HAND ARM VIBRATION
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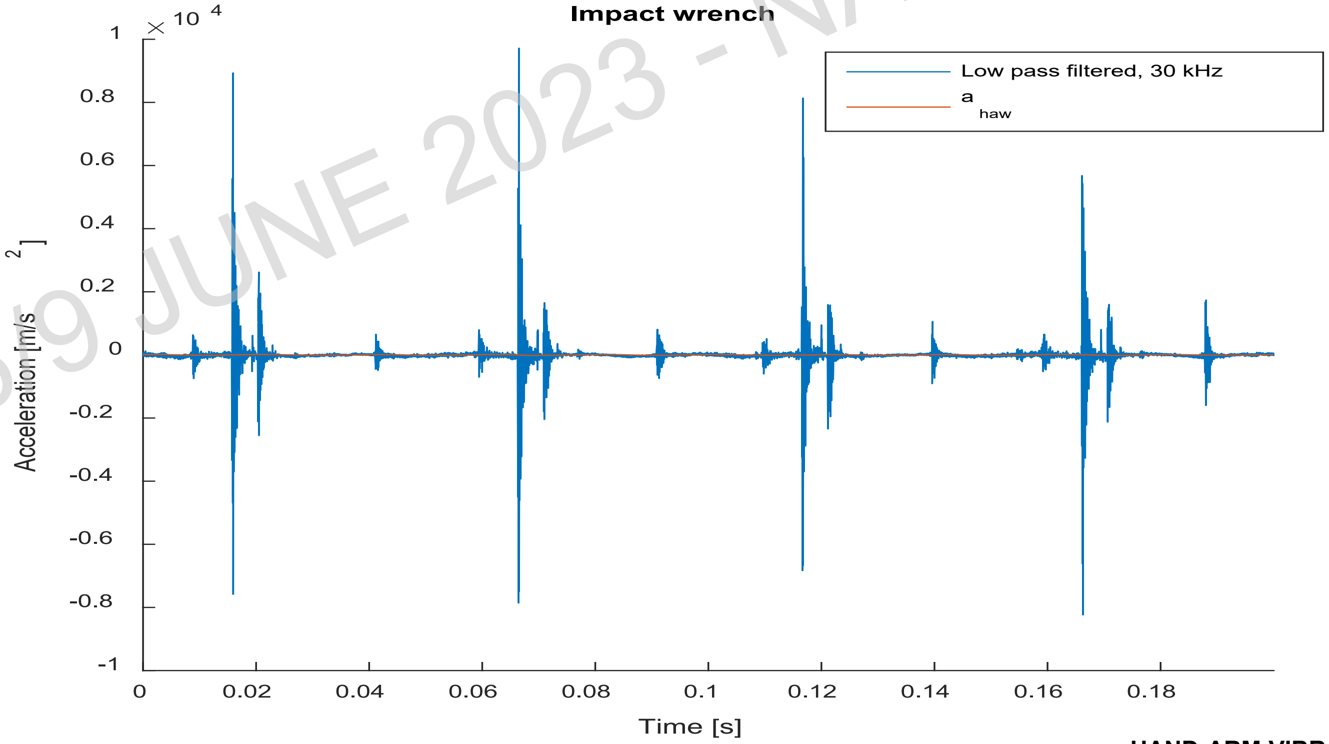
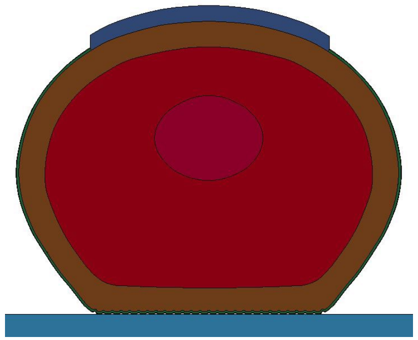
Fingertip Model for Analysis of High-Frequency Vibrations

Hans Lindell, RISE Research Institutes of Sweden

Background

- High frequency and high amplitude shock vibration from e.g. impact wrenches is since long suspected to cause vibration injuries and that the risk is underestimated in ISO5349-1.
- The objective is to increase the understanding of vibration propagation into finger tissue.





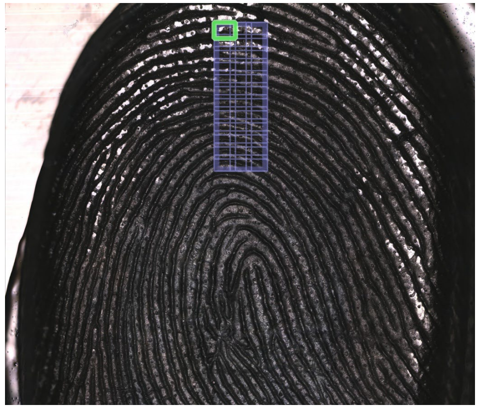
Research questions

- How are shock vibration being transmitted into the finger tissue?
- To what extent does the skin reduce the transmissibility?
- How is the pressure varying in the finger tissue?

Method

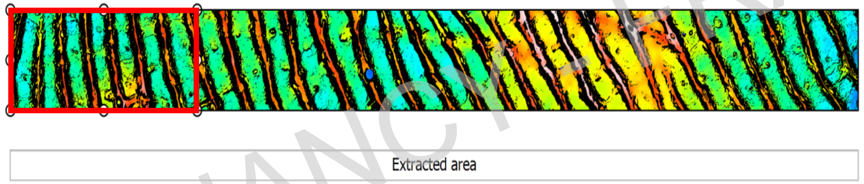
- Create a 2D FE model of a finger
- Design a test rig where representative shock vibration can be measured and used as input to the model
- Validate the FE model with experiments on finger

