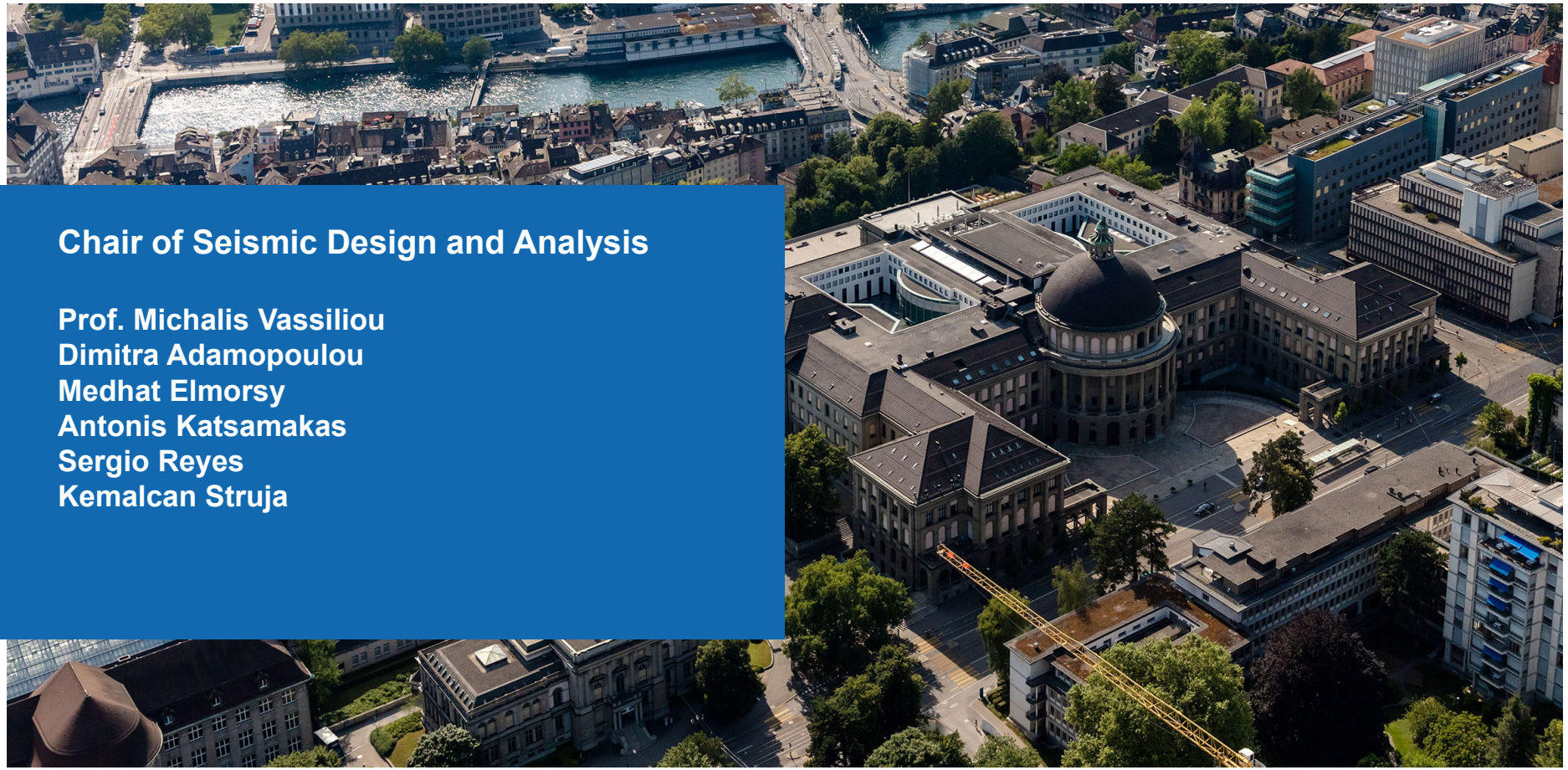
ETH zürich

ibk
Institute of Structural Engineering



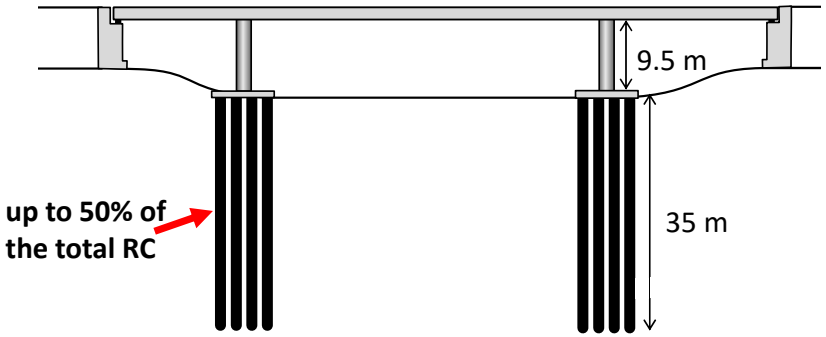
Chair of Seismic Design and Analysis

Prof. Michalis Vassiliou
Dimitra Adamopoulou
Medhat Elmorsy
Antonis Katsamakas
Sergio Reyes
Kemalcan Struja

D BAUG

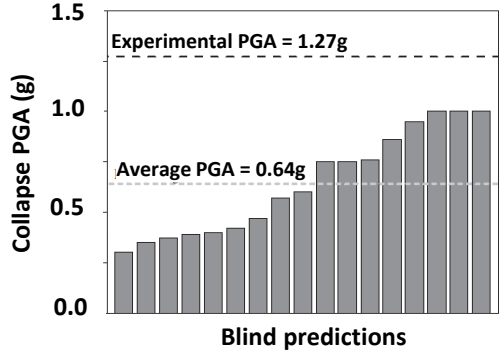
Major questions in Earthquake Engineering

Novel design methods



Rational evaluation of structures





Damage avoidance design



Low income countries

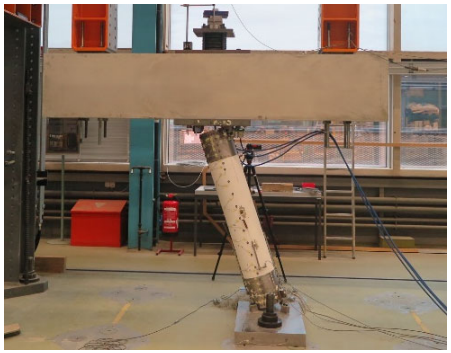


New building materials



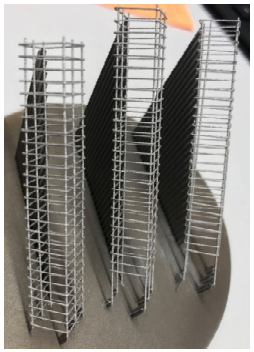
Current research directions

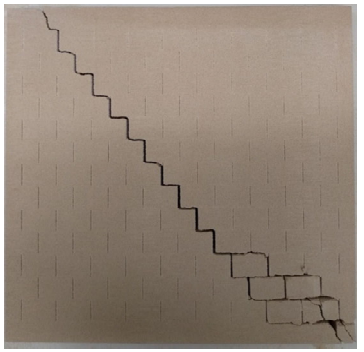
Rocking precast structures





Physical modelling of RC and Masonry structures using a 3D printer and a geotechnical centrifuge





