# *European*

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## Mesh and orientation dependance of FE models for dynamic simulations.

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# Influence of mesh density on a finite element model under dynamic loading

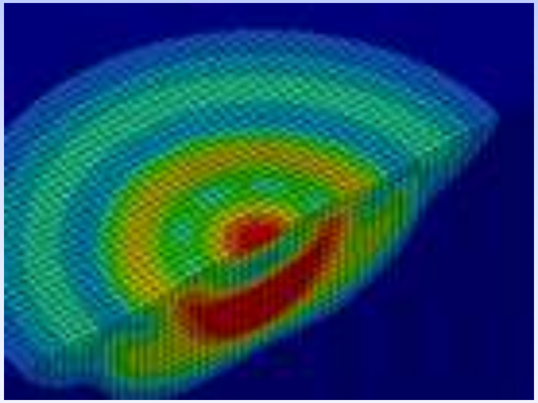
1. Introduction
2. Theoretical point of view
3. Simulations with different mesh density
4. Discussion and Conclusion

# Introduction

**Development of computer science**

**Use of numerical simulations (Finite Element Analysis) for physical problems**

Investigation of mechanical parameters at a local level



**Civil Engineering**

**Crash simulation**

**Biomechanics**

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# Introduction

**Dynamic simulations: Impact or wave propagation**

**Results of simulations are influenced by:**

**Mesh discretization**

**Material properties**

**Numerical dispersion**

**Spurious waves**

**Precision of the analysis**

**Stability of the analysis**

**Validity of the analysis**

# Theoretical point of view

**Dynamic FE codes (Altair Radioss) with explicit integration methods such as Central Difference Method (CDM)**

Numerical Statibility is assumed by the Courant Number (Hourglass Energy)

$$C = \frac{c.\Delta t_{\max}}{\Delta x} \leq 1$$

the distance traveled by the fastest wave in the model ($c.\Delta t_{\max}$) should be smaller than the characteristic element size ($\Delta x$) in the mesh

# Theoretical point of view

**Courant's condition**

**Validity of the analysis**

**Even if the simulation is valid, there are numerical errors**

**Mesh size and resulting wave propagation lead to different results for the same simulation**

*(Belytschko et al. 2000, Bazant et al. 1978)*

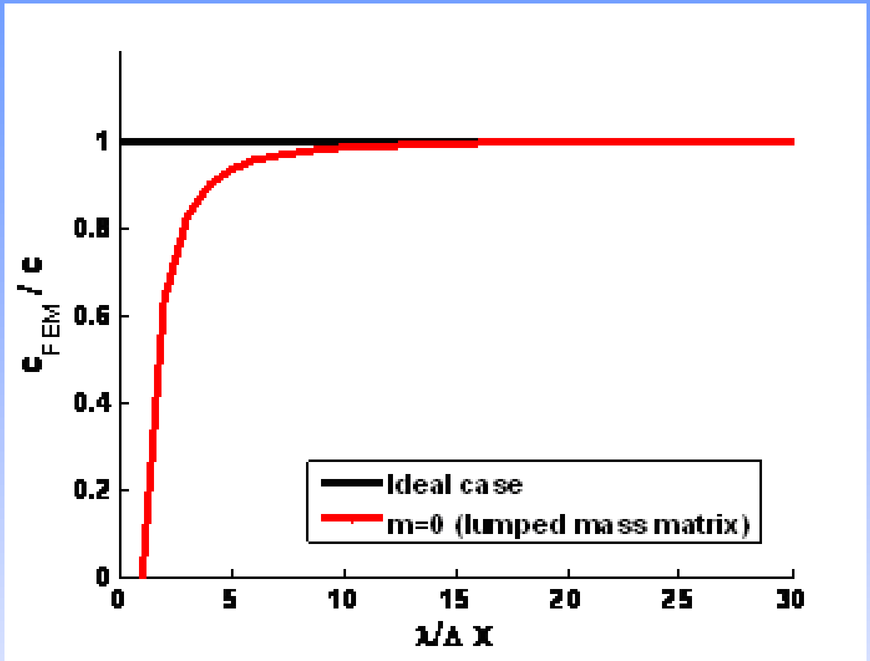
# Theoretical point of view

*Ratio between theoretical and numerical wave velocity*

$$\frac{c_{FEM}}{c} = \frac{2}{\Phi}\left[\left(\sin\frac{\Phi}{2}\right)^{-2} - \frac{2}{3}m\right]^{-1/2}$$

