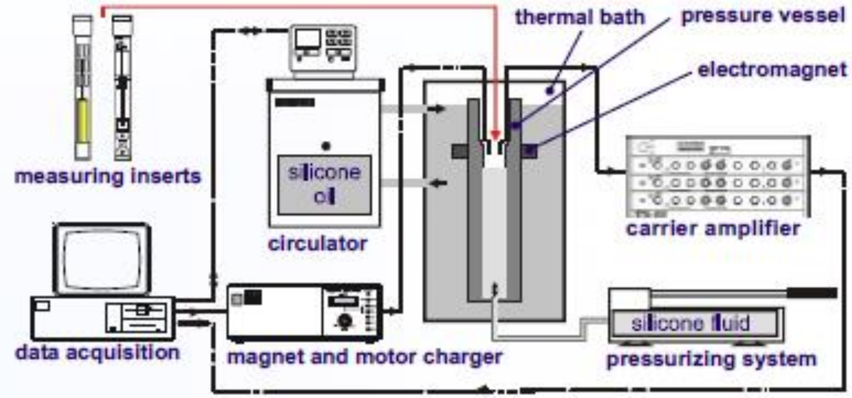
Part II: Ultimate Vibration Insulation for earthquake engineering

Proof-of-concept | **Physics**

CEM pressure apparatus

Pressure dependence of TPU

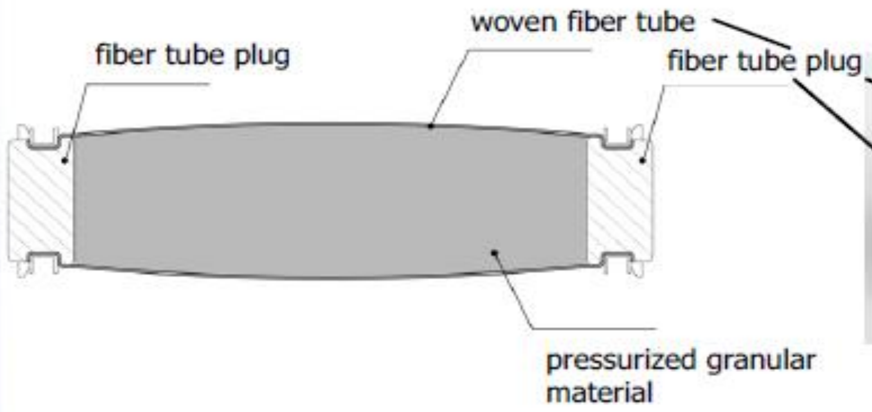




- By exposing elastomers to appropriate pressure one can shift the energy absorption peak to the desired frequency.

