



# FSI assessment of offshore structures

Martin Eriksson and Björn Ullbrand

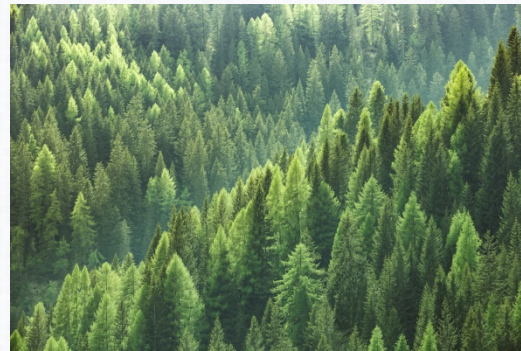
2018 Nordic LS-DYNA Users Conference

# Company presentation

Validus Engineering is a leading provider of advanced numerical simulation services, offering consultancy within FEA and CFD to customers worldwide.

Our main areas are within offshore, wind turbines, life science, process engineering, pulp and paper and electronics.

We are situated in the south of Sweden (Staffanstorp outside Malmö) and in the north of Norway (Rognan).

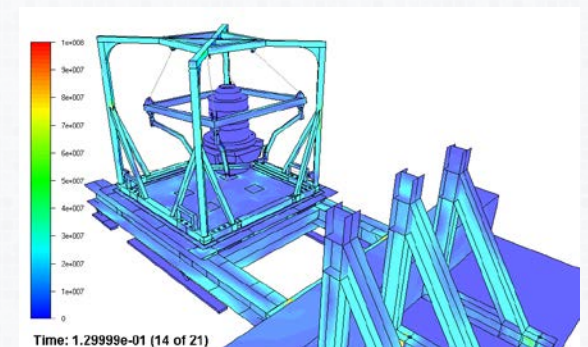
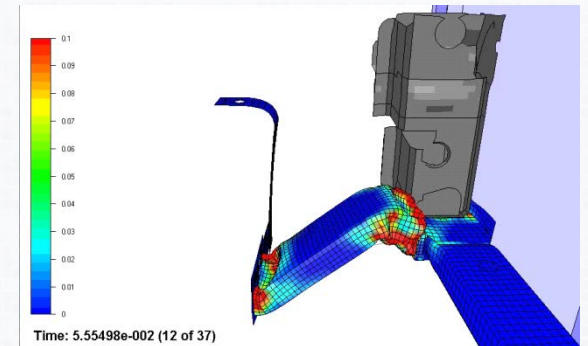
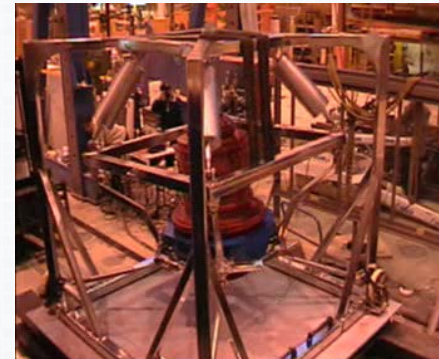
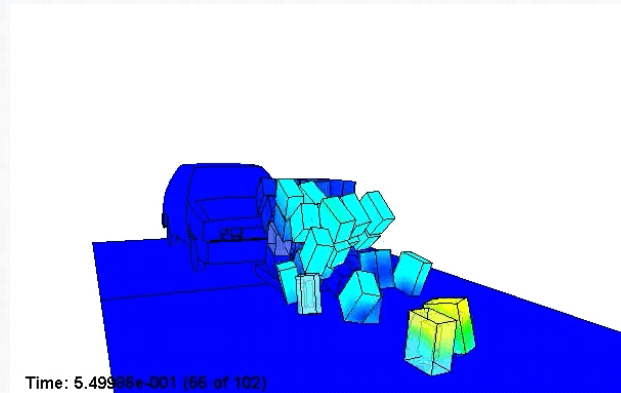
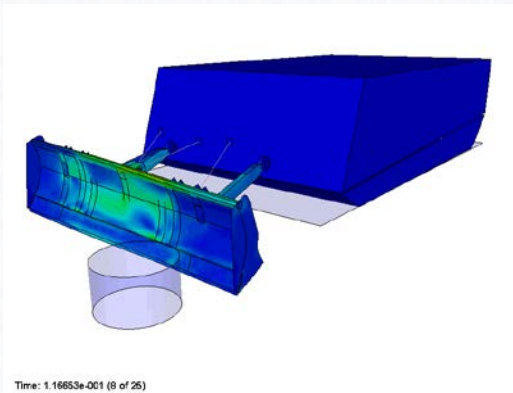




# Experience with LS-DYNA

Our competence in and experience with LS-DYNA has been gained from more than 20 years of industrial use in various fields such as:

- Automotive
- Cable towing
- Consumer products
- Defense
- Transportation system
- Wheel chairs
- Offshore



# Offshore structures

Validus is certified according to ISO and Achilles and is adhering to international and regional regulations and standards as well as living up to demands from 3<sup>rd</sup> party verification and classifications.

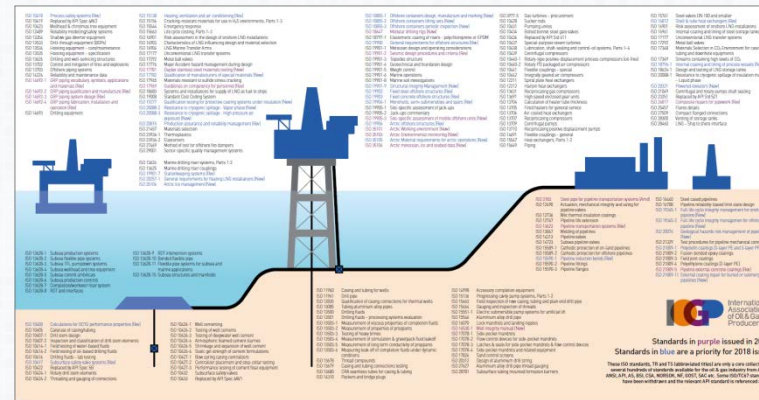
## Company Certification



## Regulations



## Standards & Recommendations



© IOGP & ISO

## 3<sup>rd</sup> party verification and classification



© Eurocode



© IIW



© DNV-GL



© BSI



© Standards Norway



# Offshore structures

ISO 10418 Process safety systems (Rev)  
ISO 10419 Replaced by API Spec 6AV2  
ISO 10423 Wellhead & christmas tree equipment  
ISO 12489 Reliability modelling/safety systems  
ISO 13354 Shallow gas diverter equipment  
ISO 13533 Drill-through equipment (BOPs)  
ISO 13534 Hoisting equipment – care/maintenance

ISO 15138 Heating, ventilation and air-conditioning (Rev)  
ISO 15156 Cracking-resistant materials for use in H<sub>2</sub>S environments, Parts 1-3  
ISO 15544 Emergency response  
ISO 15663 Life cycle costing, Parts 1-3  
ISO 16901 Risk assessment in the design of onshore LNG installations  
ISO 16903 Characteristics of LNG influencing design and material selection  
ISO 16904 LNG Marine Transfer Arms  
LNG transfer systems

ISO 10955-1 Offshore containers design, manufacture and marking (New)  
ISO 1977-5 Gas turbines – nomenclature

ISO 15761 Steel valves DN 100 and smaller

ISO 13628-3 Subsea TFL pumpdown systems  
ISO 13628-4 Subsea wellhead and tree equipment  
ISO 13628-5 Subsea control umbilicals  
ISO 13628-6 Subsea production controls  
ISO 13628-7 Completion/workover riser system  
ISO 13628-8 ROT and interfaces

ISO 10400 Calculations for OCTG performance properties (Rev)  
ISO 10405 Care/use of casing/tubing  
ISO 10407-1 Drill stem design  
ISO 10407-2 Inspection and classification of drill stem elements  
ISO 10414-1 Field testing of water-based fluids  
ISO 10414-2 Field testing of oil-based drilling fluids  
ISO 10416 Drilling fluids – lab testing  
ISO 10417 Subsurface safety valve systems (Rev)  
ISO 10422 Replaced by API Spec 5B  
ISO 10424-1 Rotary drill stem elements  
ISO 10424-2 Threading and gauging of connections

ISO 10426-1 Well cementing  
ISO 10426-2 Testing of well cements  
ISO 10426-3 Testing of deepwater well cement  
ISO 10426-4 Atmospheric foamed cement slurries  
ISO 10426-5 Shrinkage and expansion of well cement  
ISO 10426-6 Static gel strength of cement formulations  
ISO 10427-1 Bow spring casing centralizers  
ISO 10427-2 Centralizer placement and stop-collar testing  
ISO 10427-3 Performance testing of cement float equipment  
ISO 10432 Subsurface safety valves  
ISO 10433 Replaced by API Spec 6AV1

ISO 11960 Casing and  
ISO 11961 Drill pipe  
ISO 12835 Qualification  
ISO 13085 Tubing and  
ISO 13500 Drilling fluid  
ISO 13501 Drilling fluid  
ISO 13503-1 Measurement  
ISO 13503-2 Measurement  
ISO 13503-3 Testing of h  
ISO 13503-4 Measurement  
ISO 13503-5 Measurement  
ISO 13503-6 Measuring  
conditions  
ISO 13678 Thread con  
ISO 13679 Casing and  
ISO 13680 CRA seaml  
ISO 14310 Packers an

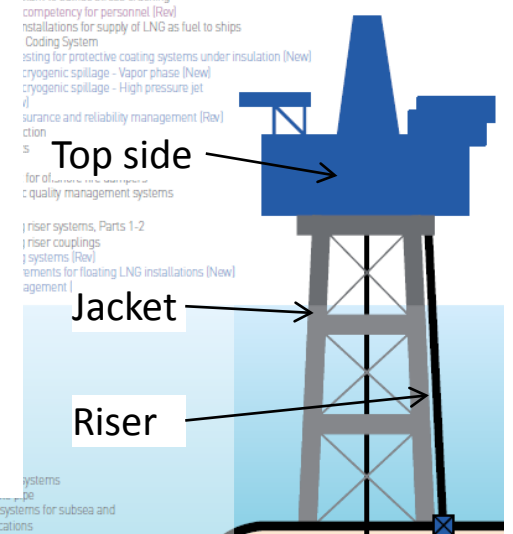
ISO 15138 Heating, ventilation and air-conditioning (Rev)  
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LNG transfer systems

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ISO 1977-5 Gas turbines – nomenclature

ISO 15761 Steel valves DN 100 and smaller

**Fixed platforms:**

- Top side weights  
≤ 20 000 Tonnes
- Jacket weights  
≤ 20 000 Tonnes
- Water depths  
≤ 120 Meters



**Experience from following scenarios:**

- Various installation loads.
- SLS - Service life due to normal use.
- FLS - Fatigue assessment of offshore details using implicit FEA as well as with traditional SCF approach.
- ULS - Assessment of resistance and remaining capacity for extreme loading.
- ALS - Accidental loading due to Ship impact analyses and/or abnormal wind and wave loading with both implicit and explicit FEA.

