Combined State of the Art Inspection and Analysis of Flexible Risers

AOG 2017

Subsea Inspection, Monitoring and Life Extension

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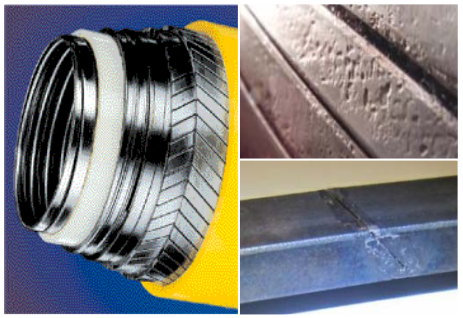
Flexible Riser Inspection and Assessment

Flexible Riser Inspection Operation

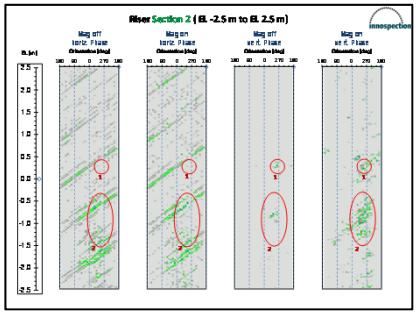
innospection

Defect Detection

(cracks, pitting, wire misalignment)



Data Reporting



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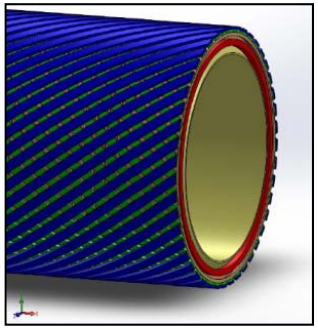
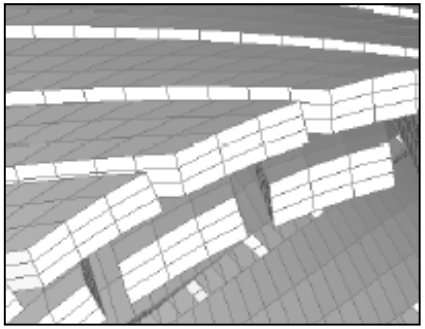
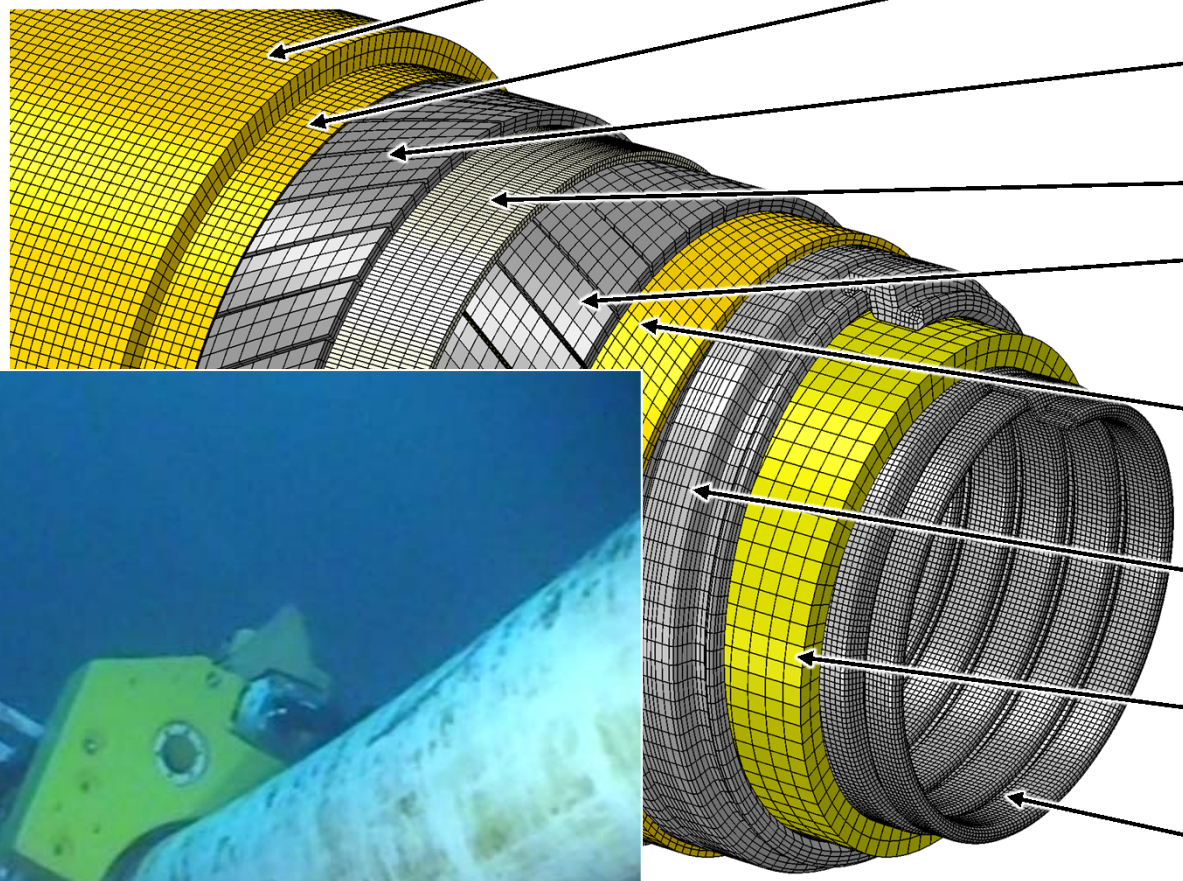
Risk / Life Time Assessment by FEM Analysis (FLEXAS™)





