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

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

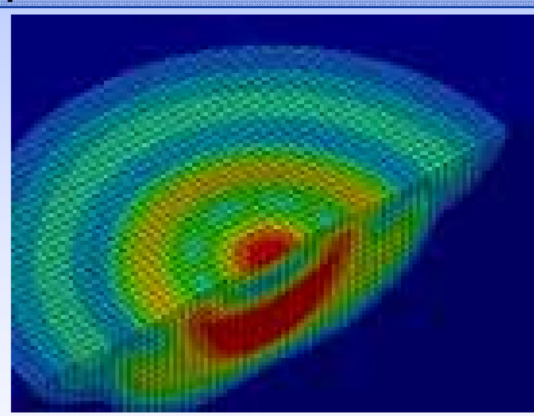
1. Introduction
2. Theoretical point of view
3. Simulations with different mesh density
4. Discussion and Conclusion

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

Introduction

Dynamic simulations: Impact or wave propagation

↓

Results of simulations are influenced by:

Mesh discretization

Material properties

Numerical dispersion

Spurious wave

}

Precision of the analysis

Stability of the analysis

Validity of the analysis

State of art

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

Numerical Stability 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 (Δx) in the mesh

State of art

Courant's condition

Validity of the analysis

Even if the simulation is valid, there are numerical errors

Mesh size and wave direction lead to different results for a simulation

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

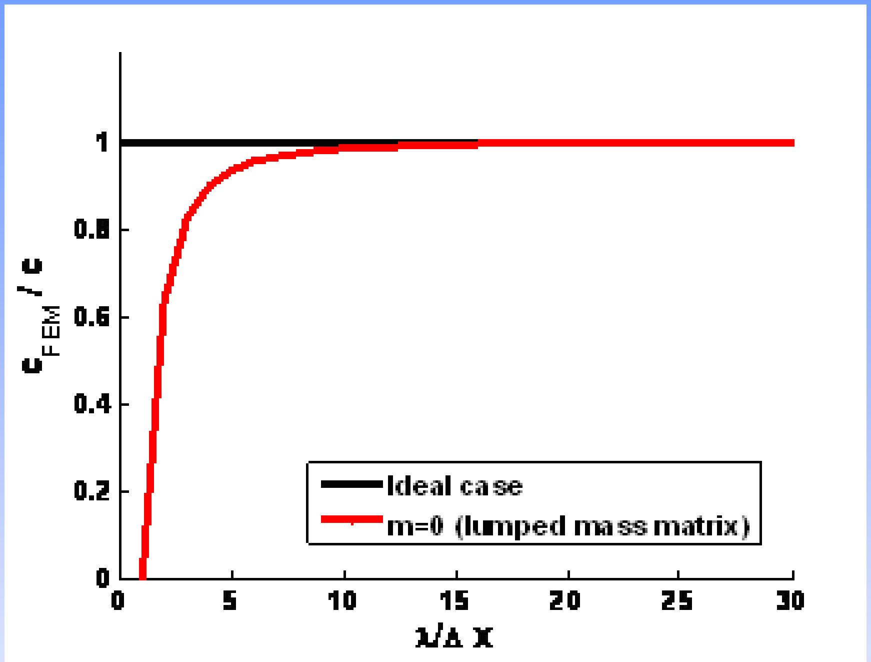
Theoretical point of view

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 $\frac{\lambda}{\Delta x} \sim 16$

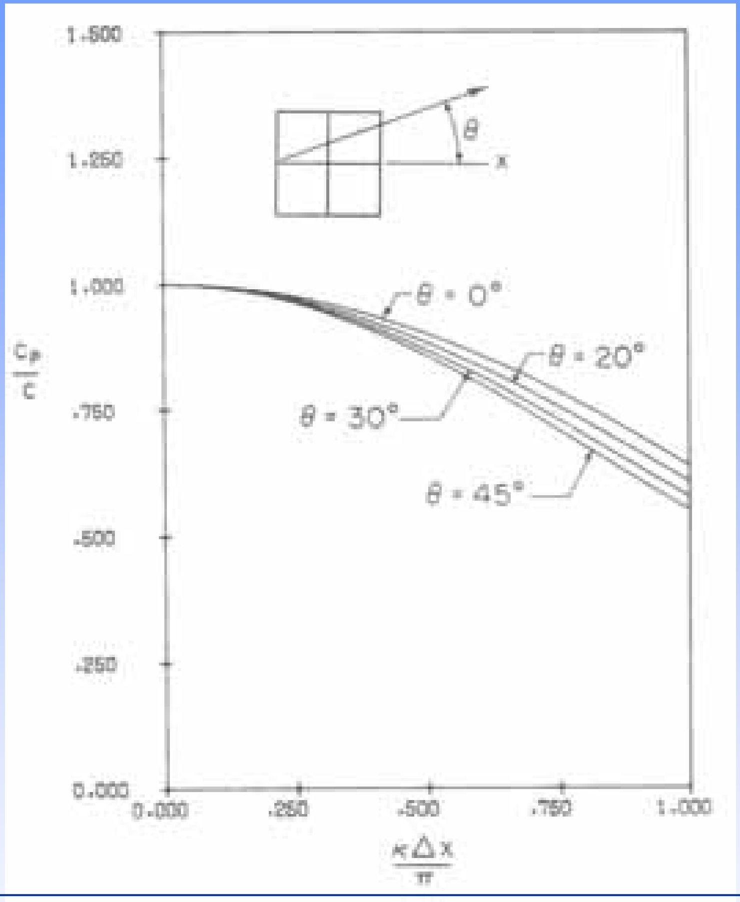
Numerical error due to the number of element per wavelength

