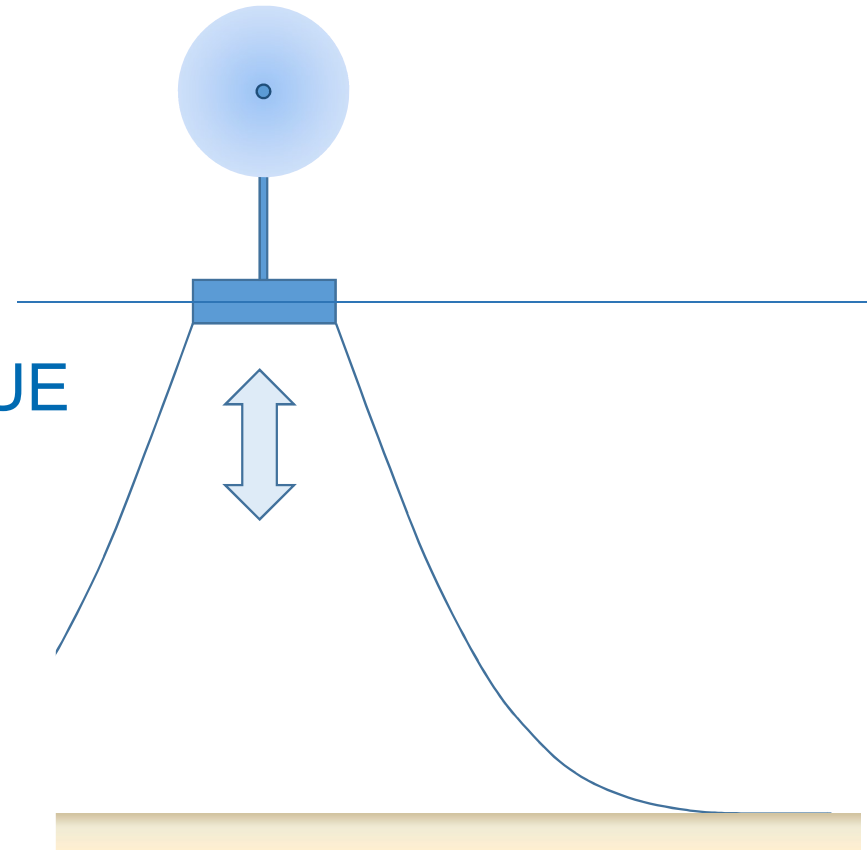


FOWT MOORING LINES FRETTING FATIGUE

M. MARTINEZ, M. GUITON, S. MONTALVO, F. BUSSOLATI (IFPEN)
P.-A. GUIDAULT, O. ALLIX (LMT, ENS CACHAN)
S. FOUVRY (LTDS, ECL)