Inspection of Flexible Pipe



Flexible Riser - InspectionTechniques

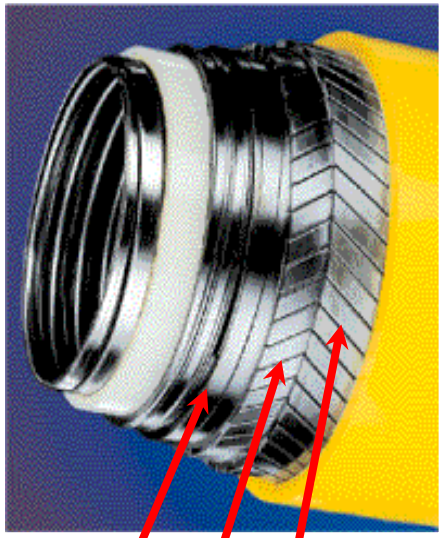
Overview of existing external deployed NDT techniques for Flexible Riser Inspection

	Ultrasonic	MAPS-FR	Digital Radiography (DRT)	MEC-FIT
PRINCIPLE	Pulsed Echo Ultrasound	(Electro-) Magnetic Field Stress	External Radiography	(Electro-) Magnetic & Eddy Current Field Induction
DETECTION	Thickness of outer tensile armour wire	Fully Severed Wires in the Outer Wire Layer when scanning	Mainly used for topsides to date, but can detect: • Cracks • Corrosion • Loss of interlock	• Corrosion (pitting) • Thickness Loss • Cracks • Wire Misalignment • Detection in 1st , 2nd and partly 3rd layer
DEPLOYMENT	ROV deployed Annulus flooding required	ROV Deployed No flooding required	Subsea operations are limited at this stage. Static shot film (CT potential for future inspection)	ROV Deployed Fast Scanning No flooding required Requires calibration

MEC-FIT™

Magnetic Eddy Current Flexible Riser Inspection Tool

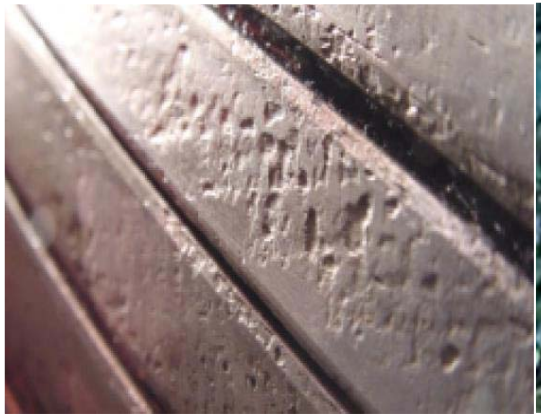
- External scan, detection in 2 (up to 3) layers:
  - corrosion pitting
  - corrosion thickness loss
  - cracking
  - wire misalignment / gaps
- Fast external scanning
- No flooding required



Pressure Armour wire Layer

2nd Armour wire Layer

1st Armour wire Layer

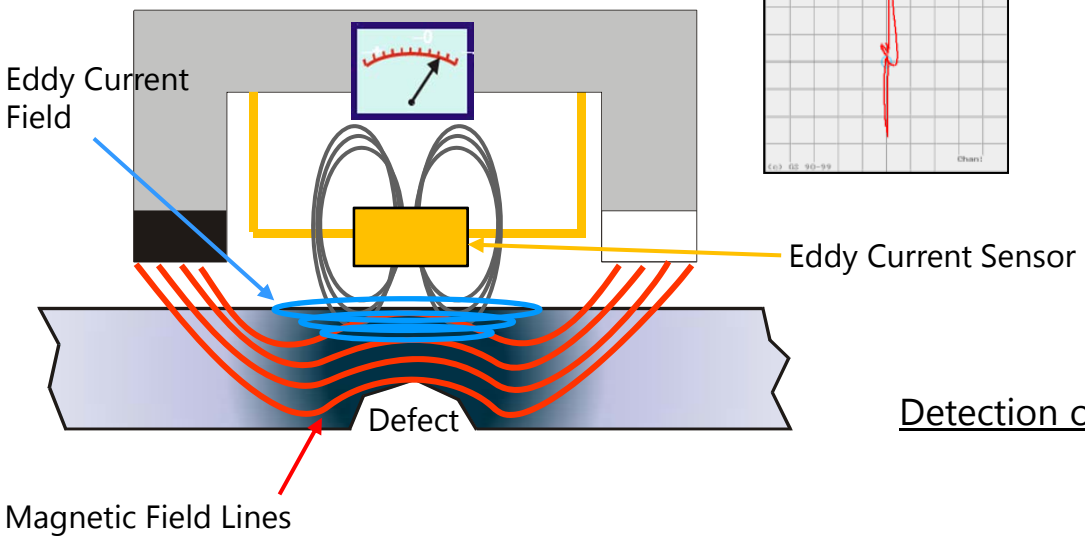


innospection

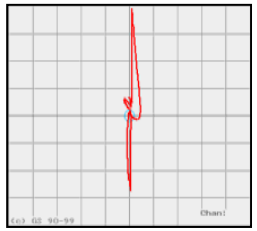
MEC (Magnetic Eddy Current)