Modelling the fingerprint geometry

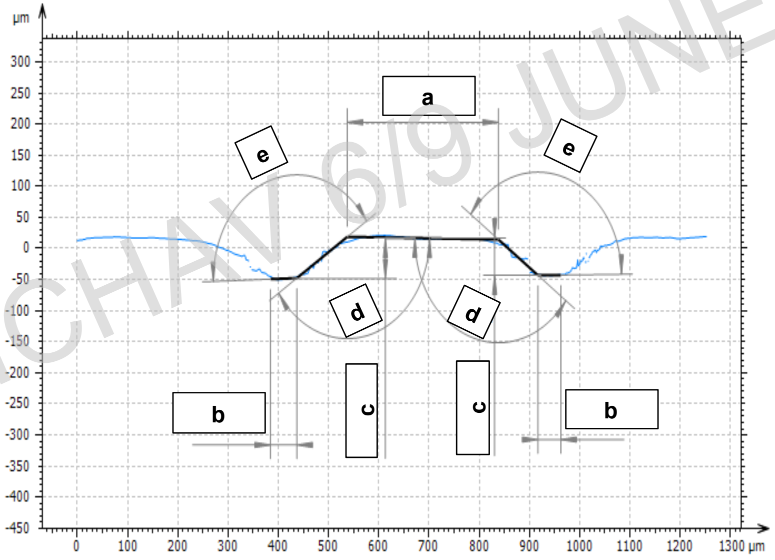


Epoxy mold, 5 N pressure

Confocal microscopy



Extract area



Outside finger

Inside finger

Finger print parameters

a = 0.22 mm ± 0.04 mm

b = 0.06 mm ± 0.02 mm

c = 0.06 mm ± 0.01 mm

d = 133° ± 12°

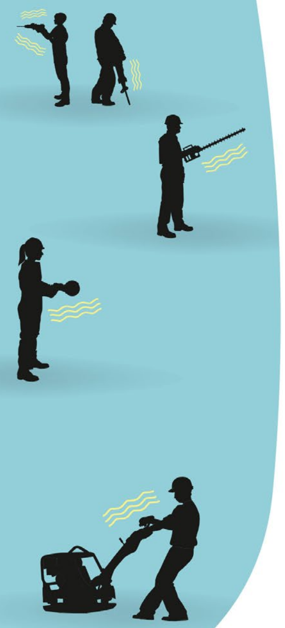
e = 132 ° ± 14 °

Material data found in literature varies greatly
- Especially for the skin

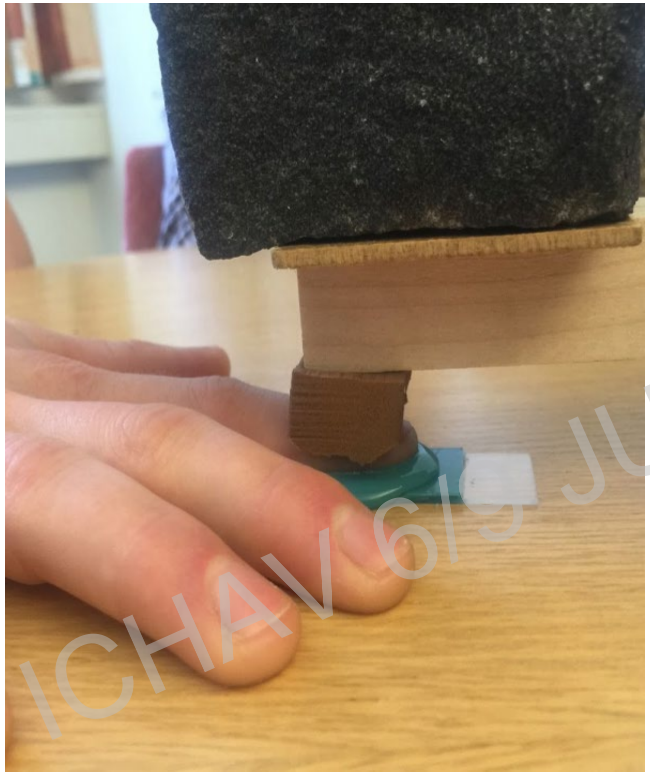
Material	Shear Modulus	Bulk Modulus
Soft Tissue Finger	0.0017 MPa - 0.017 MPa	2190 MPa
Epidermis	0.021 MPa – 0.2 MPa	2190 MPa
Stratum Corneum	0.600 MPa – 10 MPa	2190 MPa

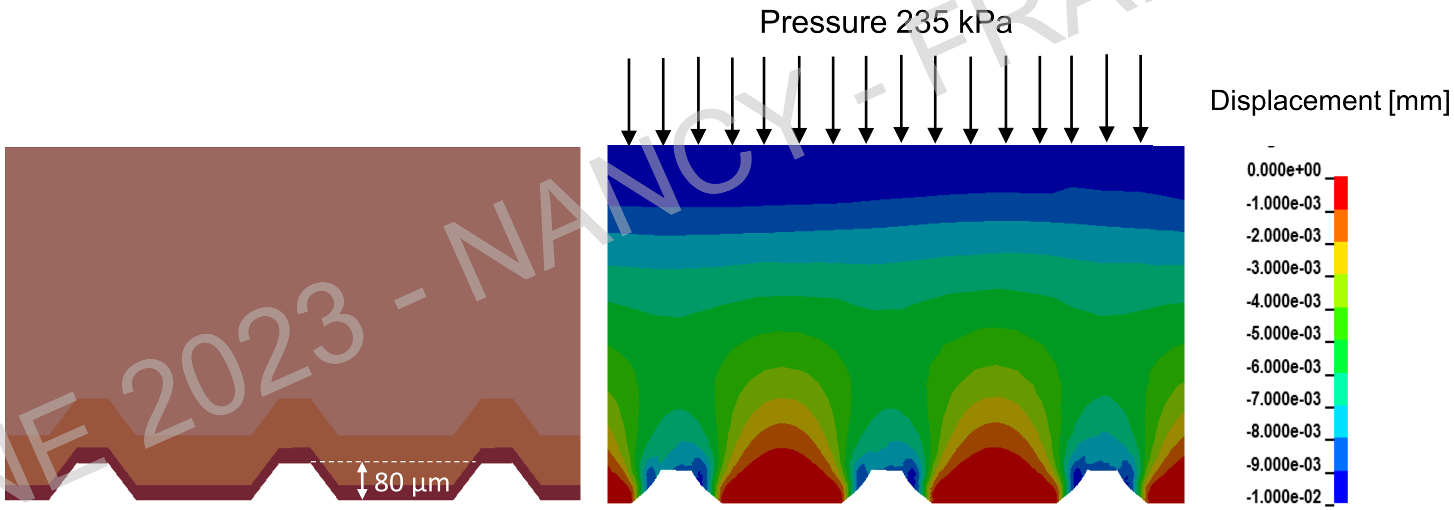
Material data + geometric data sources:

- M. Gerling: A literature review of the mechanical behavior of the stratum corneum, the living epidermis and the subcutaneous fat tissue. Technical note PR-TN 2006/00450, Philips Research Europe, 2006
- F. M. Hendriks: Mechanical Behavior of Human Skin in Vivo. A Literature Review. Report 2001/820, Philips Electronics, 2001
- M. F. Leyva-Mendvil, A. Page, N.W. Bressloff , G. Limbert: A mechanistic insight into the mechanical role of the stratum corneum during stretching and compression of the skin. J. of the Mech. Behavior of biomedical materials. 49 (2015), 197-219.
- M. Gerling: In vitro mechanical characterization of human skin layers: stratum corneum, epidermis and hypodermis, Dissertation, Technical University Eindhoven, 2006
- Stephanie Marchesseau, T. Heimann, S. Chatelin, R. Willinger, Herve Delingette. Fast porous visco-hyperelastic soft tissue model for surgery simulation: Application to liver surgery. Progress in Biophysics and Molecular Biology, Elsevier, 2010, 103 (2-3), pp.185-196.



Measurement of skin pattern deformation from varying load - FE model material data was tuned to experimental results

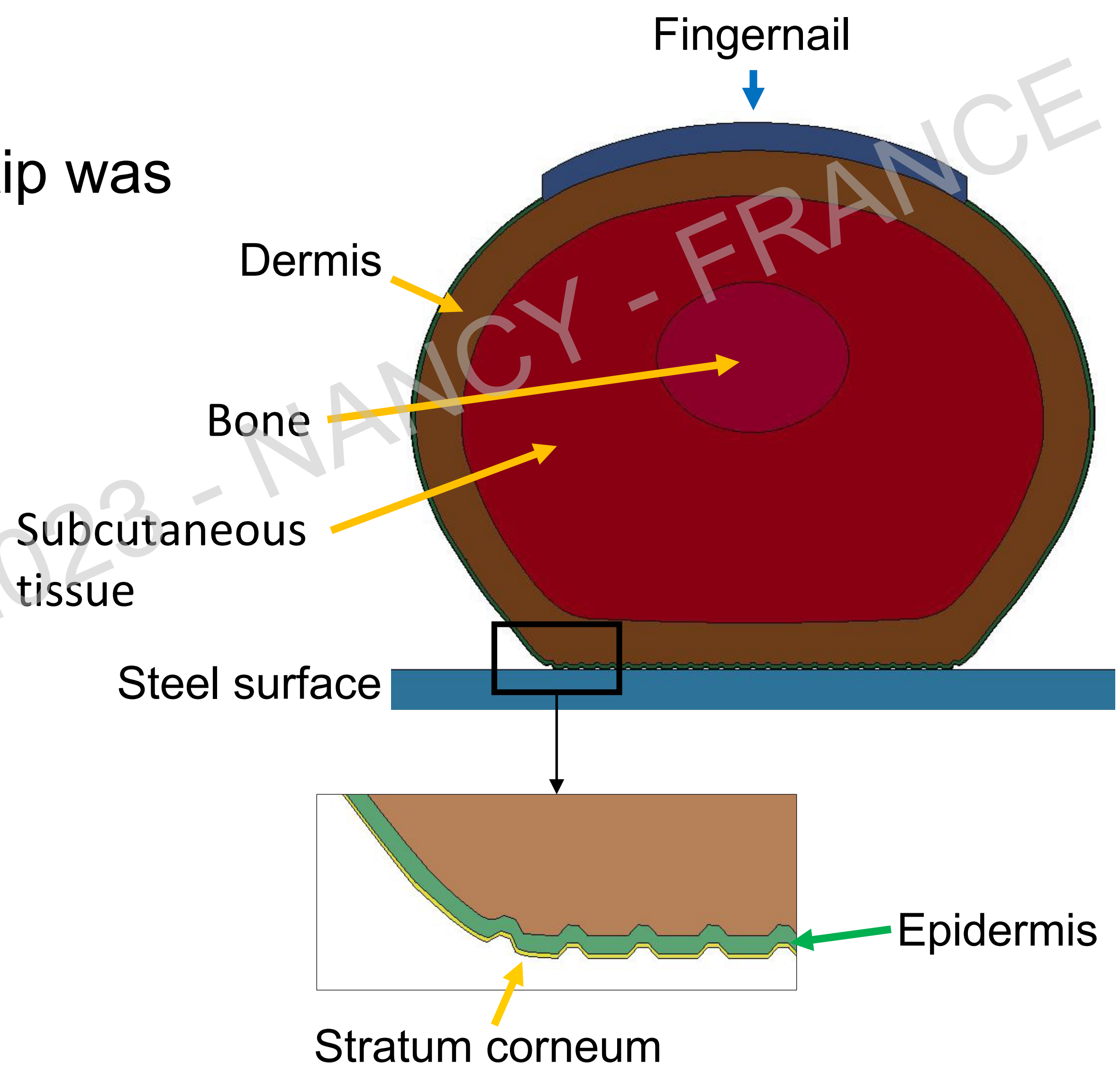




Unloaded geometry of the fingerprint (left) and numerical validation of the fingerprint distortion under constant pressure loading (right)