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

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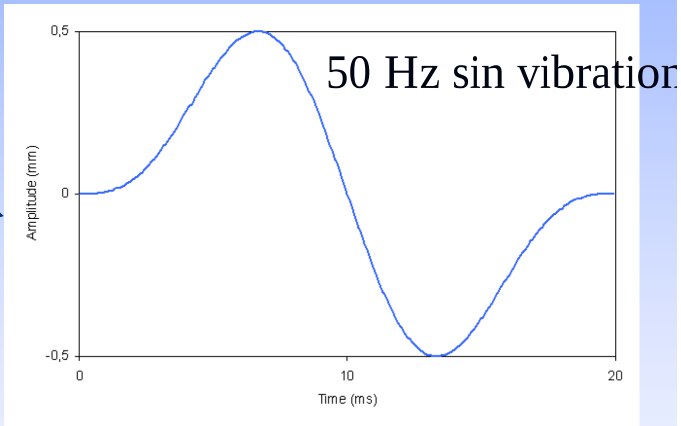
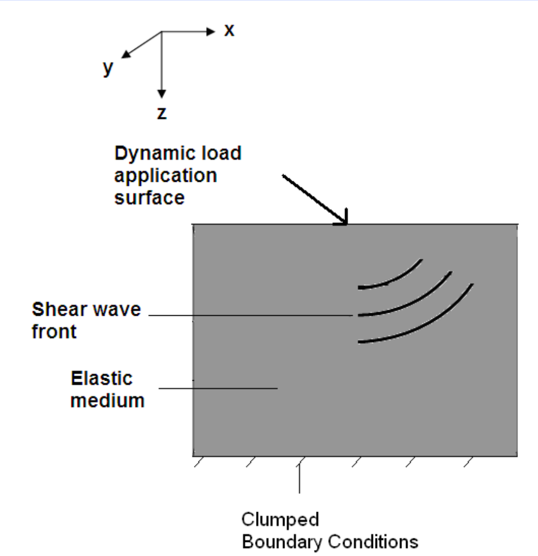
Simulations with different mesh density

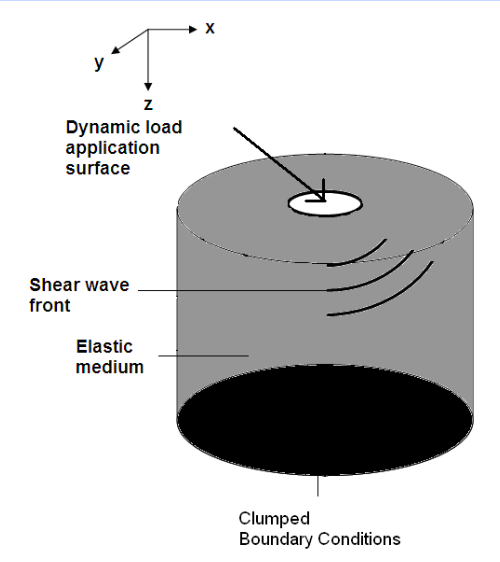
Investigation of the mesh density in a FE model under dynamic load case

Young's Modulus (kPa)	4
Poisson's ratio	0.49
Density (kg/cm³)	1

- Elasticity
- One single loading frequency







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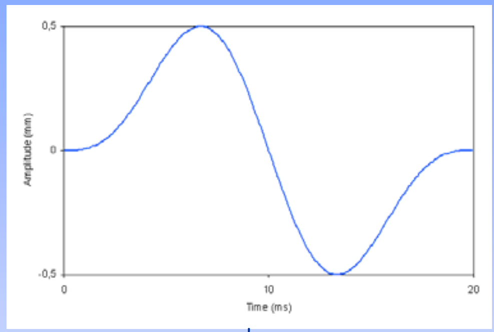
Simulations with different mesh density

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

Young's Modulus (kPa)	4
Poisson's ratio	0.49
Density (kg/cm³)	1



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

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

shear wave velocity

= 1,1 m/s

Wavelength of shear wave

= 23 mm

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Simulations with different mesh density