Magnetic Field controlled High Frequency Eddy Current

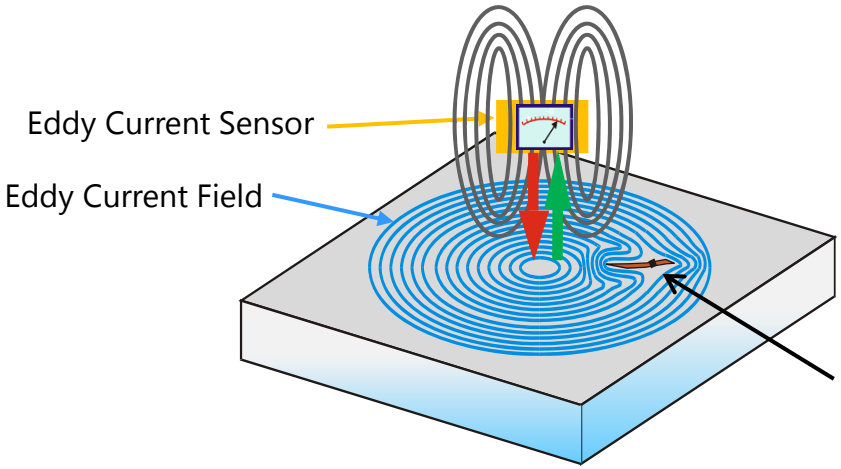
Detection of Far Side Defects



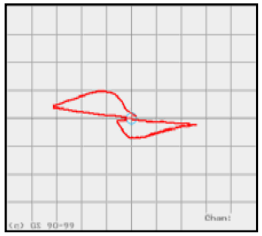
Signal Response



Detection of Near Side Defects

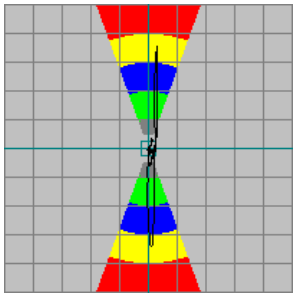


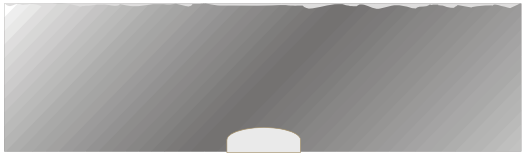
Signal Response



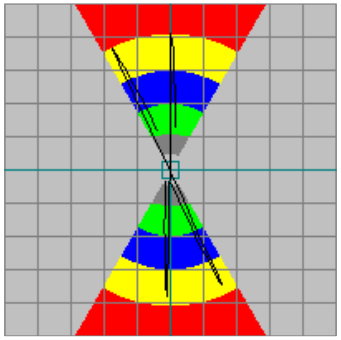
MEC - A Comparative Method

Calibration defects

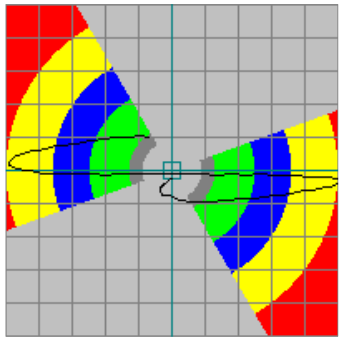




Far side defect
signal phase



Near side defect
signal phase

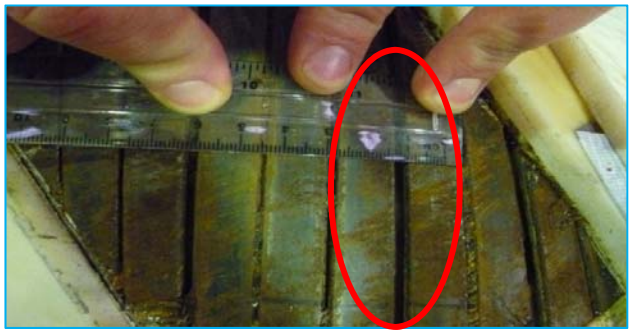


MEC-FIT Development

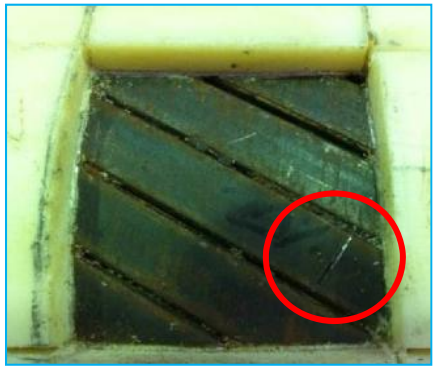
Wire Gap and Defect Indications

Signal Phase Signatures

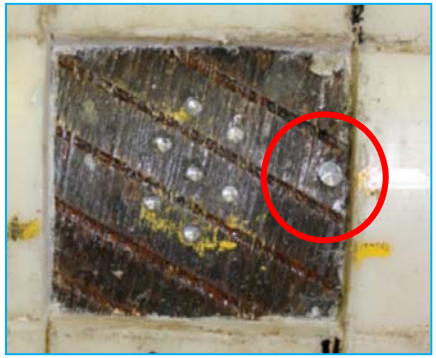
Increased Wire Gap



Crack Simulation (machined)



Localised Pitting (machined)