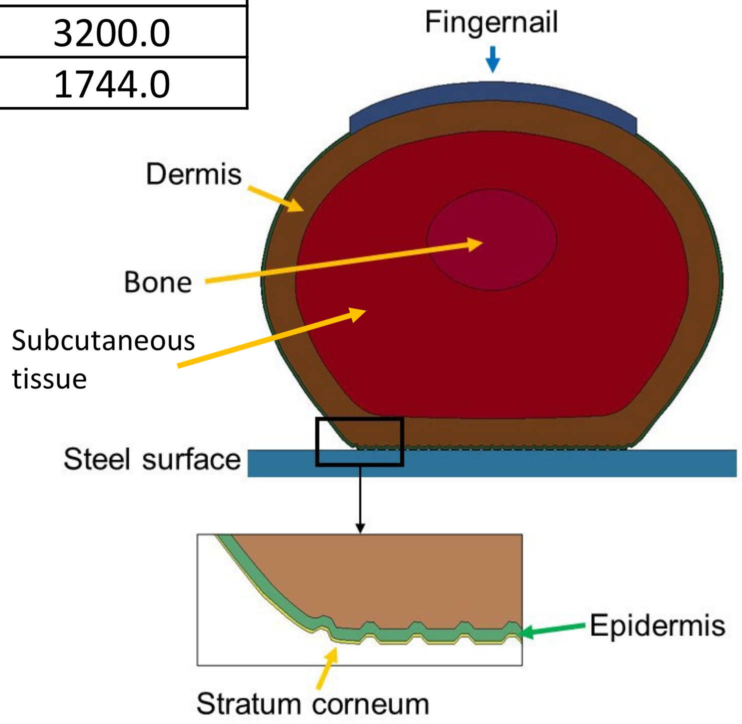
The model

- The cross-section of the fingertip was modelled in 2D
- The model is split into:
  - Stratum corneum
  - Epidermis
  - Dermis
  - Subcutaneous tissue
  - Bone
  - Fingernail
  - Vibrating steel surface



Material data used

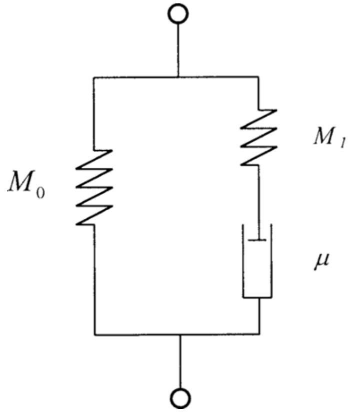
Component	Density [g/cm³]	Bulk-Modulus [MPa]	Shear-Modulus [MPa]	Sound speed [m/s]
Stratum Corneum	1.04	2259.0	3.100	1500.0
Epidermis	1.04	2259.0	0.210	1500.0
Dermis	1.04	2259.0	0.080	1500.0
Subcutaneous Tissue	1.00	2161.0	0.034	1470.0
Bone	1.96	20070.0	7719.0	3200.0
Nail (@RH55%)	1.33	1933.0	290.0	1744.0



The model

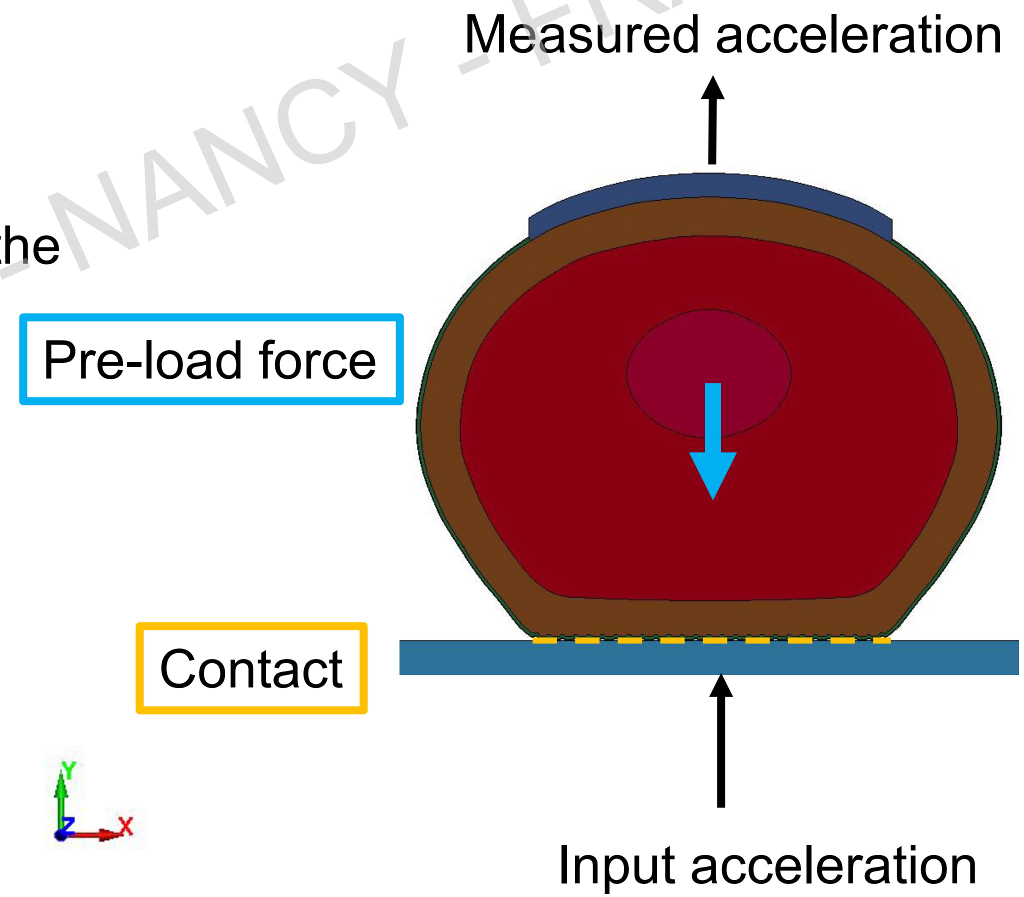
- The model has 63500, 2D plain strain elements
  - Element size varies from 0.01-0.08 mm.
- Response of skin layers is time and history dependent
  - Viscoelastic constitutive model
  - Exponential stress relaxation functions
  - Zener model with spring and spring-damper element in parallel