$$\Phi = \frac{\omega\Delta x}{c} = \frac{2\pi\Delta x}{\lambda}$$

*Bazant et al. 1978*



For one dimensional simulation : $\frac{c_{FEM}}{c} = 99\%$ for $\frac{\lambda}{\Delta x} \sim 16$

Numerical error due to the number of element per wavelength

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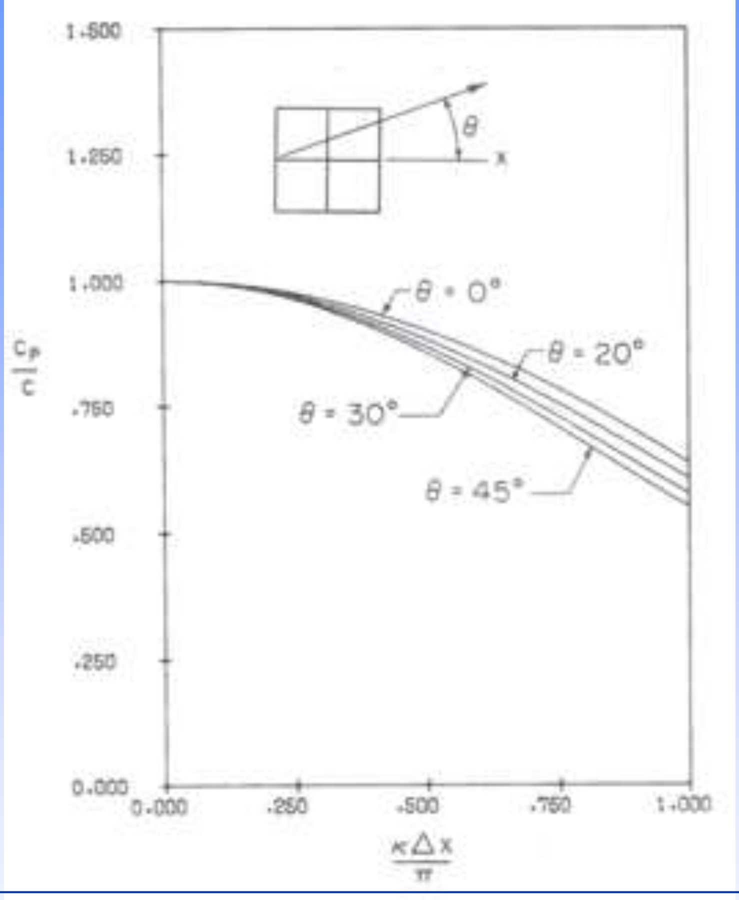
# Theoretical point of view

**Spurious wave due to the direction of the propagation**

**(***Belytschko et al. 1982***)**

*Ratio between theoretical and numerical wave velocity for different incidence angle of the wave*



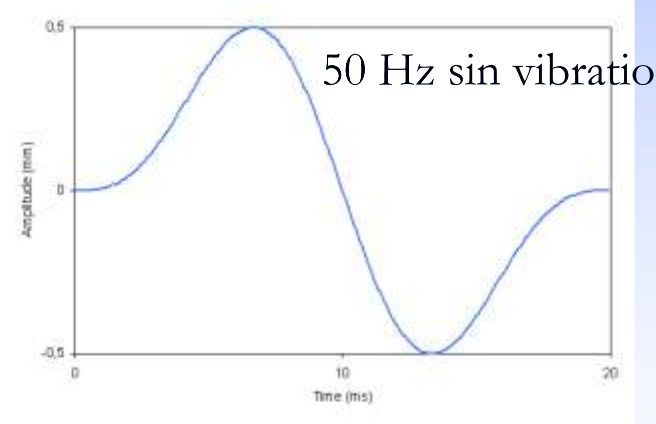
Numerical error due to the incident wave