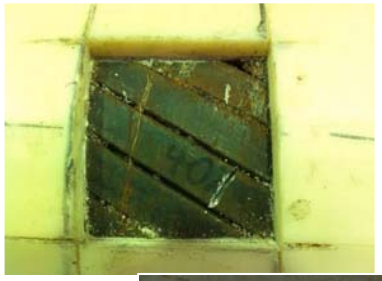
MEC-FIT Development

Defect Signature Database

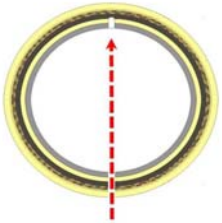
Tests / Signal analysis

Localised Wall Loss

Wire thinning



Wire crack



Defects Drilled from Inside out

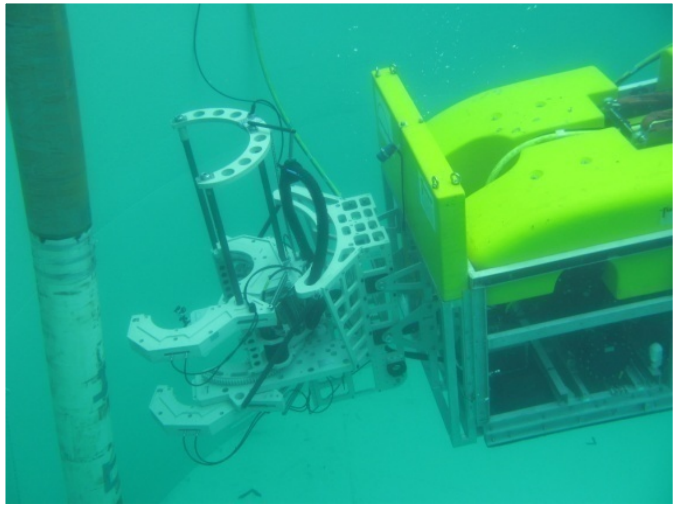
Signal Signature Catalogue

35 ° structure Flexible Pipe

Defect Type	Loop Magnet off	Loop Magnet intermediate	Loop Magnet On	Phase	Change Mag-level
1 Gap upper level				310°	Amp
2 Cut wire Lower layer	x			310°	
3 Grinding on upper wire	Center / Edge			310°	
4 Cut wire Surface (crack like)				310°	
5 Mat. in-homogeneity	x			310°	
6 Far side ml in solid Pipe	x			310° (90° for SLOFEC)	
7 Near side ml in solid pipe				310° (90° for SLOFEC)	

Flexible Riser Inspection with MEC-FIT™

MK1 – ROV deployed to MK 3 top side deployed

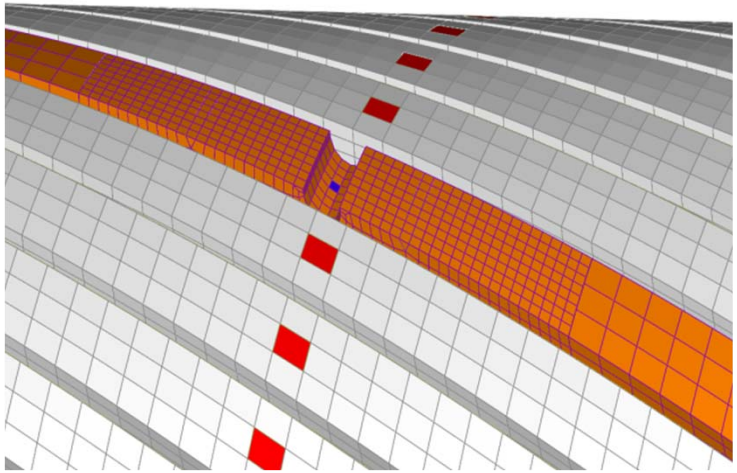


What to do with Inspection Results?

Global Analysis with MEC-FIT™ Damage Data integrated in a FLEXAS™ Model

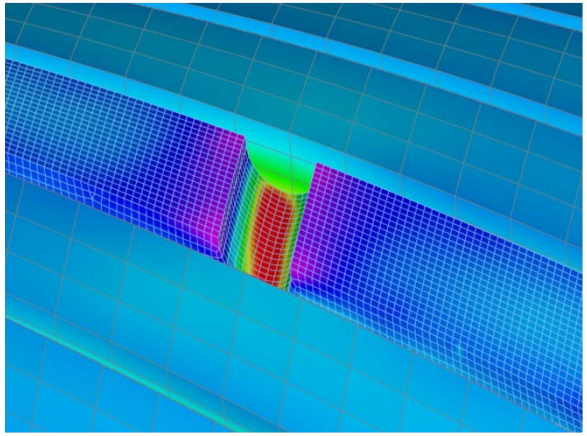
Actual Defect

Finite Element Model



MEC-FIT Signal Analysis

Stress Plot



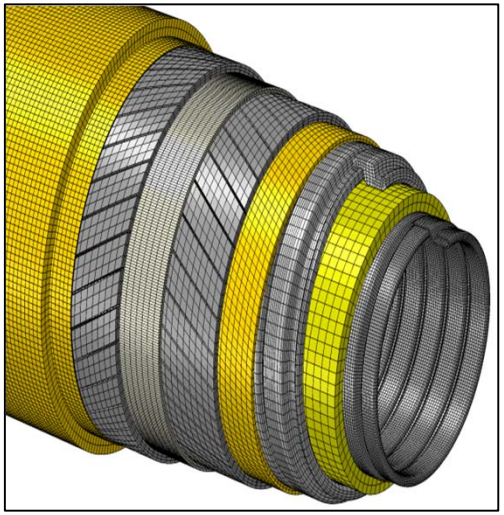
Modelling of Defects

How do you incorporate local defects into a global model?

- A detailed FEM model is required over the whole length of the riser to capture the complex geometry and nonlinear kinematics.
- In order to extract accurate flexible riser fatigue life predictions it is necessary to compute accurate tensile armour wire stress time-histories from each wire.\
- However, computing with these FEMs in commercial FE solvers is major hurdle:

- ExxonMobil/Seaflex (2007): "direct use of local analysis tools* [based on the finite element method] for long time-domain simulations is **very computationally intensive and impractical**."
- Technip/IFP (2012): Abaqus nonlinear quasi-static analysis of a 7 meter flexible for **one bending cycle 48 hours on 36 CPUs in parallel**

* includes special purpose flexible's FE analysis software, which utilize very much simplified models.