Seismic design methods for low income countries





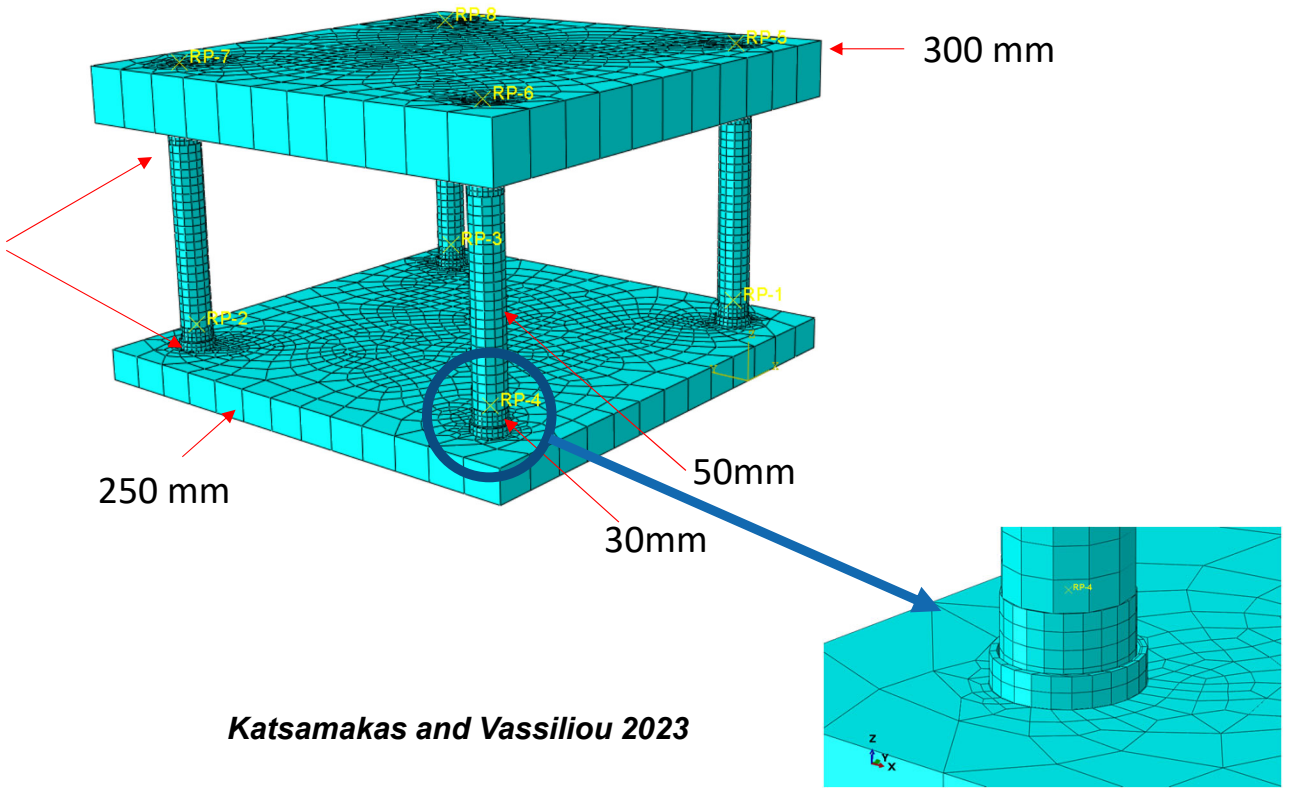
Genetically modified bamboo



Can we model it numerically?

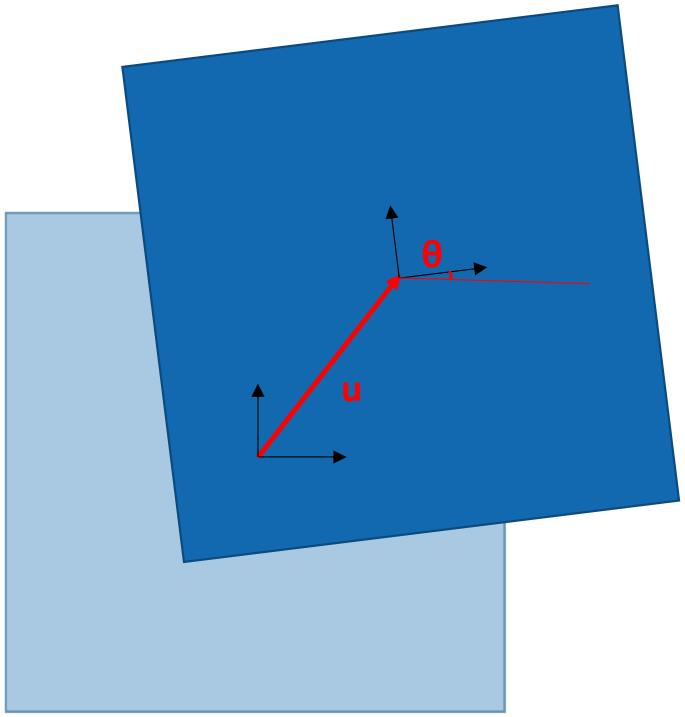
ABAQUS FE Model

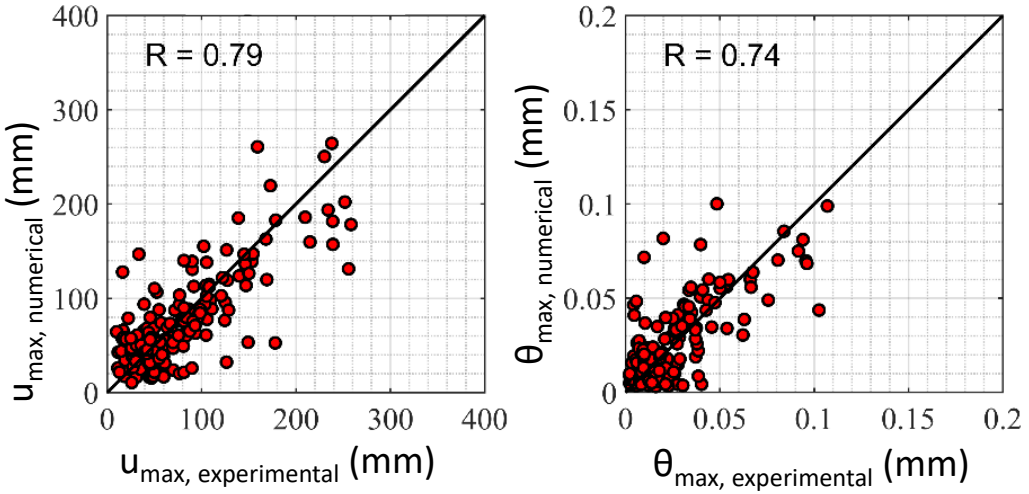
- 8-node elastic hexaedral elements
- Tendon-spring system spring element
- HHT, dt=1e-3 sec, α=-0.2

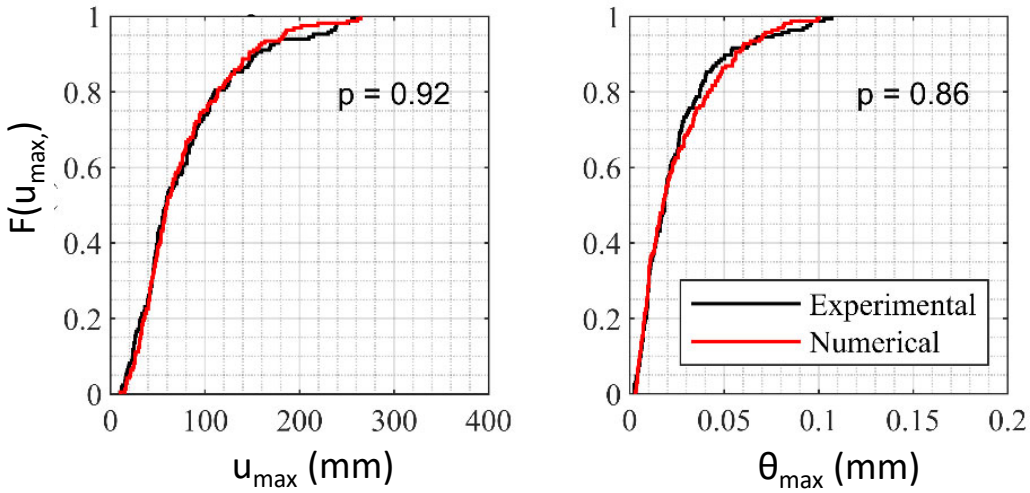


Katsamakas and Vassiliou 2023

Results: Displacement and Rotation

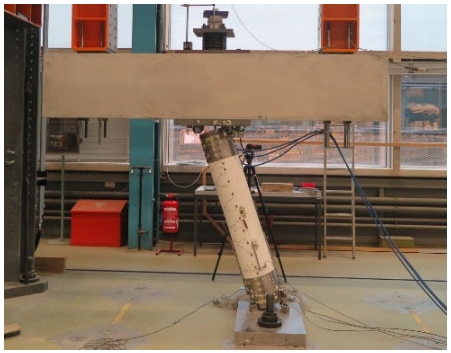






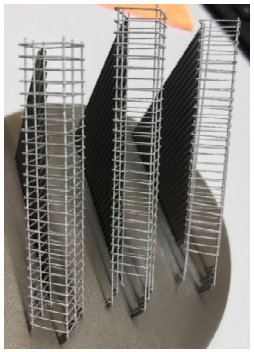
Current research directions

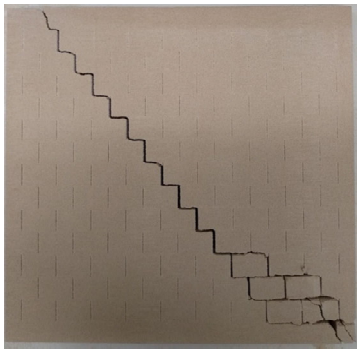
Rocking precast structures





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Seismic design methods for low income countries





Genetically modified bamboo



State of the art of seismic modelling

Masonry

Shake table tests of a simple masonry structure

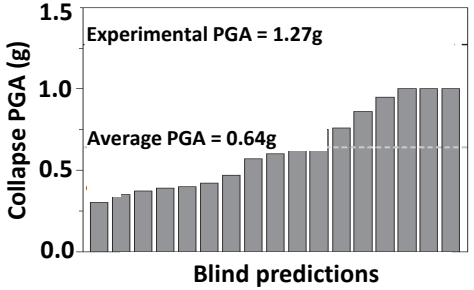


(Mendes et al. 2017 – not our group)

17 *expert* teams were invited to predict the response.