# Simulations with different mesh density

Investigation of the mesh density in a FE model under dynamic load case

- Elasticity
- One single loading frequency

| Young's Modulus (kPa) | 4 |
|---|---|
| Poisson's ratio | 0.49 |
| Density (kg/dm$^3$) | 1 |

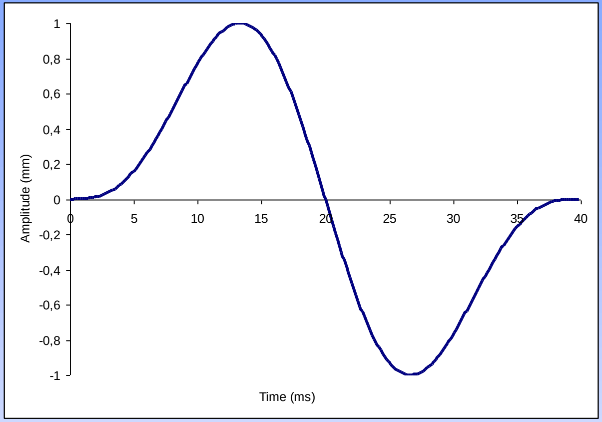


50 Hz sin vibration

# Simulations with different mesh density

Under the assumption of pure elasticity in the field of soft tissue

| | |
|---|---|
| Young’s Modulus (kPa) | 4 |
| Poisson’s ratio | 0.49 |
| Density (kg/dm$^3$) | 1 |



$$V_s = \sqrt{\frac{E}{3\rho}}$$

shear wave velocity

= 1,1 m/s

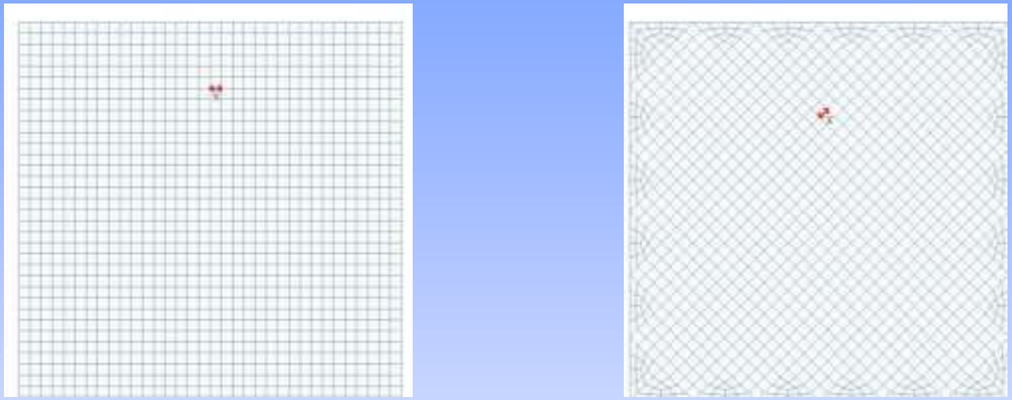
$$\lambda_s = \frac{V_s}{F_0}$$

Wavelength of shear wave

= 23 mm

# Simulations with different mesh density

## Mesh density and orientation for 3D simulation for Shell elements



| Models | Mechanical properties | | | Geometry of the mesh | | |
|---|---|---|---|---|---|---|
| | Young's Modulus kPa | Poisson ratio | Density g/cm$^3$ | Plan dimension | Element size mm | Element type |
| **3D_SHELL_1** | 4 | 0.49 | 1 | Width 70 mm<br>Heigth 70 mm | 0.25 | 4-node Shell elements |
| **3D_SHELL_2** | | | | | 0.5 | |
| **3D_SHELL_3** | | | | | 1 | |
| **3D_SHELL_4** | | | | | 2 | |
| **3D_SHELL_5** | | | | | 4 | |