Typical Flexible Riser Cross Section

Non-linear Dynamic Substructuring (NDS)

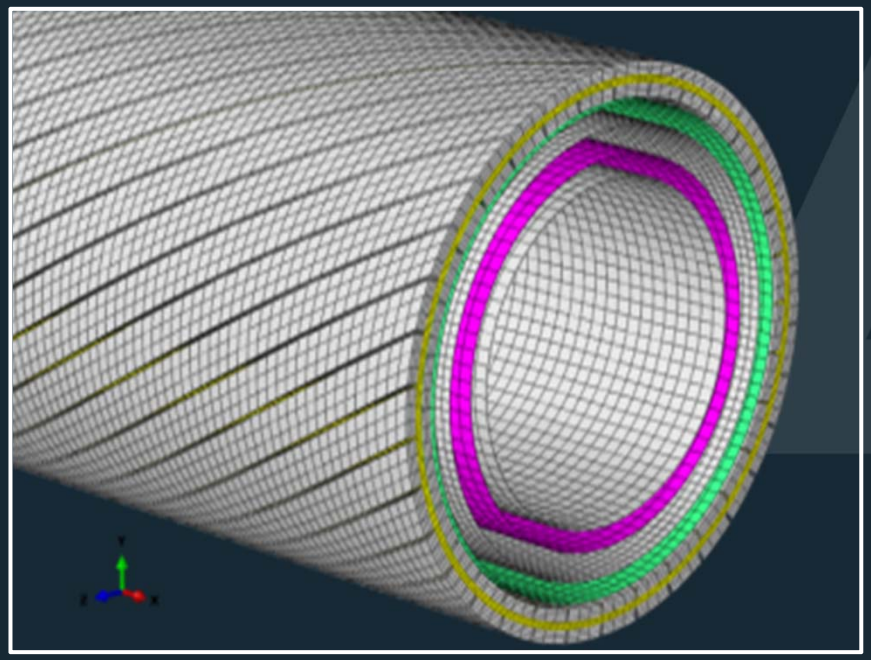
- NDS is an extension of the framework of Dynamic Substructuring* capturing its computational efficiencies while operating in fully nonlinear mode
- NDS makes feasible time-domain nonlinear dynamic simulations of complex systems represented by detailed 3D FEMs in system configurations and under full set of dynamic load time-histories
- These systems are otherwise not feasible to compute

* First developed in 1965 by W. C. Hurty, UCLA

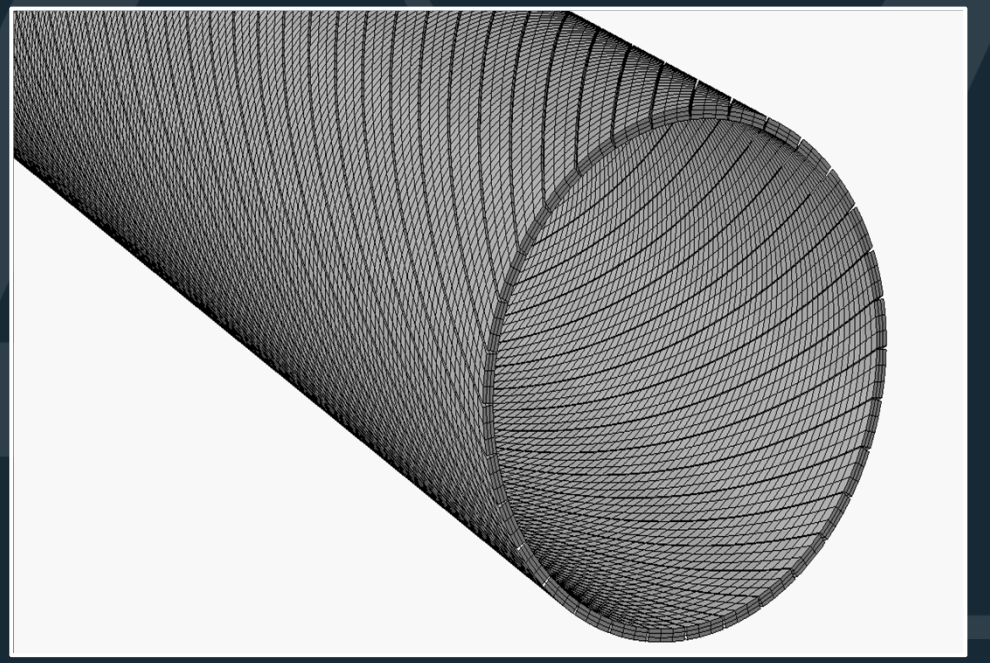
- Core analysis method in aerospace, aeronautics, defense, and automotive industries for complex system analyses
- 1000s of peer reviewed publications

NDS solver: Computational Advantages

- Enables orders of magnitude reduction in the size of the nonlinear dynamic simulations
- Enables solver algorithms to operate efficiently by updating only the nonlinear substructures undergoing a “state” change
- Enables a fully IMPLICIT solution even for global system configurations



INTECSEA’s High Fidelity FEM
with 3D armour wires



Armour Wire Kinematics
in Axial Extension

FLEXAS™ – an NDS Solver

- FLEXAS™ is INTECSEAs multibody NDS solver

- Provides computationally efficient time-domain nonlinear dynamic simulations of systems comprised of finite element models (FEMs)

- Input FEMs can be as detailed as required to accurately capture non-linear kinematics and produce realistic stress time-histories over the whole length of a flexible.