# Structural representation

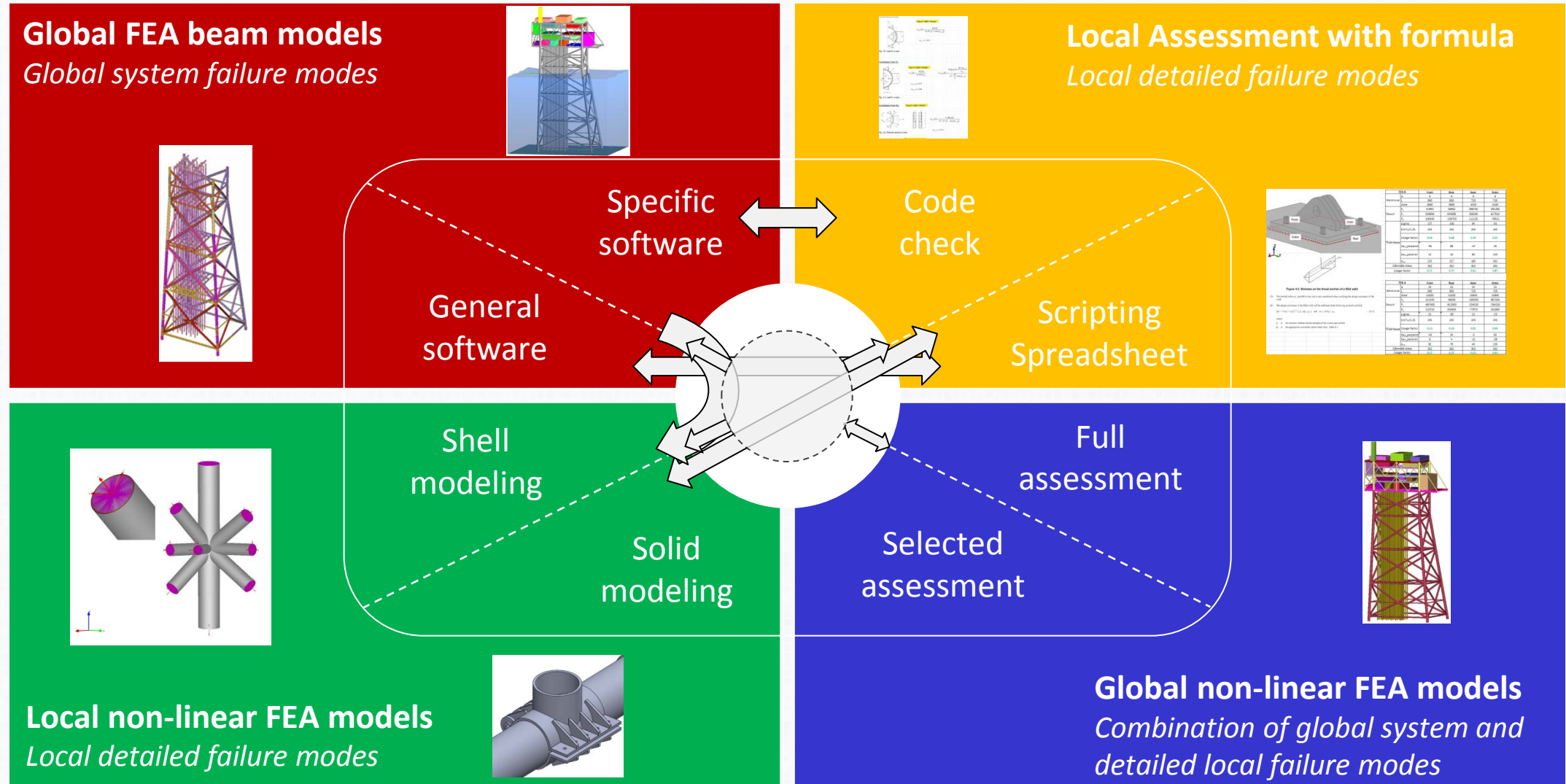
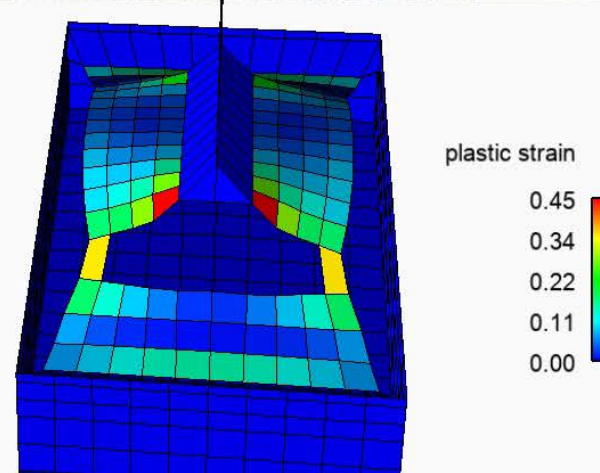
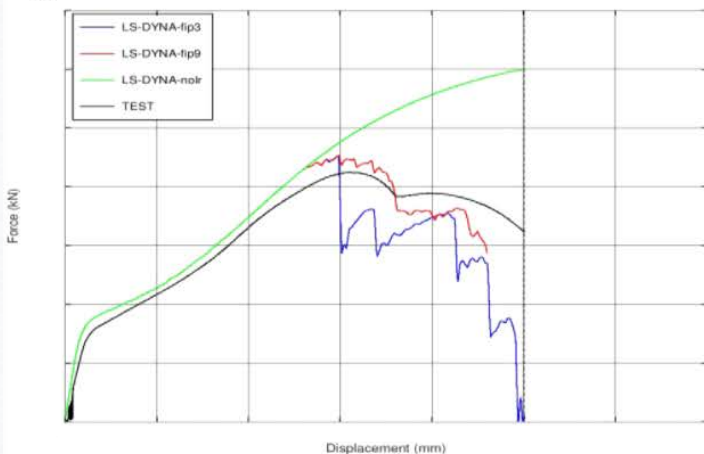
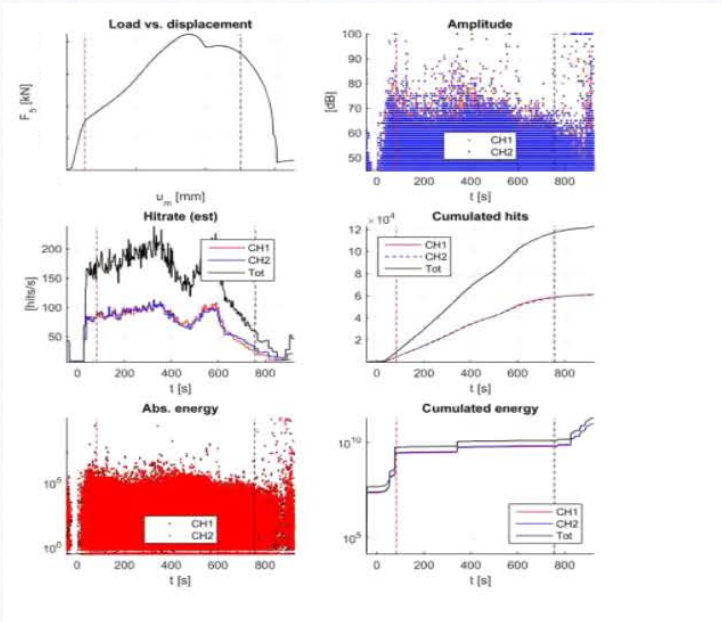


Figure 4-1: Tables on the front section of a ship hull

Table	Table	Table	Table	Table
Table 1	Table 2	Table 3	Table 4	Table 5
Table 6	Table 7	Table 8	Table 9	Table 10
Table 11	Table 12	Table 13	Table 14	Table 15
Table 16	Table 17	Table 18	Table 19	Table 20
Table 21	Table 22	Table 23	Table 24	Table 25
Table 26	Table 27	Table 28	Table 29	Table 30
Table 31	Table 32	Table 33	Table 34	Table 35
Table 36	Table 37	Table 38	Table 39	Table 40
Table 41	Table 42	Table 43	Table 44	Table 45
Table 46	Table 47	Table 48	Table 49	Table 50
Table 51	Table 52	Table 53	Table 54	Table 55
Table 56	Table 57	Table 58	Table 59	Table 60
Table 61	Table 62	Table 63	Table 64	Table 65
Table 66	Table 67	Table 68	Table 69	Table 70
Table 71	Table 72	Table 73	Table 74	Table 75
Table 76	Table 77	Table 78	Table 79	Table 80
Table 81	Table 82	Table 83	Table 84	Table 85
Table 86	Table 87	Table 88	Table 89	Table 90
Table 91	Table 92	Table 93	Table 94	Table 95
Table 96	Table 97	Table 98	Table 99	Table 100

# Validation of Structural method



## Validated FEA methodology for welded details

- Based on an extensive testing campaign involving
  - 16 test series with various failure mechanisms
  - Varying levels of Bending in combination with Tension
  - In-plane shear failures
- Calibration adheres to ISO 19902:2007

## Validation includes

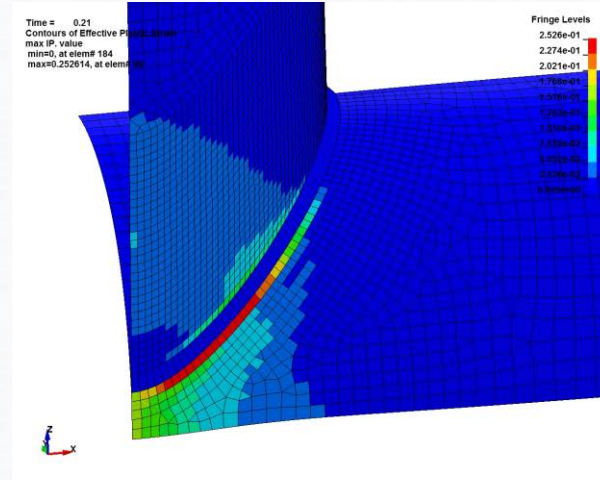
- Material
  - Stress-strain curve
  - Failure strain (eroding)
  - Number of layers to element failure
- Shell definition
  - Element formulation
  - Number of through thickness integration points
- Mesh resolution
  - Along welds
  - Over gaps
  - At weld terminations
- Weld modelling

## Failure criteria/limits

- Mean and characteristic strain limits:
  - Crack initiation / Local necking (degrading fatigue properties)
  - Ultimate tensile failure

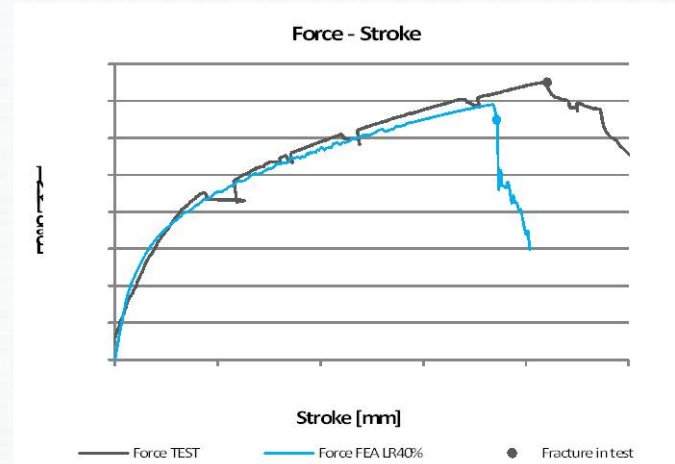


# Validation of Structural method



## Validated FEA methodology for Tubulars

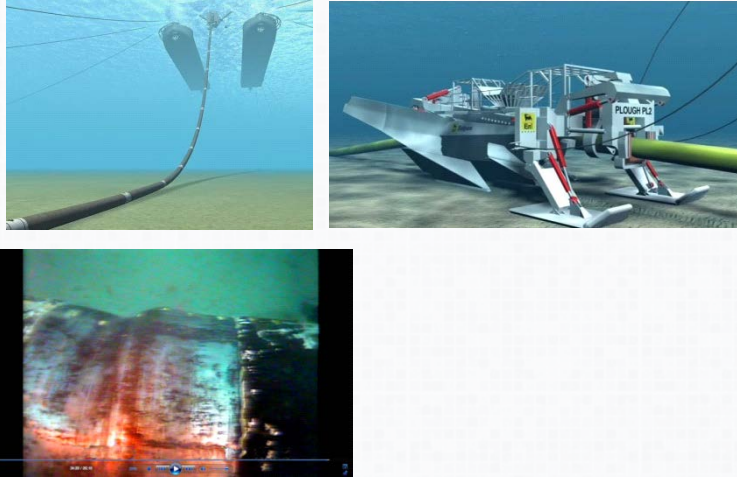
- Reassessment of previously performed validation
- Confirmation of welded section modelling and failure criteria/limits
- Weld modelling rules for tubular joints
- Cold forming (UOE pipe)