Mesh density for 2D simulation

Models	Geometry of the mesh			
	Plan dimension	Element size mm	Element type	number of element per wave length
2D_QUAD_1	Width 90 mm Heigth 60 mm	0.25	4 nodes Quad elements	92
2D_QUAD_2		0.5		46
2D_QUAD_3		1		23
2D_QUAD_4		2		11
2D_QUAD_5		3		8
2D_QUAD_6		Bias		/

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Simulations with different mesh density

Mesh density for 3D simulation

Models	Geometry of the mesh			
	Plan dimension	Element size mm	Element type	number of element per wave length
3D_SHELL_1	Width 90 mm Heigth 60 mm	0.25	4 nodes Shell elements	92
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3D_SHELL_6		Bias		/

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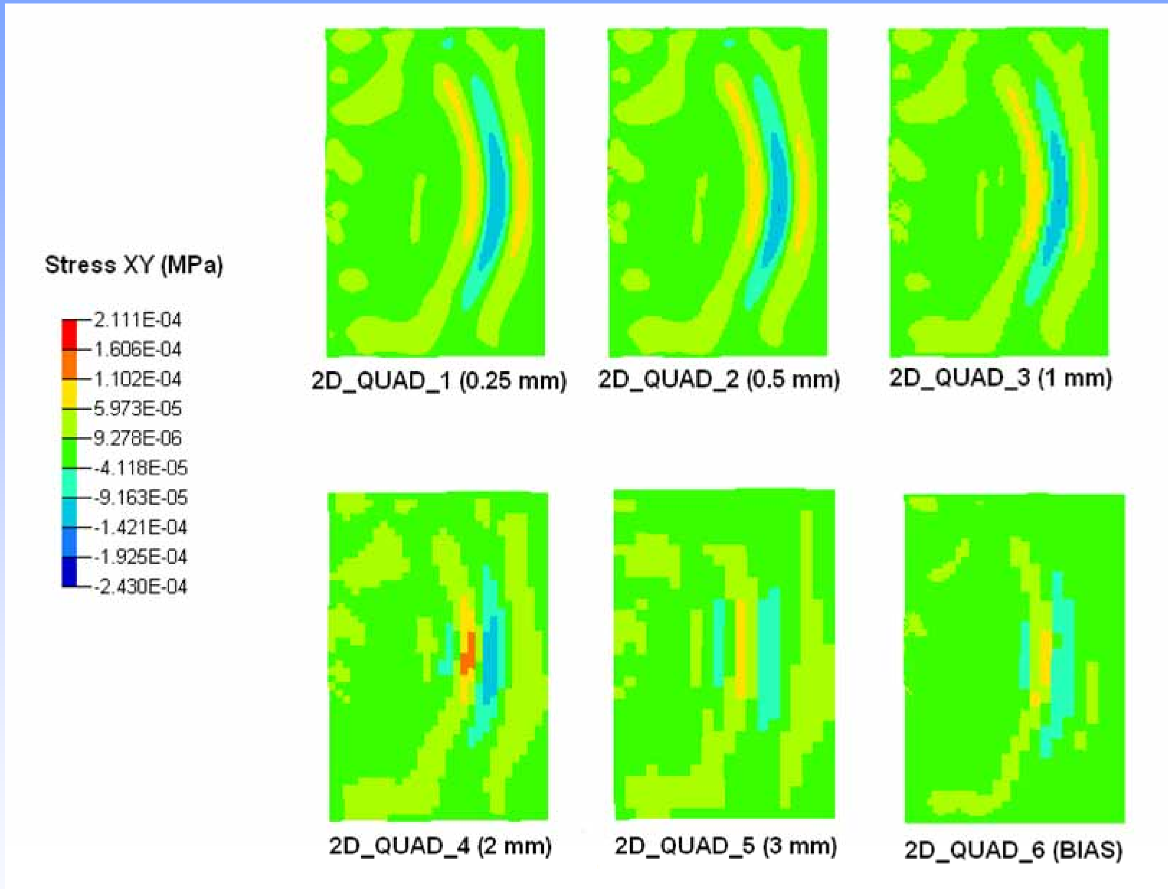
Simulations with different mesh density

