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# Experimental Characterization and FE Simulations of Ribs under Impact Loads

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## Introduction

Several authors have been studying the behaviour of ribs subjected to impact loads both in medical and biomechanical domains. The advances in numerical techniques and their advantages over expensive and painstaking experiments have led to the development of finite element human models. Despite their extensive use, these models have respective constraints. Knowing the realistic behaviour aids in the comprehension of the relation between injury criteria and fracture of ribs and indeed the severity of injury.

## Objectives

- To develop an experimental methodology in order to accurately characterize the bone fracture induced by impacts to chest
- To develop a three-dimensional finite element model of bone to simulate bone fracture and to predict its occurrence under specific dynamic environments

## Material and Methods

- Modified Split Hopkinson Pressure Bar for three-point bending tests using nylon bars [1]. Experimental data classified as (i) Short duration tests  $t_{frac} \leq 0.8E - 3 s$  (ii) Medium duration tests  $0.8E - 3 s \leq t_{frac} \leq 1.0E - 3 s$  and (iii) Long duration tests  $t_{frac} \geq 1.2E - 3 s$

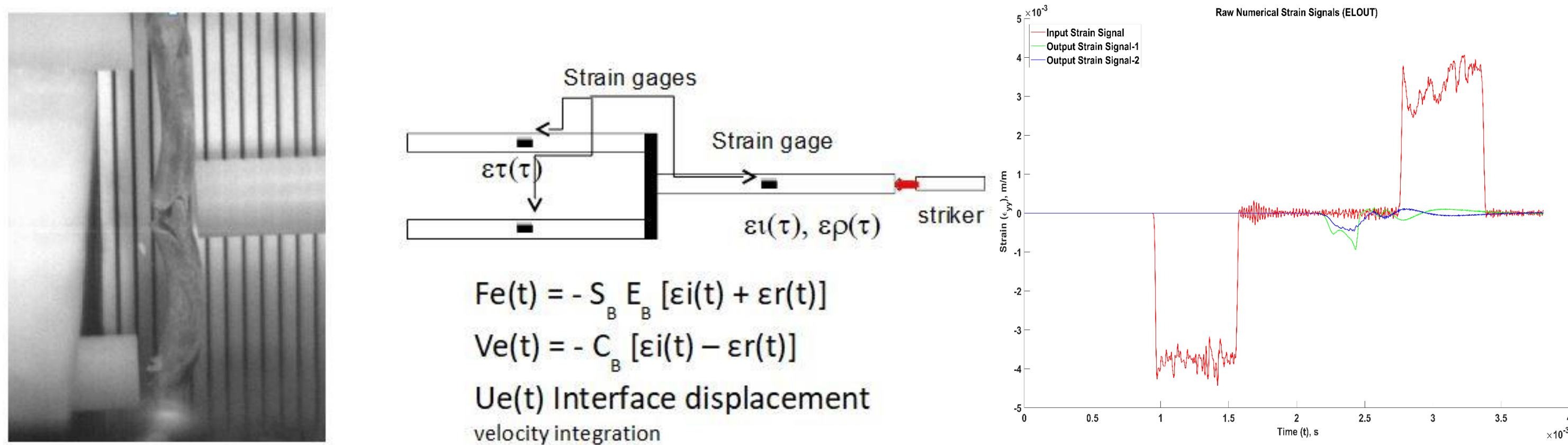


Figure-1 : Three point bending setup of SHPB

- Numerical rib sample was generated from DICOM images of HR-pQCT scans. The apparent density  $\rho_{app}$  was interpolated through a linear relation with  $CT_{bone}$  (Eq.1) as in [2].  
$$\rho_{app} = 1.2907 CT_{bone} \quad (1)$$
- Mechanical properties were assigned through power law regression with  $\rho_{app}$  as independent variable. Respective equations were used with respect to porosity  $P_o$

Property	Cortical bone	Trabecular bone
Apparent Density $\rho_{app}$	1690.090 kg. m <sup>-3</sup>	222.611 kg. m <sup>-3</sup>
Young's Modulus $E$	10.46 GPa	0.378 GPa
Tensile Yield $\sigma_{yT}$	75.36 MPa	2.096 MPa