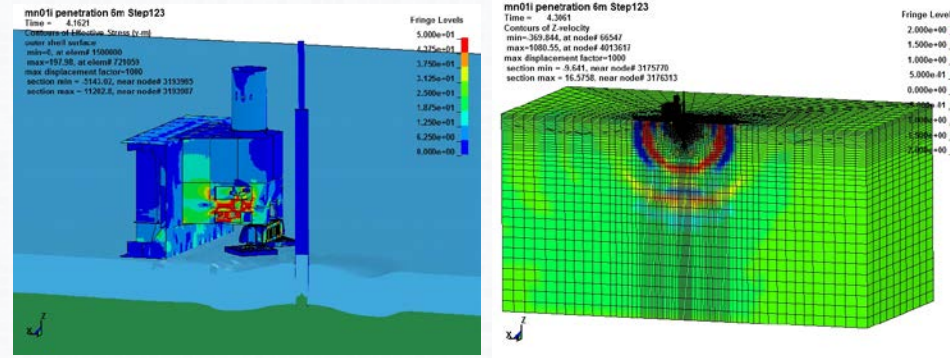


# Structural assessment - Offshore structures

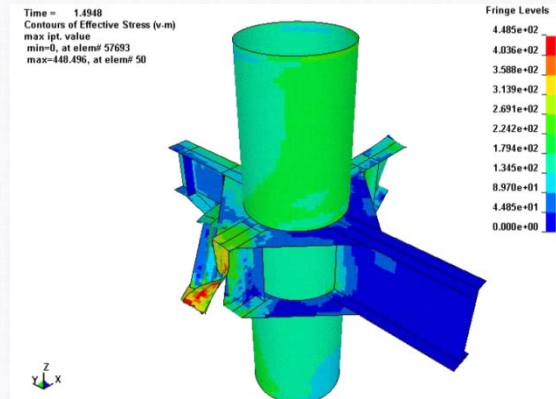
Pipeline installation



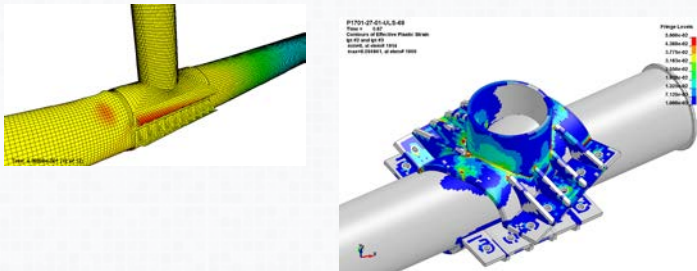
Pile driving – SLS, FLS



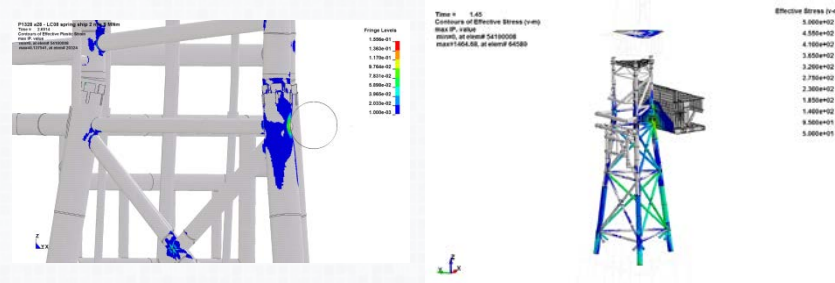
Ultimate capacity – ULS



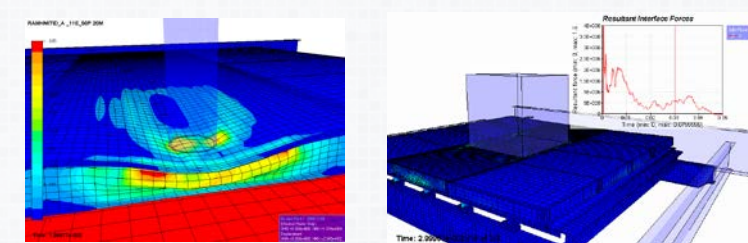
Bolted clamps – ULS, ALS



Ship impact – ALS

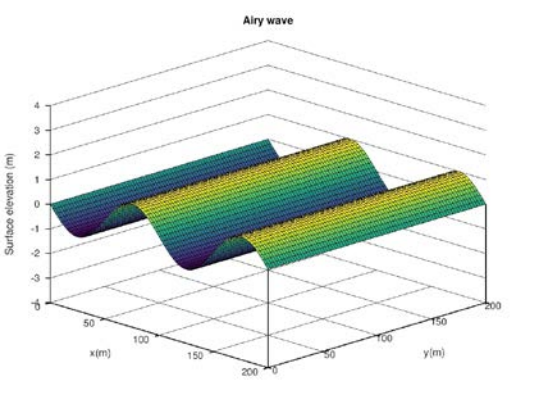


Dropped objects – ALS

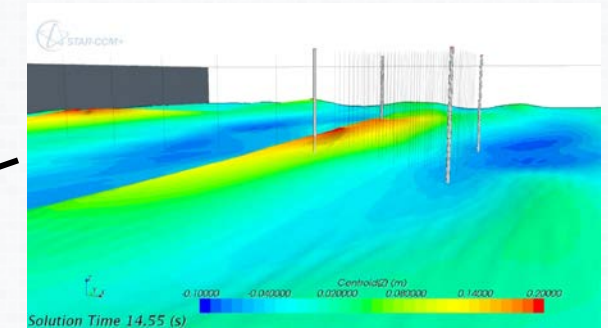


# Wave Modeling – Offshore structures

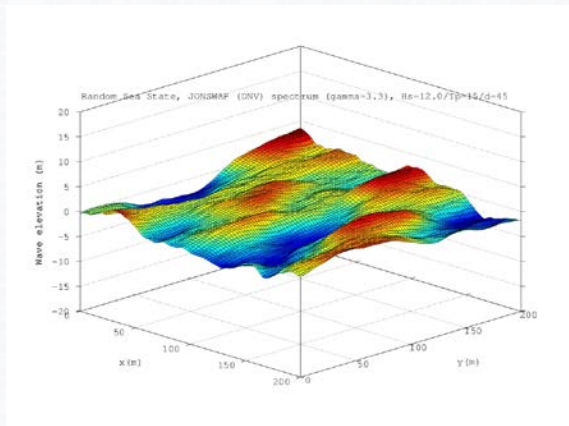
Linear waves



Irregular non-linear waves



Irregular linear waves



## Morison equation

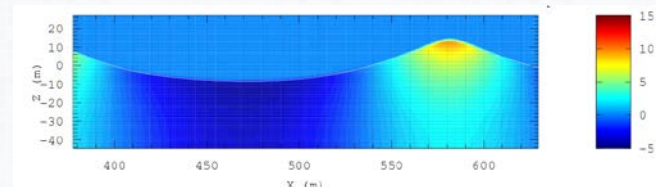
- Force calculated from kinematics
- No direct interaction between fluid and structure

$$F(t) = C_M \rho \frac{\pi}{4} D^2 \dot{u}(t) + C_D \frac{1}{2} \rho D u(t) |u(t)|$$

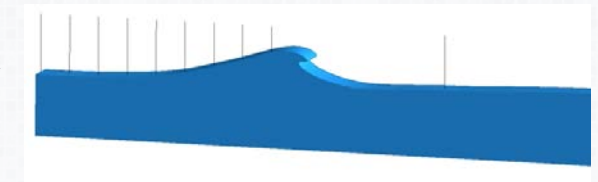
## CFD

- Pressure mapped onto structural model
- Interaction between fluid and structure (FSI)

Stokes 5<sup>th</sup> order waves

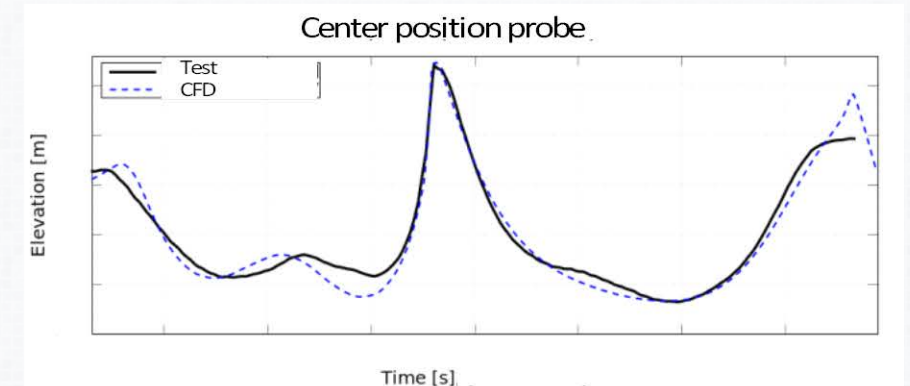
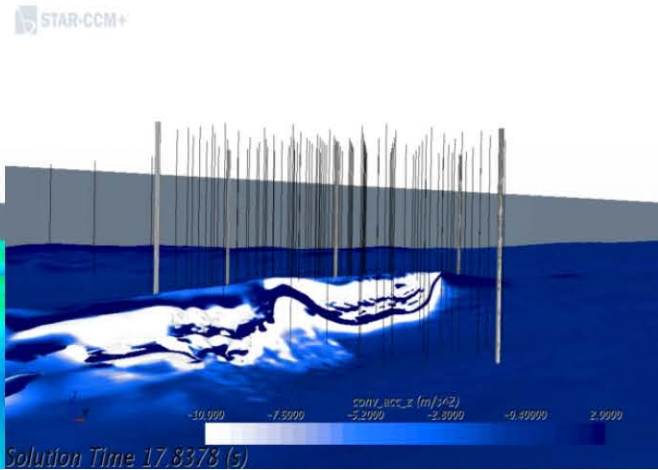
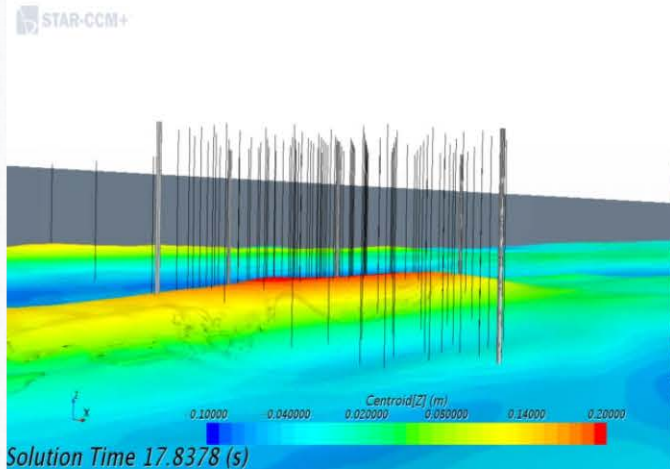
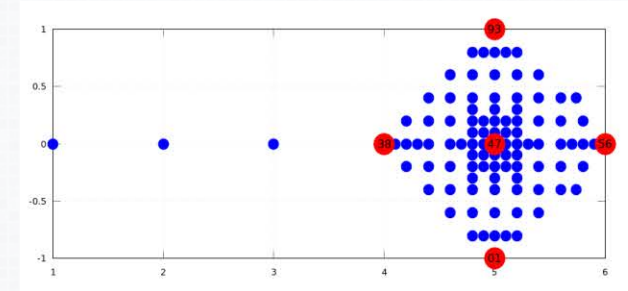
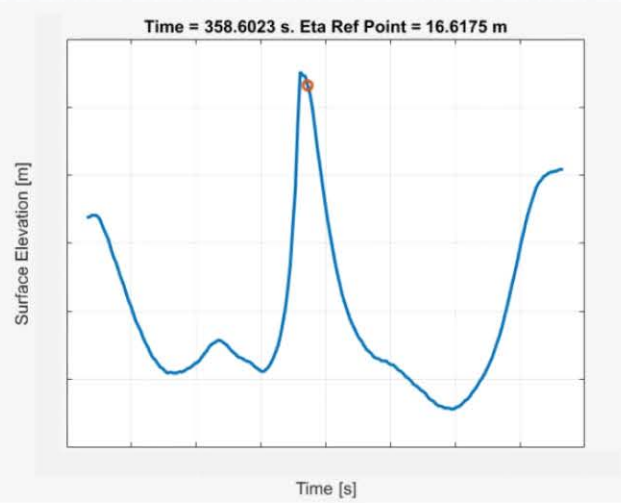