Part II: Ultimate Vibration Insulation for earthquake engineering

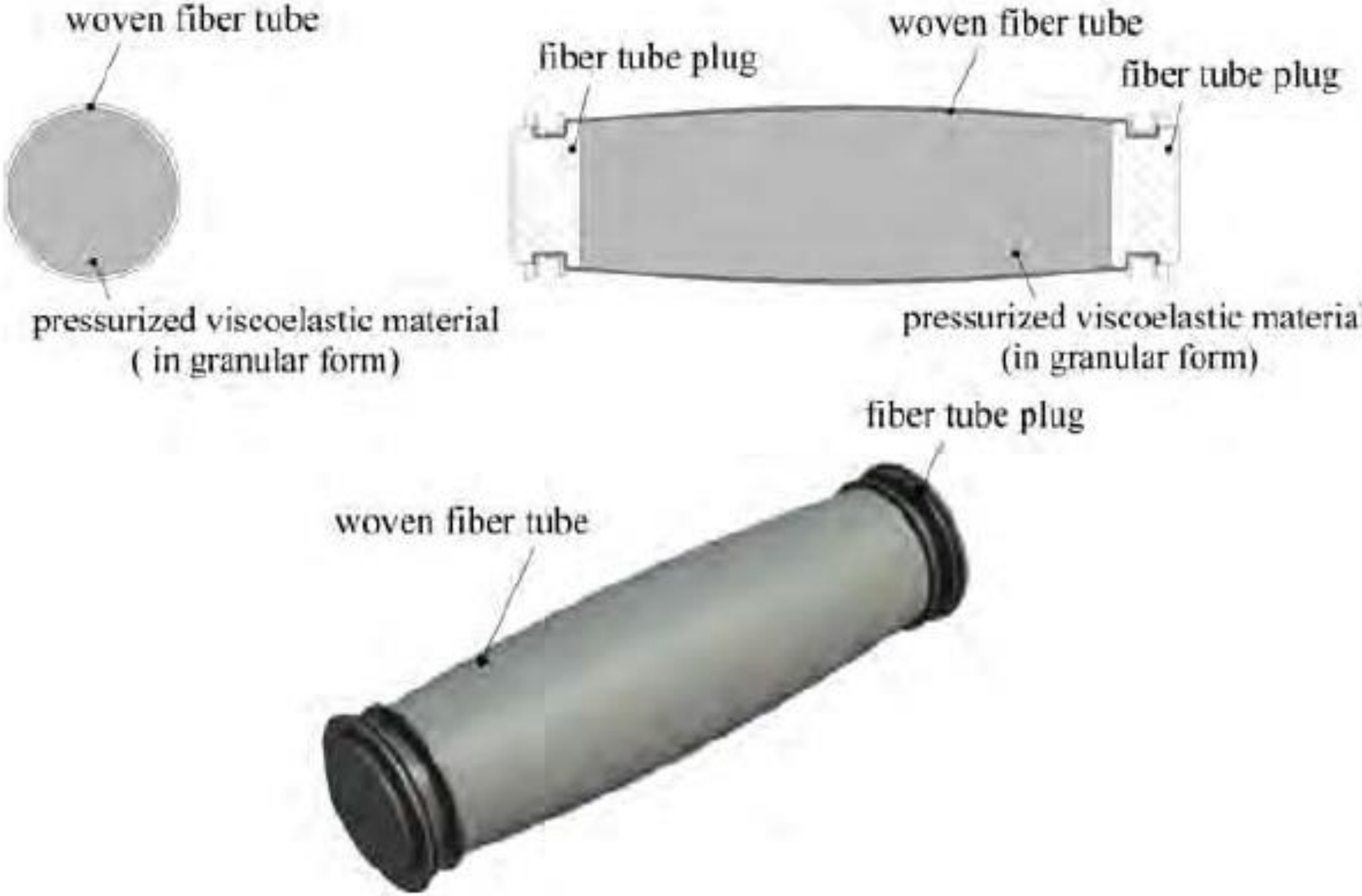
Higher energy absorption is achieved by pressurizing granular polymeric material(s) inside a closed flexible woven fiber tube.



GDE: Granular Damping Elements

- By exposing polymers to 3D (hydrostatic) pressures one may adjust their frequency dependent energy dissipation properties with the excitation frequency, to achieve the ultimate damping (energy absorption) characteristics of a vibration isolation.
- 3D pressure state is achieved by using granular material.
- By using granular materials we introduce Coulomb friction as an additional dissipative mechanism.

1. **Using hydrostatic pressure for material damping properties frequency adjustment**
2. **Improving granular material flow properties for their self-pressurization**

