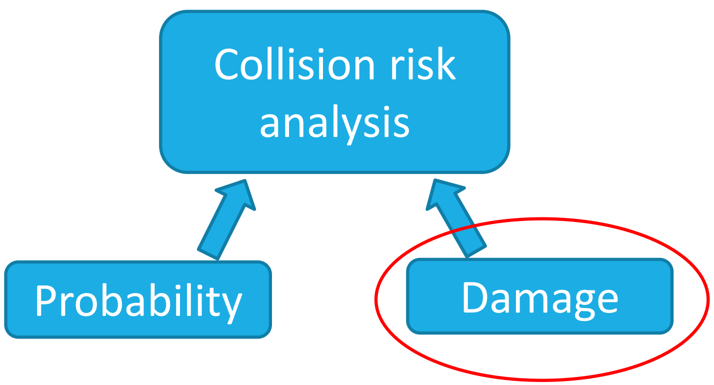
Presentation of a simplified method for the crashworthiness of offshore wind turbine jackets

Timothée Pire (ULg, FRIA fellowship)
Hervé Le Sourne (GeM/ICAM)
Loïc Buldgen (ULg)
Philippe Rigo (ULg)

Université de Liège ULg
GeM Institut de Recherche en Génie Civil et Mécanique
icam

Context

- More and larger wind farms
- Closer to traffic lanes (passengers and commercials)
- Need of maintenance



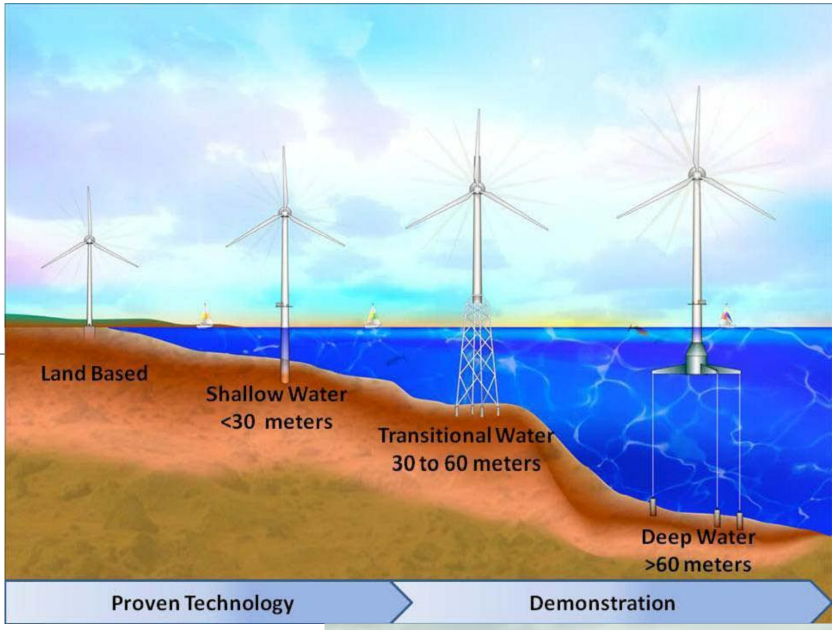
[offshorenergytoday.com]
[northnorfolknews.co.uk]
[maritimejobs.org]

Context

- Several wind turbine supporting structurures :
  - Monopile
  - Tripod
  - **<u>Jacket</u>**
  - Floating

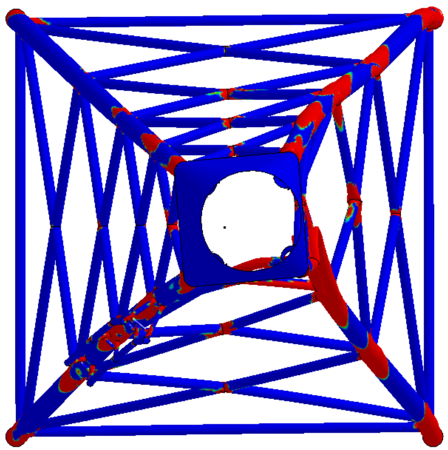
- Finite elements : accurate but time demanding

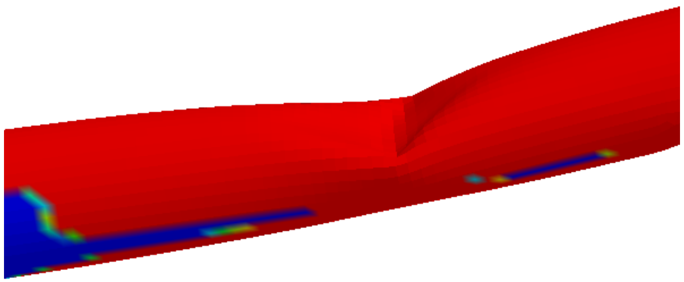
- Need for a faster method for pre-design stage : **<u>Continuous Elements Method</u>**

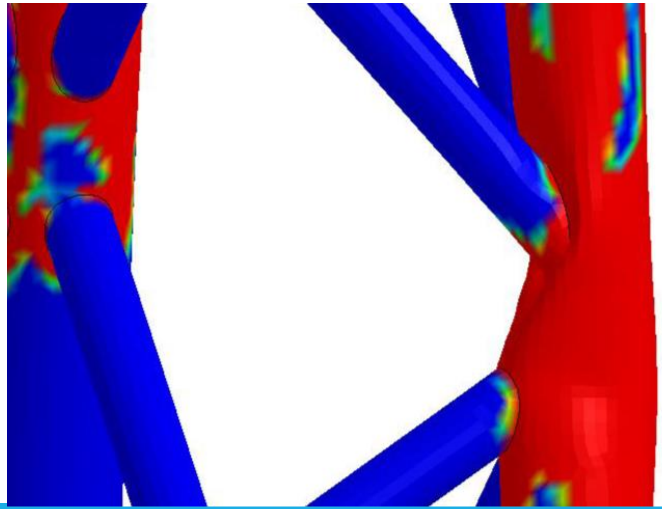


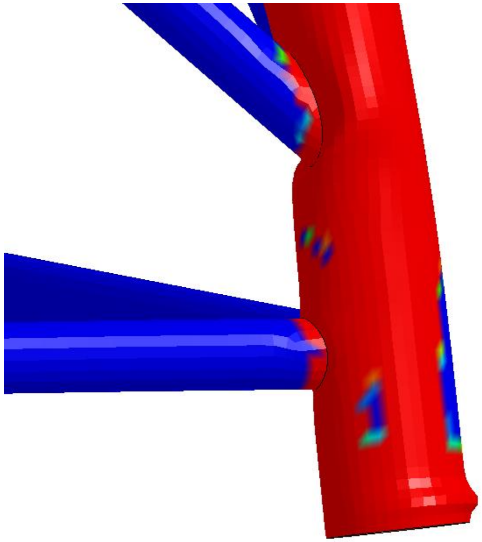
[boem.gov], [smulders-hoboken.com]