- FLEXAS™ is qualified by major operators for highly complex system simulations not feasible in FE solvers:
  - **BP**
  - **ExxonMobil**
  - **DeepStar**

DeepStar and ExxonMobil validation through FLEXAS™ local benchmarking

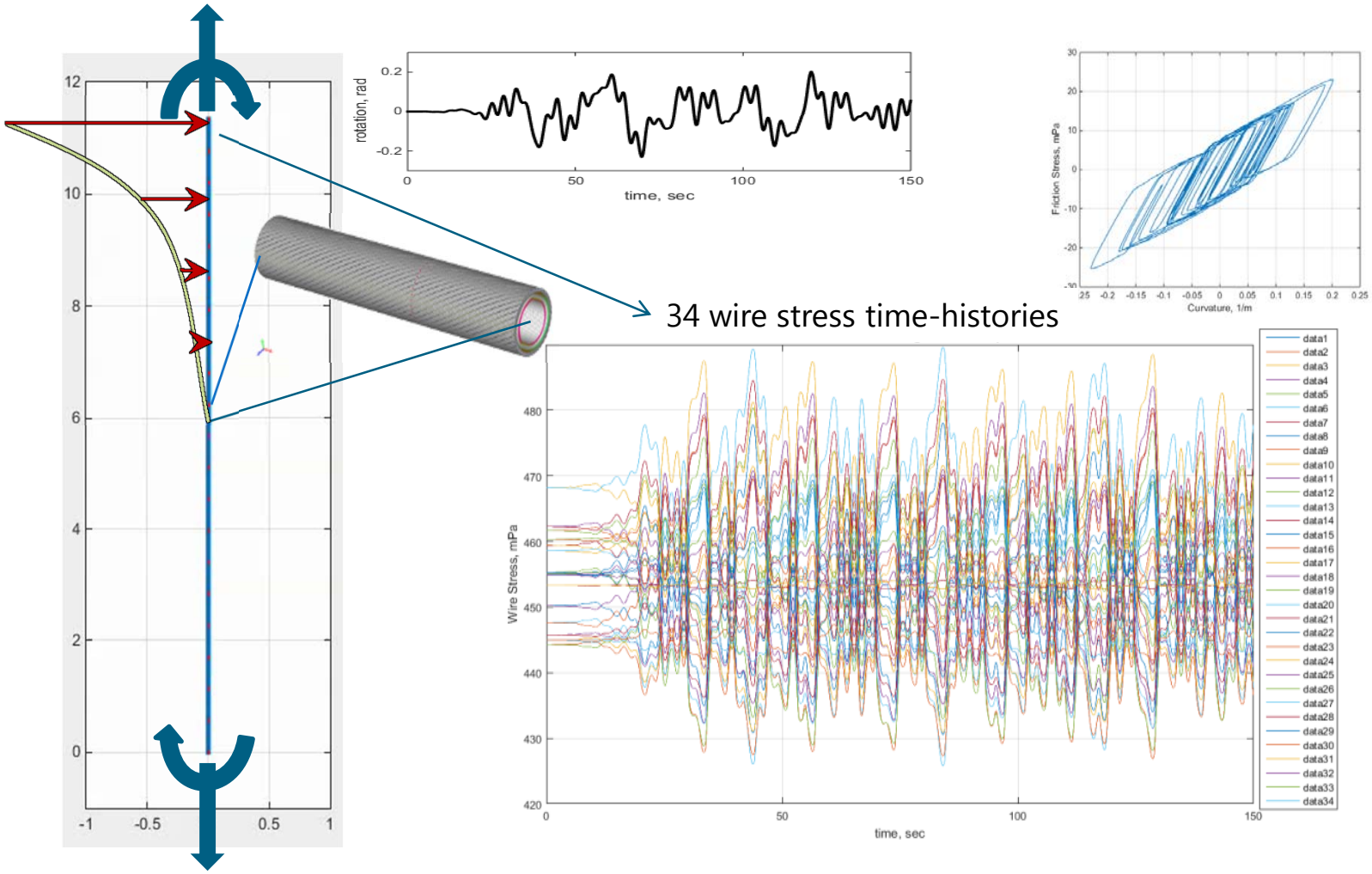
- Experimental benchmarking[1]:
  - 8 pitch lengths, cyclic loading
  - 238 computed armour strains were compared against strain gauge measurements for axial tension and bending cases resulting in very good agreement

The FLEXAS solver is capturing the complex kinematics of the flexible's helically wound layers resulting in excellent numerical and very good experimental comparisons