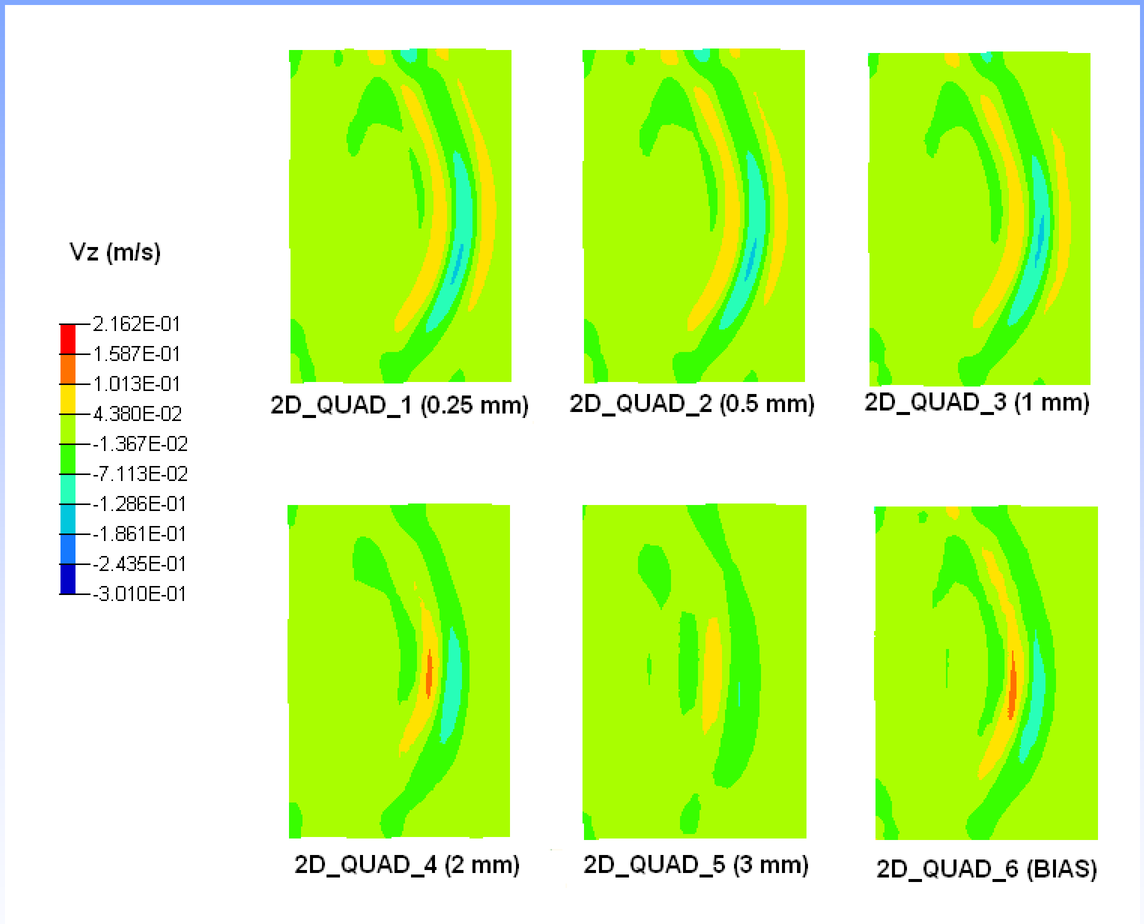
Results for 2D simulations



Discrepancies in terms of stress distribution (55% difference)

Simulations with different mesh density

Results for 2D simulations



Discrepancies in terms of velocity

(50 % difference)

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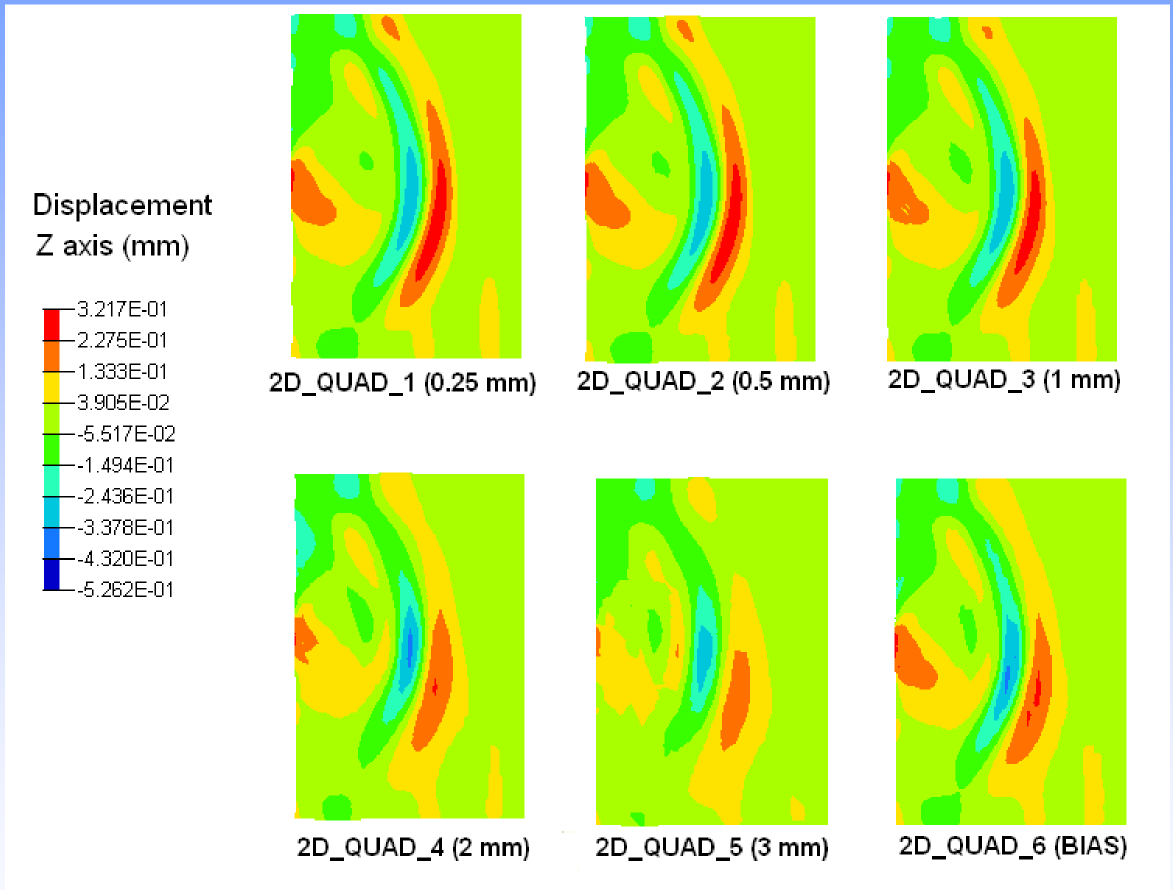
Simulations with different mesh density