Table-1 : Mechanical properties of porcine rib constituents

## Constitutive Law

- Both cortical and trabecular bone were assigned a modified elastic-plastic law to consider the effects of strain rate  $\dot{\epsilon}$  to have an elasto-viscoplastic behaviour through Cowper-Symmonds model (Eq.2).

$$\sigma_{y_d} = \sigma_{y_0} \left[ 1 + \left( \frac{\dot{\epsilon}}{C} \right)^P \right] \quad (2)$$

- Where:  
 $\sigma_{y_d}$  is dynamic yield stress  
 $\sigma_{y_0}$  is initial yield stress  
 $C = 2.5$  and  $P = 7.0$  are Cowper-Symmonds parameters [3]

## Damage Law

- An incremental, stress state dependent damage law was coupled externally to the constitutive law. It also considers damage accumulation (Eq.3) and instabilities (Eq.4) due to damage and also the effects of strain rate  $\dot{\epsilon}$  on fracture strain  $\epsilon_f$ .

$$\Delta D = \frac{n}{\epsilon_f(\eta)} D^{(1-1/n)} \Delta \epsilon_p \quad (3)$$

$$\sigma = \tilde{\sigma} \left[ 1 - \left( \frac{D - D_{crit}}{1 - D_{crit}} \right)^m \right] \quad (4)$$