Breaking waves

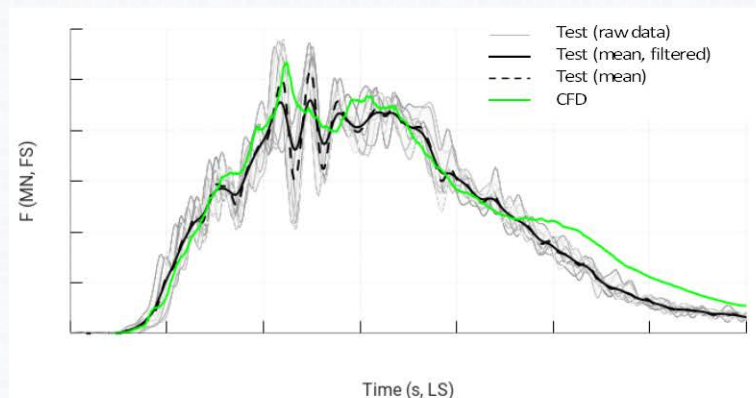
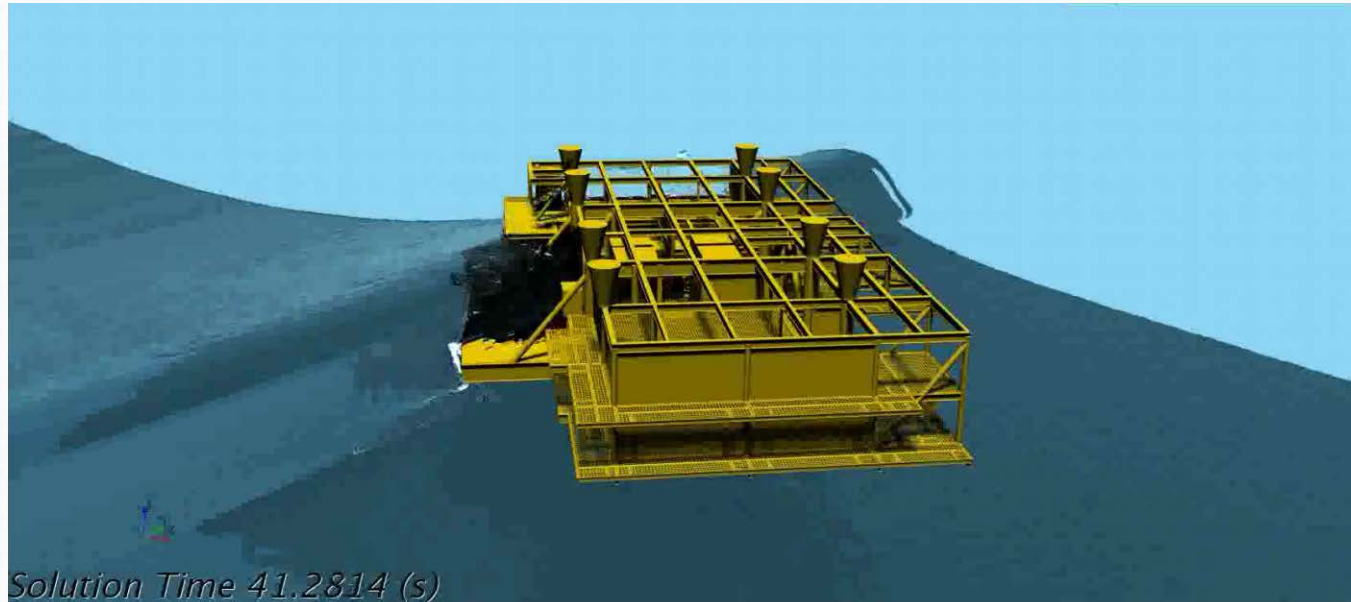




# CFD Wave characteristic validation



# CFD Wave load validation



## Validated CFD methodology for Wave loads

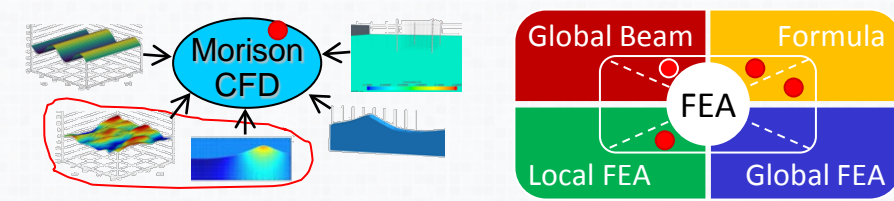
- Method
  - Numerical schemes for discretization and time integration
  - Meshing approach and resolution
  - Time step optimization
- Surface elevation
  - Comparisons with measured wave gauges (2D flume and 3D basins with regular, irregular and breaking waves)
  - Comparisons with HD video
  - Comparisons with theoretical linear irregular waves (spectrum)
- Kinematics
  - Comparisons with PIV and LDA data
- Loads
  - Comparisons with measured loads on scale models (regular and breaking waves)



# Fatigue evaluation

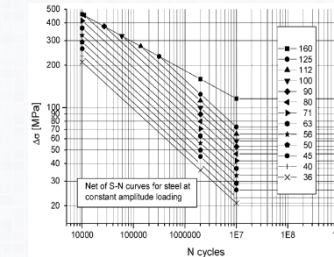
## Project description:

Fatigue (FLS) evaluation by e.g. Influence Factor (IFs) approach.  
Extrapolation of stress according to e.g. IIW and DNV RP-C203.

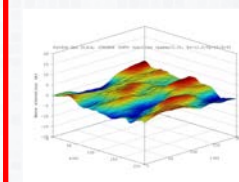
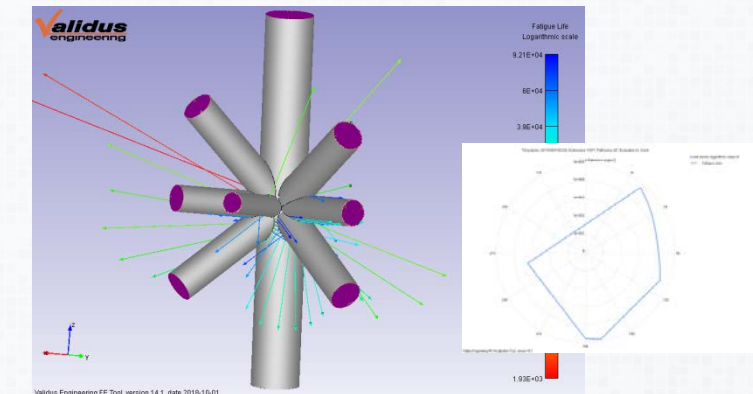


Global Beam-model

SN-curves



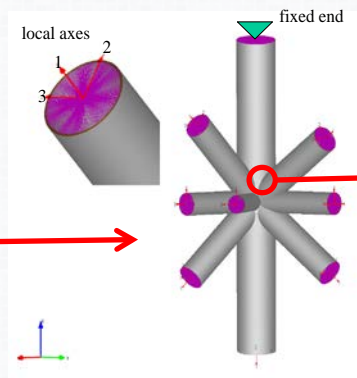
Fatigue life



Load histories for several sea states

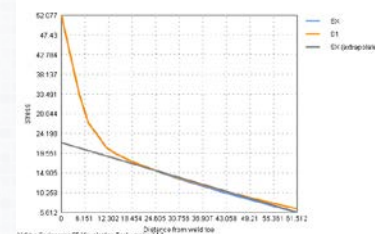
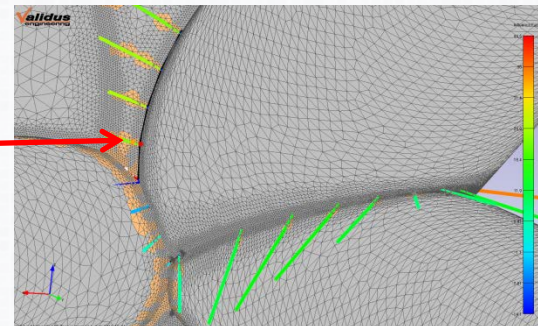
Local FE-model (IF-model)

Model extent



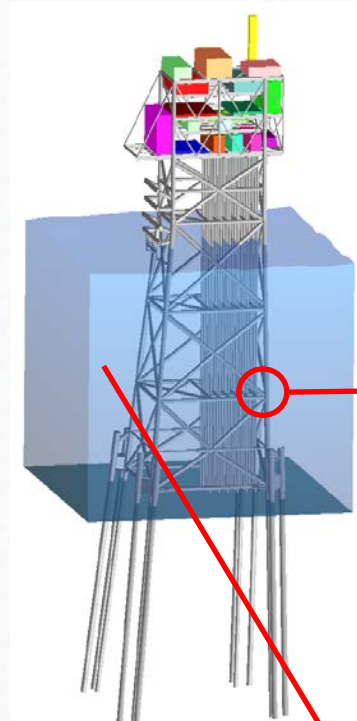
All Tubular intersection welds evaluated

Weld toes – Stress range extraction



Sea level

Seabed



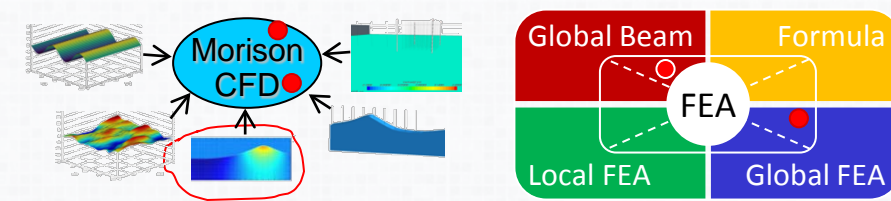
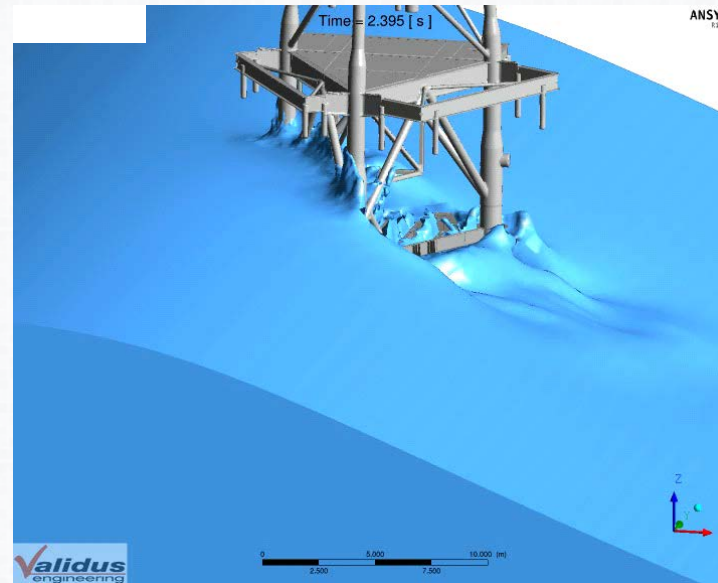
# Wave in deck evaluation

## Project description:

Assessment of structural integrity of complete platform due to extreme wave in deck loading (ULS).

## Loading:

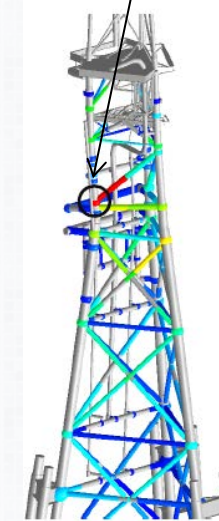
- Steady state wind load
- Stokes 5<sup>th</sup> order wave
- Detailed 1-way FSI analysis that fails in the global beam analysis.
- Repeated wave loading should also be evaluated (90% wave height for 2<sup>nd</sup> wave according to standards).



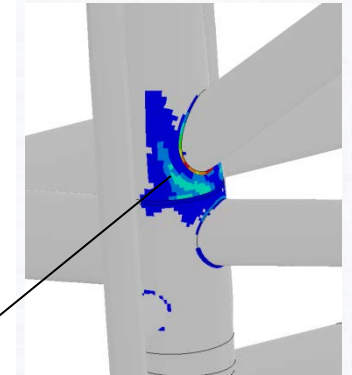
## 1<sup>st</sup> wave peak results

Global beam model

Failure location



LS-DYNA shell model

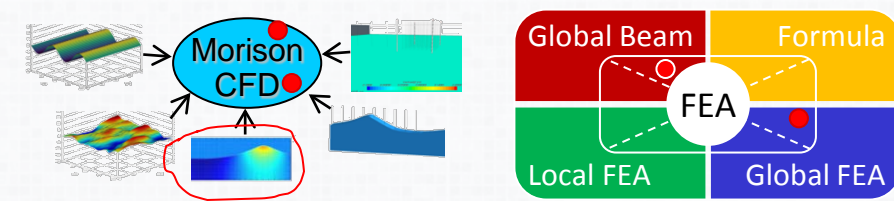


- Problem areas seen in LS-DYNA analysis agrees with observations in the global analysis.
- Overall structural integrity is obtained.