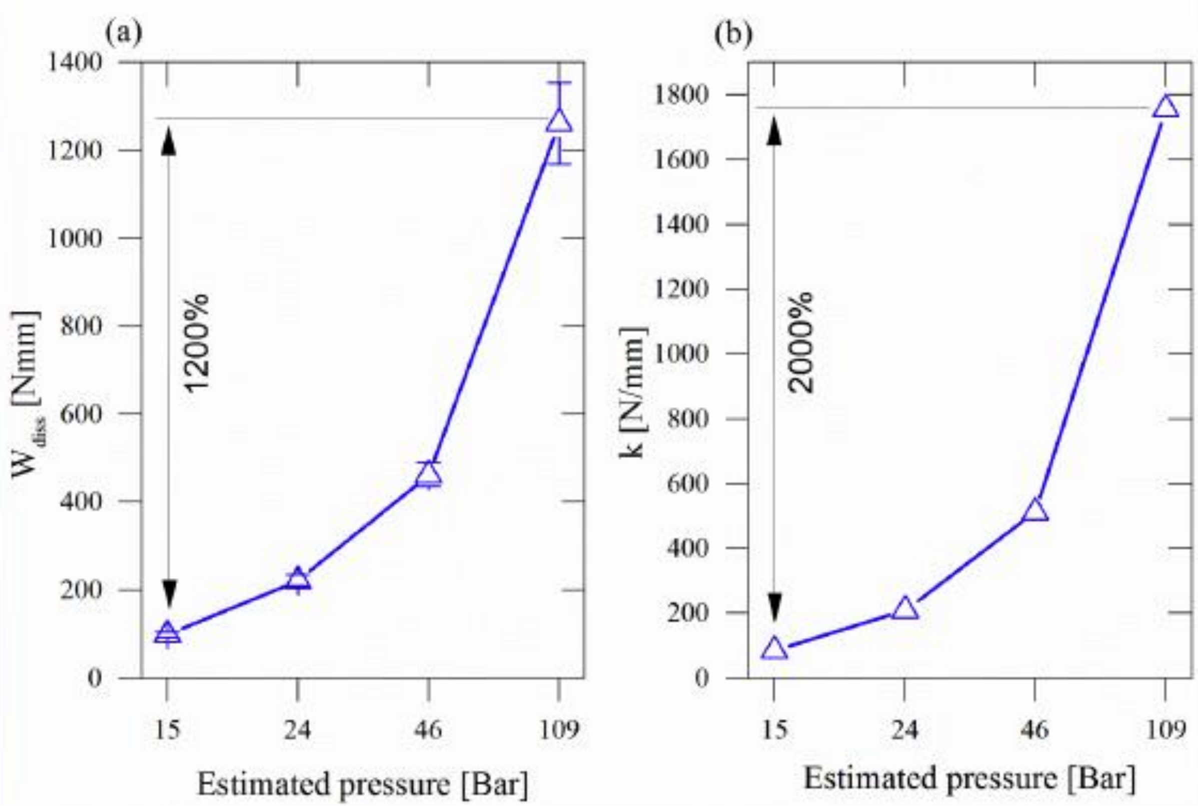


GDE consists of a container, made of woven basalt, carbon or glass fibers, which is filled and pressurized with polymeric granular materials with multi-modal particles size-distribution. Due to the flow-like behavior of granulated polymers, the generated pressure within the container will be hydrostatic and will act on polymeric particles themselves, and consequently modify frequency dependence of their energy absorption properties.

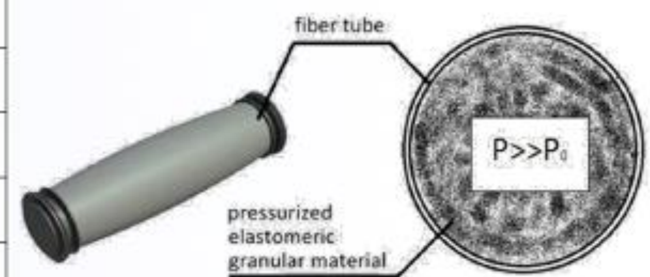
Part II: Ultimate Vibration Insulation for earthquake engineering

Proof-of-concept | Measurements on a prototype

- Using waste tires rubber and exposing it to hydrostatic pressure we were able to increase energy absorption W_{diss}, and stiffness k, of a damping element.
- With 109 bar we achieved increase of energy absorption by factor 12 and stiffness by factor 20.