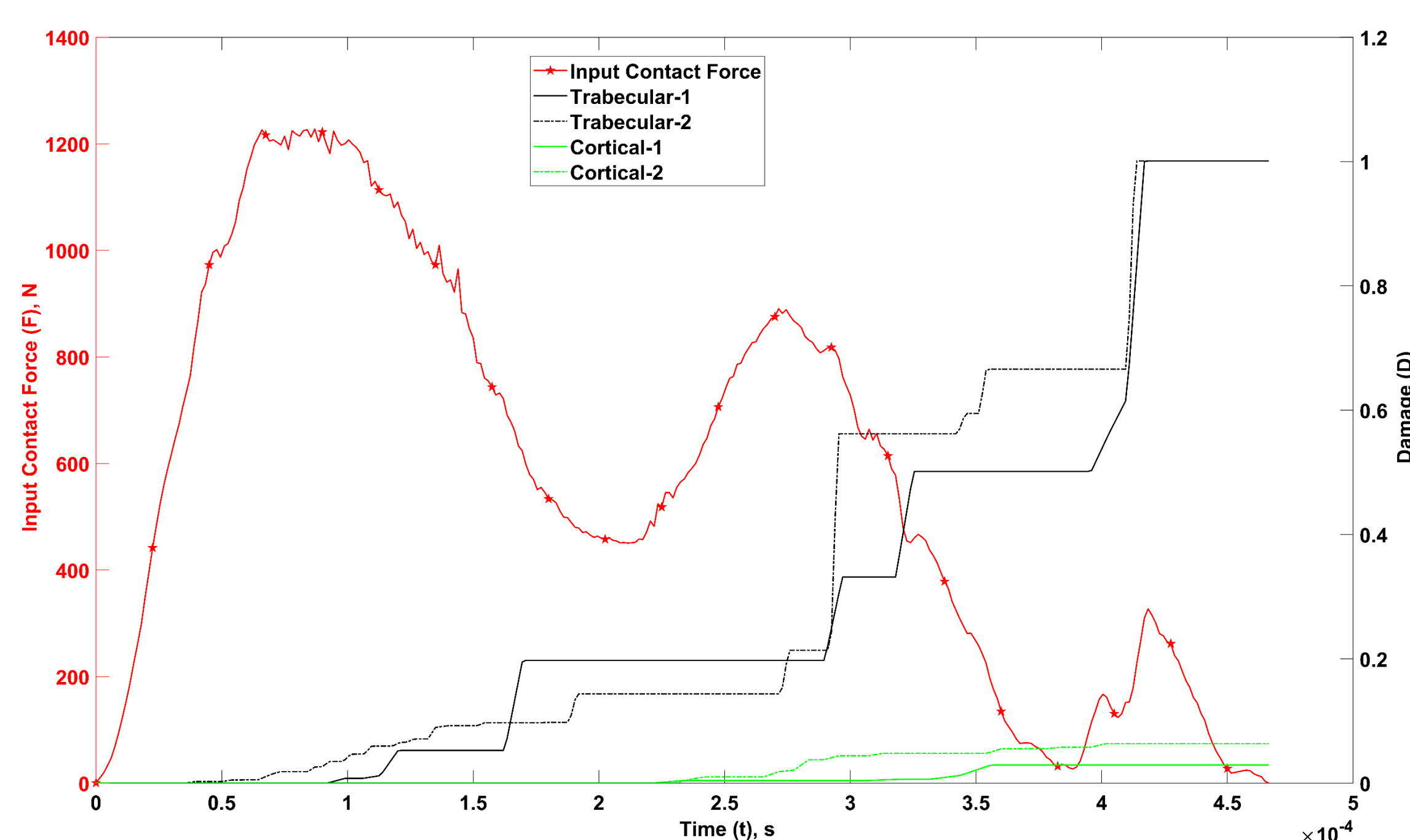


Figure-2 : Damage Evolution with respect to Force

## Results

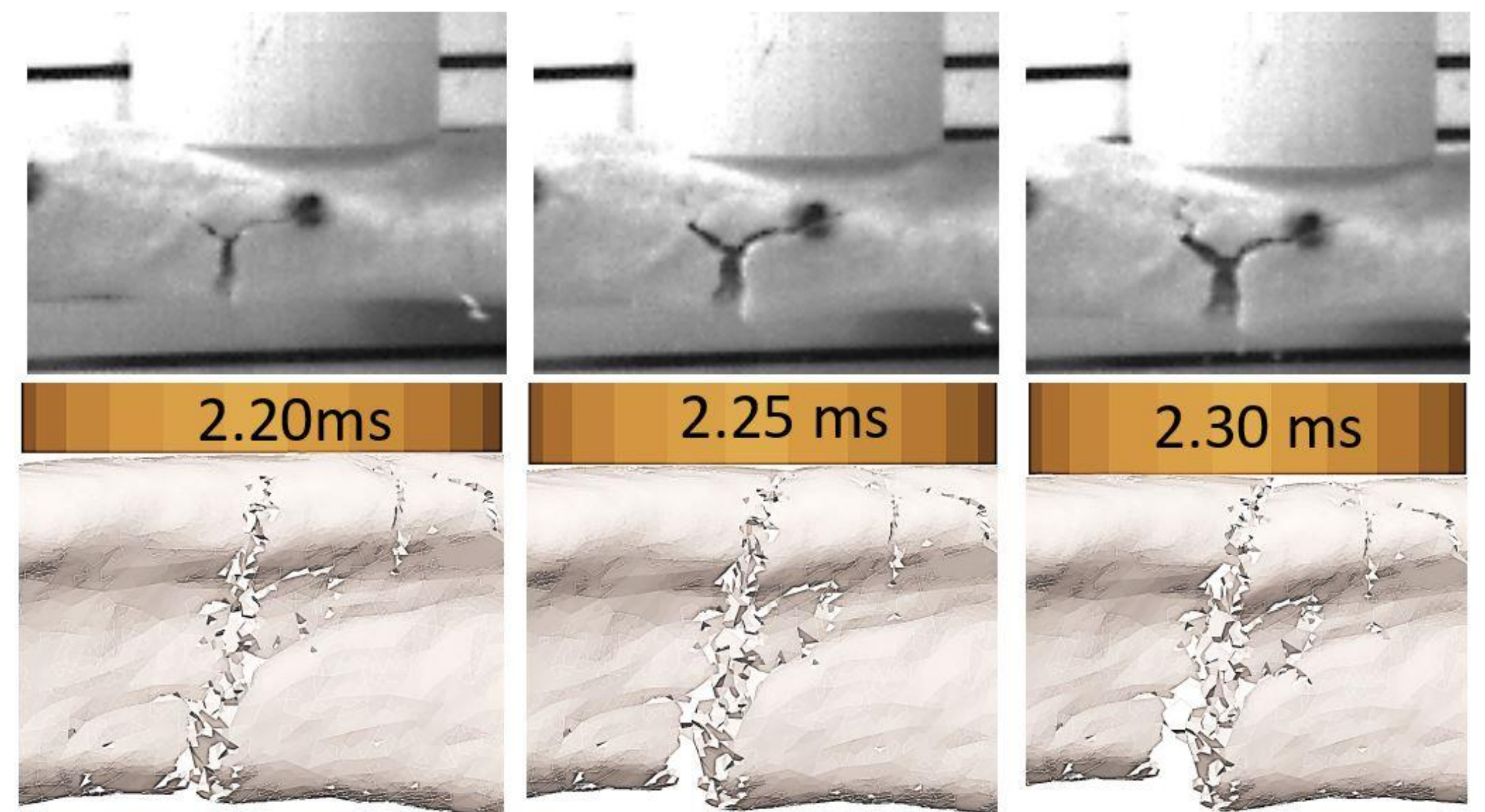


Figure-3 : Fracture Pattern

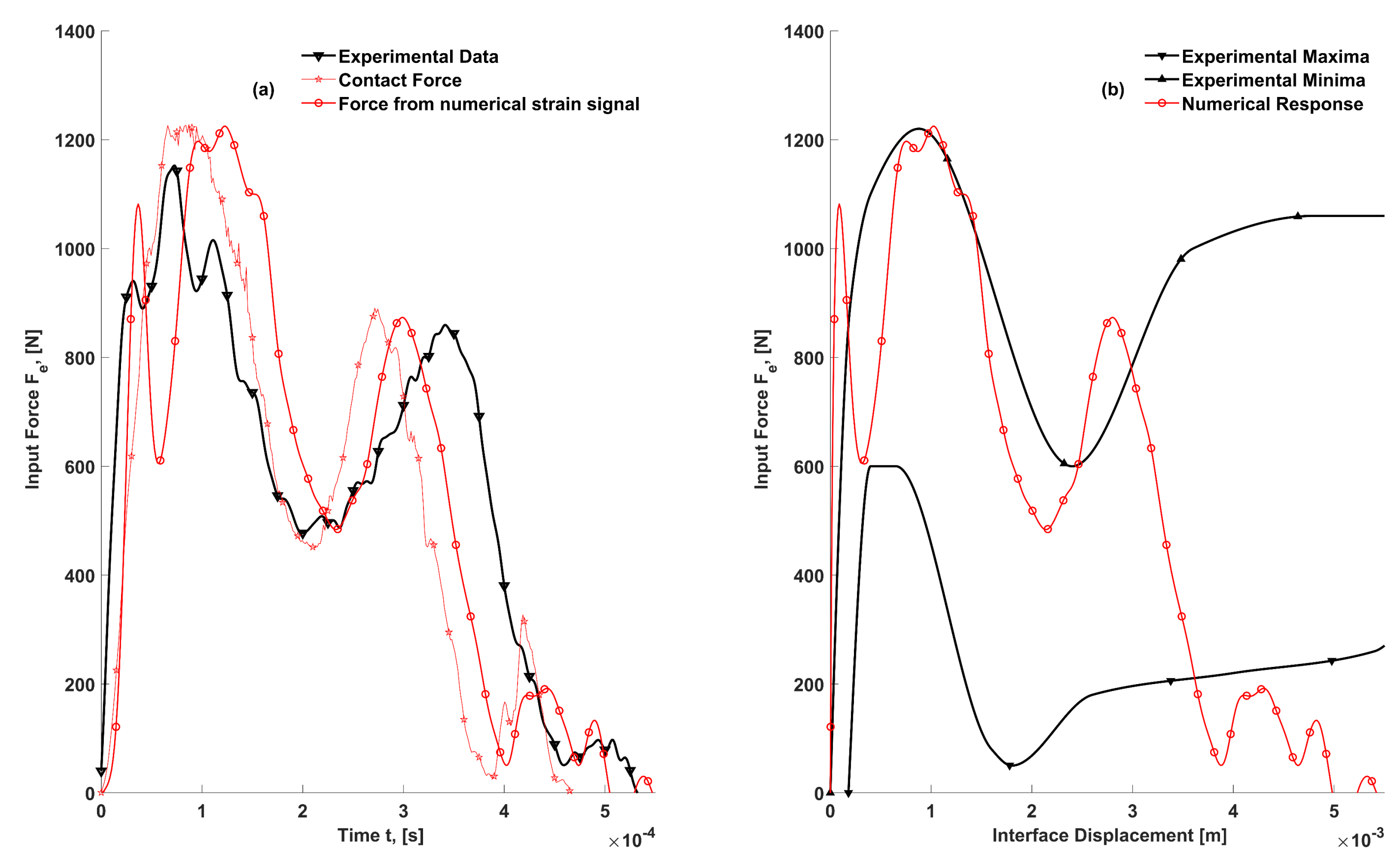


Figure-4 : Comparison of numerical and experimental response

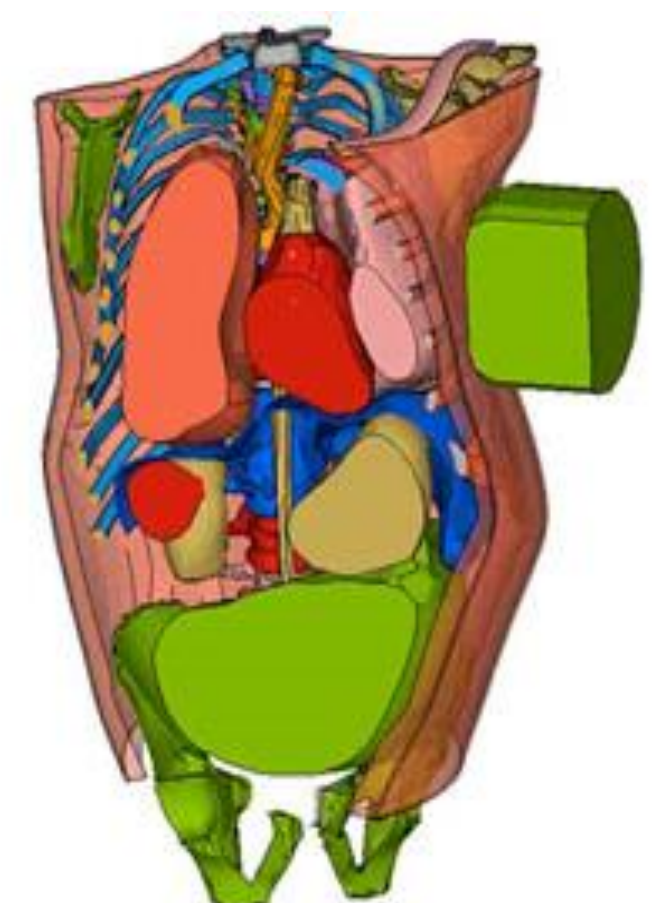
## Conclusions

- Apparent density  $\rho_{app}$  as an independent variable for dependence of mechanical properties is sufficient for coherent results, given that it is correctly correlated to grey scale intensity  $CT_{bone}$ .
- Elasto-viscoplastic constitutive law for trabecular bone produced promising results at a preliminary stage.