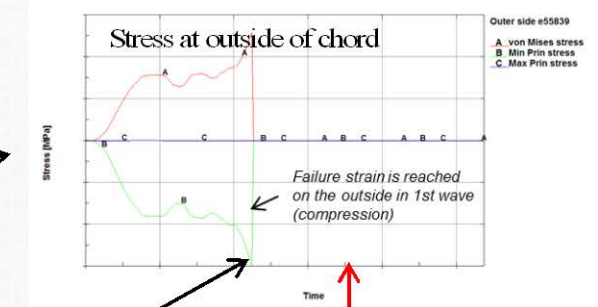
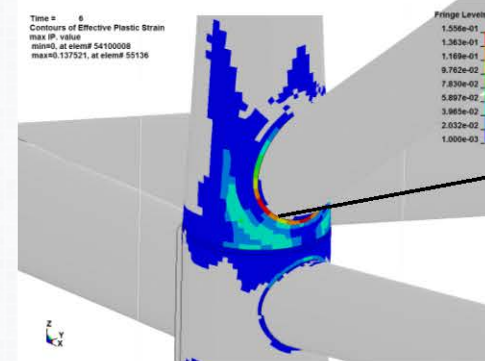
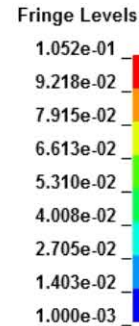


# Wave in deck evaluation

Assessment of two subsequent wave loads

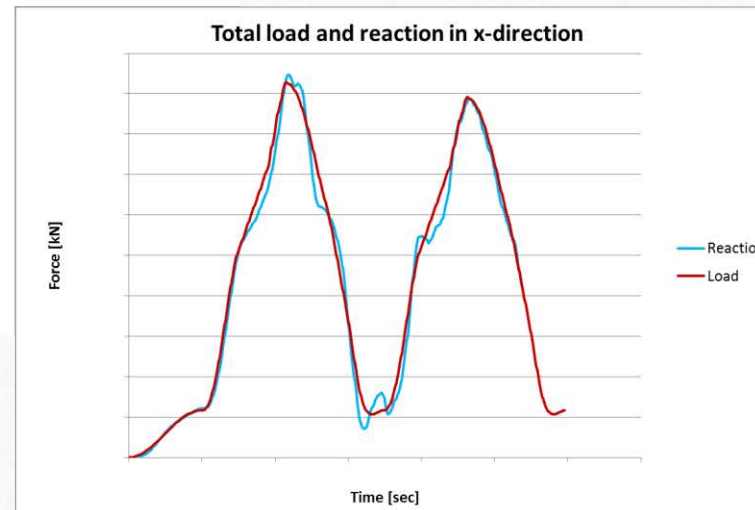


Time = 5.6  
Contours of Effective Plastic Strain  
outer shell surface  
min=0, at elem# 54100008  
max=0.137521, at elem# 55136  
max displacement factor=20



IP failure in compression

Start of 2nd wave



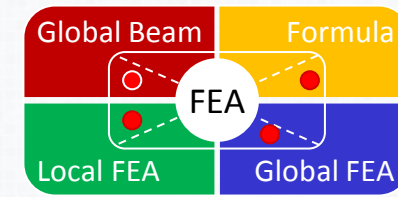
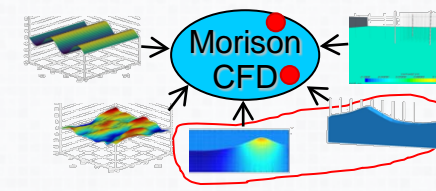
## General conclusions:

Overall structural integrity is obtained.  
However local failure develops in compressions.

The yield surface grows during 1st wave loading, unloading and 2nd wave.

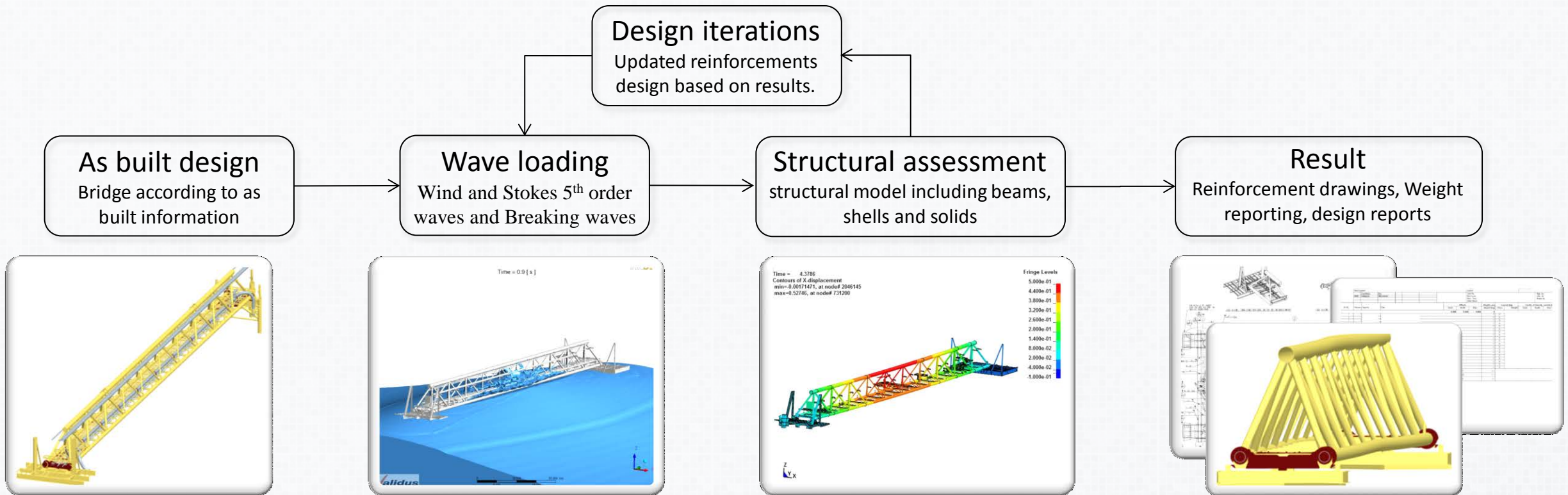
Displacement scale factor = 20

# Wave in Bridge evaluation



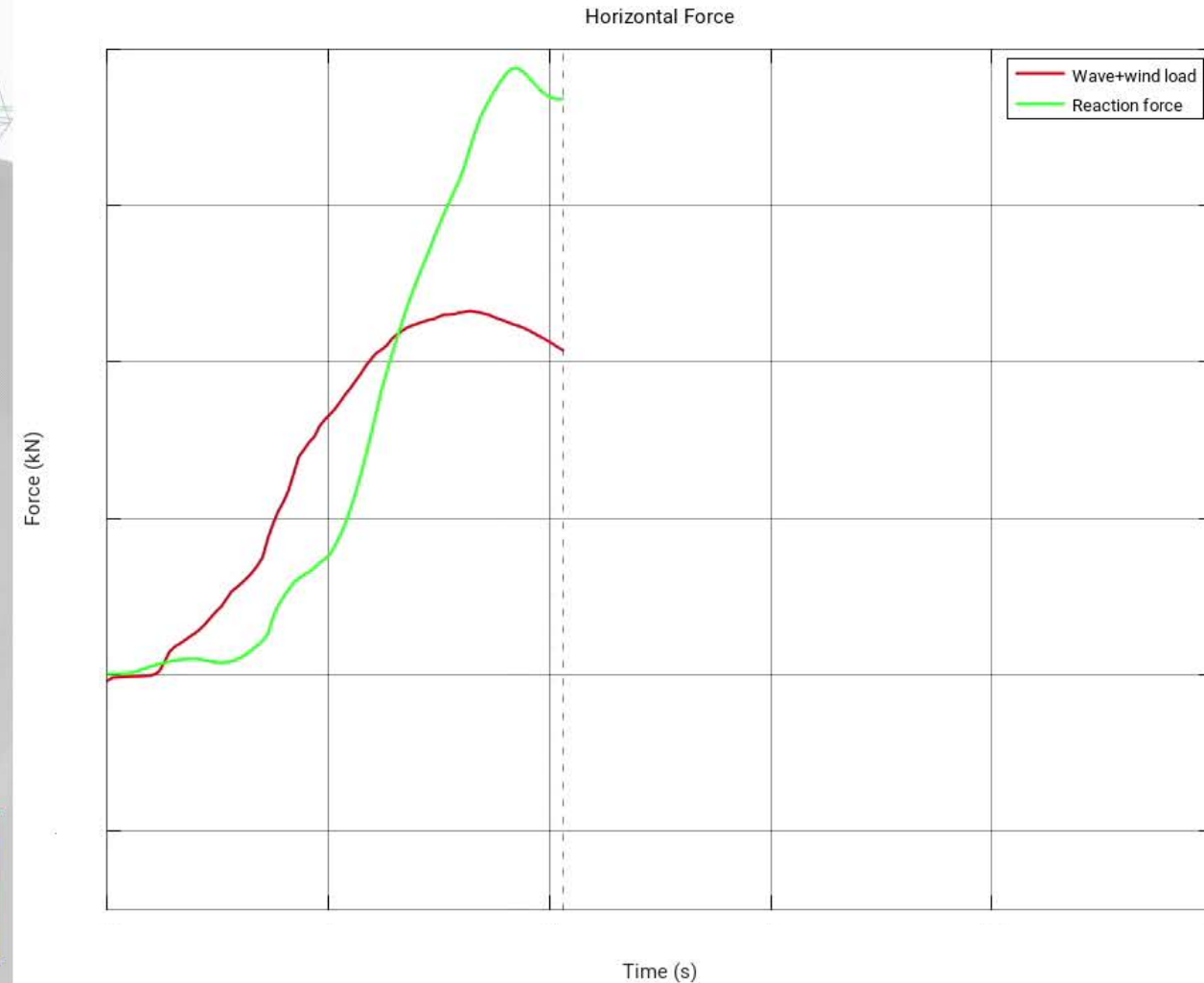
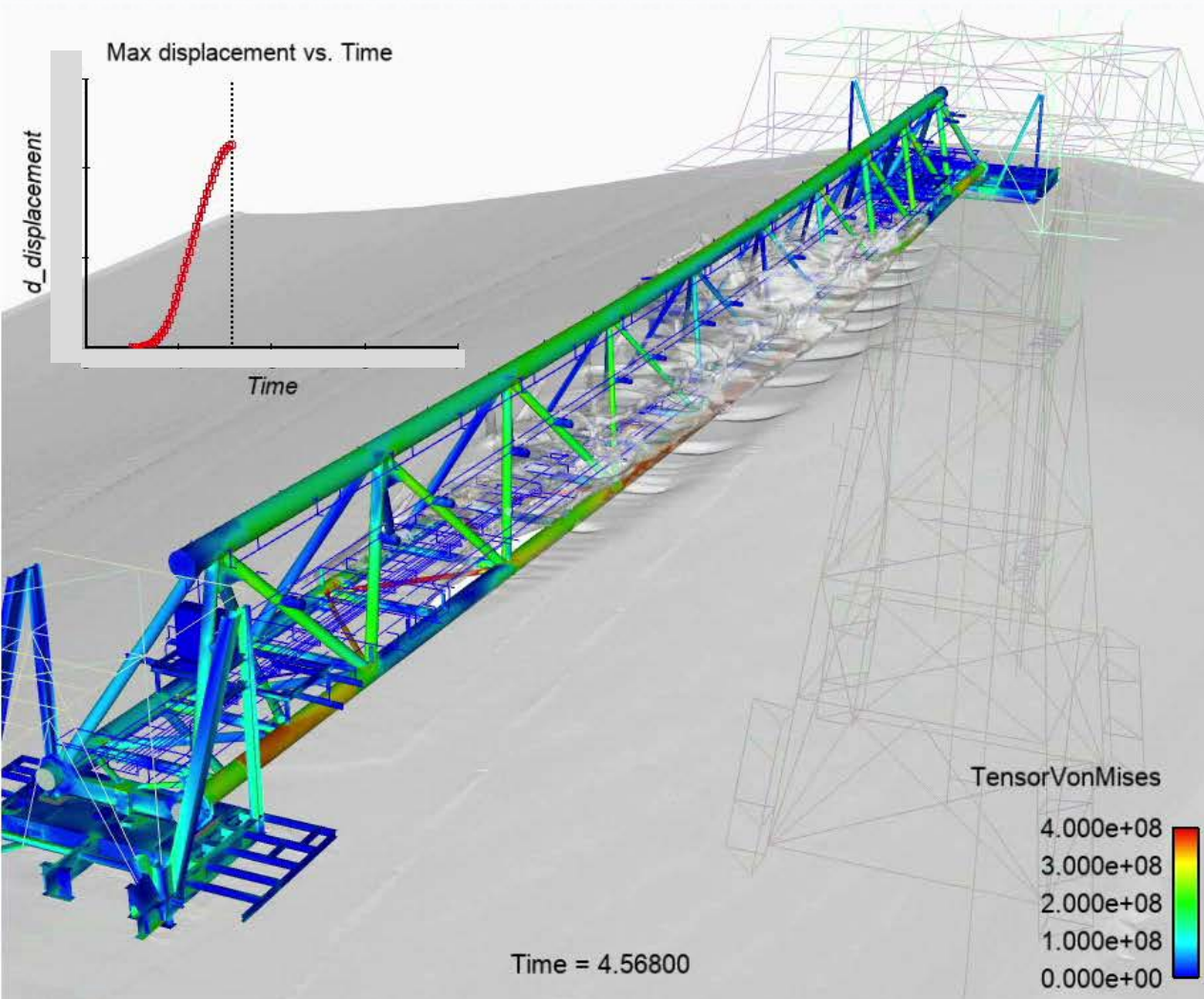
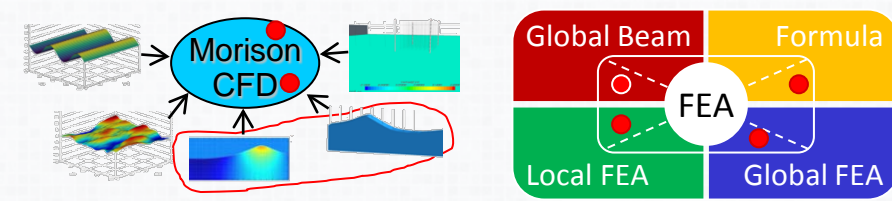
## Project description:

Bridges structure reinforced to comply with an Accidental Limit State (ALS), i.e. the bridge must be able to survive the 10'000 year Wave in Bridge scenario without total collapse.