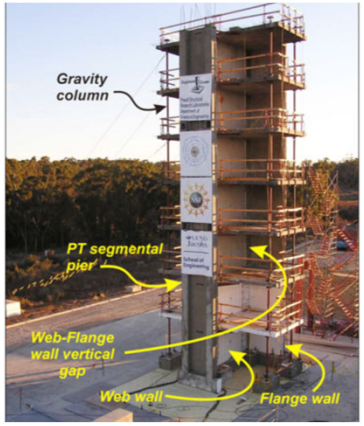


Results



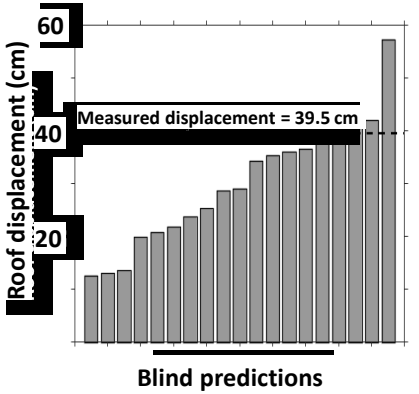
Reinforced Concrete

Shake table tests of a slice of an RC building



(Panagiotou et al. 2011 – not our group)

Results



(Courtesy of Marios Panagiotou)

Hard truth: After decades of earthquake engineering **we cannot predict the response not even of these simplistic specimens**.

How can we evaluate whether we need to **retrofit** a structure?

From material to system level behavior

1) Material Level



Given: Composition of concrete
Find: Compression strength

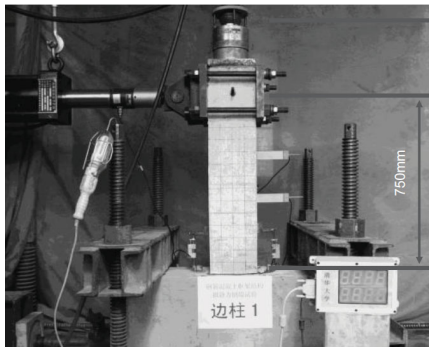
Models work relatively well + there is quality control in terms of material properties.

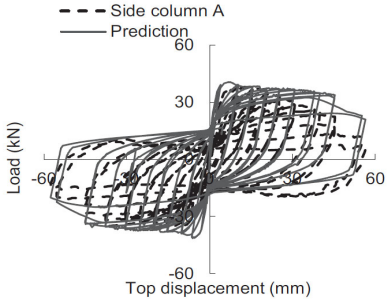
Results given in a statistical sense.

Assumptions A: Beam theory, fiber element, etc



2) Component Level

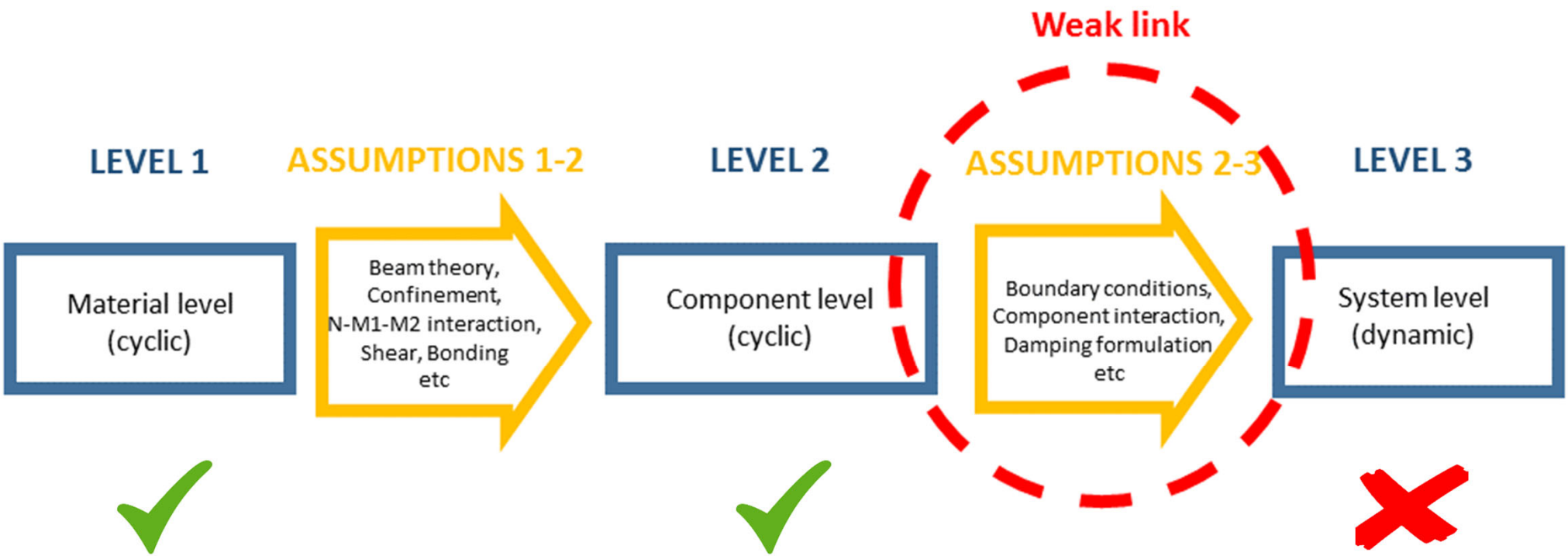




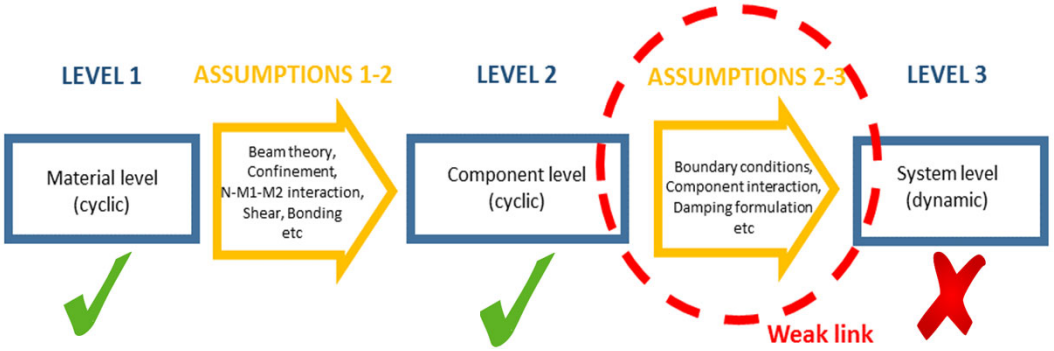
3) System level (dynamic)

Assumptions B: Interaction of components, damping, etc

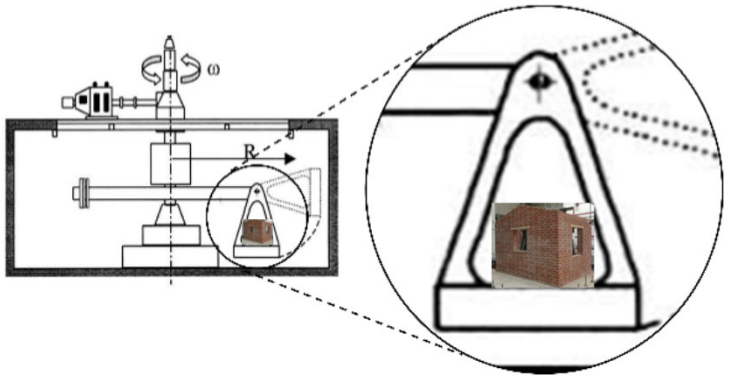
Where is the weak link?