Results for 2D simulations



Discrepancies in terms of displacement distribution (30% difference)

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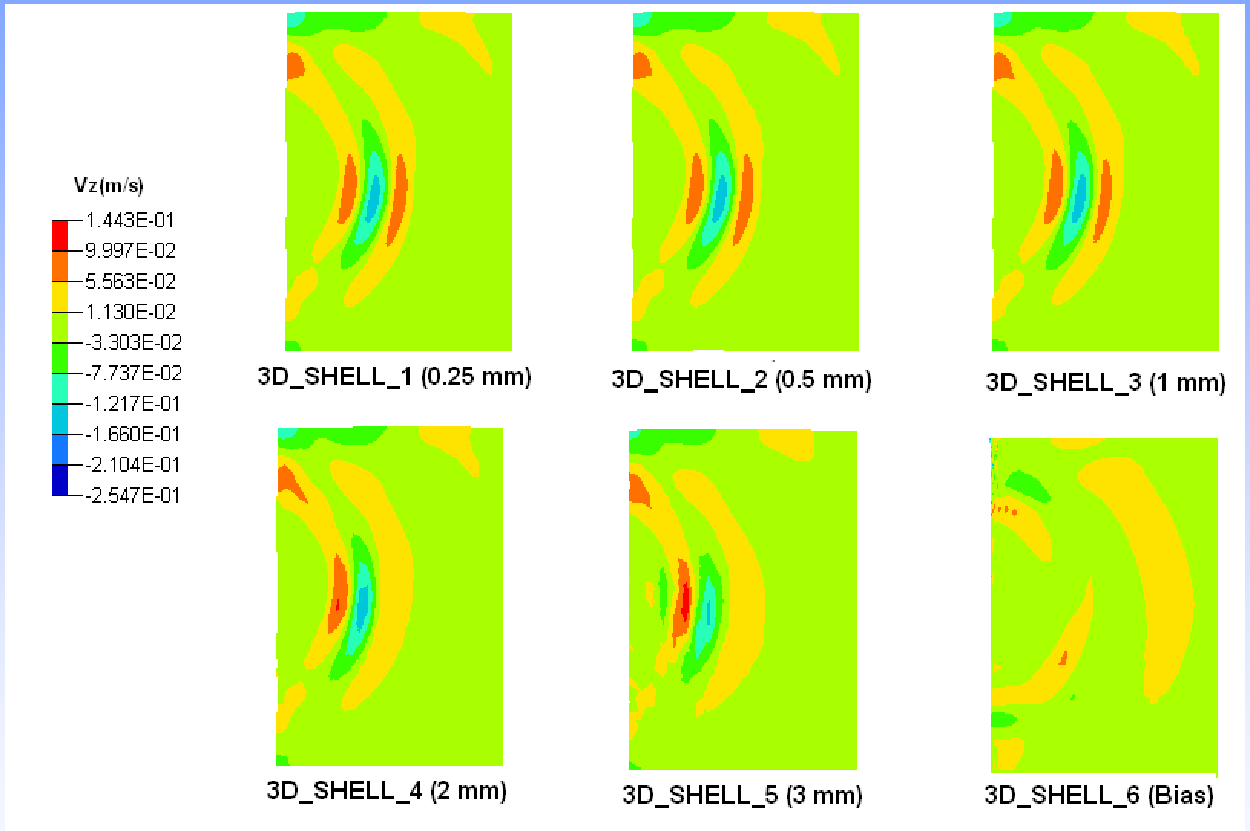
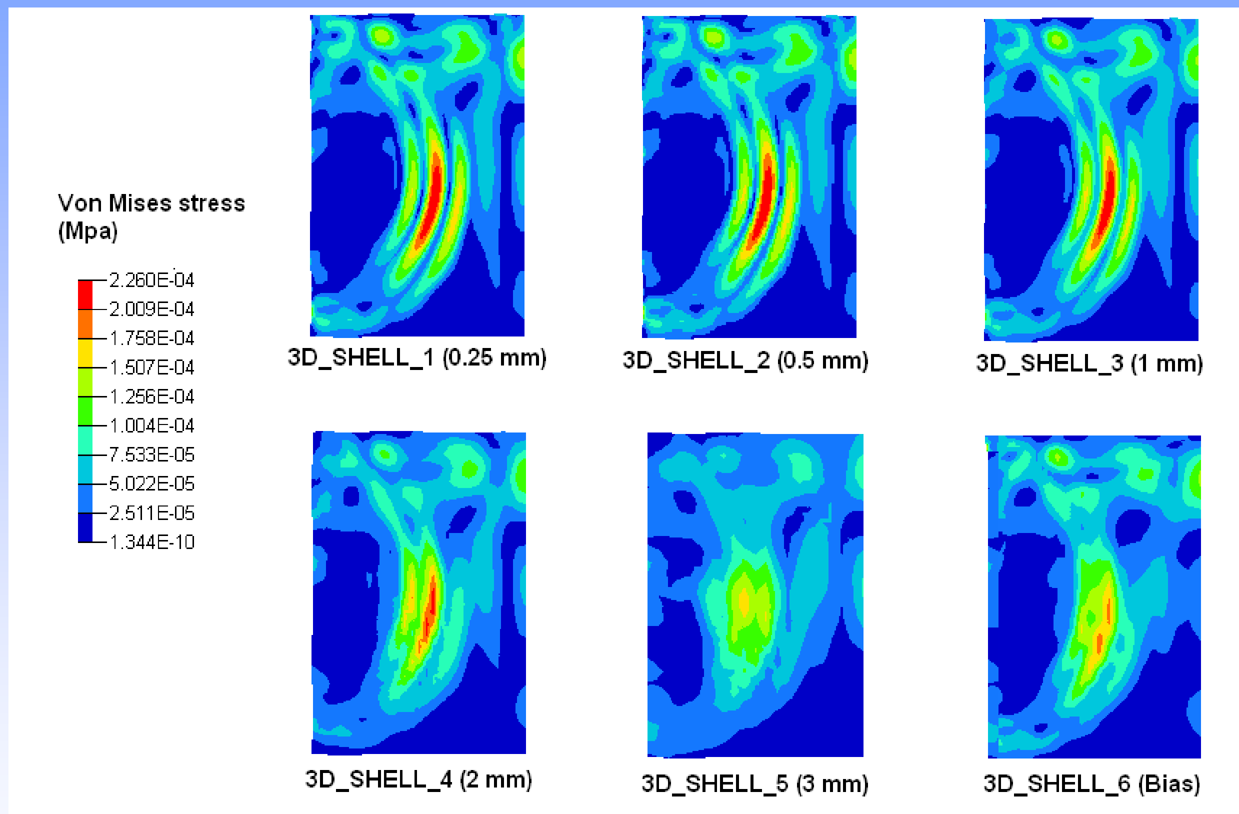
Simulations with different mesh density