$$G(t) = G_{\infty} + (G_0 - G_{\infty})e^{-\beta t}$$



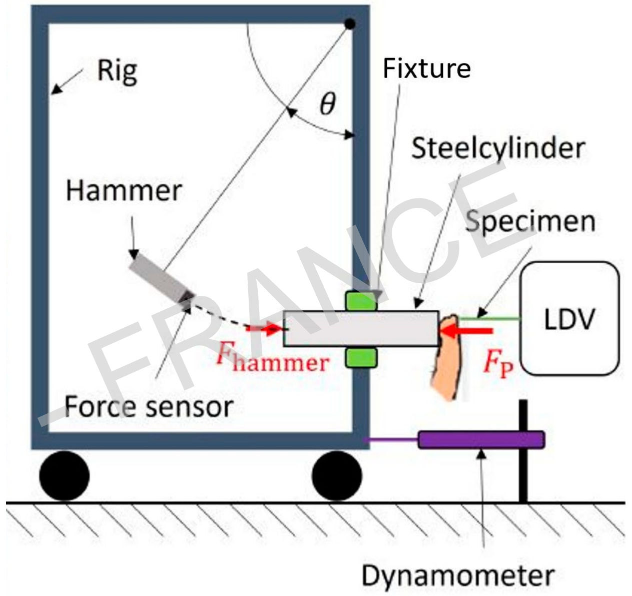
FE numerical aspects

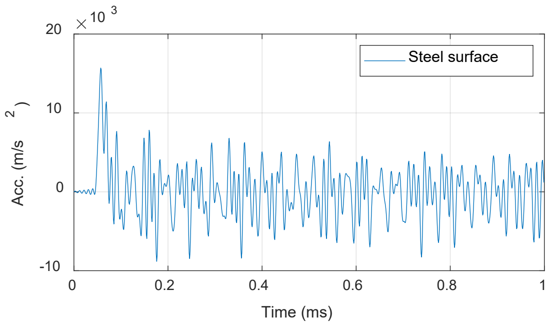
- LS-Dyna was used for simulations
- Two step simulation with different numerical schemes
   1. Static phase were pre-load is applied to the bone.
      - Implicit time integration used
   2. Transient phase were the steel surface vibrates
      - Explicit time integration used

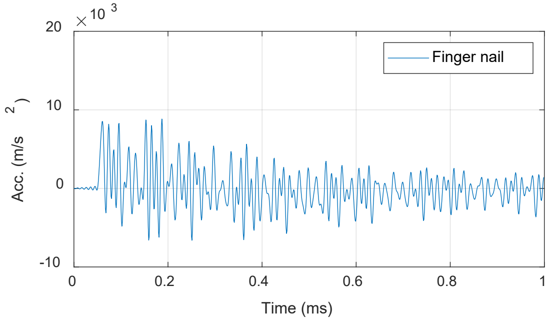


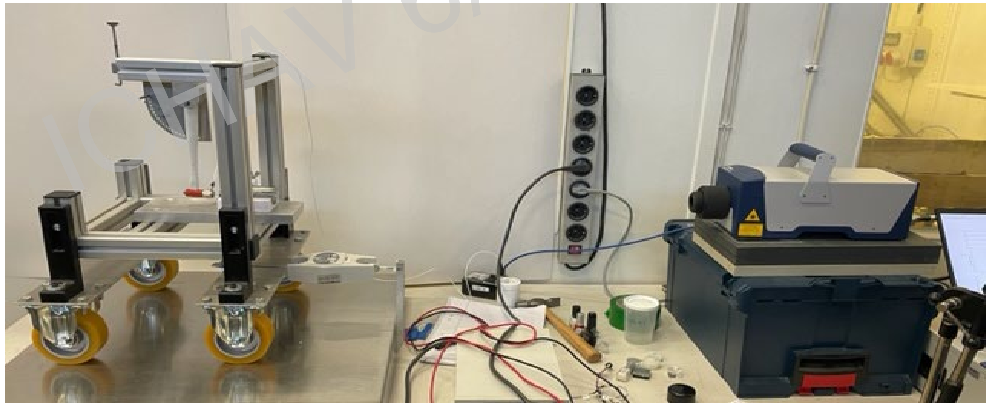
Experimental validation

- An impact rig was designed to generate pulses with high repeatability
  - The hammer is released from a fixed height.
  - Hits a steel cylinder resulting in a high amplitude transient, 17 km/s^2
  - Fingertip pressed against the steel cylinder
  - The finger force is measured
- The acceleration was measured up to 100 kHz with a laser doppler vibrometer:
  1. On the steel surface
  2. On the fingernail