Deformation modes



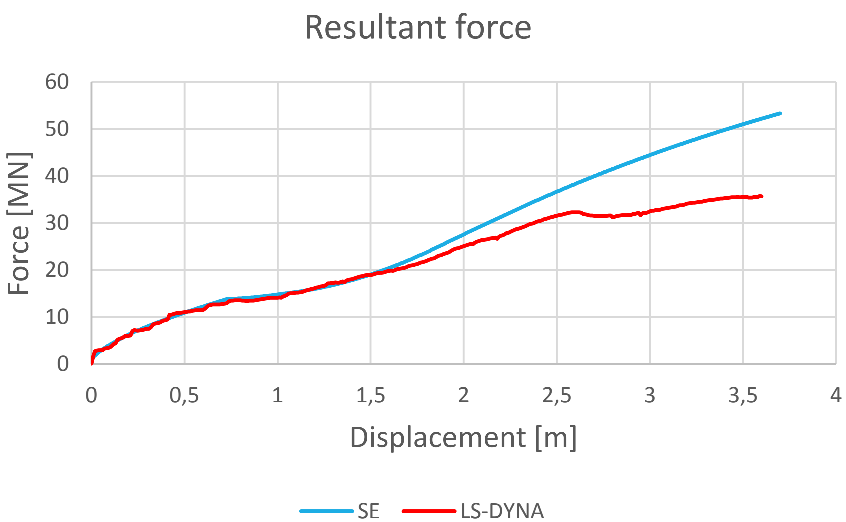


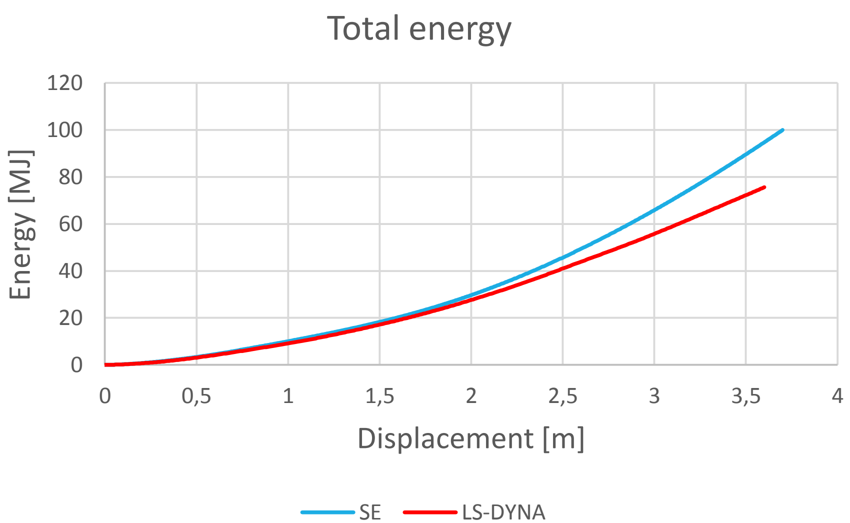




State of art

- Only local crushing taken into account
- Good results for low energy impacts

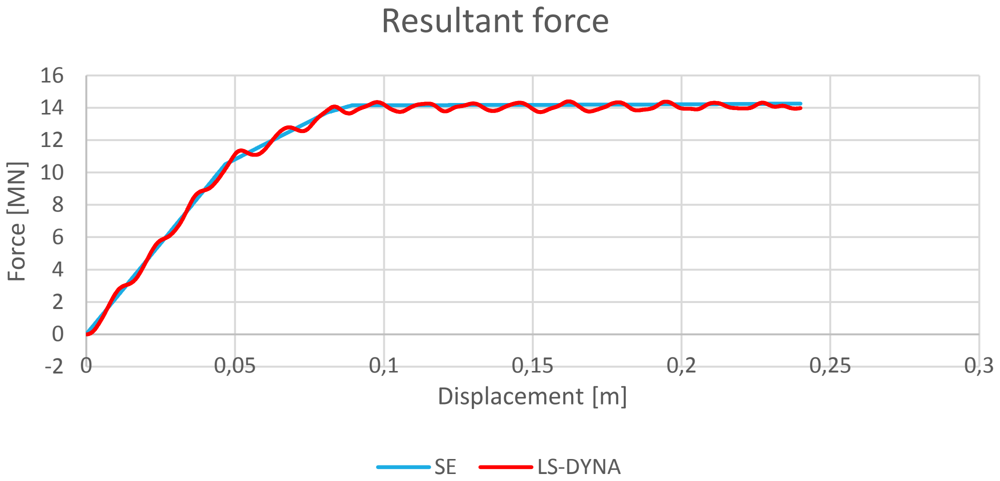


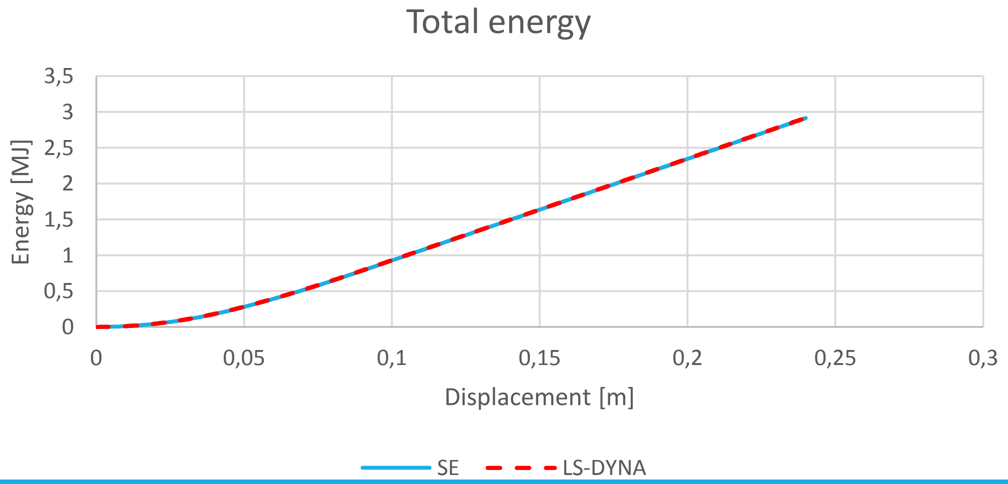


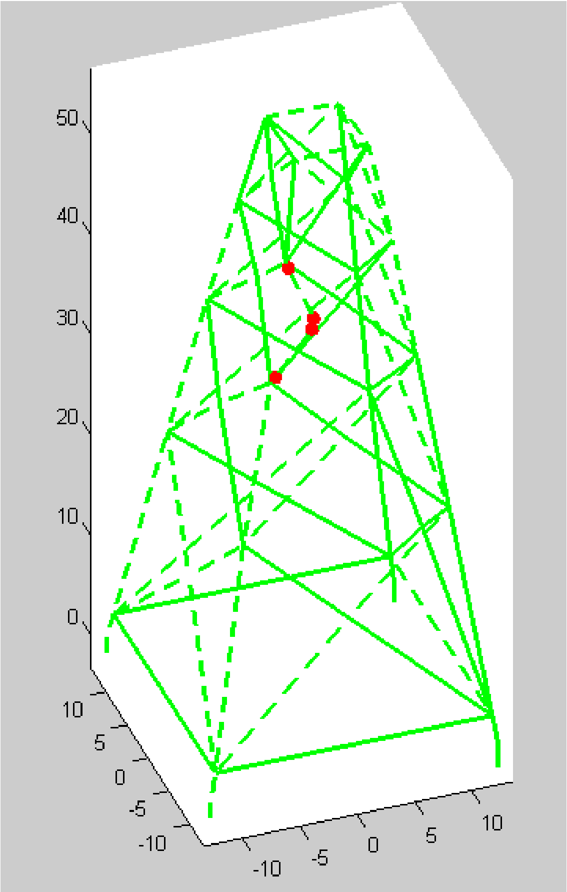
- Model too rigid in case of large energy impacts
- Other deformation modes have to be added