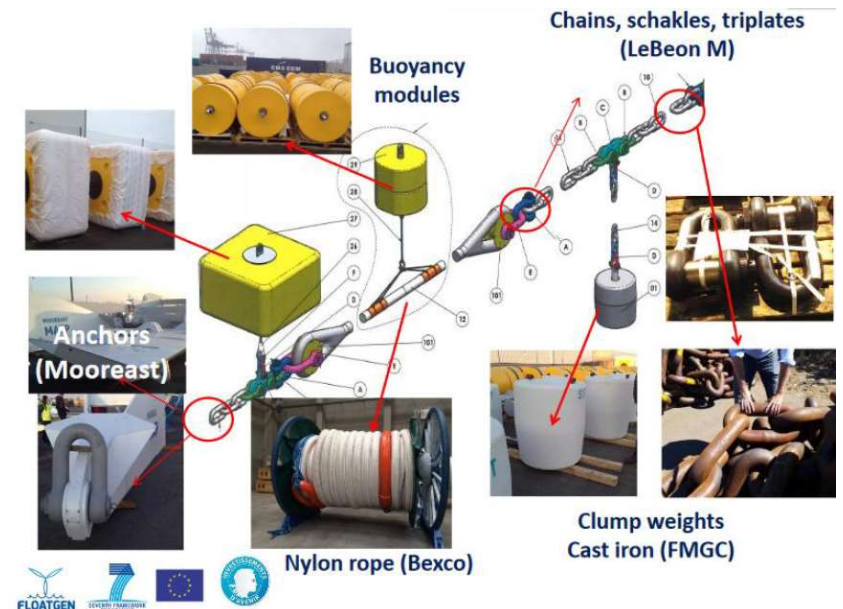


MOORING LINES

- Mooring lines are essential components for ensuring FOWT reliability for station keeping and stability
- Choice of material (chain, spiral strand wire rope, fiber ropes) depends on the configuration (water depth, floater system, taut vs catenary mooring lines)
- Usually mooring lines combine chain at the top (tensioning) and bottom (abrasion resistance, weight for catenary) and steel wire rope or fiber ropes in the middle.
- To ensure proper dynamic behaviour, additional clump weights and or buoyancy modules may be added which complicates installation procedure and increases the mooring cost.



H2020 Mooring Sense D2.2 (GA no 851703)



Floatgen mooring components for 33m water depth, in H2020 CoreWind D2.1 (GA no 851083)

CHAINLESS CONNECTION AND CHALLENGES

- **Top chain is the weak point of the mooring line**
 - Poor fatigue properties, corrosion
 - Footprint on the platform
- **Solutions exist to connect directly the rope on the platform**
 - Turret-rope connectors
 - Tension the mooring line away from the platform : mid-water chain tensioner
- **In chainless connection, ropes are loaded in tension + bending**
 - Fatigue properties in tension and bending are not known
 - Maybe critical for steel ropes
- **Increasing interest for fiber rope but steel wire rope are still selected (e.g. Hywind Tampen) and avoid non-linear mechanical behaviour with possible time-dependency**

FPSO key turret wire rope connection
(Leeuwenburgh et al, 2014 OTC-25323)



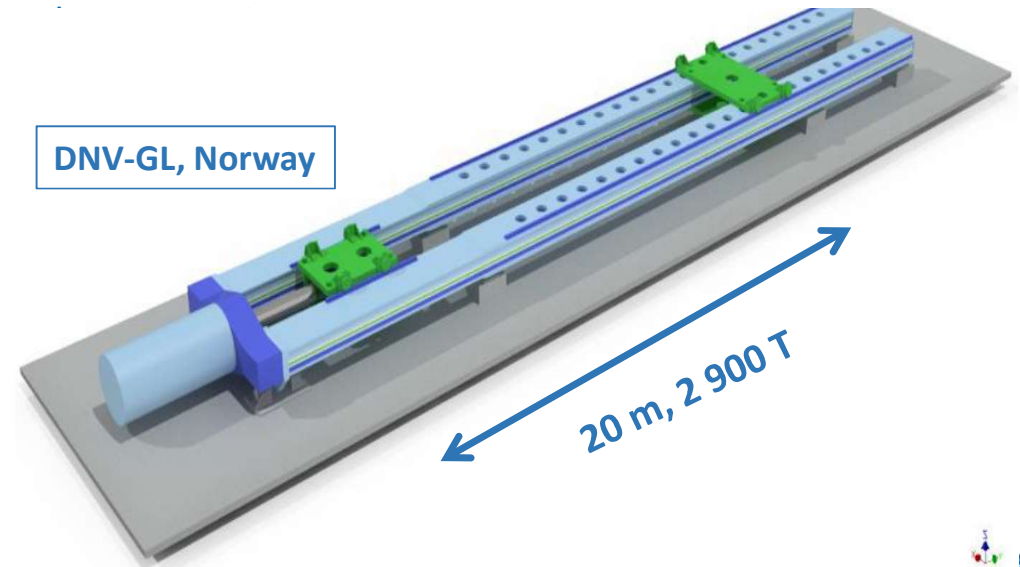
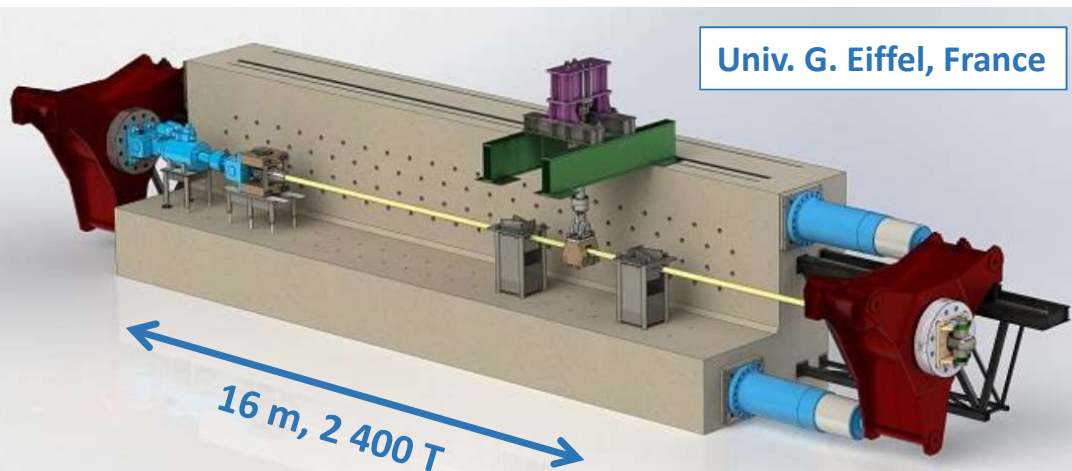
<https://www.bridon-bekaert.com/en-gb/about-us/what-we-do/news/equinor-hywind-tampen-floating-wind-project>