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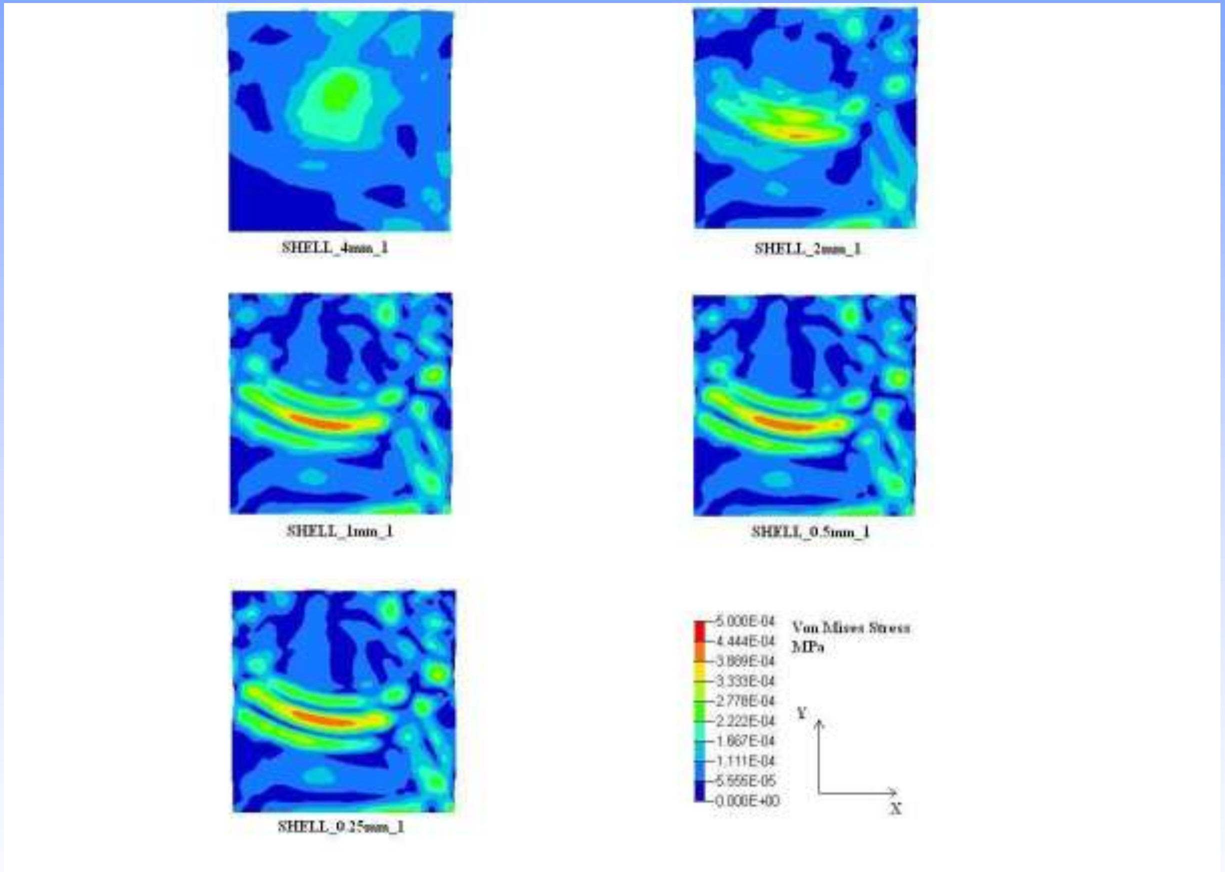
# Simulations with different mesh density

## Results for 3D simulations



Discrepancies in terms of stress distribution (45% difference)