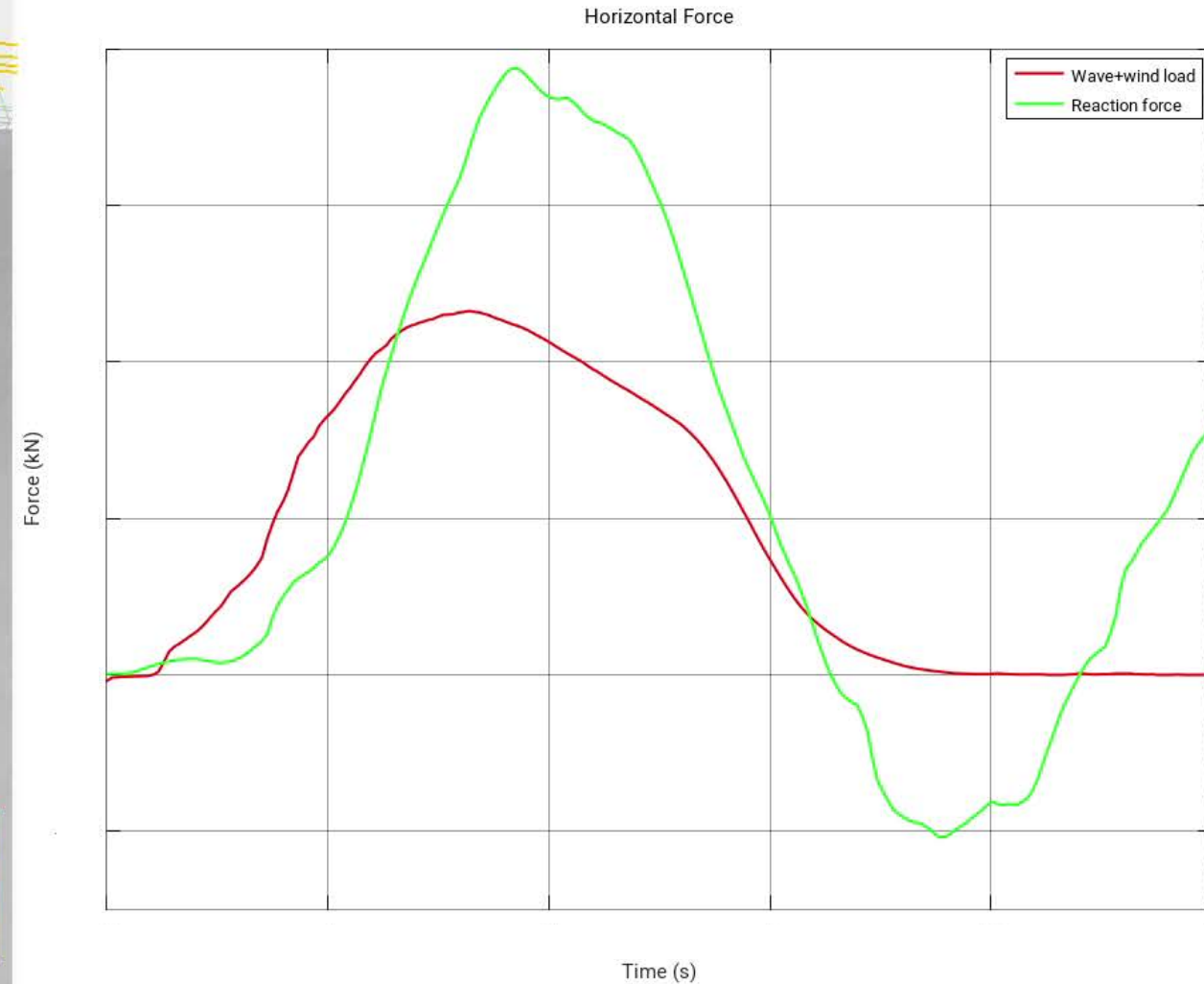
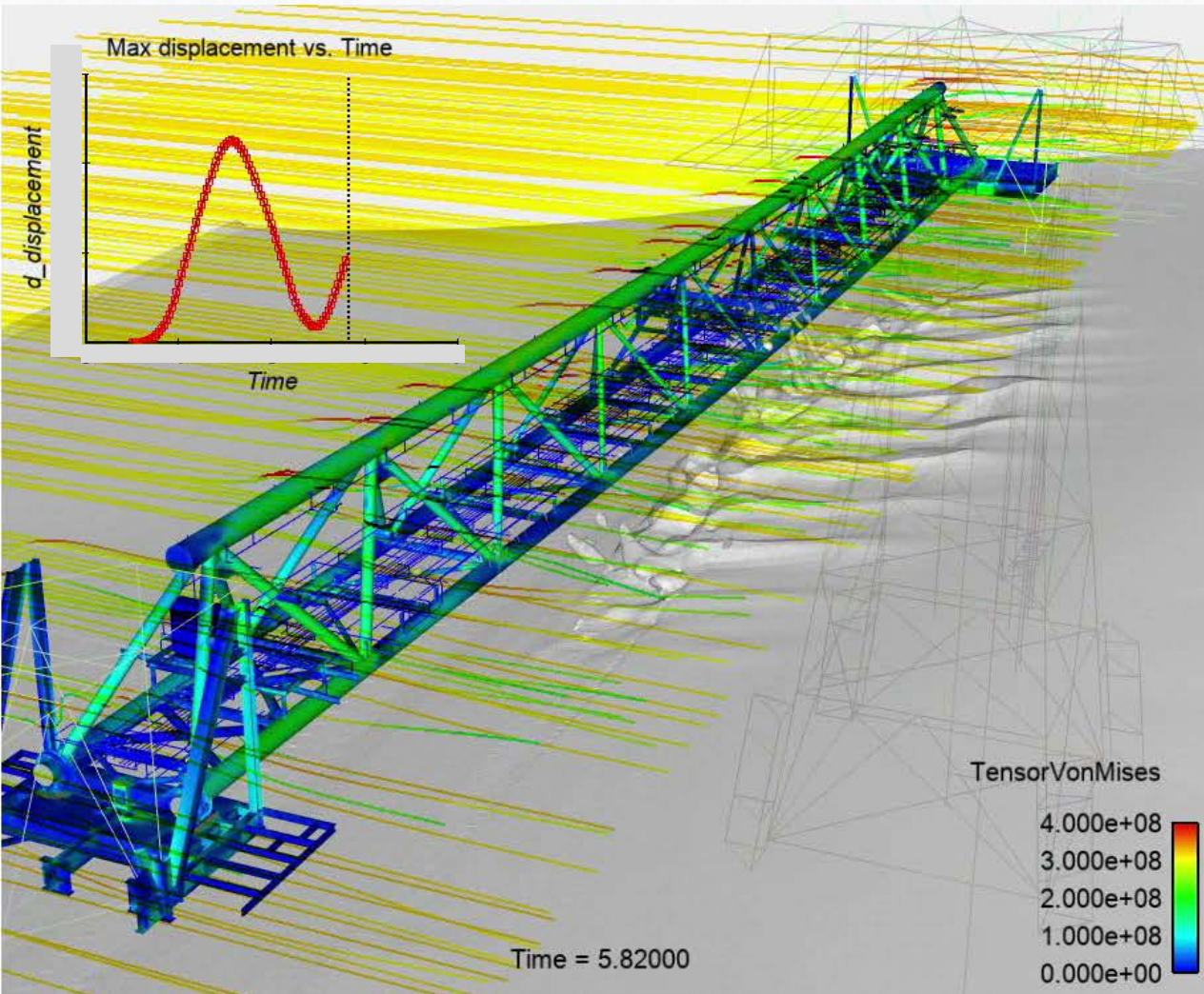
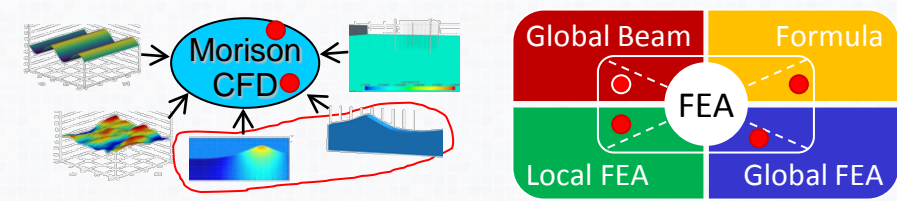