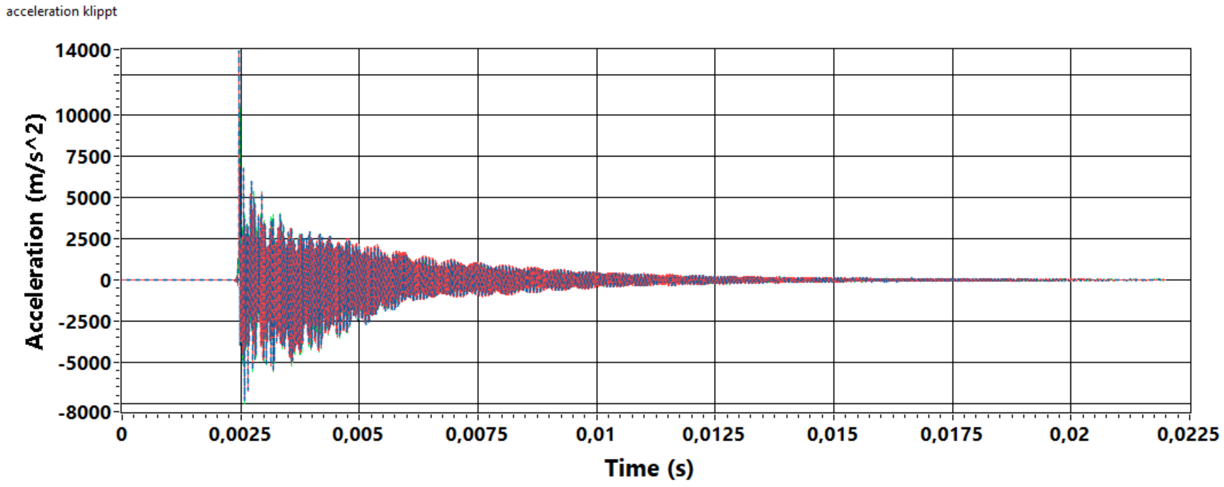


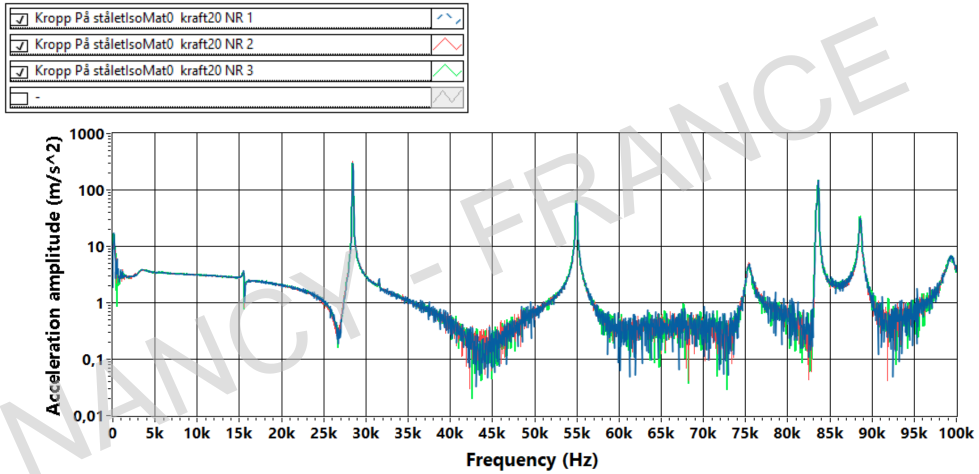


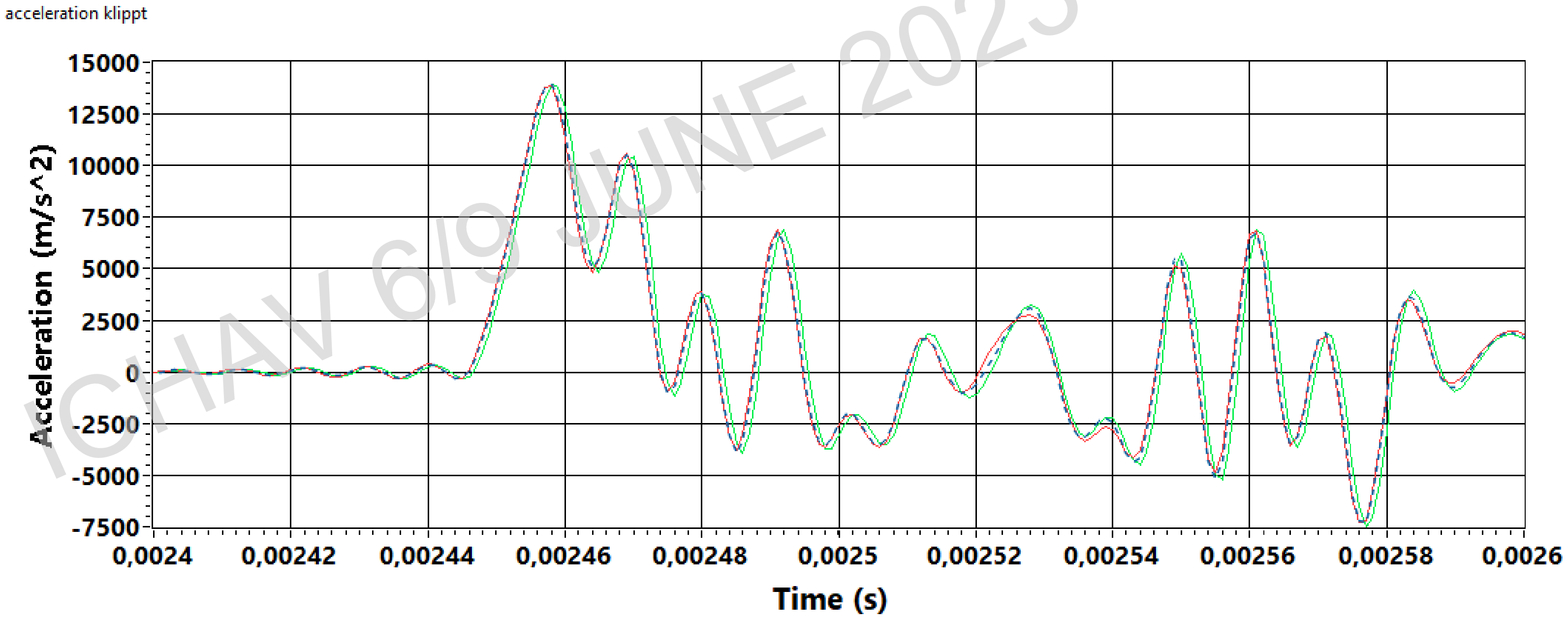


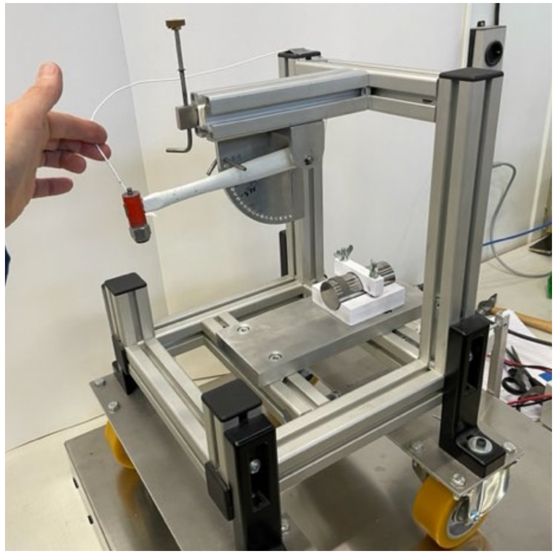


High repetability of shock from test rig









High repetability of shock

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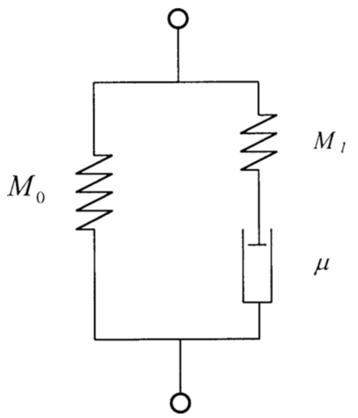