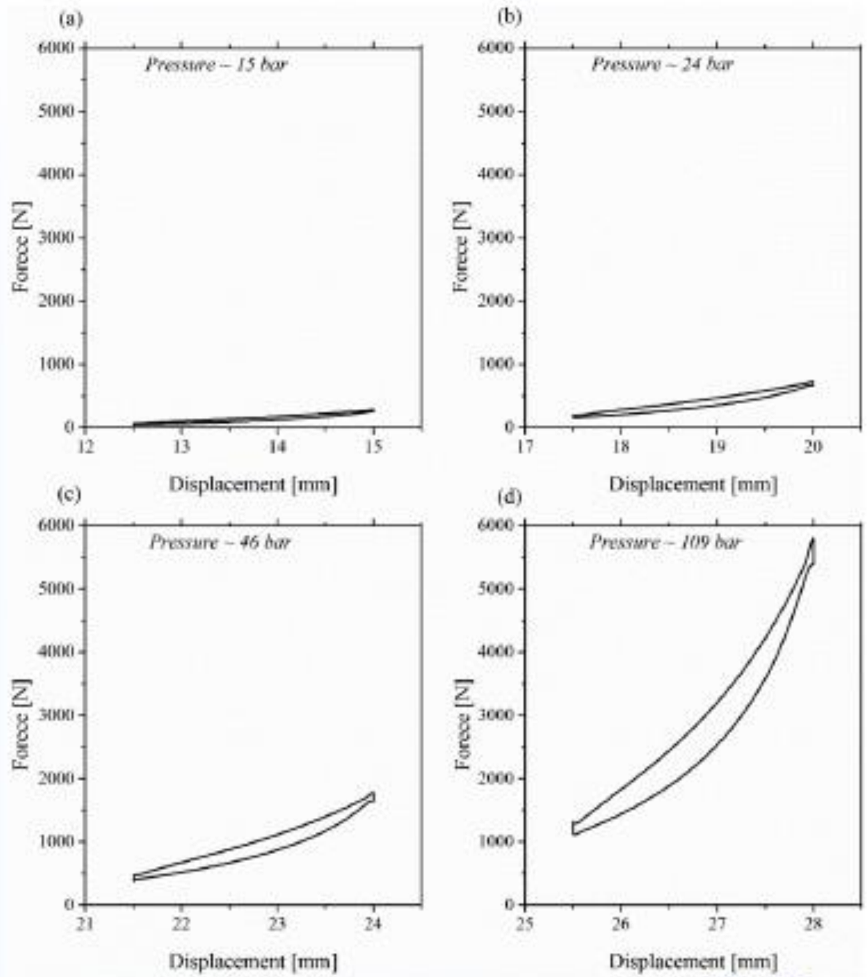
Granular damping element



Part II: Ultimate Vibration Insulation for earthquake engineering

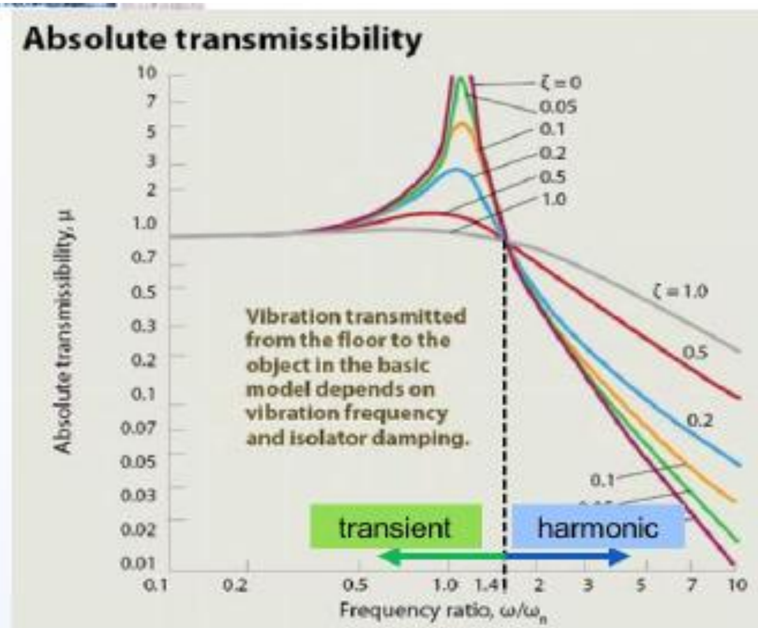
Proof-of-Feasibility

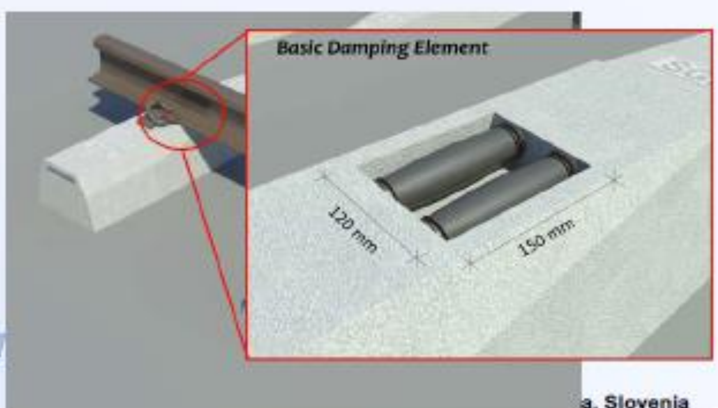
- With 109 bar we achieved increase of energy absorption by factor 12 and stiffness by factor 20.
- Due to limitations of the commercial sleeves the applied pressure was limited.
- With proper fiber tubes (sleeves) and higher pressure one will utilize the full potentials of energy dissipation.



Part II: Ultimate Vibration Insulation for earthquake engineering