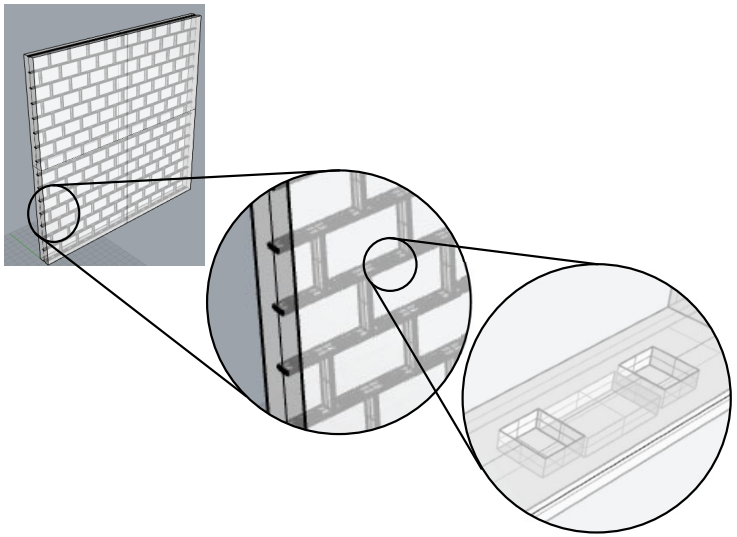
Physical modelling of masonry structures using a 3D printer



We will 3D print small scale specimens that will resemble masonry, and test them on a **shaking table** inside the **ETH geotechnical centrifuge.**

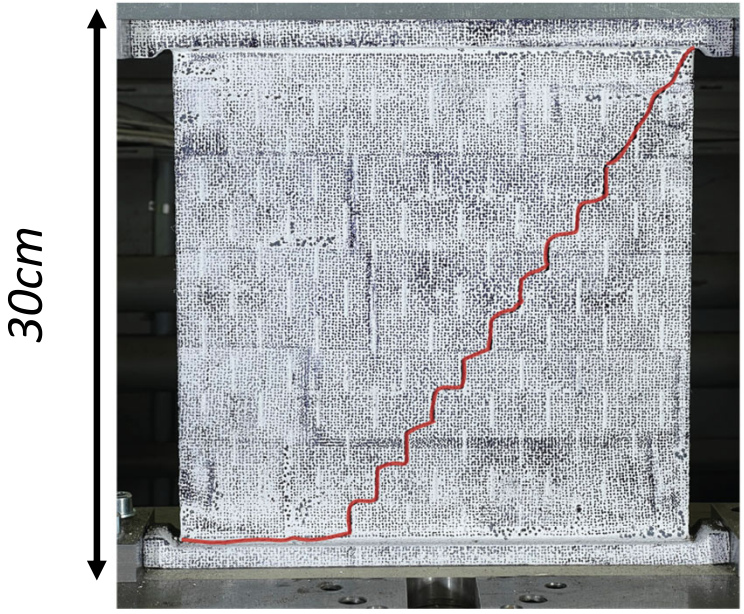


A single test costs **$100 and takes a few hours**.

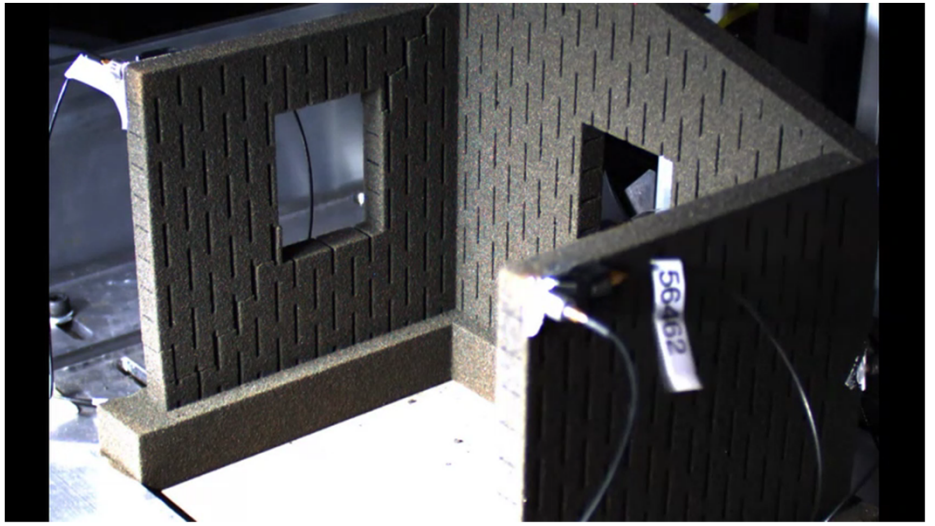


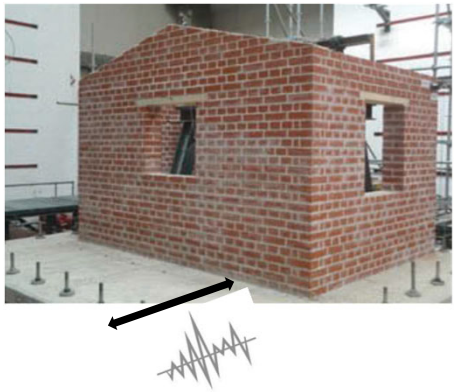
Key Challenge: Print material with properties ***similar*** to masonry by controlling their micro geometry: ***"meta-mortar"***

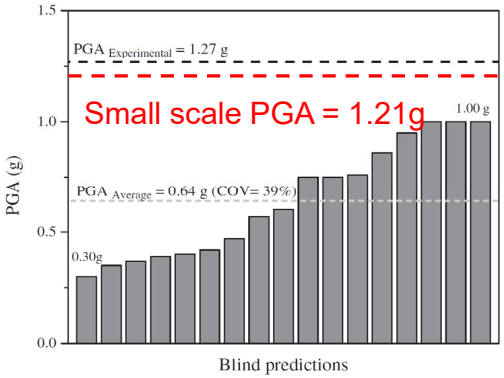
Physical modelling of masonry structures using a 3D printer



Del Giudice et al. 2023







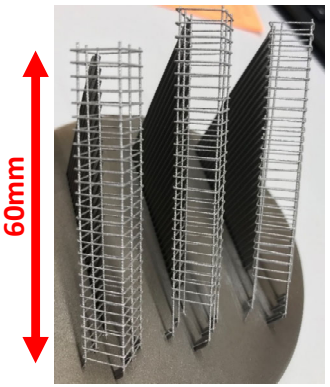
Physical modelling of RC structures using a 3D printer

Hand made specimens by geotechs

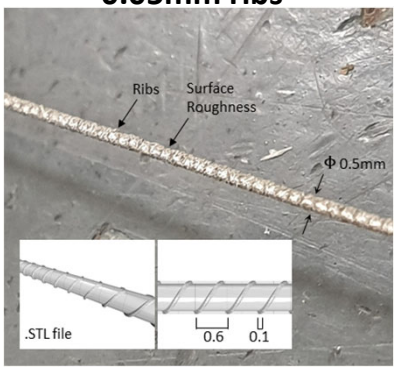


(*Loli et al. 2014*)

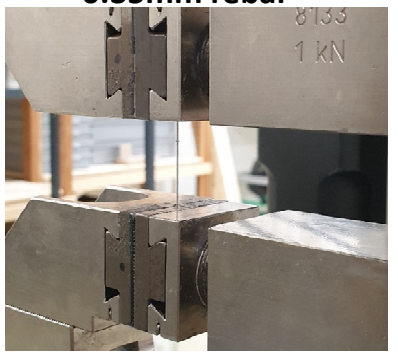
3D printed cages



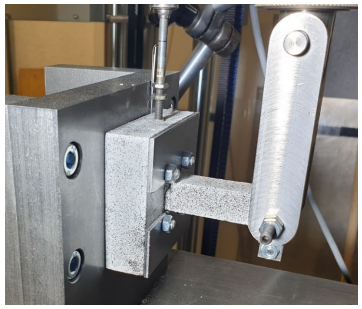
Φ0.5mm rebar with 0.05mm ribs



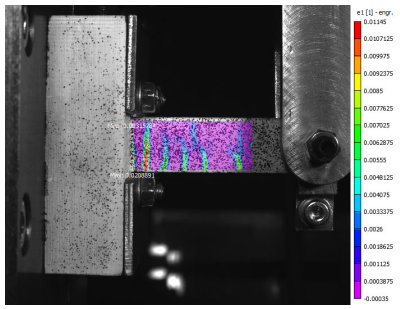
Tensile tests of 0.35mm rebar



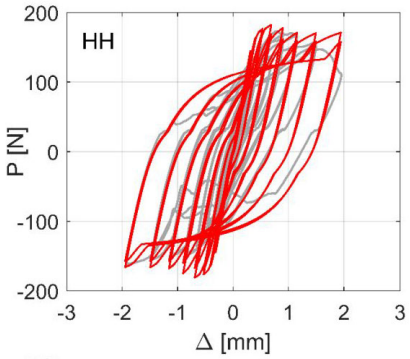
Cyclic loading 1:40 scale tests

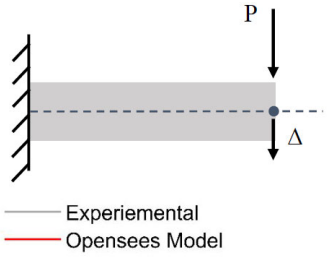


Strain field



Force deformation loops

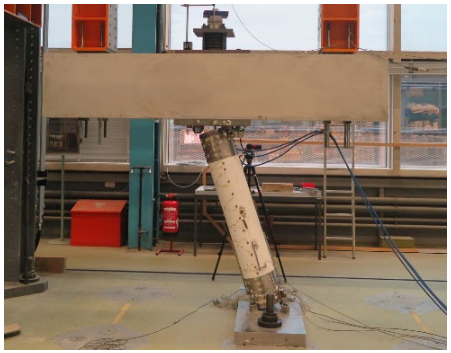




Del Giudice et al. (2021)
Elmorsy et al. (2023)