Results for 3D simulations



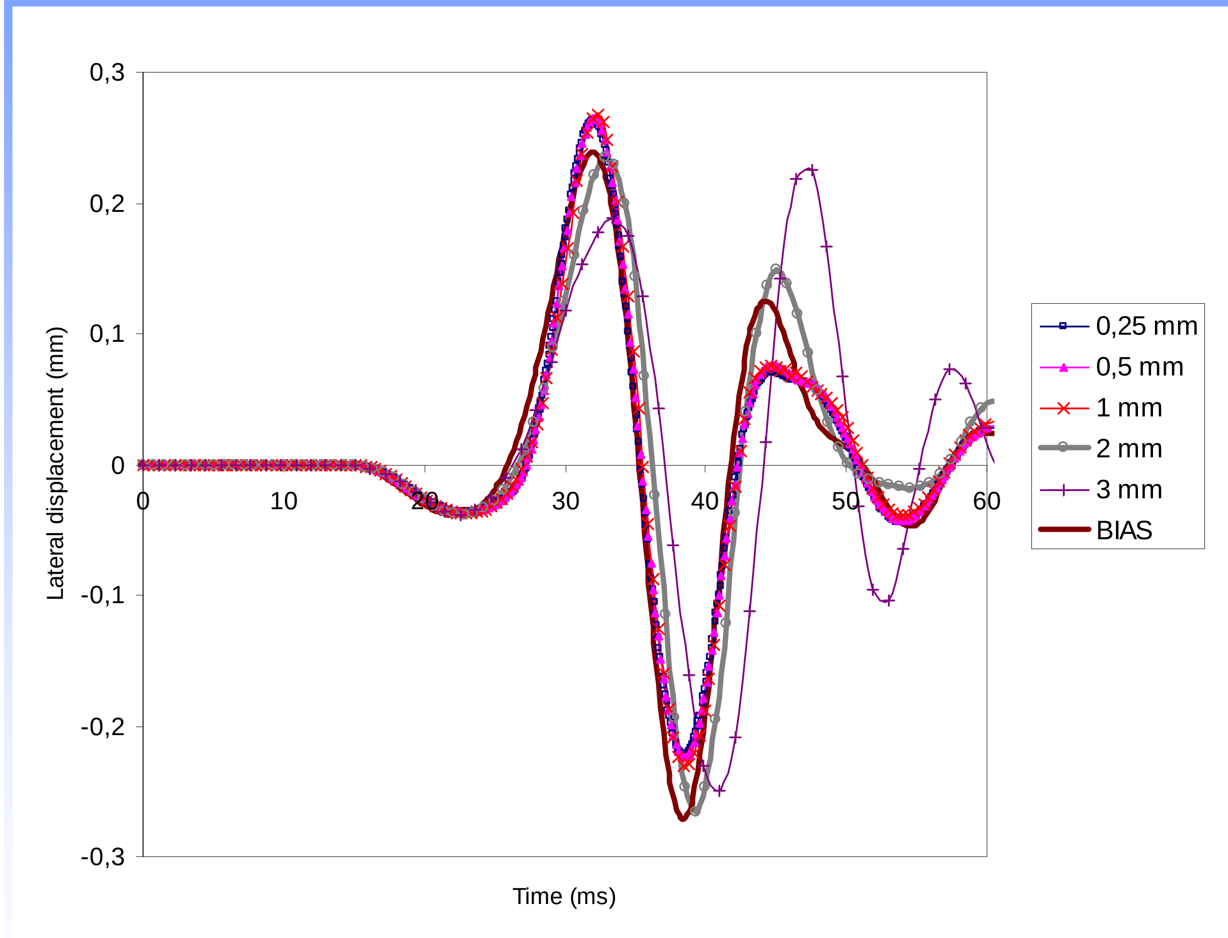
Simulations with different mesh density

Results for 3D simulations



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

Frequency dependence

Simulation performed with a 25 Hz sine vibration

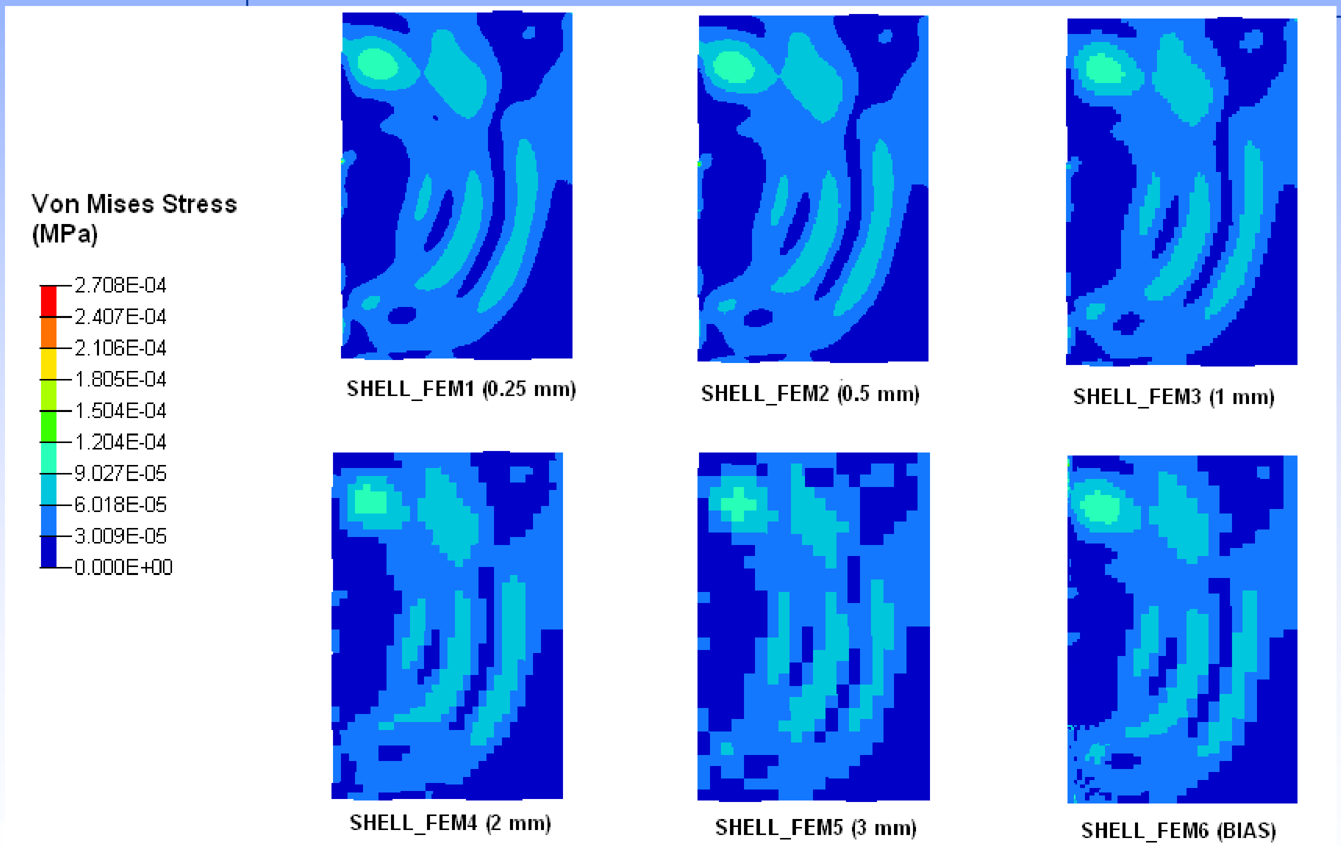
Models	Geometry of the mesh			
	Plan dimension	Element size mm	Element type	number of element per wave length
3D_SHELL_1	Width 90 mm Heigth 60 mm	0.25	4 nodes Shell elements	184
3D_SHELL_2		0.5		92
3D_SHELL_3		1		46
3D_SHELL_4		2		23
3D_SHELL_5		3		16
3D_SHELL_6		Bias		/