Potential applications of the granular damping element - I





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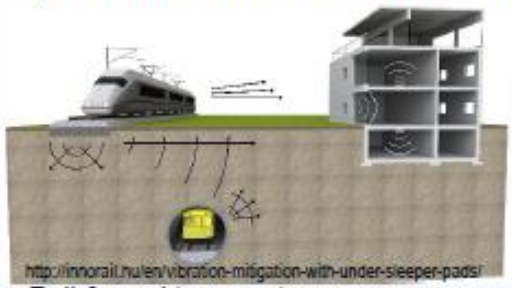
Potential applications of the granular damping element - II

- Mechanical vibrations can have negative effects on people as well as on the performance and reliability of machines and devices.



Rail & road transport

http://goo.gl/VQYCDp

Home appliances

www.jbha.org

Earthquake/civil engineering

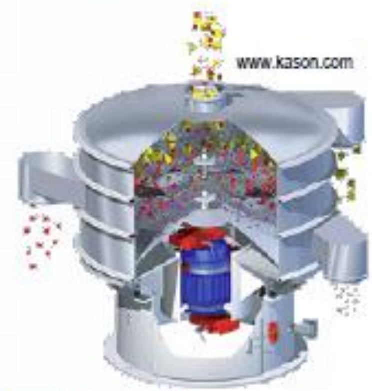
www.kineticsnoise.com

Industrial machines

- However, in some cases vibrations are desirable and needed.