[BULDGEN L., LE SOURNE H., PIRE T., *Extension of the Super-Elements Method to the Analysis of a Jacket Impacted by a ship*, Marine Structures, 2014, vol. 38, pp. 44 – 71]

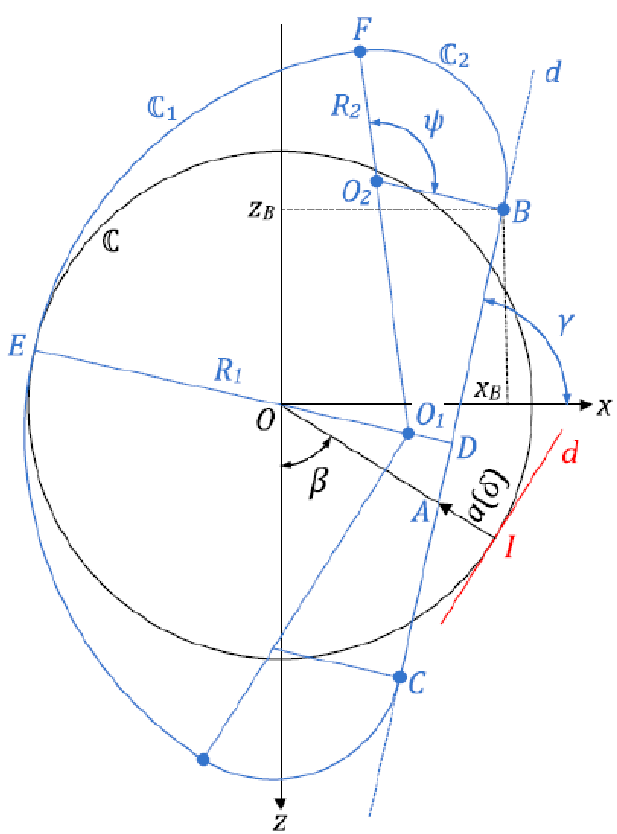
Global deformation

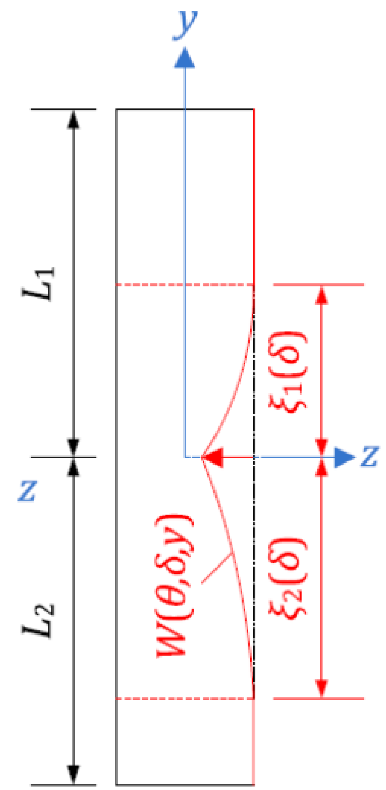






Local crushing : model





[BULDGEN L., LE SOURNE H., PIRE T., *Extension of the Super-Elements Method to the Analysis of a Jacket Impacted by a ship*, Marine Structures, 2014, vol. 38, pp. 44 – 71]

Local crushing : developments

- Local crushing
  - Rings

$$\dot{E}_b = 2m_0\left(\frac{V_B}{R_2} + \left(\frac{1}{R_2} - \frac{1}{R_1}\right)V_F + \int_F^E \dot{\chi}_1 dl + \int_D^F \dot{\chi}_2 dl\right)$$

  - Generators

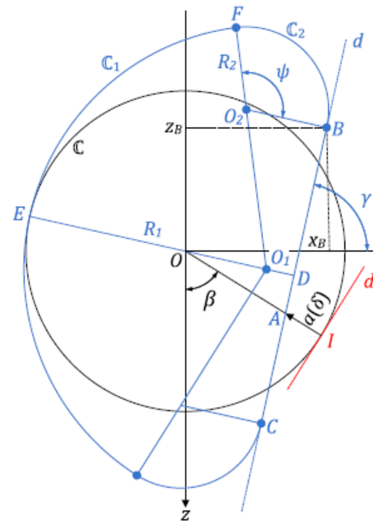
$$\dot{E}_m(\theta,\delta) = n_0 \int_{-\xi_2}^{\xi_1} \dot{\varepsilon}_m(\theta,\delta,y)dy = n_0\dot{\delta}\left(\frac{1}{\xi_1} + \frac{1}{\xi_2}\right) w(\theta,\delta)\frac{\partial w}{\partial \delta}$$

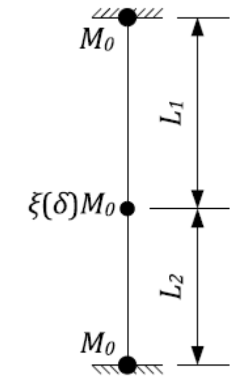
  - Total

$$P_l(\delta)\dot{a}(\delta) = \sum_i \dot{E}_i$$

- Three-hinges mechanism

$$P_g(\delta) = \frac{L_1 + L_2}{L_1 L_2}\left((1+\xi_t)M_0\left(1 - \frac{N(\delta)^2}{N_0^2}\right) + N(\delta)(\,\delta - \delta_t\,)\cos\gamma_t\right)$$