# Wave in Bridge evaluation

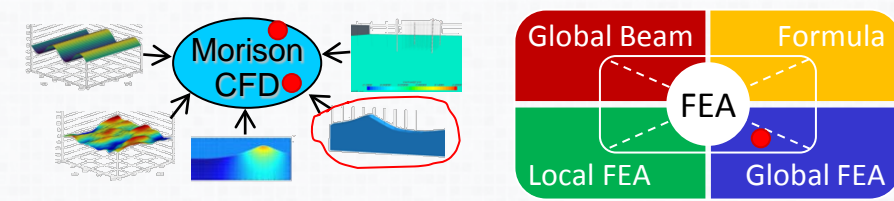


# Wave in Bridge evaluation





# Wave in Riser evaluation

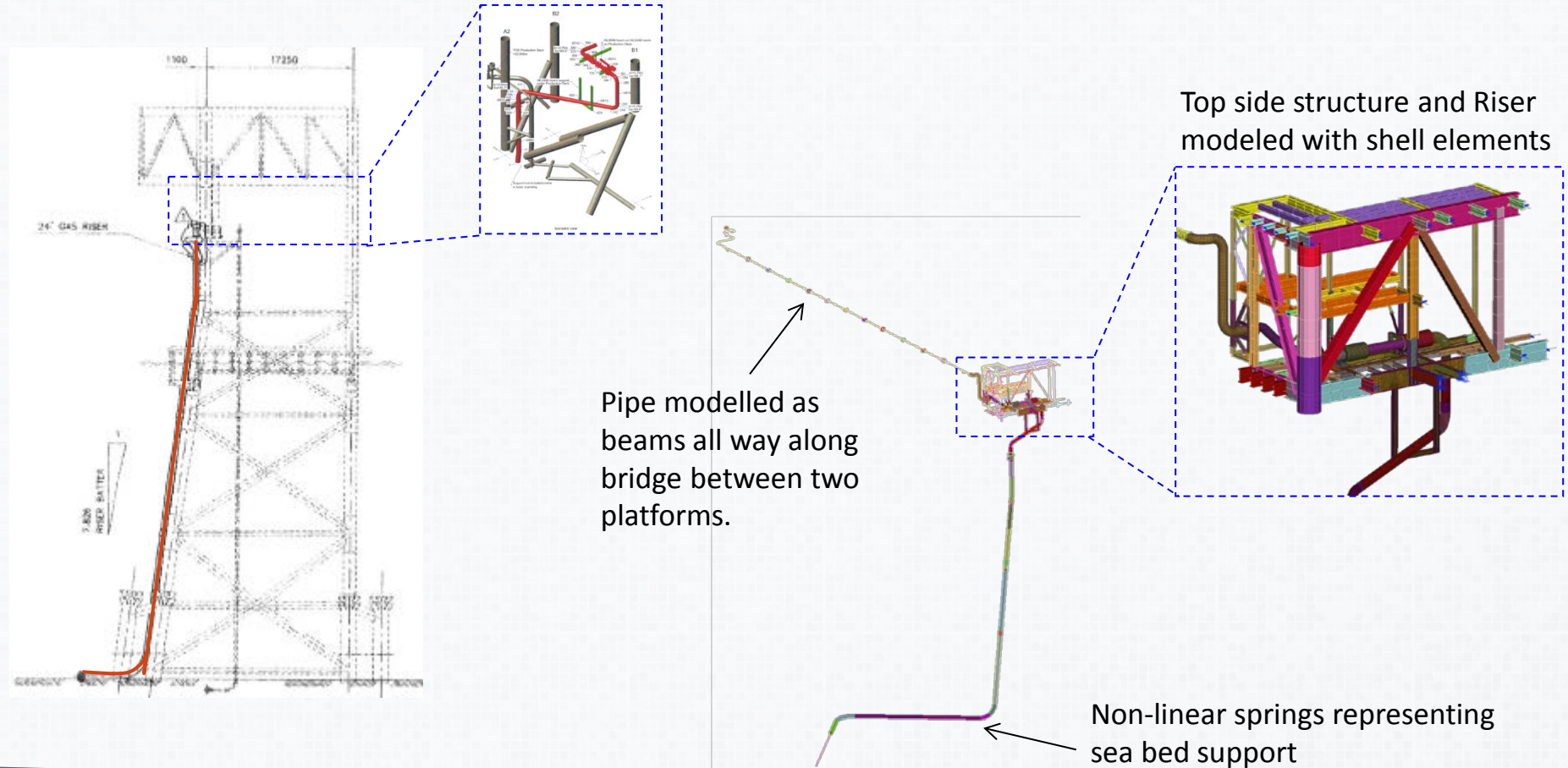


## Project description:

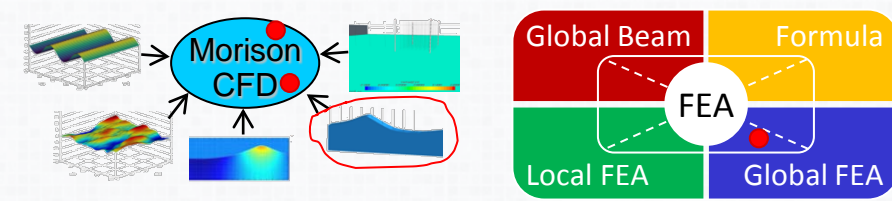
Assessment of structural integrity of risers due to Abnormal breaking (ALS) waves

## Loading:

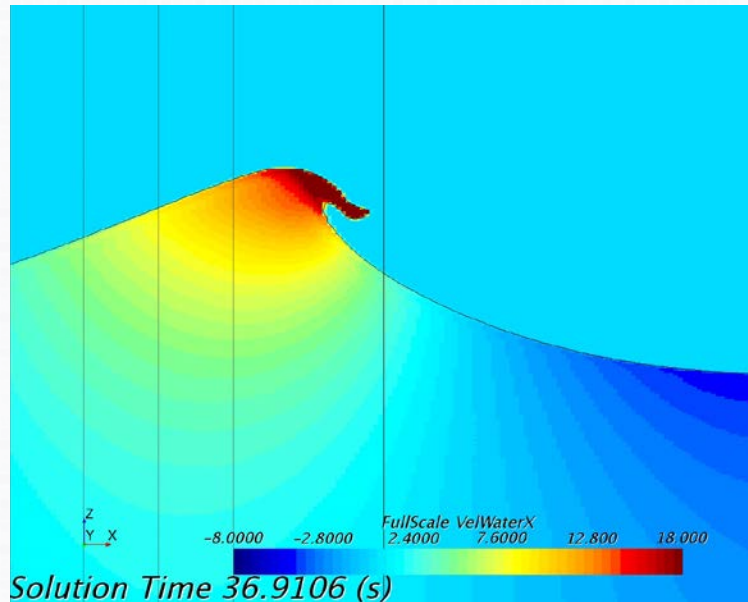
- Gravity
- 12 MPa internal pressure
- Hydro static pressure
- Wave loading with kinematics extracted from 3D CFD analyses
- Morison equation applied on structural elements



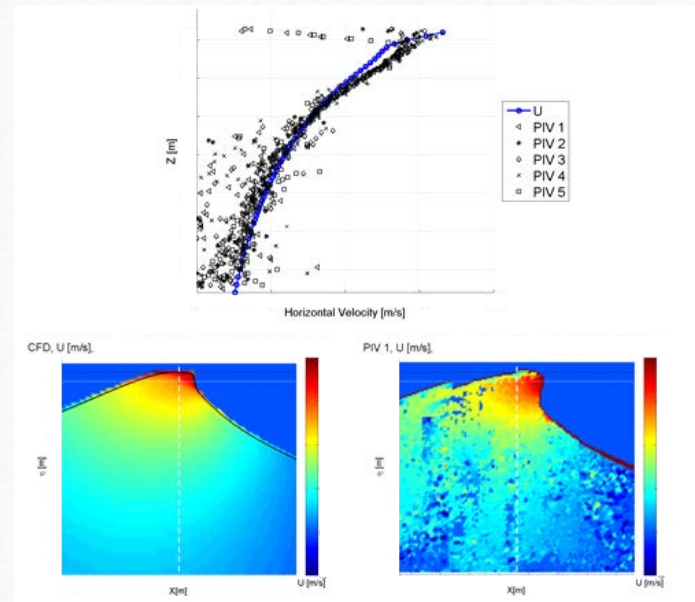
# Wave in Riser evaluation



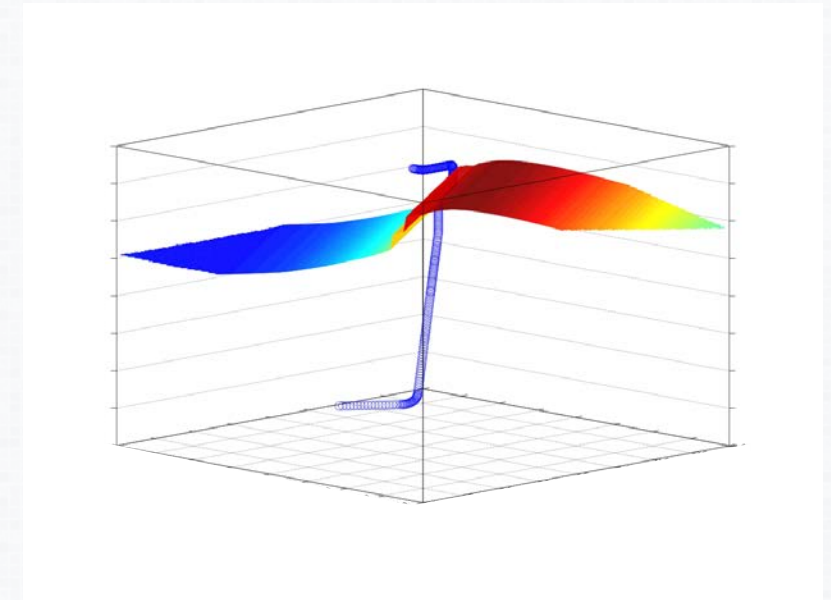
## Wave load generation



CFD analysis of breaking wave providing kinematics (velocity and acceleration fields) as input to subsequent Morison analyses.



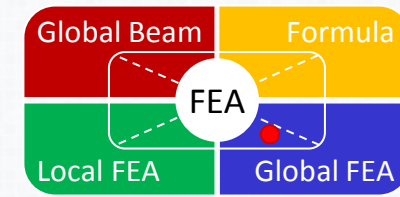
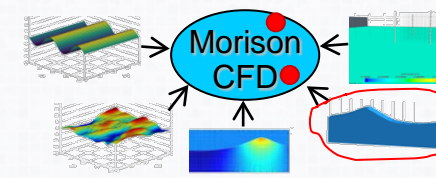
Validation of CFD results using PIV.



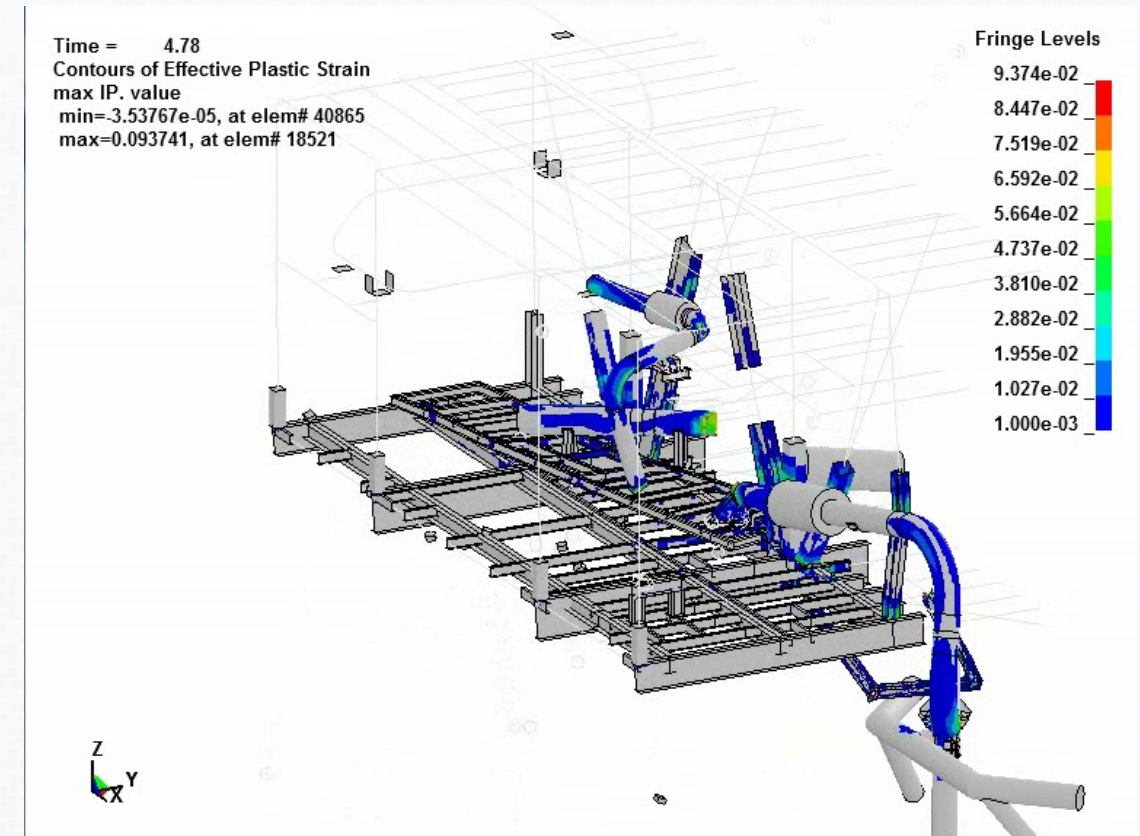
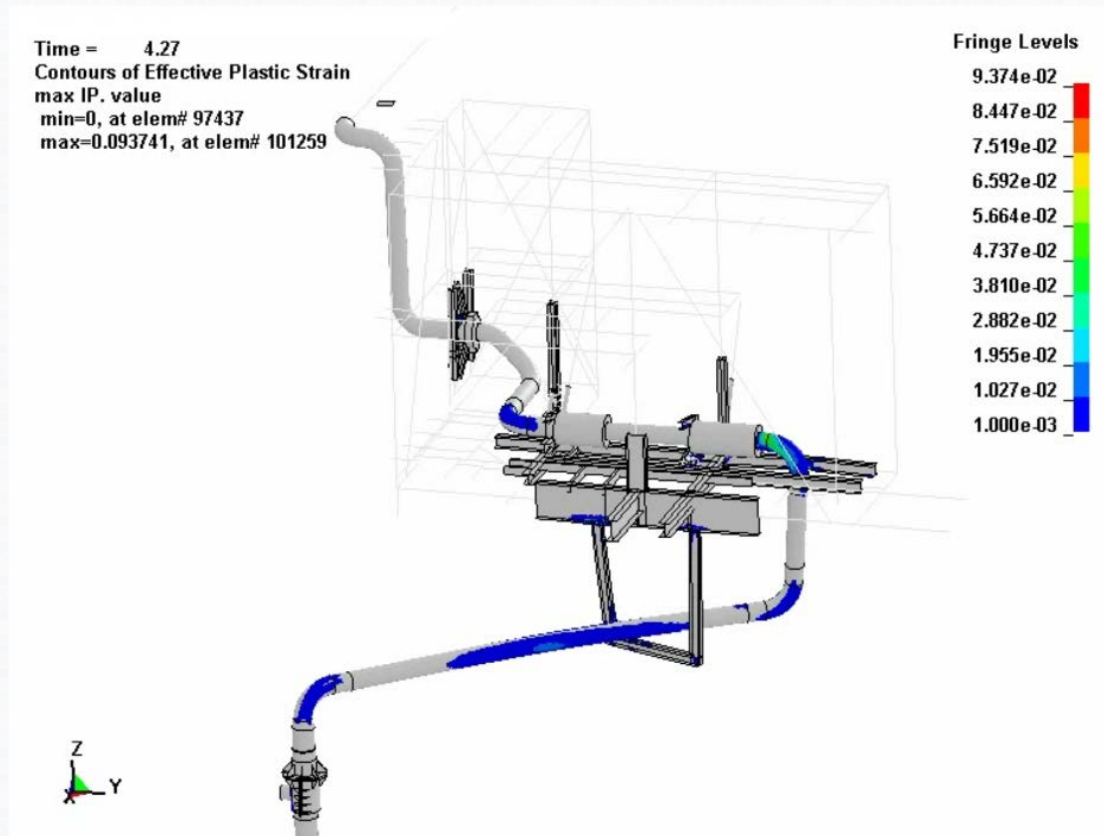
Octave script for generating loads on LS-DYNA riser model based on Morison equation using kinematics from CFD analysis without structure.