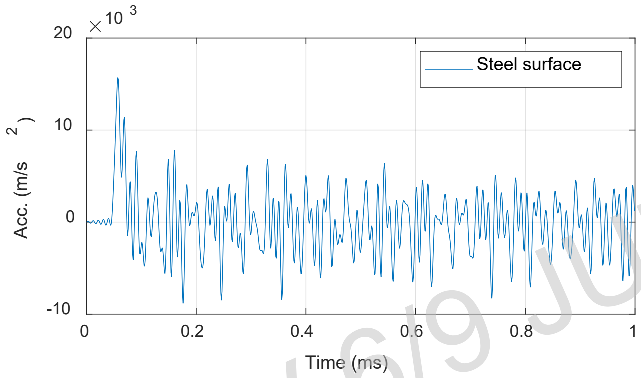
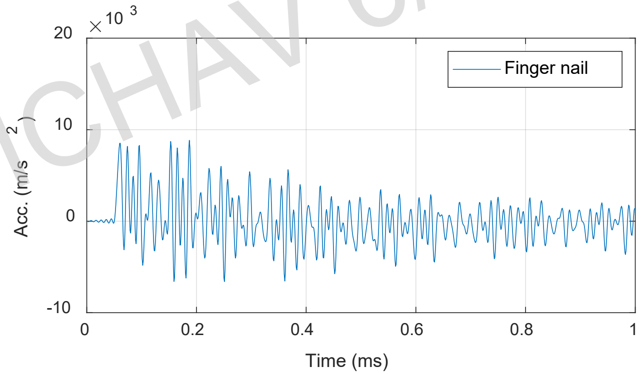


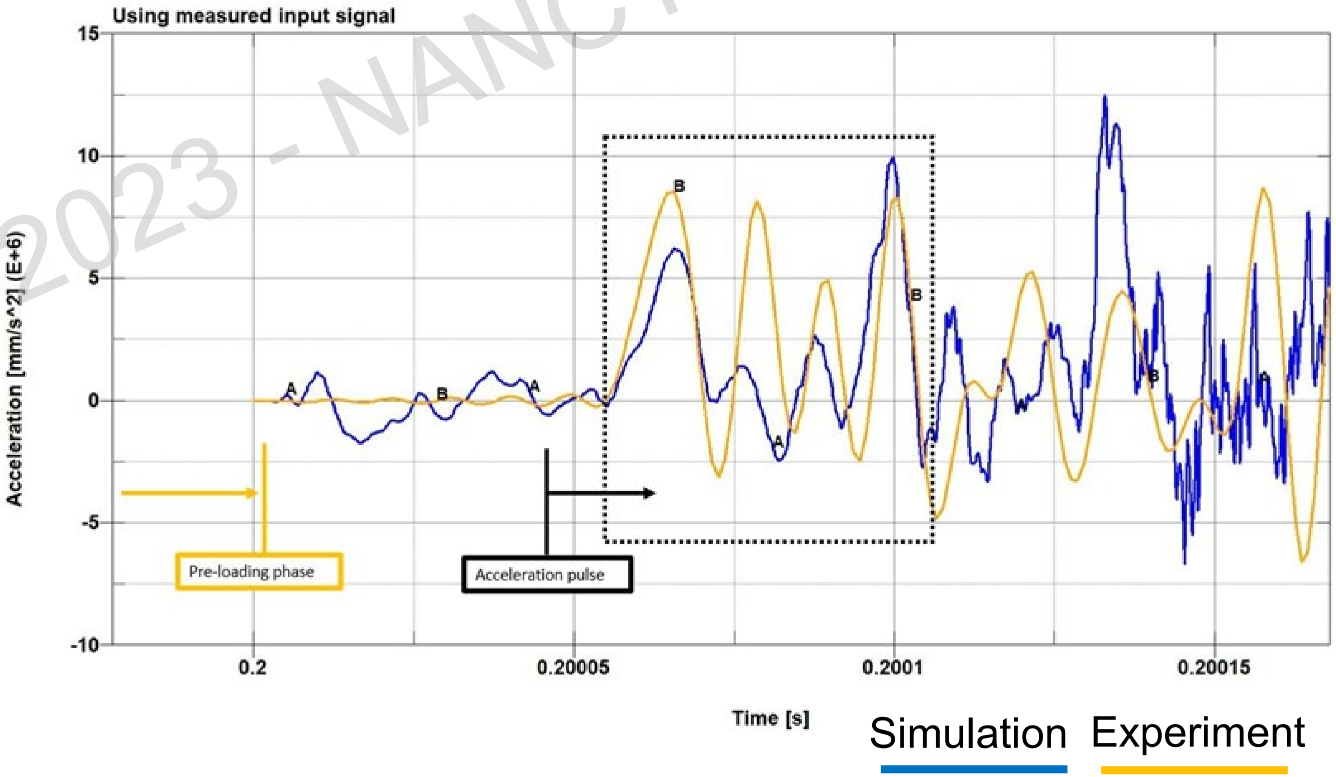
Results – Acceleration

- Acceleration on finger nail
  - Numerical noise prior to acceleration pulse
  - Fairly good correlation for first peaks
  - The amplitude is reduced approx. 50% to the finger nail