Local crushing : results

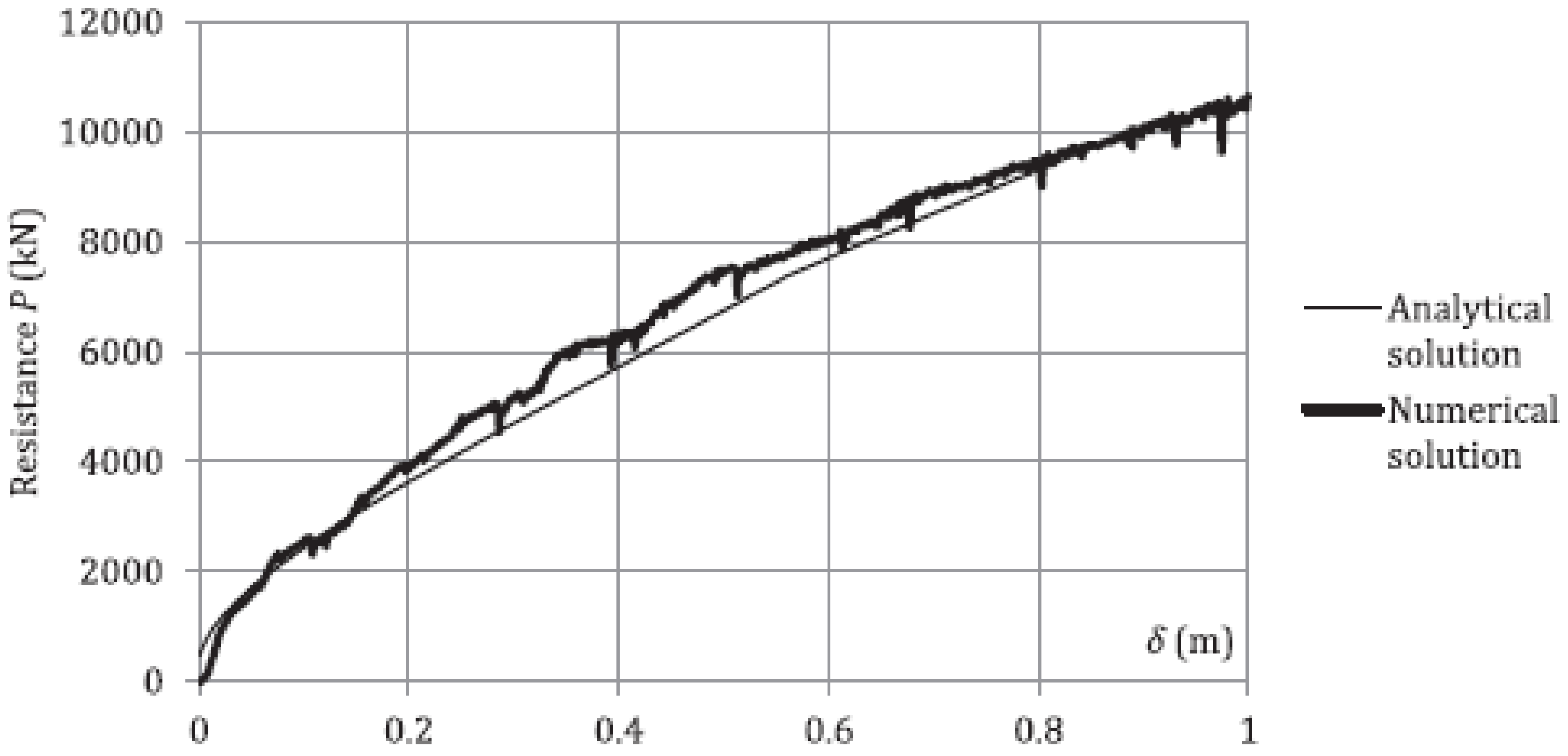
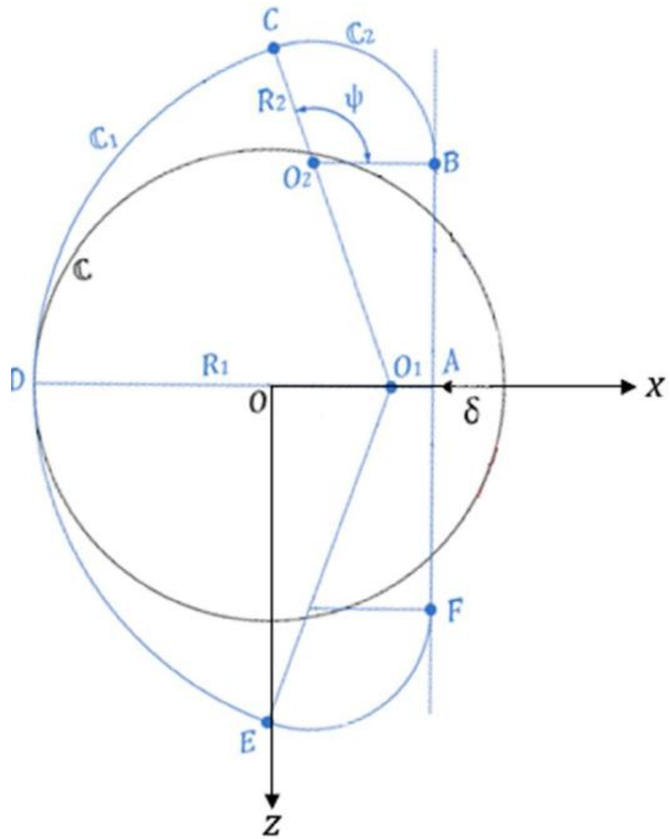
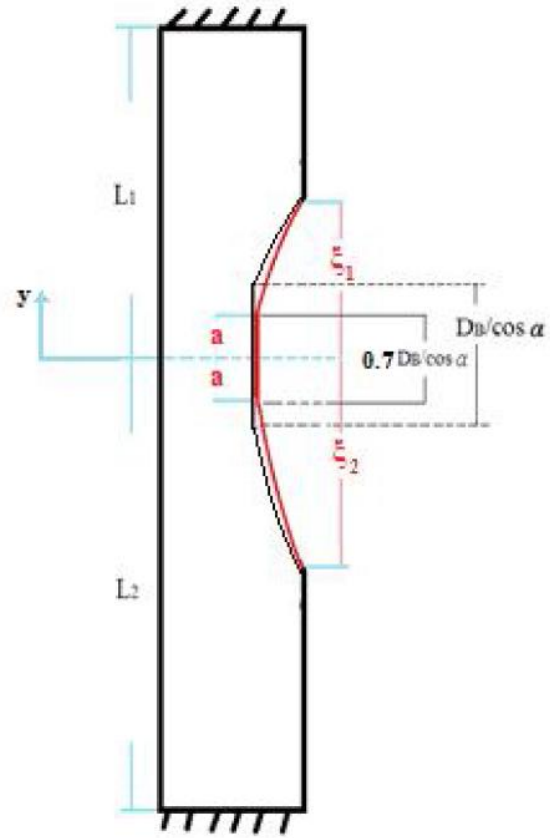


Fig. 20. Comparison of the analytical leg resistance to the numerical one for scenario 1.2.