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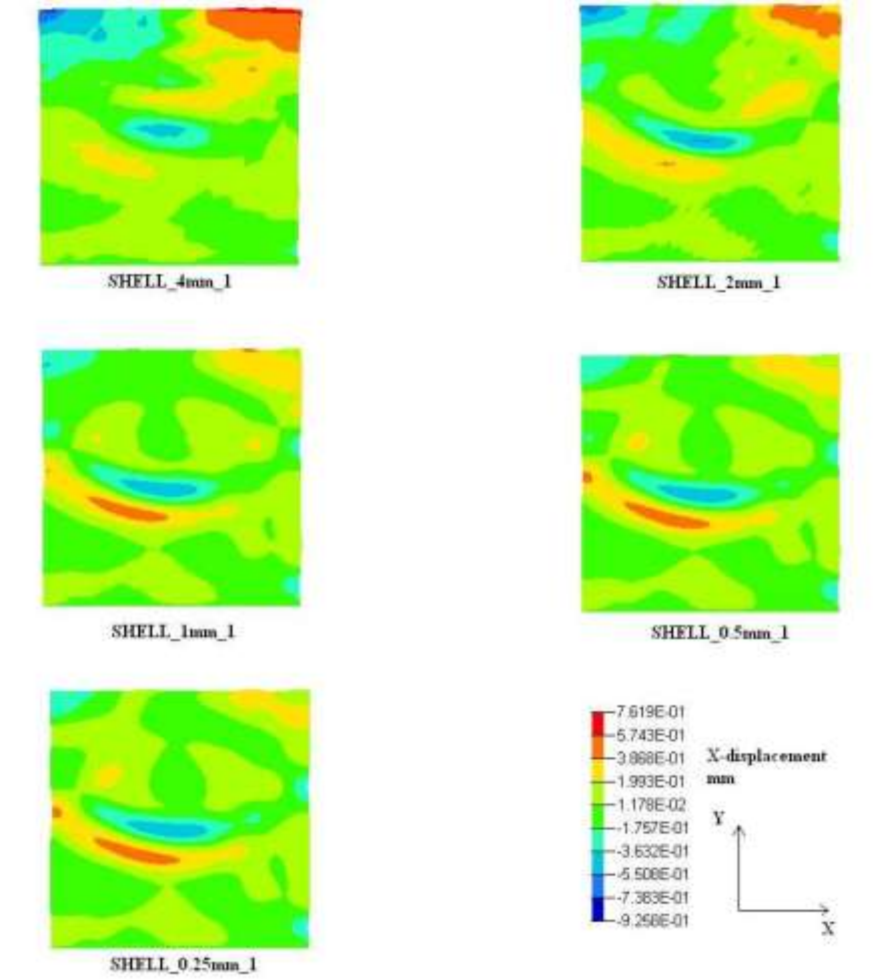
# Simulations with different mesh density