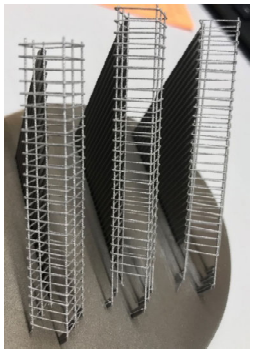
Current research directions

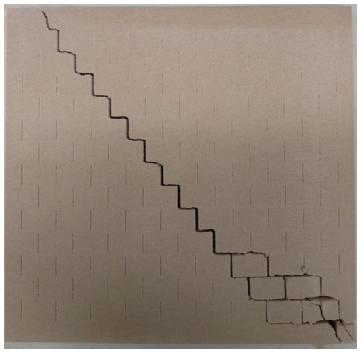
Rocking precast structures





Physical modelling of RC and Masonry structures using a 3D printer and a geotechnical centrifuge





Seismic design methods for low income countries

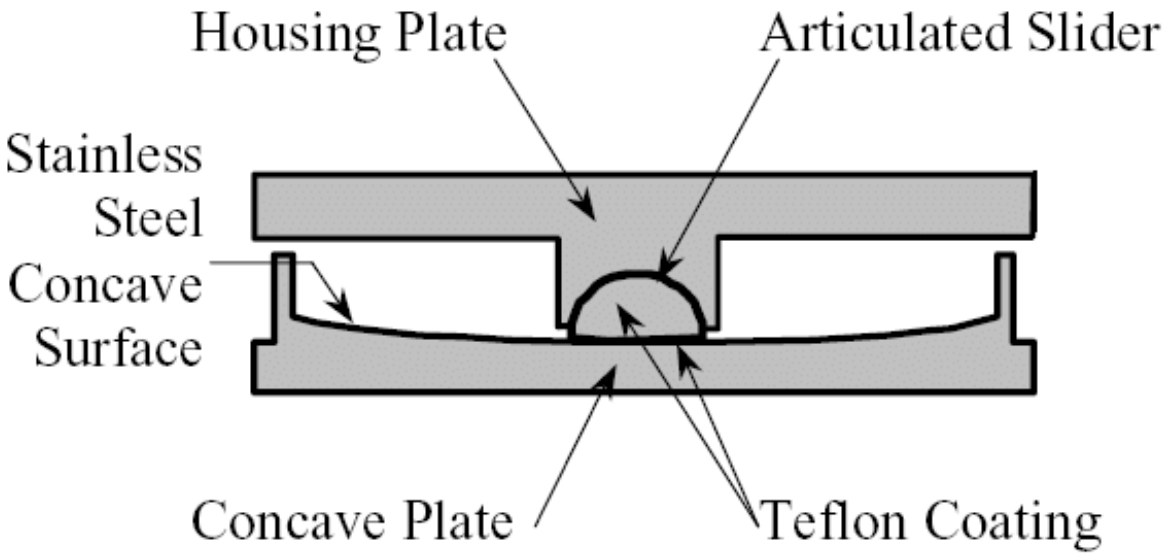




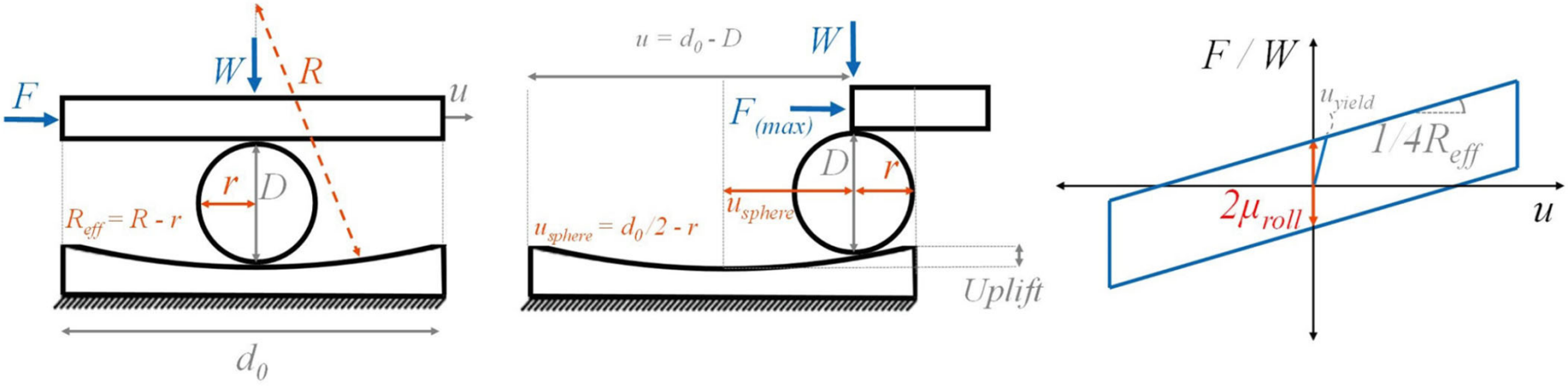
Genetically modified bamboo



FPS: Can we reduce its cost?



A low cost FPS



Make everything out of steel and it gets **heavy**, **expensive** and **with little energy dissipation**.

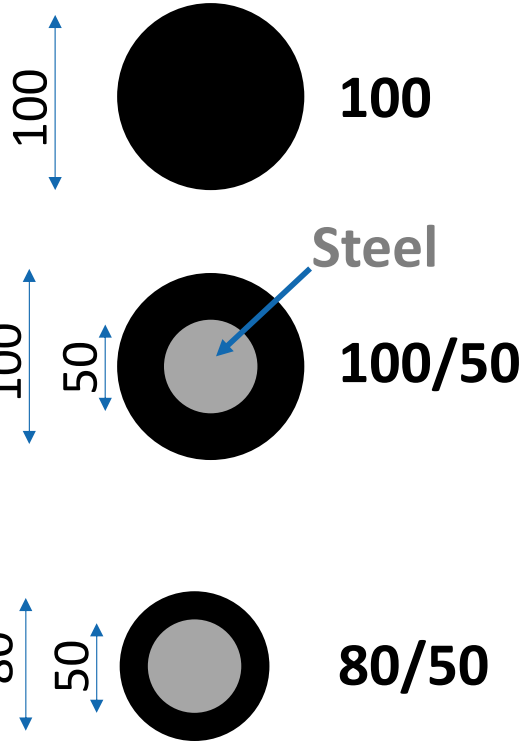
Cilsalar and Constantinou: Use a **rubber** sphere and roll on a **concrete** surface.

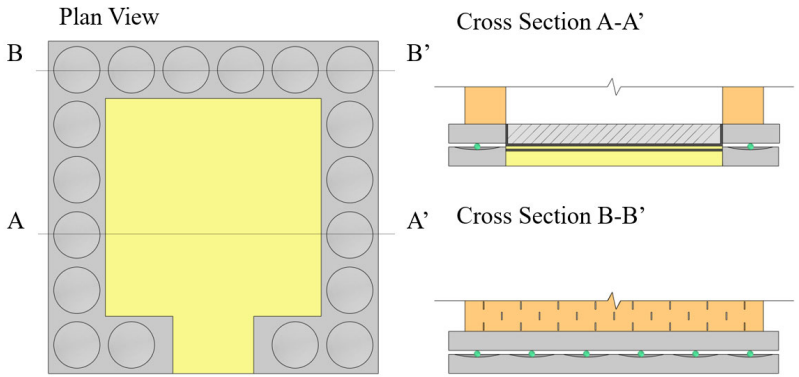


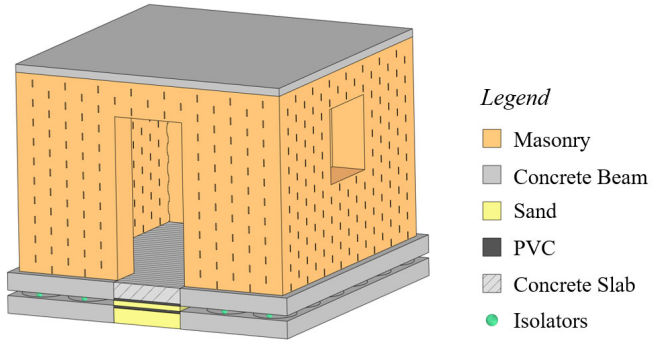
Cilsalar and Constantinou (2019)