<https://europe.arcelormittal.com/newsandmedia/europenews/Hywind-Tampen>

FATIGUE IN TENSION-BENDING

NEW ENERGIES

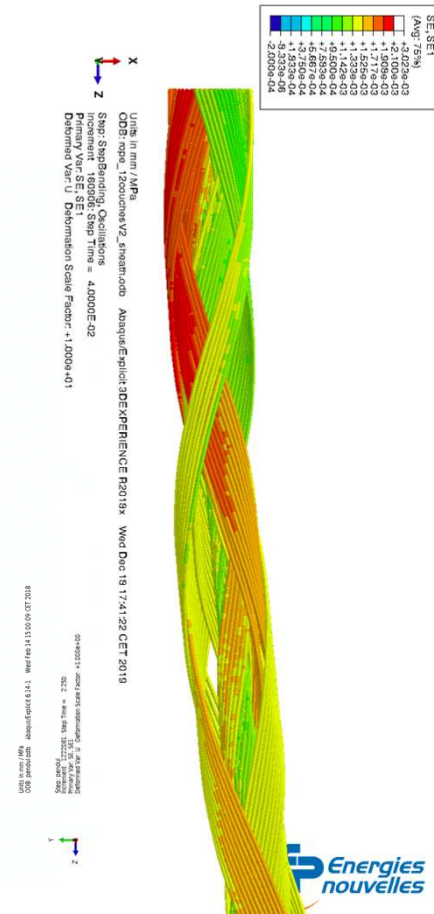
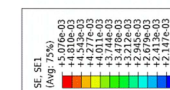
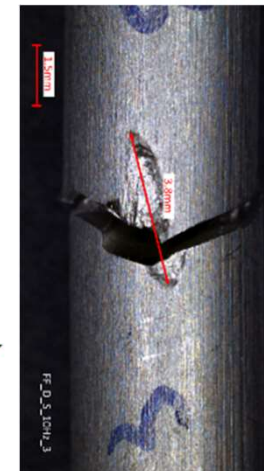
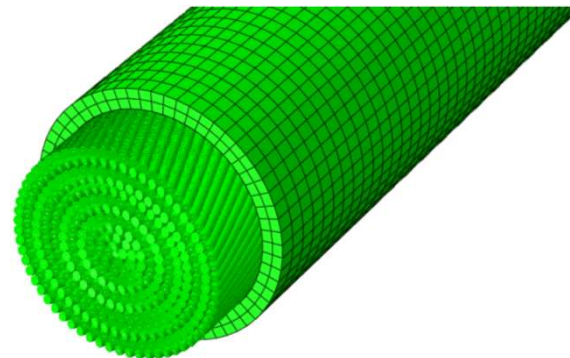
- Mooring ropes are designed and qualified in tension-tension but not in tension-bending
- Qualify ropes for bending fatigue can be a heavy process
 - High capacity ropes → high capacity test rigs
 - Very few experimental data base
 - Fatigue tests in cyclic bending + tension are expensive and complex
 - Loading somewhat different from the real ones
 - Dedicated tests required for bending fatigue