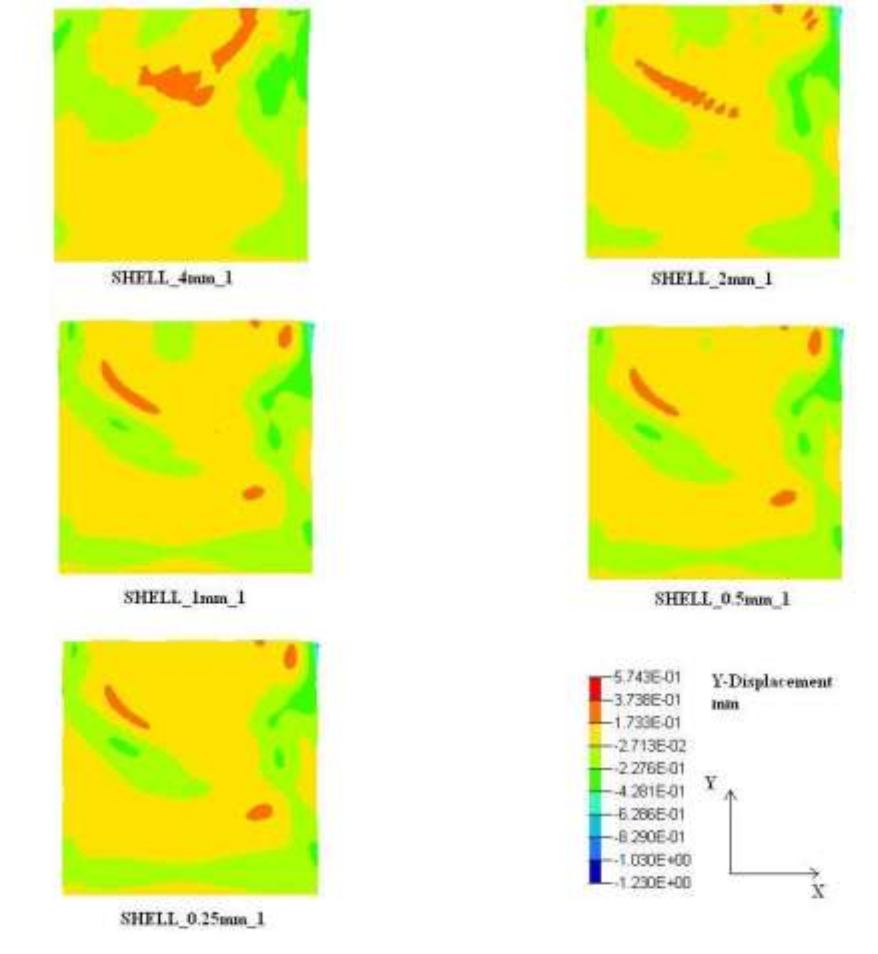
## Results for 3D simulations



Discrepancies in terms of displacement distribution (45% difference)