- Despite the possibility to generate numerical sample with different parts, dynamic fracture propagation in porcine ribs consisting only one cortical and one trabecular bone material was successfully simulated.
- Optimization of damage and constitutive laws parameters through experimental characterization of human ribs will permit us to extent fracture prediction in human numerical models

## Forthcoming Research

Implementation of current damage coupled constitutive law to generalized human thorax model and FE thorax model HUBYx of Radioss courtesy of Altair Hyperworks, to study and quantify the response of human thorax under different impact cases such as Automotive accidents and Ballistic impacts (Non-lethal projectiles).

This aids us in the comprehension of injury criteria and to predict the severity of the injury.



## References

- R. Aubert, J. Pavier, N. Eches, A. Langlet, and P. Bailly. On the use of Hopkinson bar-bending apparatus to study soft impact on porcine ribs. *Computer Methods in Biomechanics and Biomedical Engineering*, 15(sup1):311–312, September 2012.
- W. R. Taylor, E. Roland, H. Ploeg, D. Hertig, R. Klabunde, M. D. Warner, M. C. Hobatho, L. Rakotomanana, and S. E. Clift. Determination of orthotropic bone elastic constants using FEA and modal analysis. *Journal of Biomechanics*, 35(6):767–773, June 2002.
- Zuoping Li, Matthew W. Kindig, Jason R. Kerrigan, Costin D. Untaroiu, Damien Subit, Jeff R. Crandall, and Richard W. Kent. Rib fractures under anterior-posterior dynamic loads: experimental and finite-element study. *J Biomech*, 43(2):228–234, January 2010.