LOCAL APPROACH ON FATIGUE

NEW ENERGIES

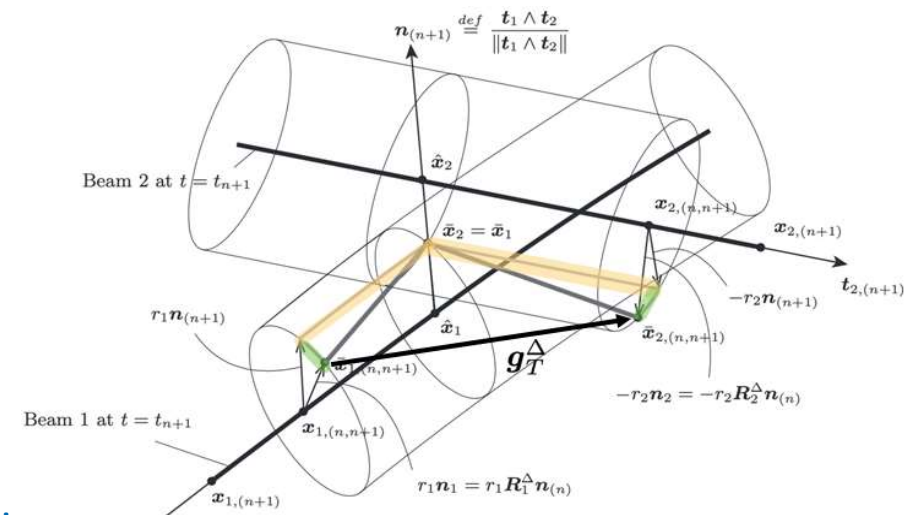
- **Numerical simulation and a local fatigue approach may ease the design process**
 - Spiral strand is a relatively « simple » structure with helicoidal wires
 - Finite Element simulations provide the local loading with wire contact and friction
 - Small scale fatigue tests provide the local fatigue criterion
- **IFPEN has been working on this topic since 2014**
 - Service offers to offshore companies
 - A multi-partners project (French private innovation program Citeph)
 - Two PhDs
 - F. Bussolati with LMT, ENS Paris-Saclay (2019)
 - One with LTDS, Ecole Centrale Lyon (on going)
 - **Several communications in conferences**
 - OIPEEC 2015
 - OIPEEC 2019
 - OMAE 2018
 - OMAE 2020



PHD ON A USER CONTACT AND FRICTION ELEMENT

NEW ENERGIES

- Phd of F. Bussolati from 2016 to 2019 with P.-A. Guidault & O. Allix of LMT, ENS Paris Saclay, UMR8535
- **Development of a user contact and friction element in Abaqus/Standard™ dedicated to ropes**
 - Node-to-node contact and friction between beams
 - No need to update contact pairing during simulation
 - Small sliding and finite rotations kinematics
- **Very large improvement of the simulation time**
 - Contact forces vary smoothly with section rotations which provides robustness for convergence of solver
 - Simulation time reduced by a factor around 60 for a sample of about 60mm diameter and 7m length when compared to Abaqus/Explicit finite sliding contact
 - no loss of of precision in the results and less numerical noise



F. Bussolati, M. Guiton, P.-A. Guidault et al., A New Fully-Detailed Finite Element Model of Spiral Strand Wire Ropes for Fatigue Life Estimate of a Mooring Line, OMAE2019-96165

VALIDATION OF THE NUMERICAL MODELS

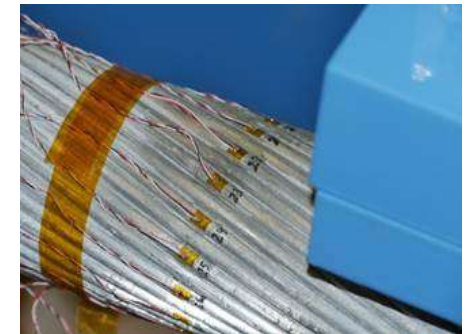
NEW ENERGIES

● Citeph project : benchmark of numerical models on a full scale test on a spiral strand