# Simulations with different mesh density

Results for 3D simulations



SHELL_4mm_1

SHELL_2mm_1

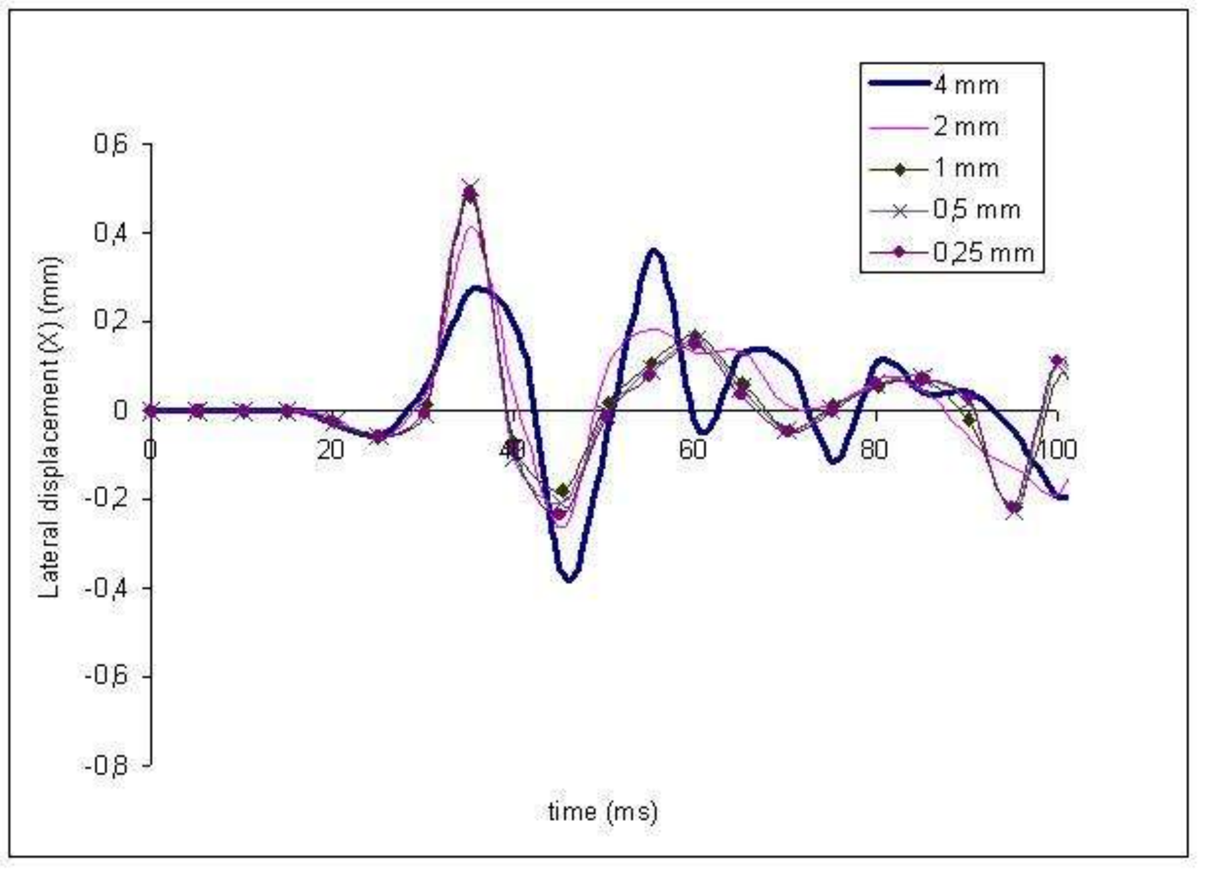
SHELL_1mm_1

SHELL_0.5mm_1

SHELL_0.25mm_1

# Simulations with different mesh density

Results for 3D simulations



Equivalence of results for 92 (0,25 mm),

46 (0,5 mm),

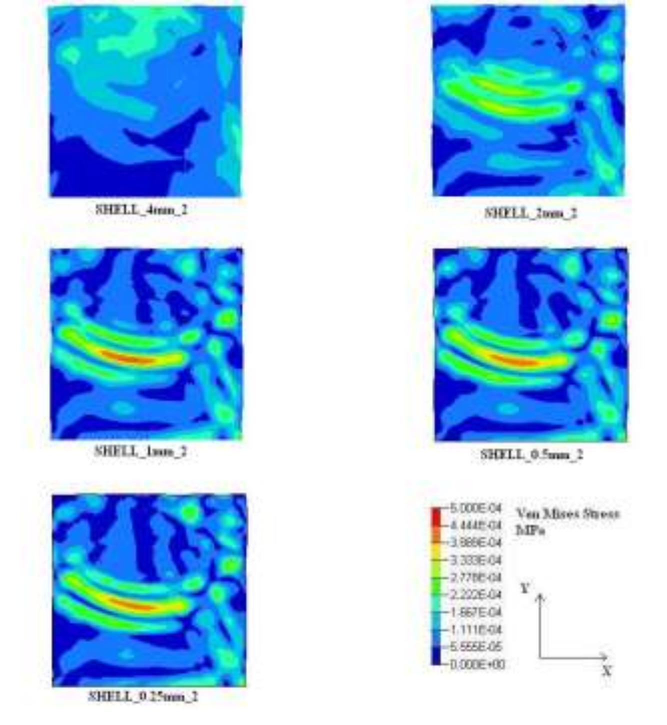
24(1 mm)

elements per wavelength.

For others model discrepancies appear

# Simulations with different mesh density and different orientation

## Results for 3D simulations

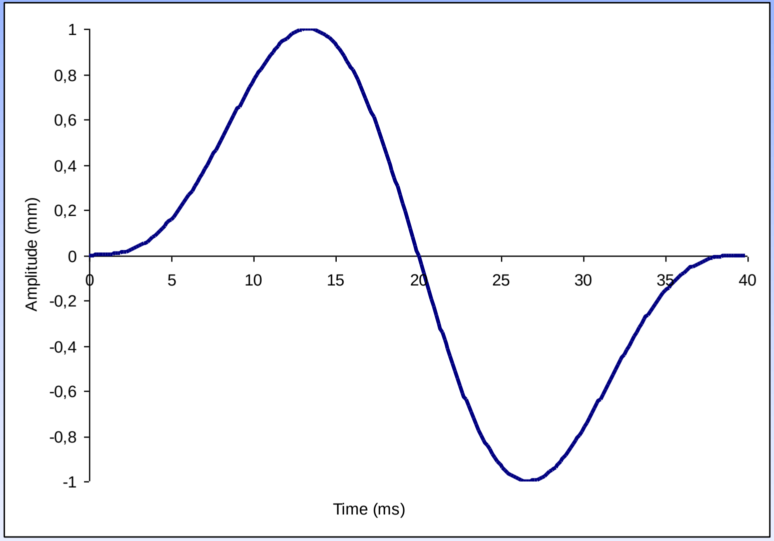


- Equivalence of results for element smaller than 1 mm.
- Same results for the 2 different mesh orientation if the element size is smaller than 1 mm