# Wave in Riser evaluation

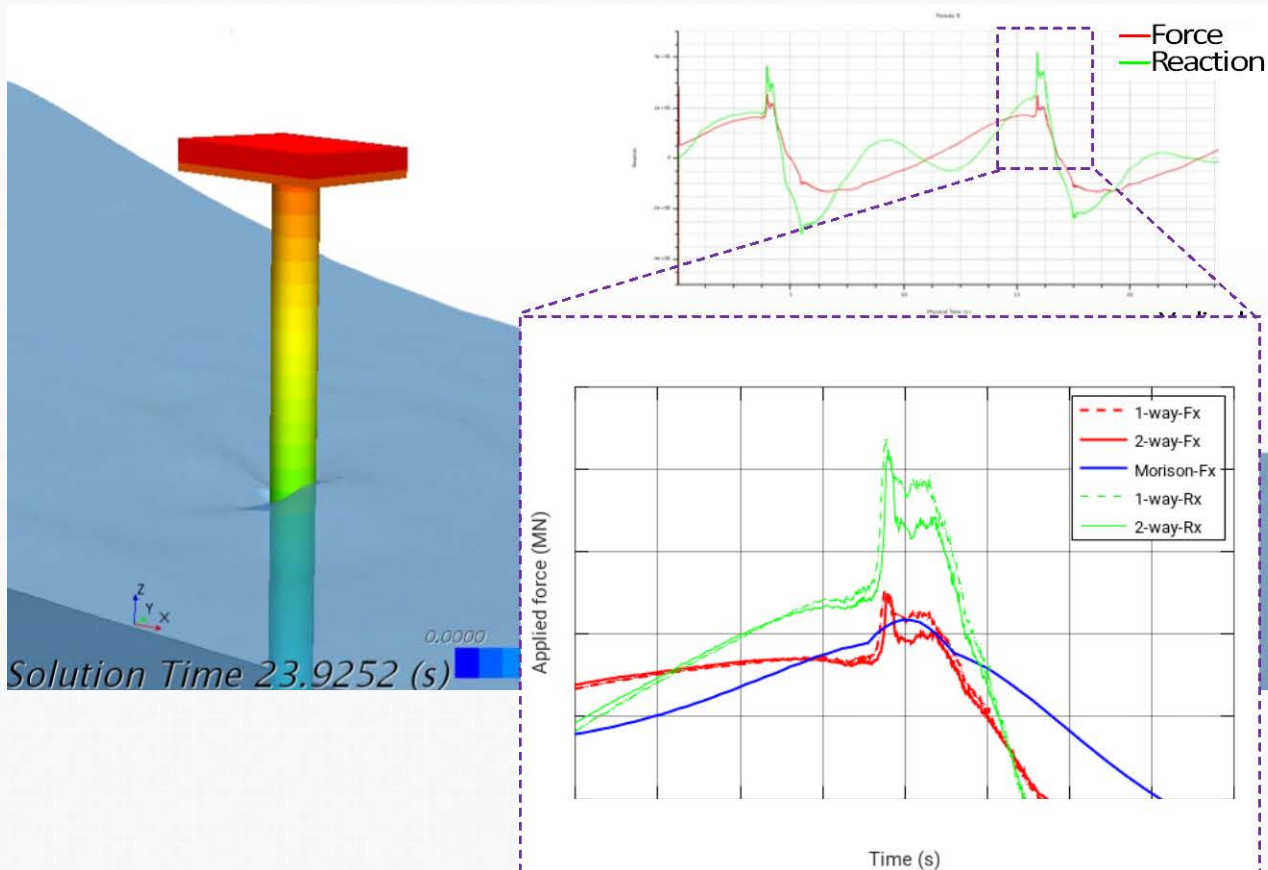


## Structural response

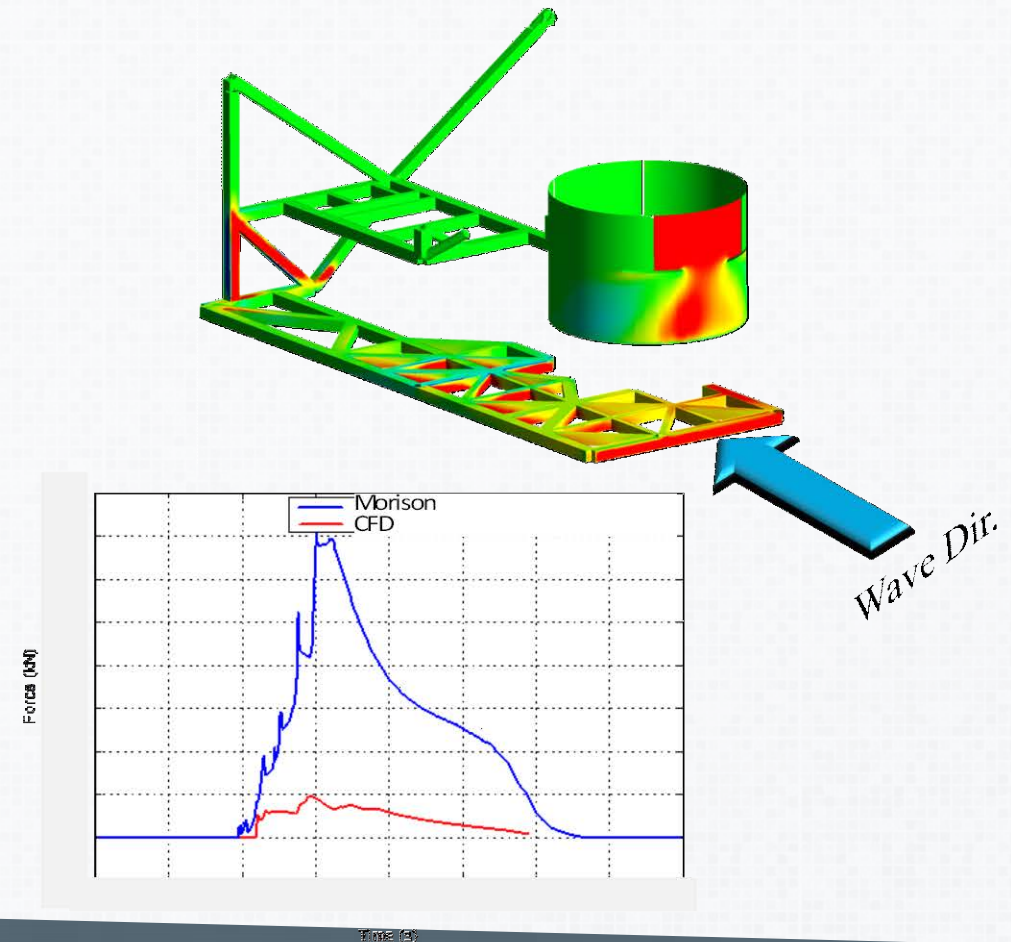


# Future challenges – Loading

Increased accuracy on loading through:  
2-way FSI



Adapted loading: Morison, SPH ...



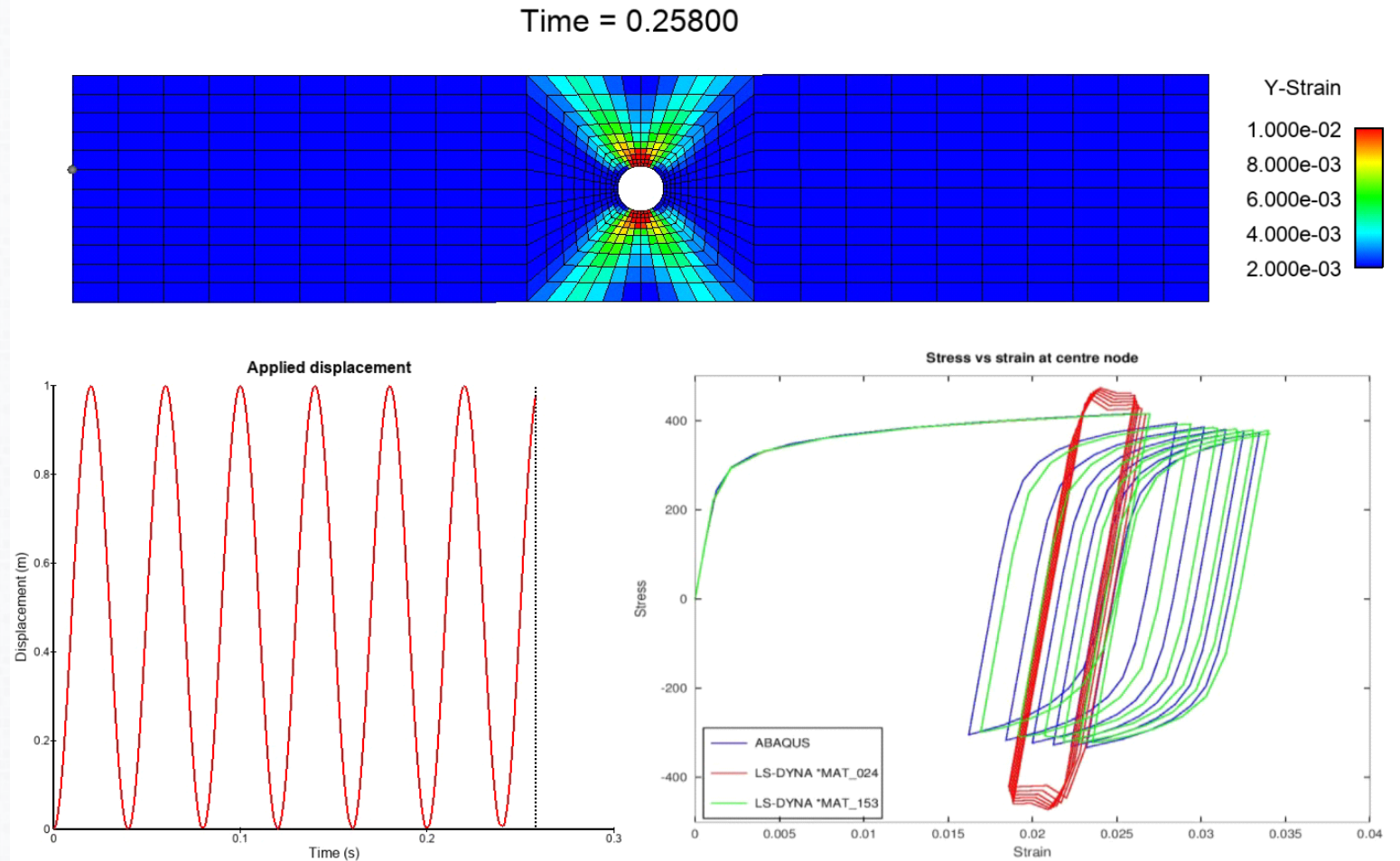


# Future challenges – Material & Execution

## Improved structural response evaluation due to cyclic loading

- Use Non-linear kinematic hardening such as the Chaboche material model\*.
- Further utilization of automatic shift between implicit and explicit solver scheme to allow for assessment of Irregular non-linear waves.

\* Implementation into LS-DYNA R11.0.0 made available by DYNAmore Nordic.



Example 8.10 from DNV-GL\_RP-C208

# Thank you for your attention



*Breaking wave on a monopile offshore platform in shallow water (© [www.flyingfocus.nl](http://www.flyingfocus.nl))*



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