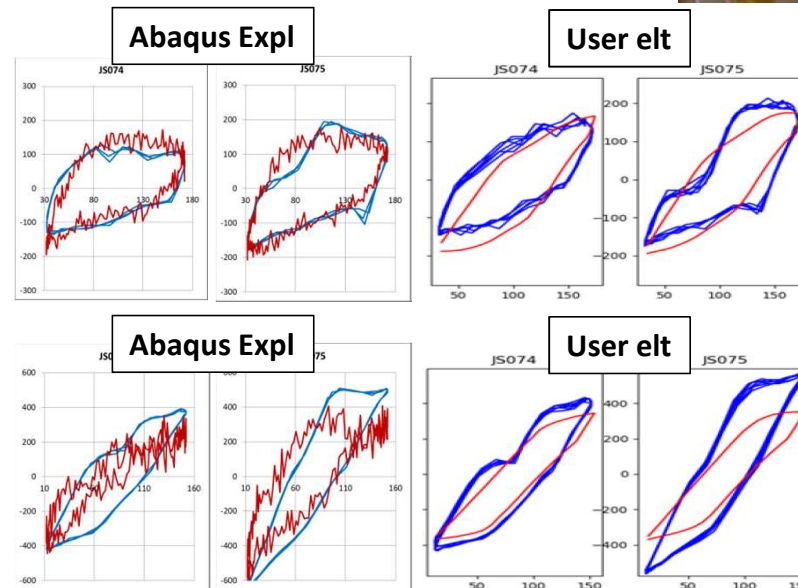
- sponsored by Total, Saipem, Arcelor-Mittal, BV
- performed by IFPEN (Abaqus Explicit and User Elt) and Principia (Multifil model of D. Durville, MSSMAT, Centrale Supélec)

● Spiral strand rope under tension + cyclic bending

- Tension = 20 T and 60 T, bending radius = 4,525 m
- Stress in the wires of the outer layer measured with strain gages



IFPEN 5 000 kN rig



20 T

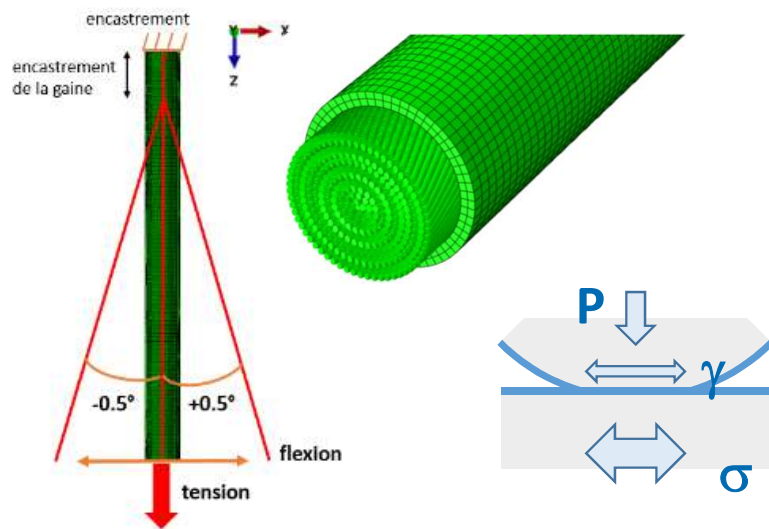
— Model
— Exp.

60 T

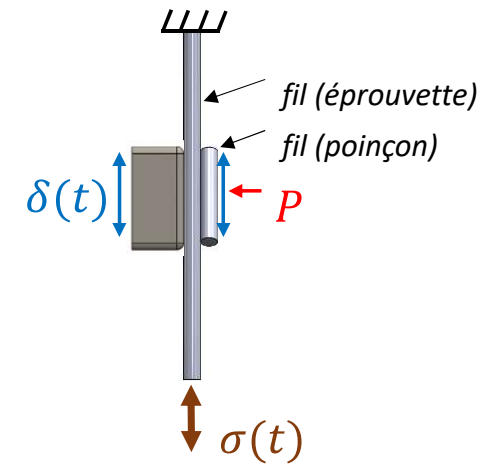
FATIGUE CALCULATION

NEW ENERGIES

- PhD of S. Montalvo started in 2019 with S. Fouvry, LTDS, Ecole Centrale Lyon, UMR CNRS 5513
- In cyclic bending, fatigue is driven by the axial stress in wires **AND** the fretting
- Critical relative sliding is of tens of μm order