All the model have more than 16 elements per wavelength

Simulations with different mesh density

Frequency dependence

Simulation performed with a 25 Hz sine vibration



Equivalence of results for all models

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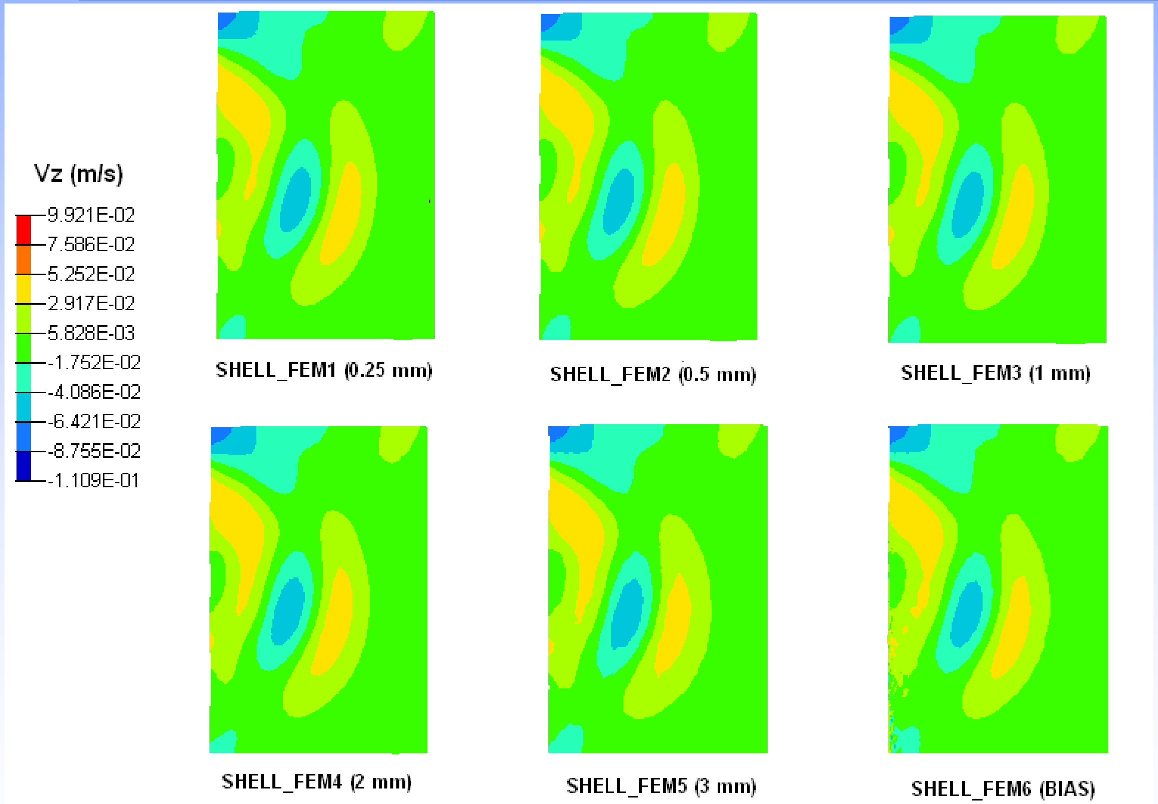
Simulations with different mesh density

Frequency dependence

Simulation performed with a 25 Hz sine vibration



Equivalence of results for all models

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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©) : 15/16 element per wavelength for accurate results.

Element per wave length 15/16 elements (consistent with previous studies)

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

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

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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)

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