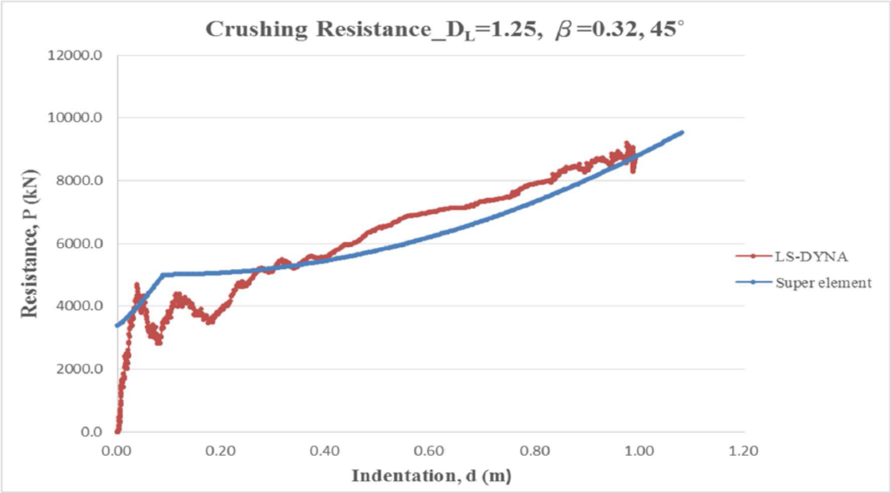
Punching : model

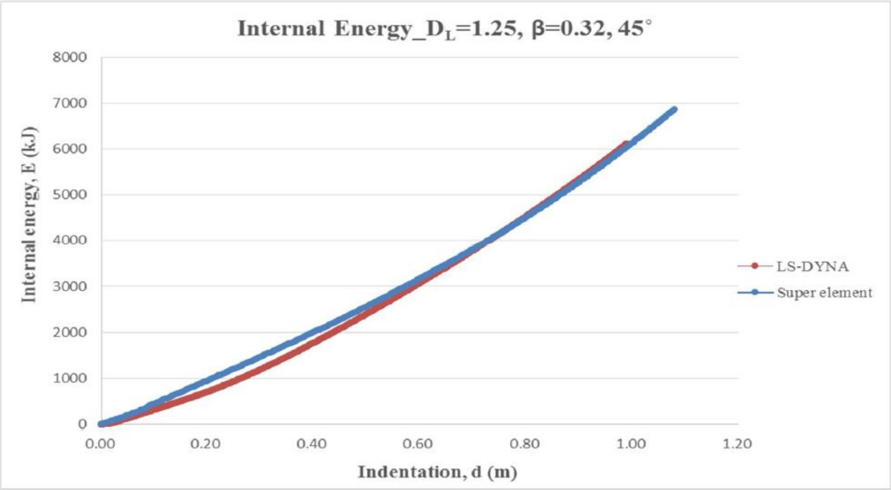


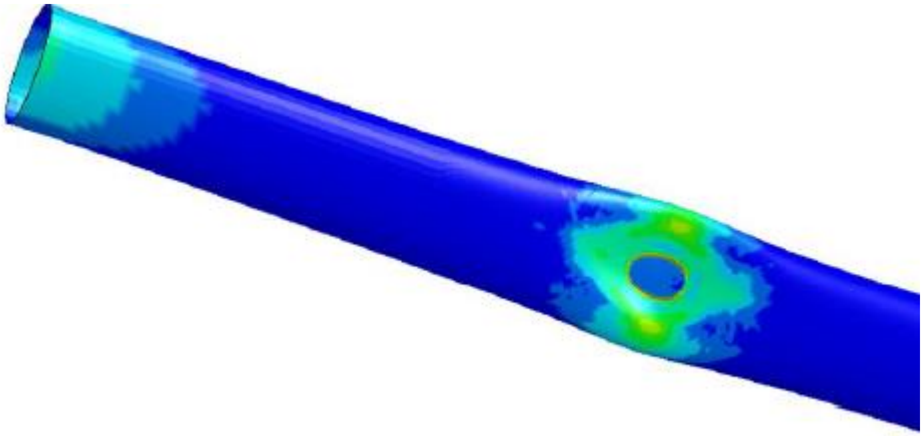


[HSIEH J.-R., *Analytical formulations for ship-offshore wind turbine collisions*, Master thesis, Nantes : ICAM (EMSHIP Erasmus Mundus Master Course), 2015, 104 p.]

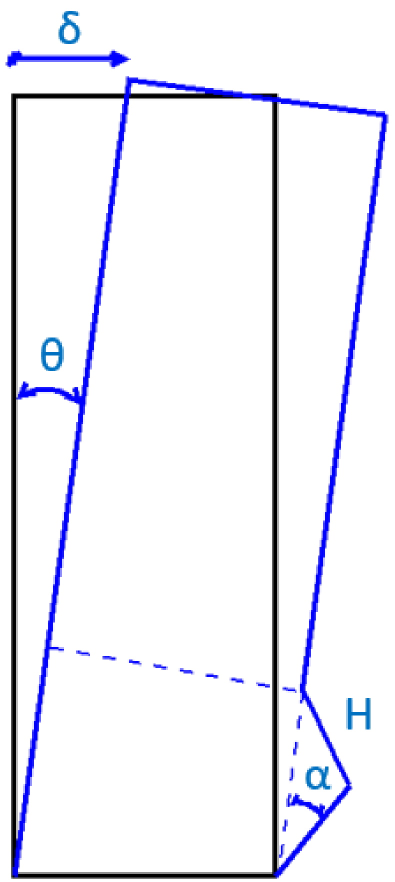
Punching : results

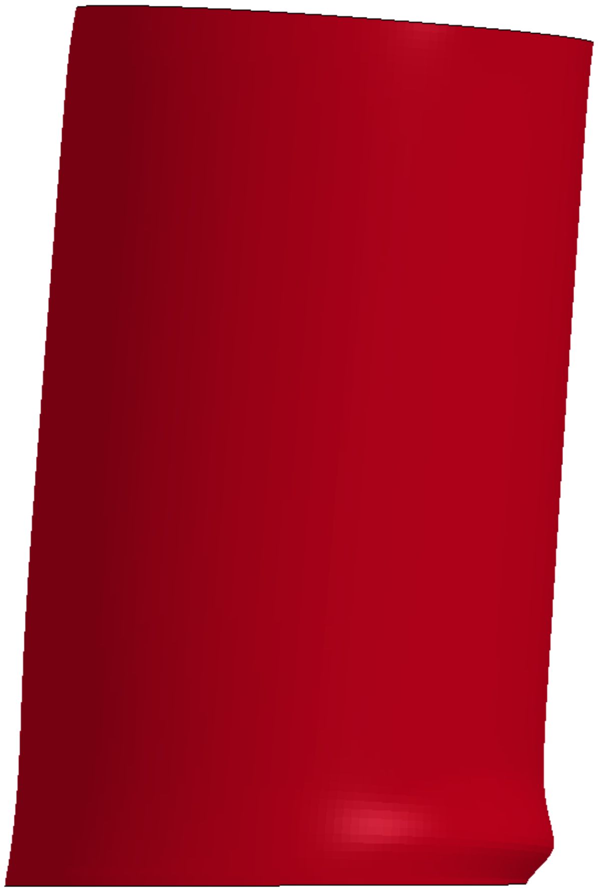






Buckling : model





Buckling : developments

- Hinges 1-3

$$\dot{E}_{H,1-3} = 2m_0 \int_0^{\pi/2} \frac{\partial\alpha}{\partial\theta} R d\theta\, \dot{\theta}$$

- Hinge 2

$$\dot{E}_{H,2} = 4m_0 \int_0^{\pi/2} \frac{\partial\alpha}{\partial\theta} \overline{ds} d\theta\, \dot{\theta}$$