# Simulations with different mesh density

Frequency dependence

Simulation performed with a 25 Hz sine vibration



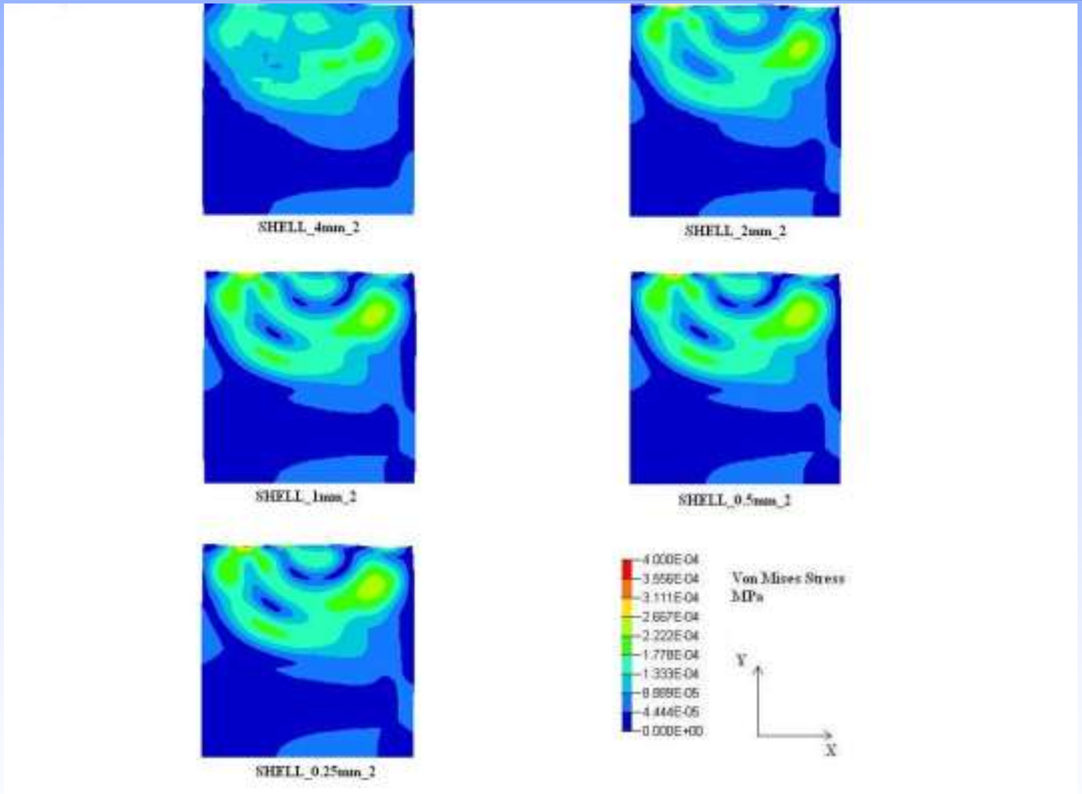
Only 4 mm model have less than 16 elements per wavelength

# Simulations with different mesh density

Frequency dependence

↓

Simulation performed with a 25 Hz sine vibration



Discrepancies appears for 4 mm size models (less than 16 element per wavelength)

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# Discussion and Conclusion

FE modelling → Discretization of the field → Mesh density ??

The study investigates the influence of mesh density with an explicit FE code (Radioss Altair© ) : more than 15-16 elements per wavelength for accurate results.

Elements per wave length: confirmation of a minimum of 15/16 elements (consistent with previous studies)

For an accurate discretization and a correct propagation of the wave.

More than 15/16 elements per wavelength increase CPU time with no significant improvement of the results.

# Discussion and Conclusion

Future work :

- Influence of element formulation (Number of integration points, anti hourglass formulation)
- Investigation of multi frequency loading (crash simulation)
- Investigation of the propagation angle of the wave
- Simulation with more complex material laws

Conclusion :

Great influence of the mesh on simple models.

For complex model (biomechanical models), a minimum number of element are necessary according to the loading case (frequency), with an important care on mesh homogeneity