Tests on polyurethane spheres

Polyurethane Shore 95A







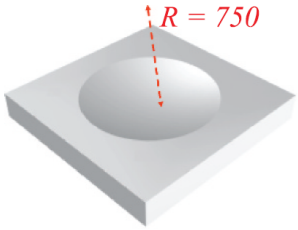
Design load around 11kN/m

Rolling tests

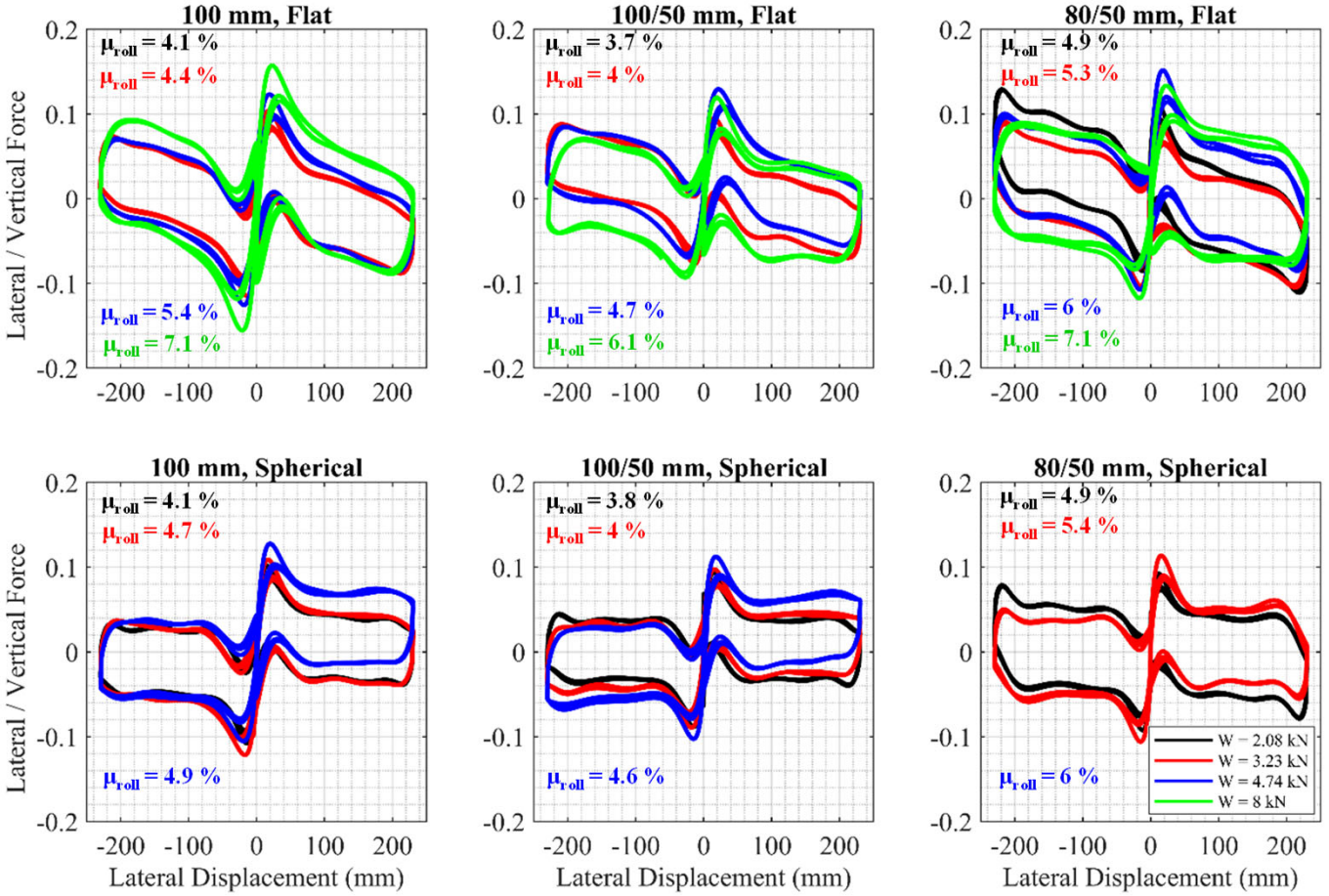
Flat bearing



Spherical bearing

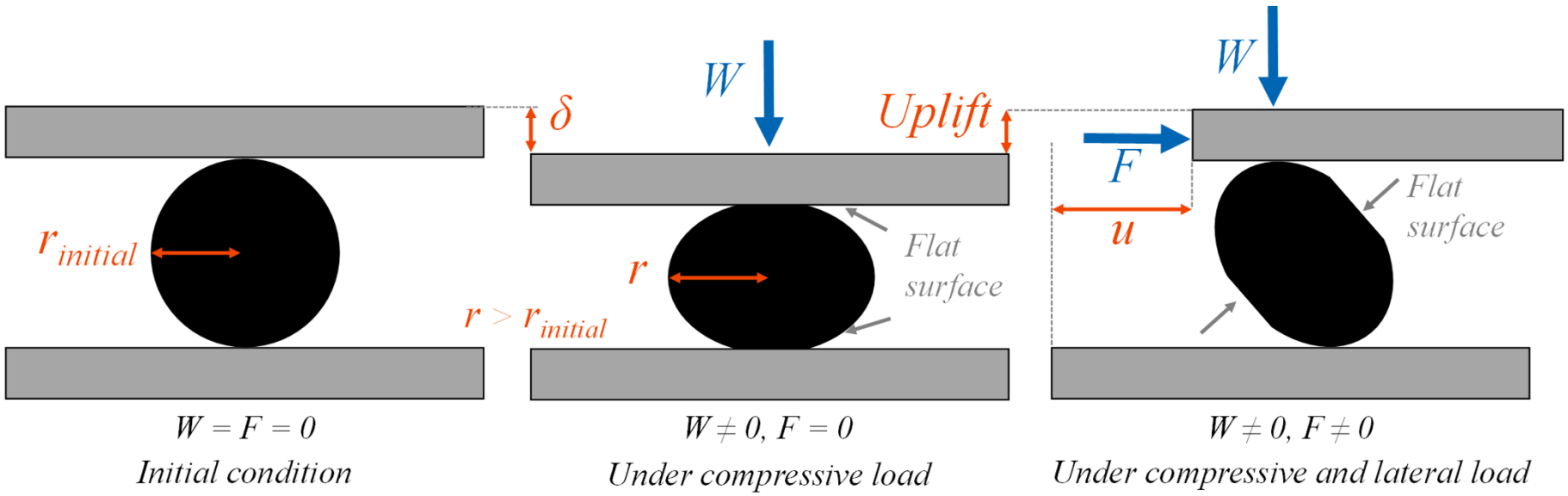


Scale 1:2 T=3.44 sec
Scale 1:1 T=4.87sec



Katsamakas et al. (2023)

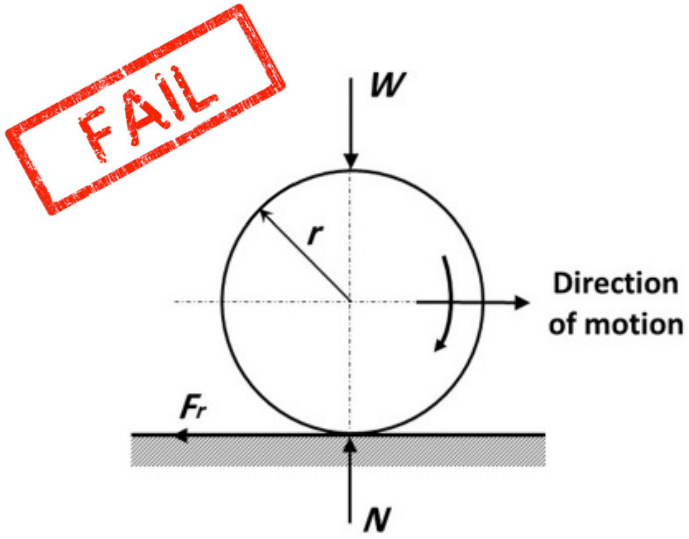
Why the deviation from the bilinear model?