[1]Experimental work published by De Sousa Et al, OMAE2013-11384, OMAE2015-41436

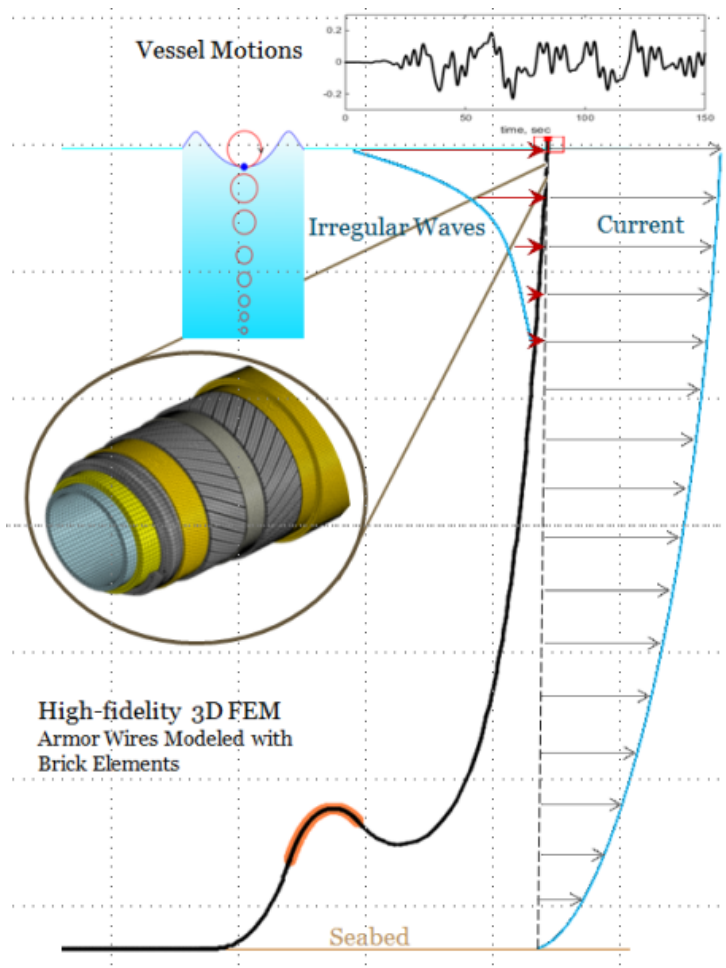
Integrated Local and Global Modelling

20 pitch (12m) riser simulation with 80 million DoF using FLEXAS™



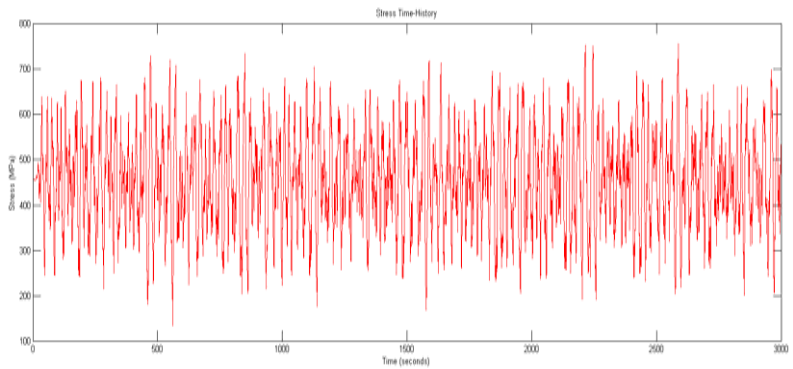
Total computation time for this nonlinear dynamics simulation (FLEXAS™): 300 secs

Integrated global analysis, NO separate local analysis required

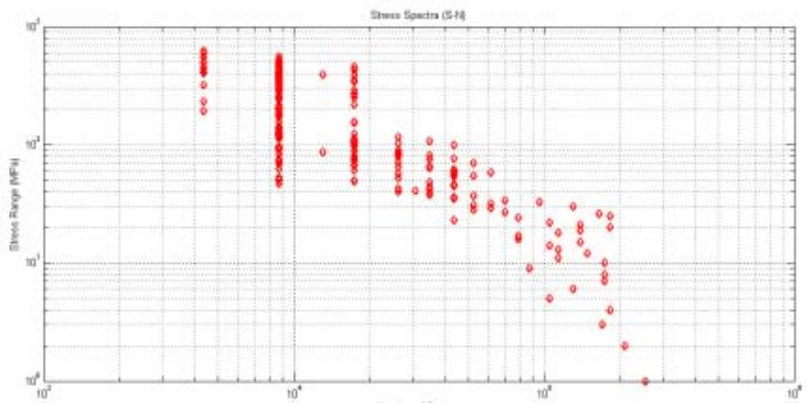


Global Analysis

Entire riser made of detailed FEMs (NDS)



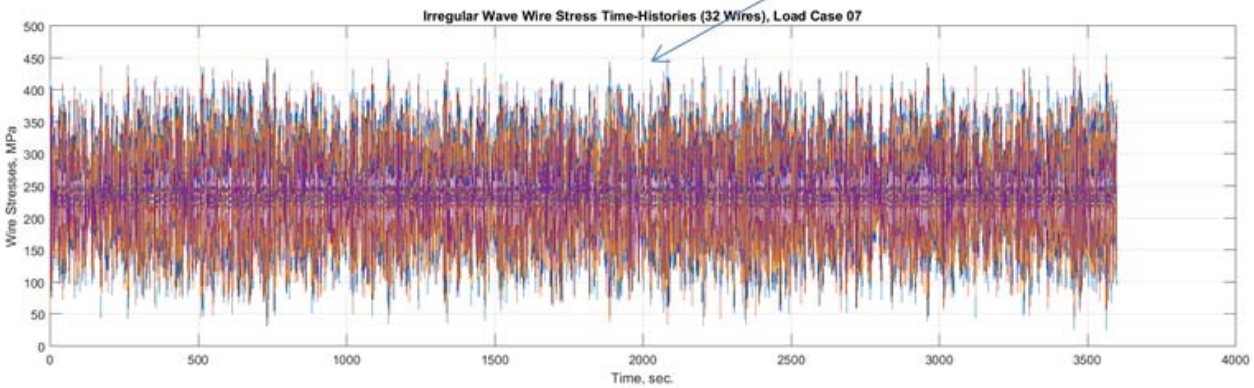
Wire Stress Timehistory - Fatigue Spectra