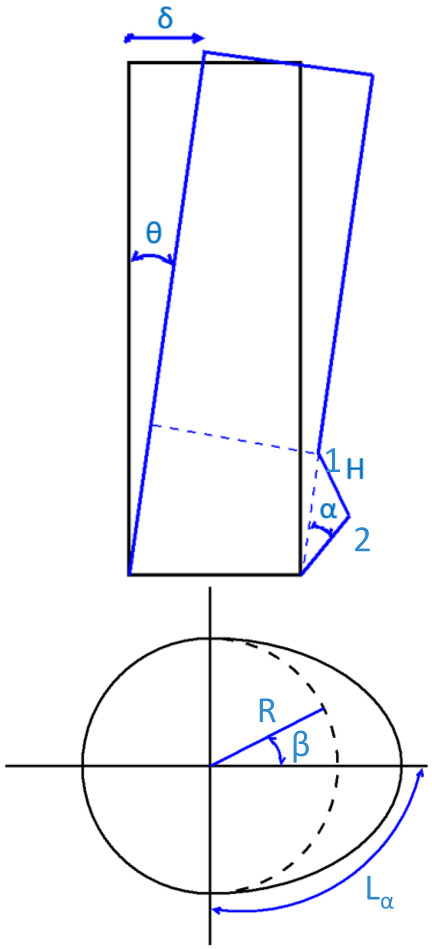
- Membrane effect

$$\dot{E}_M = 4n_0 \int_0^H \int_0^{\pi/2} \dot{\varepsilon}\overline{ds} d\beta dz$$

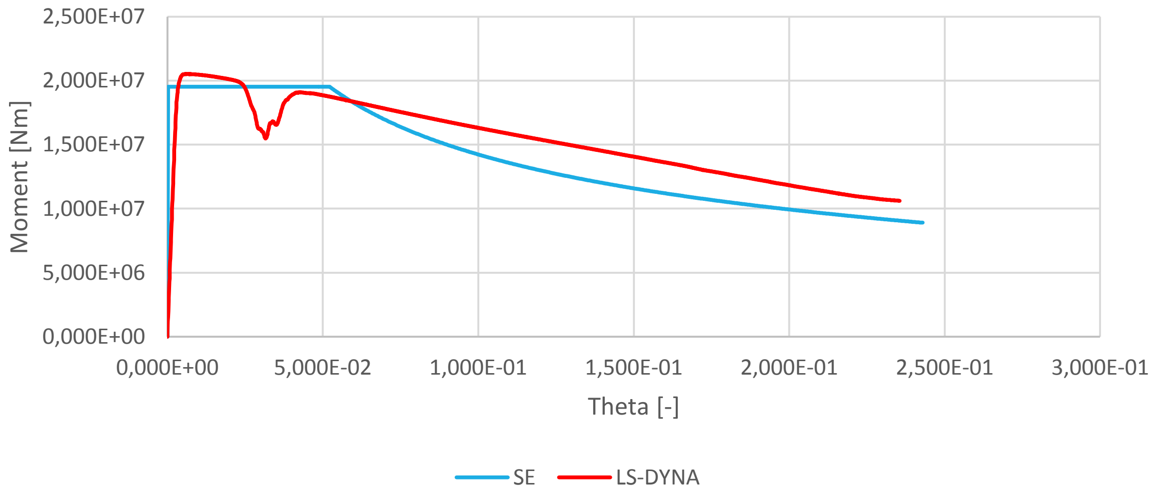
$$= 4n_0 \frac{\dot{\theta}}{\pi R} \int_0^H L_\alpha^2\, dz$$