Testing/Electrodynamic shakers

Soil compaction

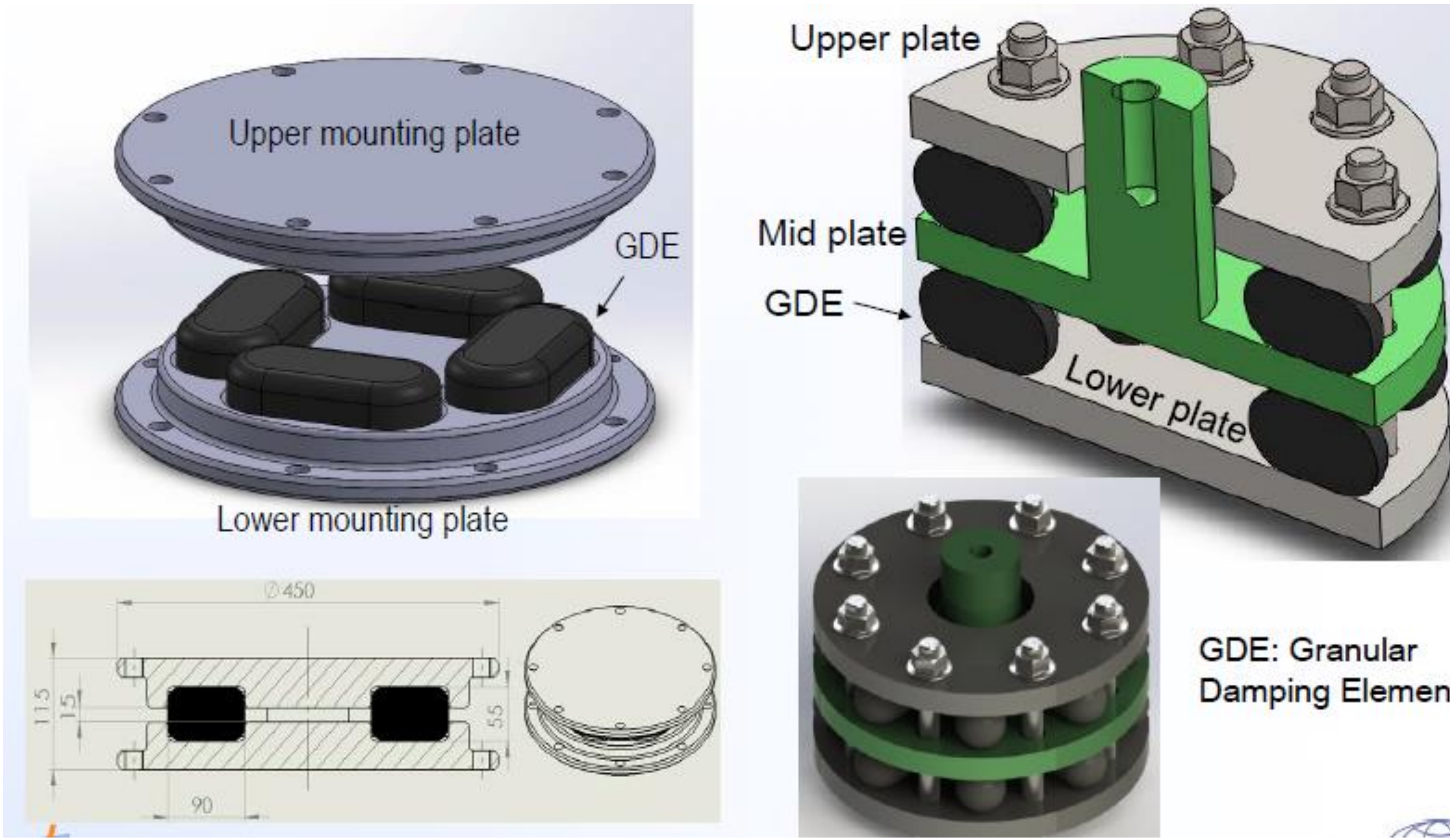


Material separator

Controlling mechanical vibrations is vital in both cases.

Part II: Ultimate Vibration Insulation for earthquake engineering

Potential applications of the granular damping element - III



Part II: Ultimate Vibration Insulation for earthquake engineering

Summary

- We can built dampers with orders of magnitude higher damping.
- We can built dampers with high stiffness that can carry high loads.
- We can instantaneously control and adjust the damper properties to the excitation frequency such so to minimize vibrations.
- The invented technology ultimately utilizes energy absorption properties of the employed materials.
- The invented technology may utilize shredded tires and basalt fibers, hence, it is environmental friendly and sustainable.
- Two patents (fundamental + application) have been granted.

謝謝您的聆聽
Thank You for Your Listening