Stress and fretting loads



Fretting-fatigue curves

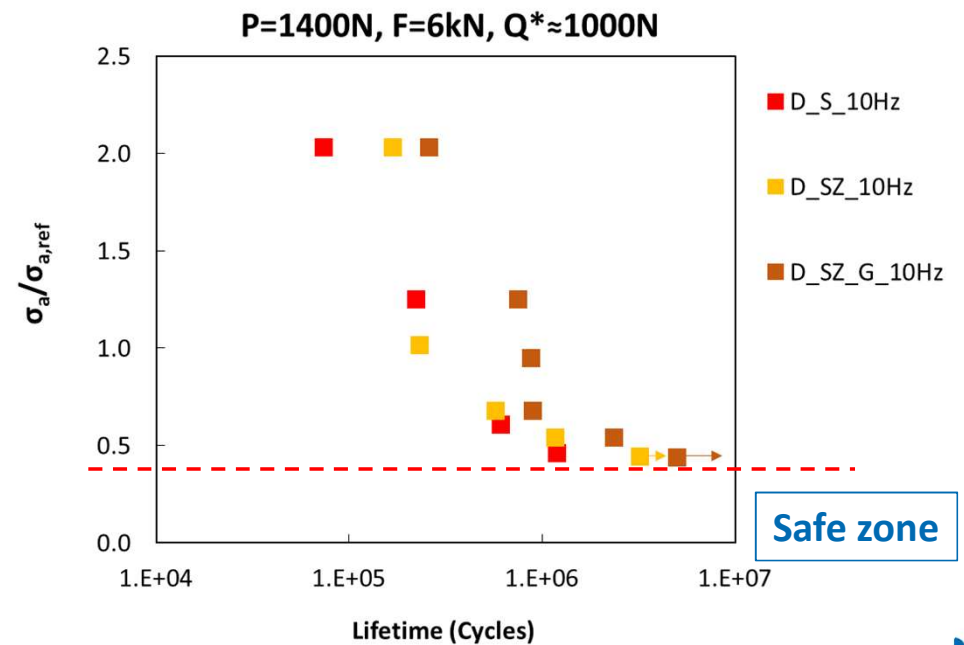
Fatigue OK - NOK

EXAMPLE OF FATIGUE CURVE (PHD S. MONTALVO)

NEW ENERGIES

● Wöhler curves determined by fretting fatigue tests (LTDS, Ecole Centrale de Lyon)

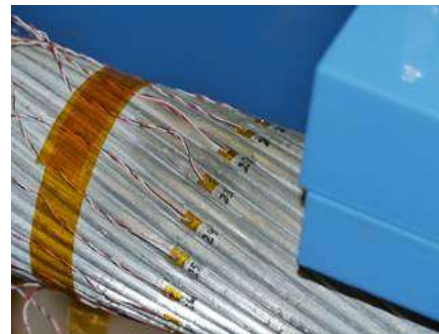
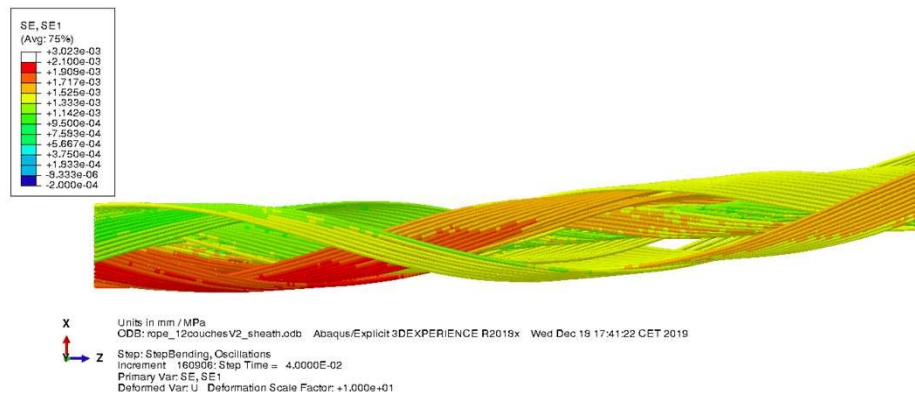
- Contact pressure and sliding amplitude fixed → worst mechanical condition extracted from the numerical simulation
- Three contact conditions : steel-steel, zinc-zinc, zinc-zinc + grease



CONCLUSION

NEW ENERGIES

- Chainless connection is a solution to top chain problems
- Chainless connection requires the knowledge of the rope bending behaviour
- Fatigue properties of ropes in bending are not known
- Evaluate them with full scale tests is expensive and time consuming
- A methodology is proposed to evaluate them on spiral strands thanks to numerical simulation and local fretting-fatigue tests



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