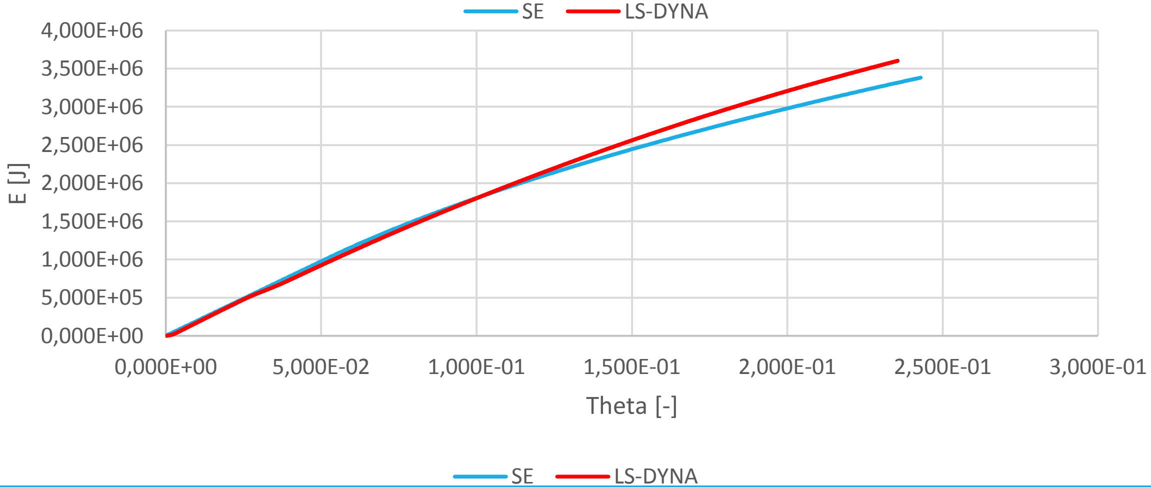
- Total

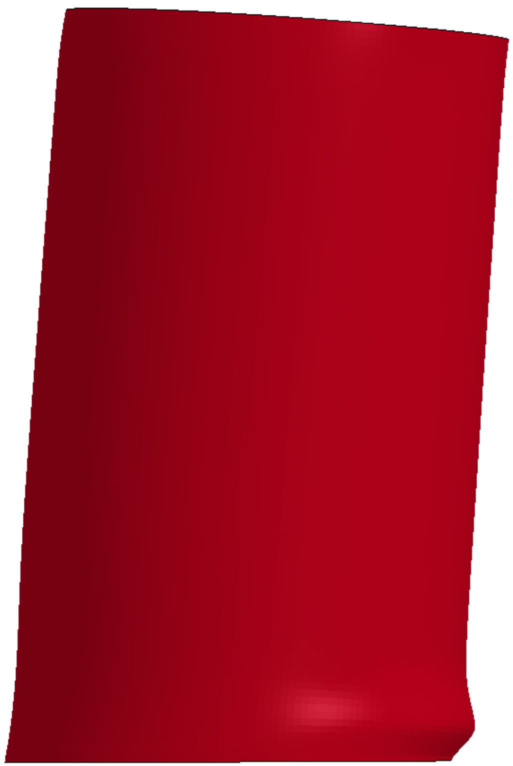
$$M\dot{\theta} = \sum_i \dot{E}_i$$



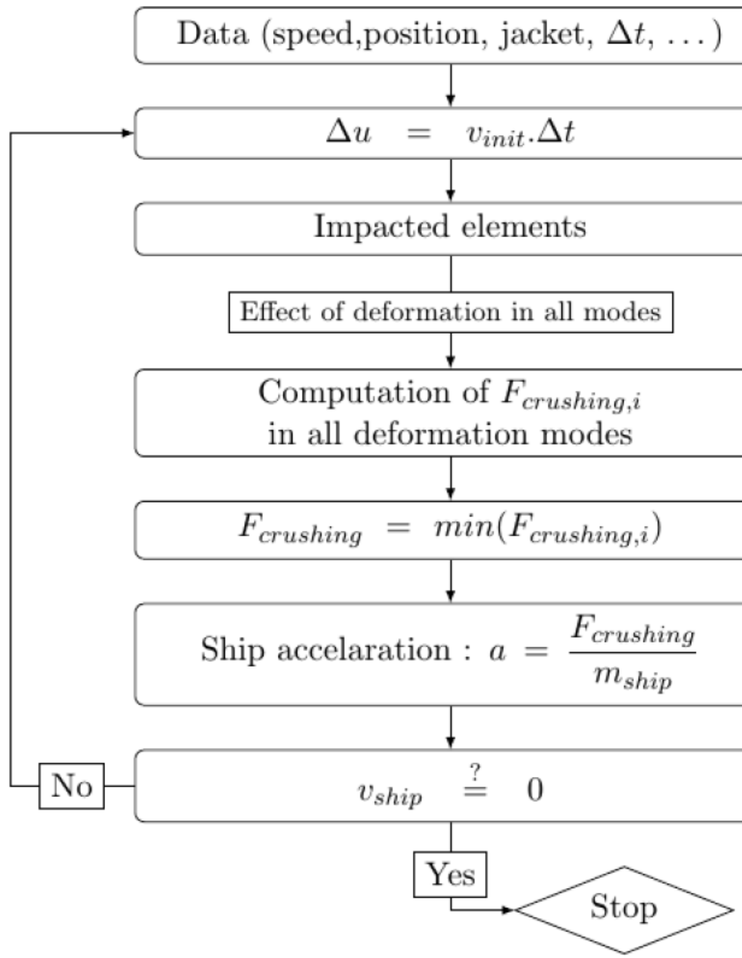
Buckling : results







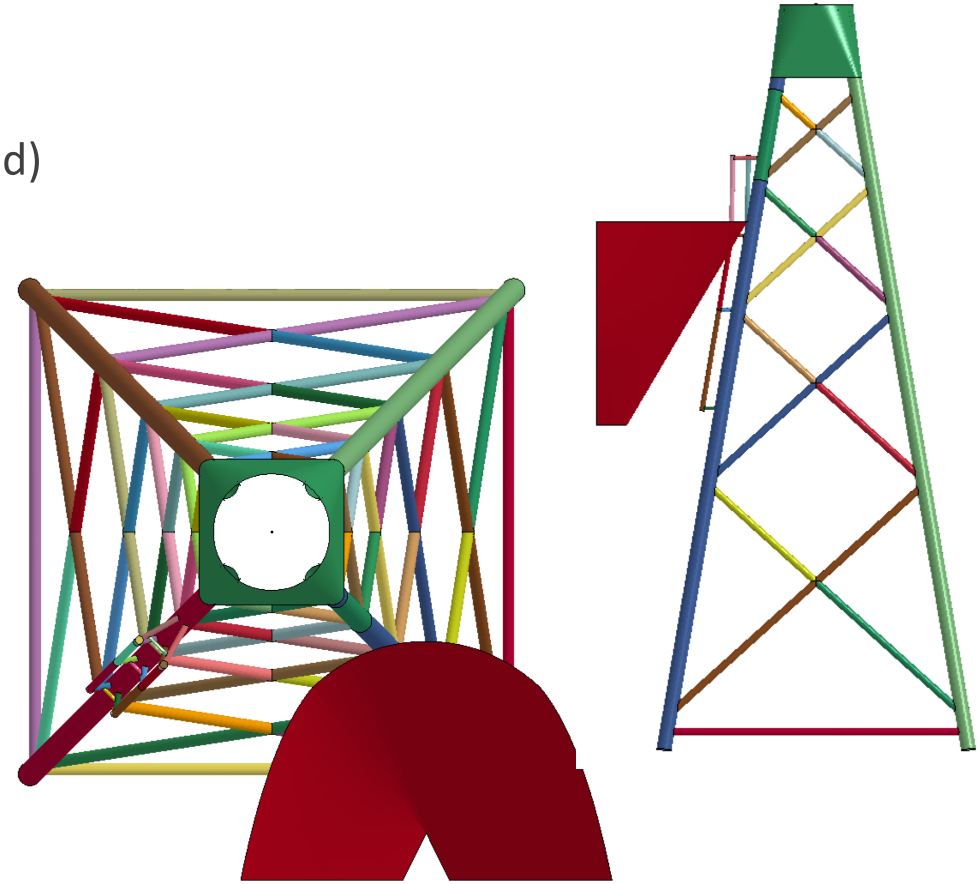
Complete algorithm



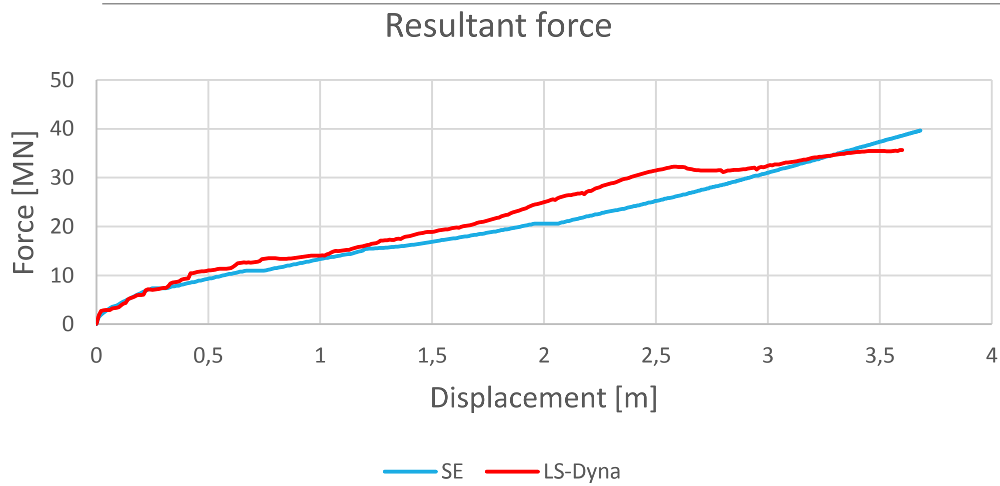
Complete model : scenario

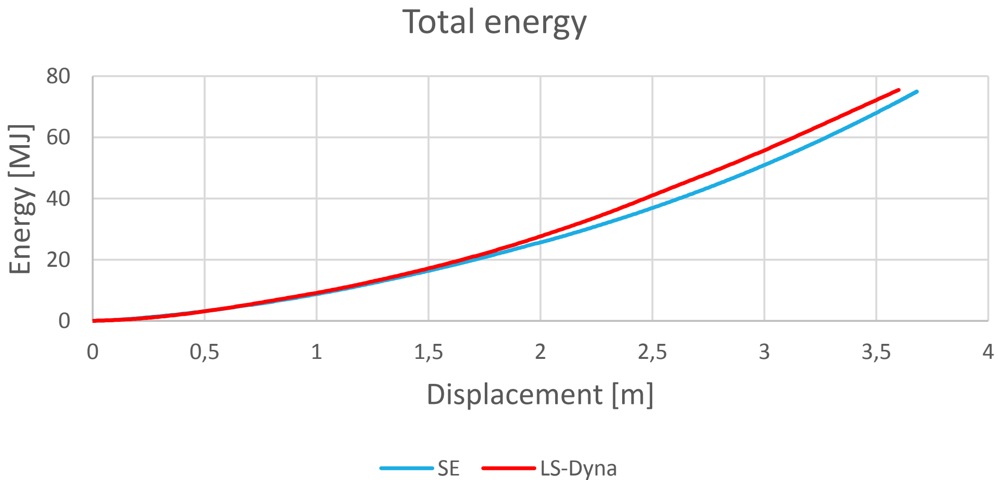
- Colliding ship :
  - Non-bulbous OSV
  - 6000 tons (added mass included)
  - 5m/s initial speed
  - 75 MJ kinetic energy