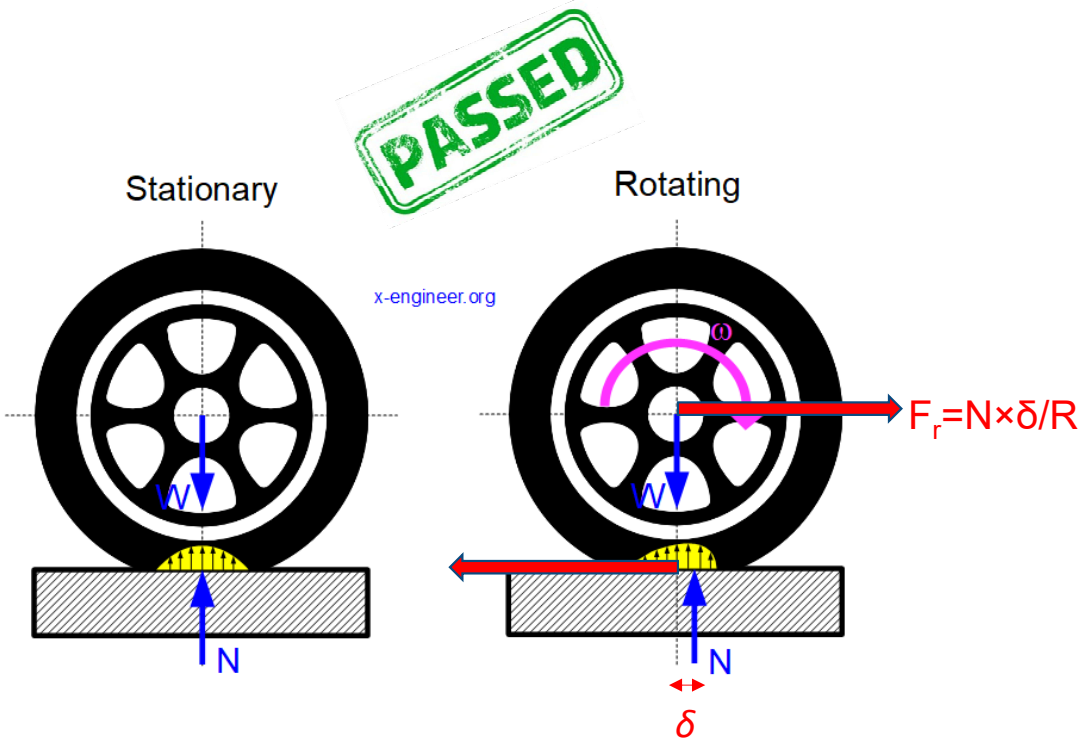


Start **Creep for 1 week** **Roll for a few seconds**

We are not rolling a ball. We are rolling an egg!

How is energy dissipated? What is the mechanism of friction?





1) Coefficient of "rolling friction" depends on δ. δ depends on the deformability of the ball and on the vertical load.

2) Energy is dissipated within the material; not at the interface. Hence it depends solely on the rolling ball material, not on the surface it is rolling.

Numerical modelling

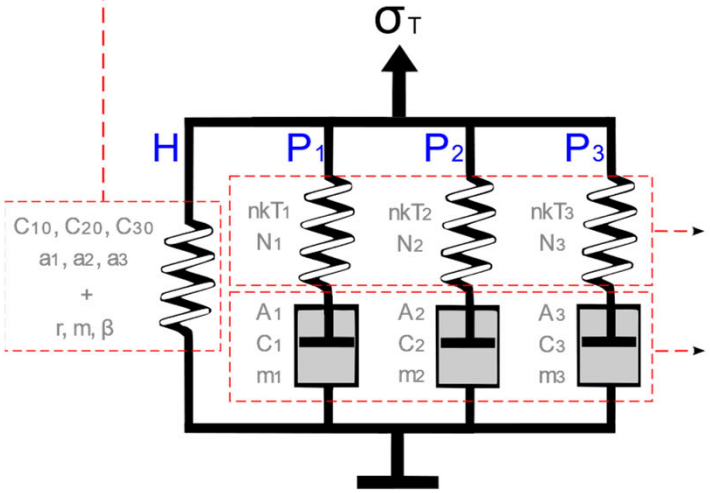
The model should capture:

1) Creep, to capture the change of shape. Creep should have a component that recovers and a component that does not recover (we have non recoverable creep in the tests)

2) Energy dissipation for the strain rates that rolling motion applies, to capture the energy dissipation during rolling

The above evolve in different time scales. Any attempt to use a **single dashpot is doomed**.

Generalized Yeoh + Mullins:



$$W'_{dev} = \eta \cdot W_{dev} + \phi(\eta)$$

$$W_{dev}^{Gen-Yeoh} = C_{10}(I_1 - 3)^{a_1} + C_{20}(I_1 - 3)^{a_2} + C_{30}(I_1 - 3)^{a_3}$$

$$\eta = 1 - \frac{1}{r} erf\left(\frac{\max(W_{dev}) - W_{dev}}{m + \beta \max(W_{dev})}\right)$$

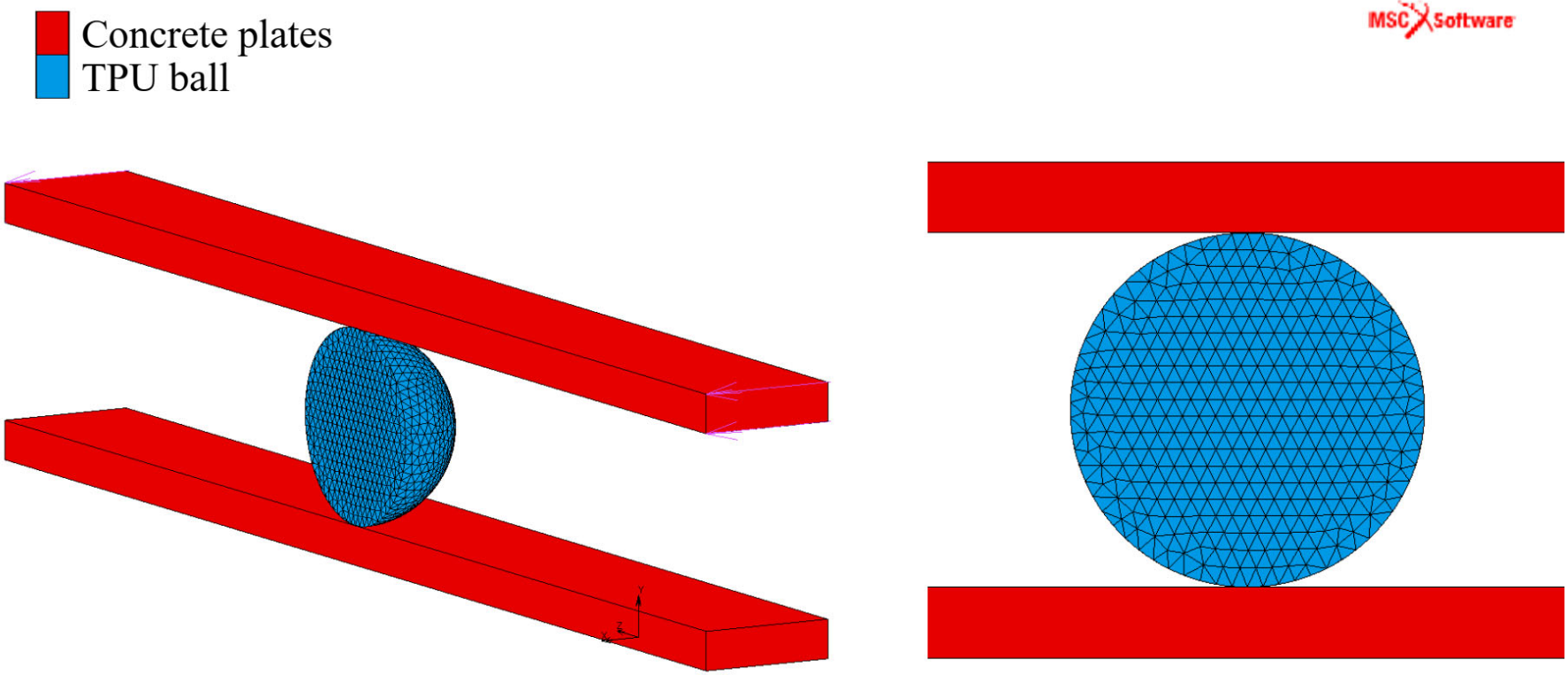
$$W_{dev} = nkT\left[\frac{1}{2}(I_1 - 3) + \frac{1}{20N}(I_1^2 - 9) + \frac{12}{1050N^2}(I_1^3 - 27) + \frac{19}{7000N^3}(I_1^4 - 81) + \frac{519}{673750N^4}(I_1^5 - 243)\right]$$