Acceleration on fingernail

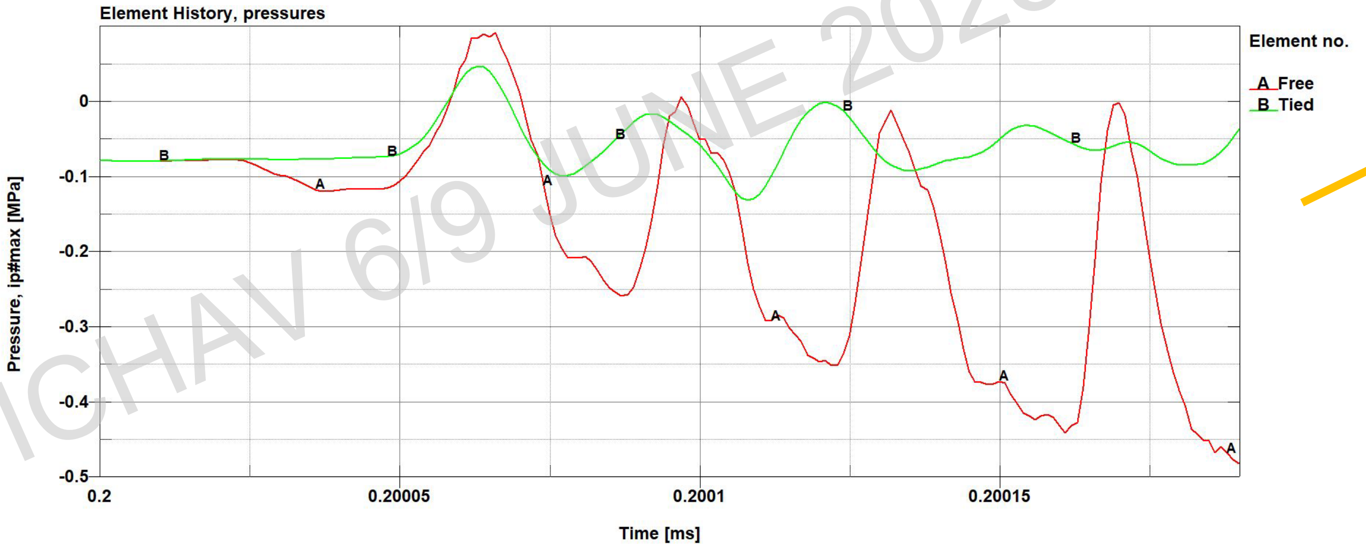


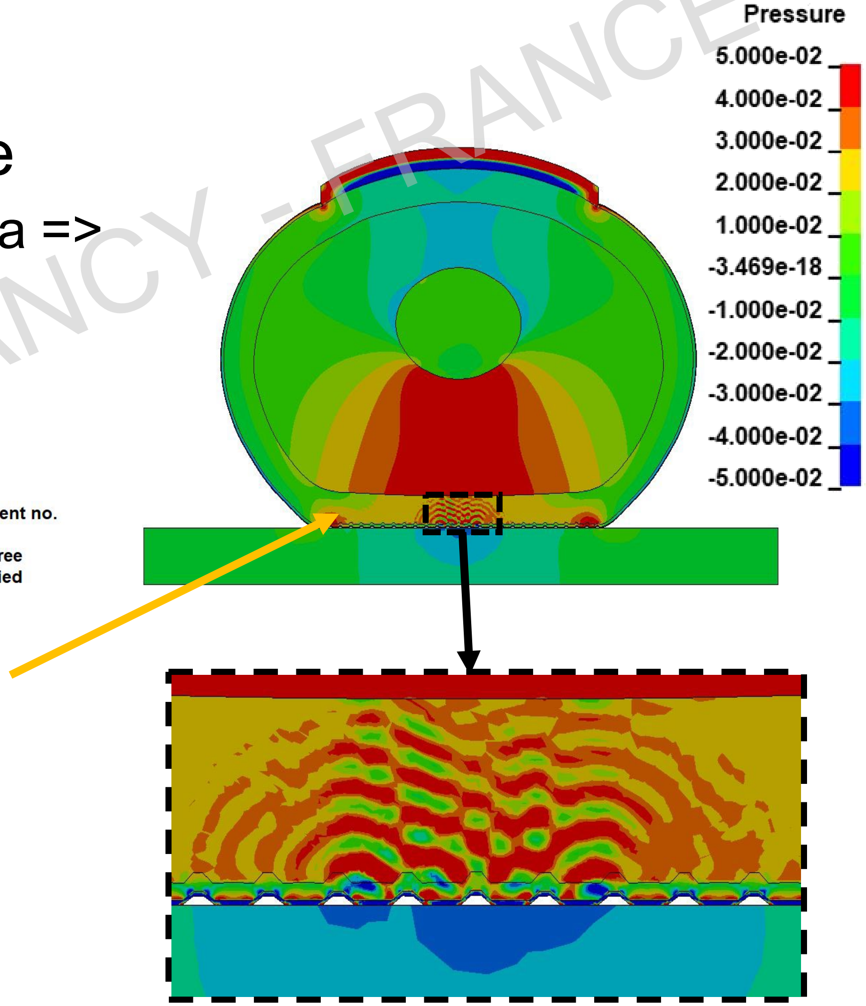




Results – Pressure

- High varying pressure amplitude in the tissue
  - Negative pressures close to -1 Bar in the skin area => Cavitation in tissue can occur





Conclusions

- The model yields first order correspondence with experiment
- Large pressure variations within finger tissue
  - Negative pressure around 1 Bar => Risk for cavitation
- The skin surface has a minor effect on reducing the propagation of the vibration
- Material model and data could be improved
- Results indicate need for deeper knowledge of injury processes

Further validation could be achieved by measuring the pressure in tissue with fibre sensor pressure transducer