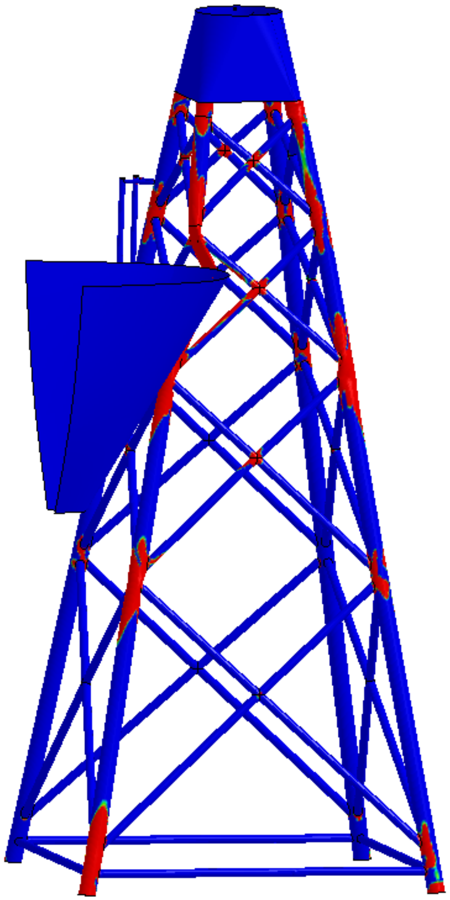
- Impact point
  - On a leg, between two nodes
  - Perpendicular to one plan



Complete model : results

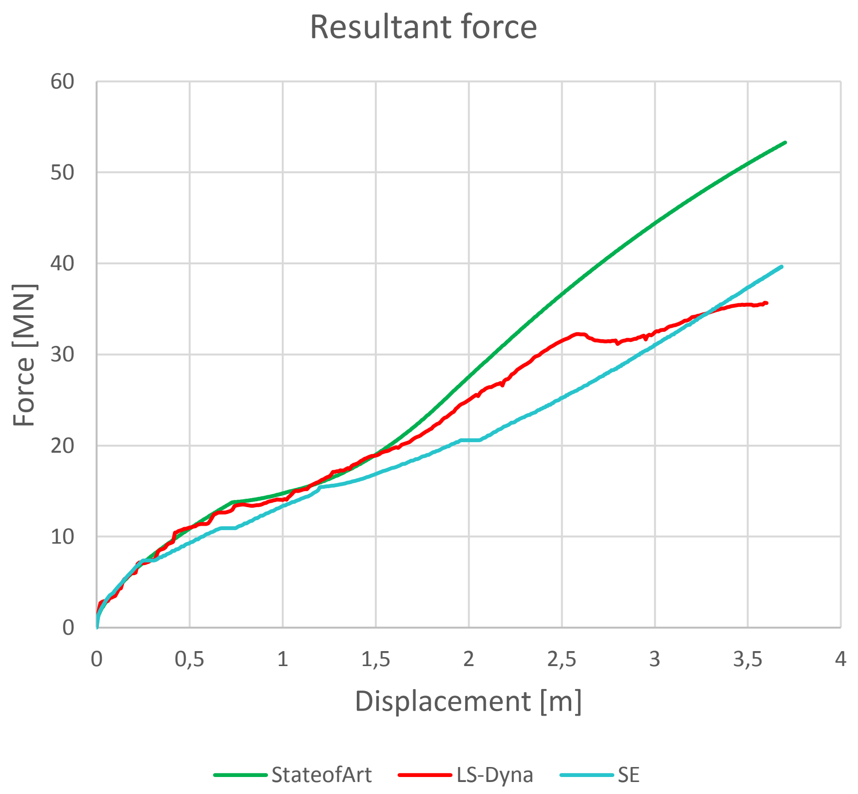


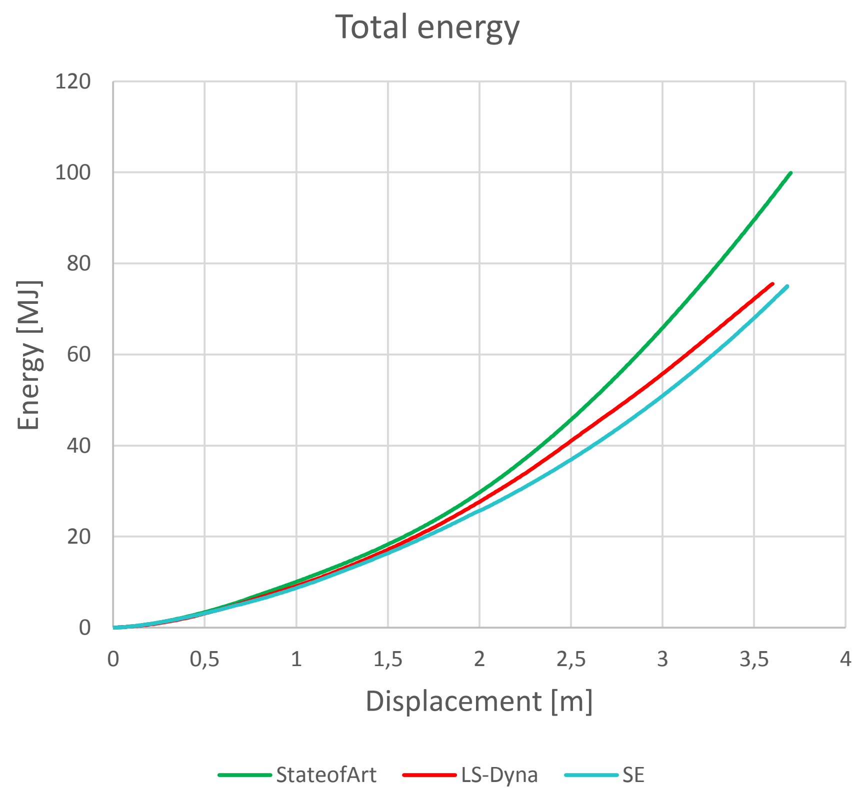




Complete model : comparison

- Better accuracy for large energy impact





Conclusions

- Short computation time : ≈ 5 minutes (instead of ≈10h for FE)
- Good accuracy in results : difference of max. 10% in terms of energy
- Still needs more validation tests

Good tool for pre-design stage

Acknowledgements

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MSC Software Corporation

Technical support to the use of the software *Patran* and *Nastran* to create numerical models and perform finite element analyses.

Thank you