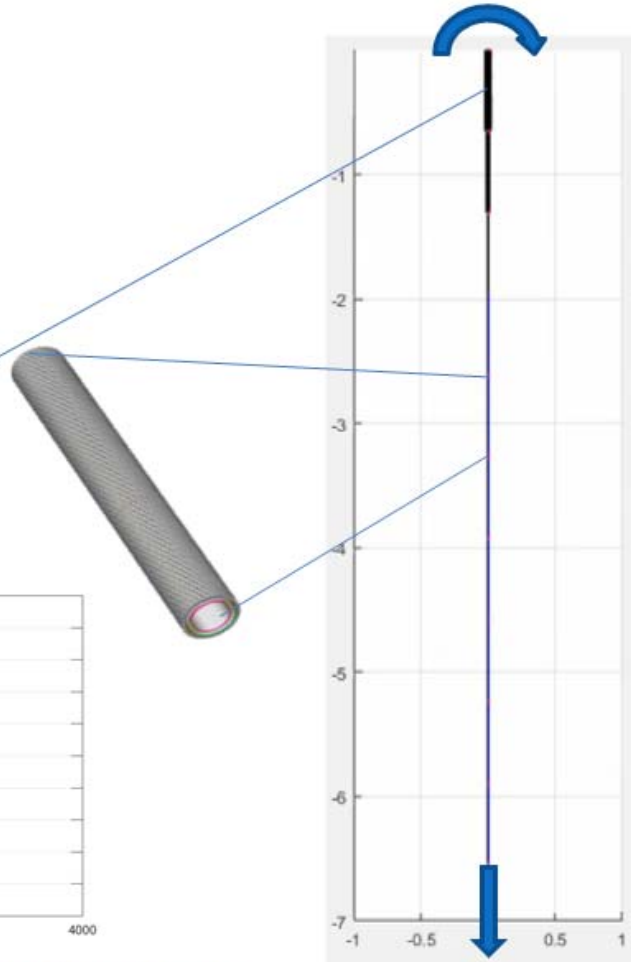
Fatigue Analysis

1. Execute global fatigue analyses on a flexible in lazy wave configuration
   - 24 irregular wave cases (1hr each)
   - 26 regular wave cases

2. Extract tension and curvature for simulations of local hang-off model
   - Irregular wave cases:
     1 hr long tension/curvature
   - Regular wave cases:
     max tension/curvature



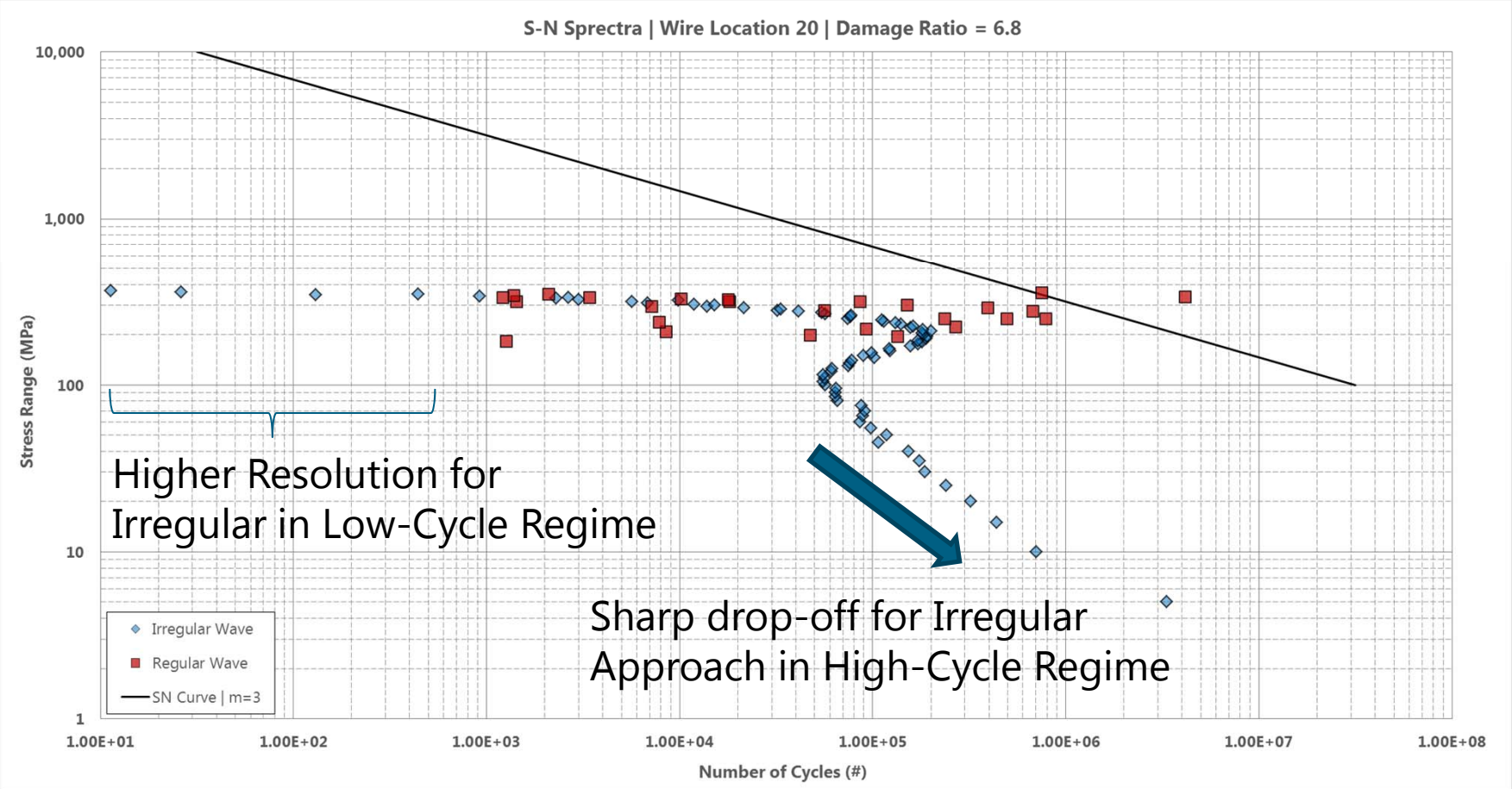
Irregular Wave Load Case 07



32 wire corner stress locations

Fatigue Analysis

S-N Fatigue Spectra - Regular vs Irregular



Benefits of this New Approach

- MEC-FIT provides accurate defect measurements.

- Non-Linear Dynamic Sub-structuring software (FLEXAS) allows efficient analysis, which permits the inclusion of:
  - As-built data
  - Measured defects
  - Fatigue Analysis based upon Irregular Wave Analysis

- Unlock fatigue life by replacing simplifications, conservatisms and assumptions with actual data.

- Extend the life of flexible pipe.

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