$$\tilde{L}^v = A\left[\lambda_{chain} - 1 + \xi\right]^C (\tau)^m N_{P_i}$$

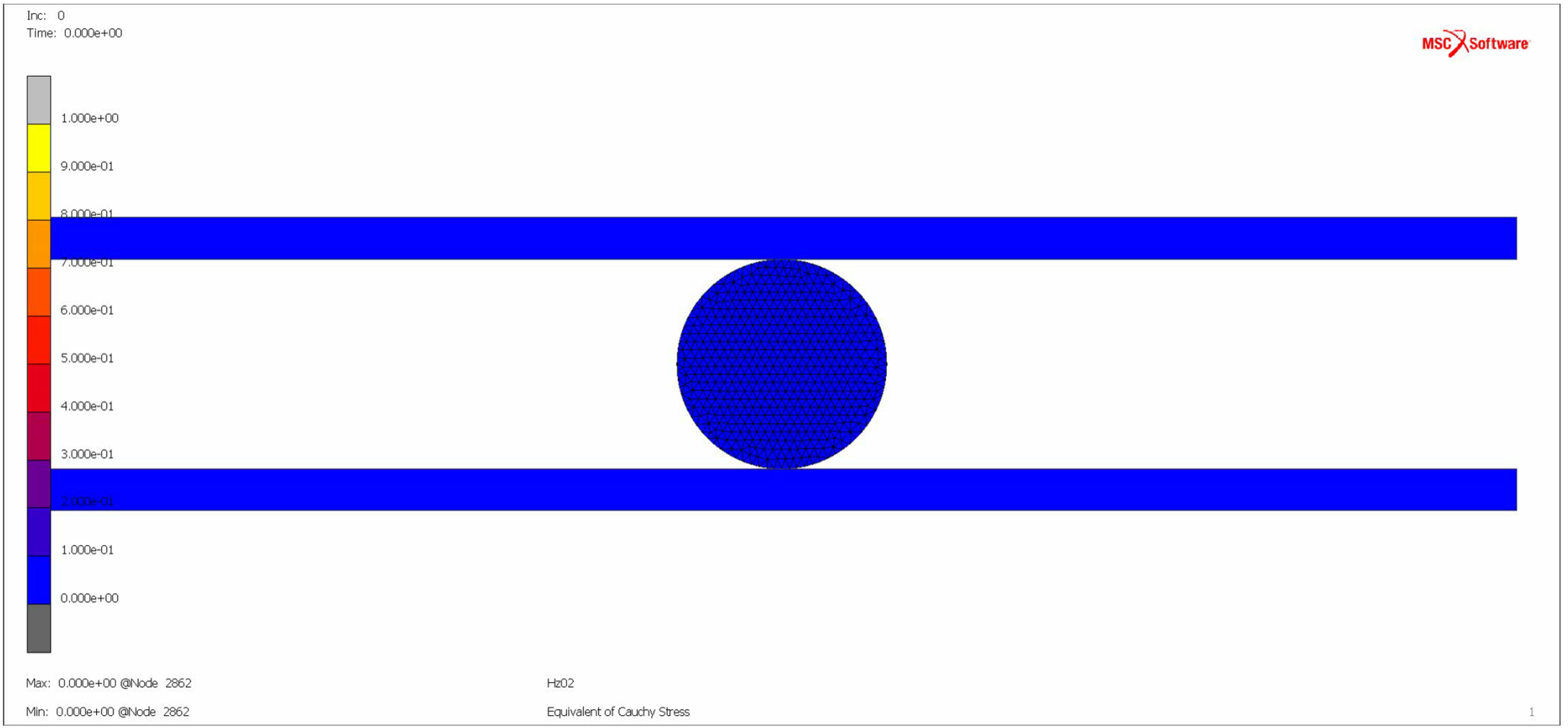
(24 parameters)

Reyes et al. (2023)

Validation on a rolling ball made of solid rubber

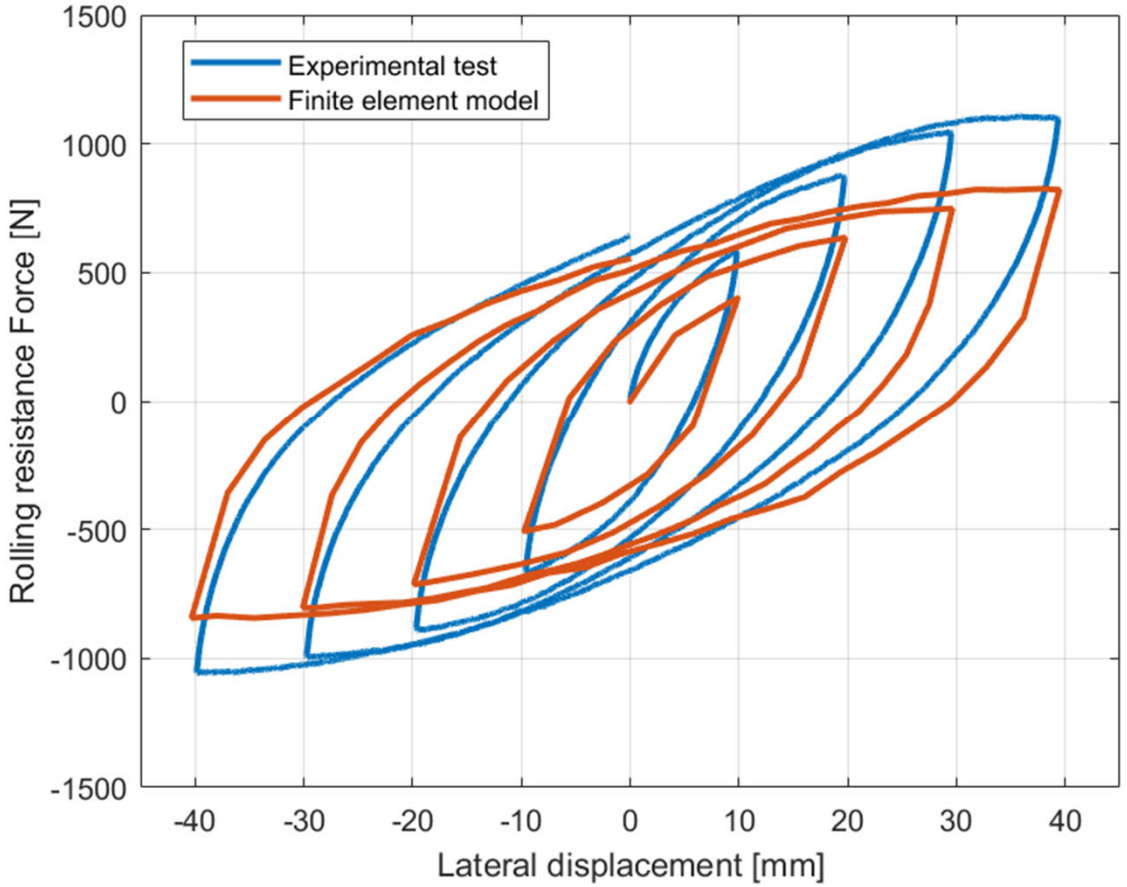


Validation on a rolling ball made of solid rubber



ETH zürich

Rolling simulation validation: Good but not perfect



By calibration only on tensile, compressive and volumetric tests.

Only a Universal Testing Machine needed!

Tennis balls filled with grout

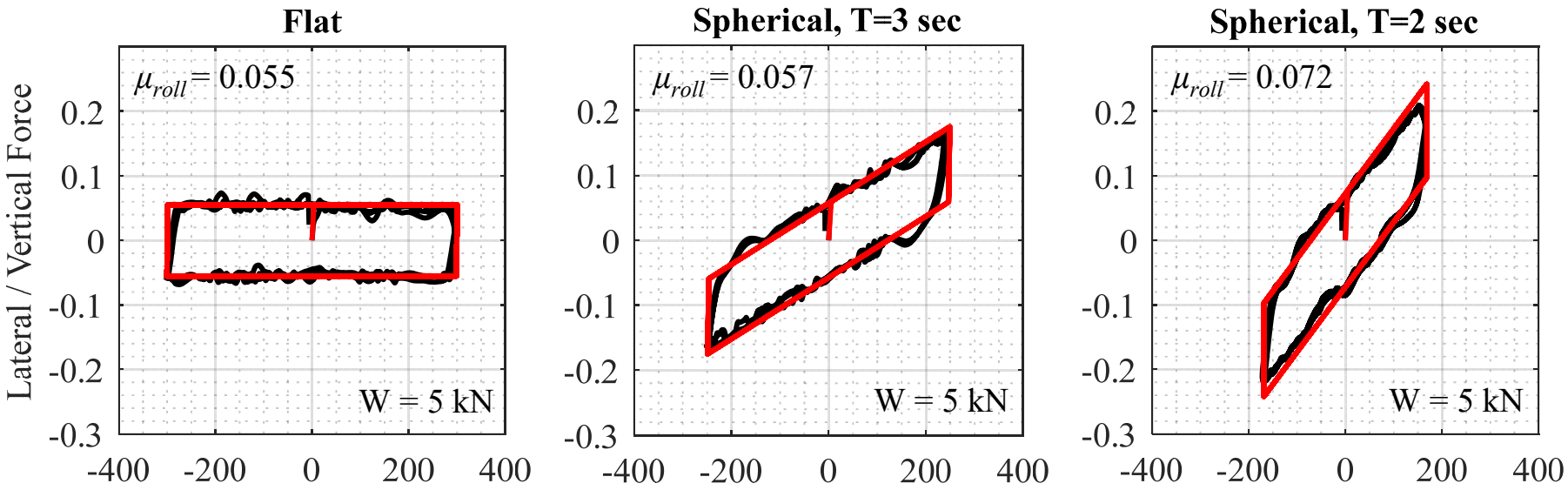




Diameter: **65mm**
Rubber layer thickness: **3.5mm**
Vertical capacity: around 30kN

Katsamakas et al. (2021, 2023)

Tennis balls filled with grout



Tests in PUC Chile





Thank you for your attention!!!