The correct use of the numerical simulation in the engineering activities: some considerations

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THE INTERNATIONAL ASSOCIATION FOR THE ENGINEERING MODELLING, ANALYSIS, AND SIMULATION COMMUNITY.

AGENDA

1. Use of CAE in energy offshore engineering
2. Introduction
3. Firstly theory, then simulation
4. The different design phases
5. Possible analysis tools
6. “Reproduction” vs “Simulation”
7. Numerical simulation as a tool
8. Uncertainties in the numerical simulation
9. Risks associated to powerful software and hardware
10. What is NAFEMS

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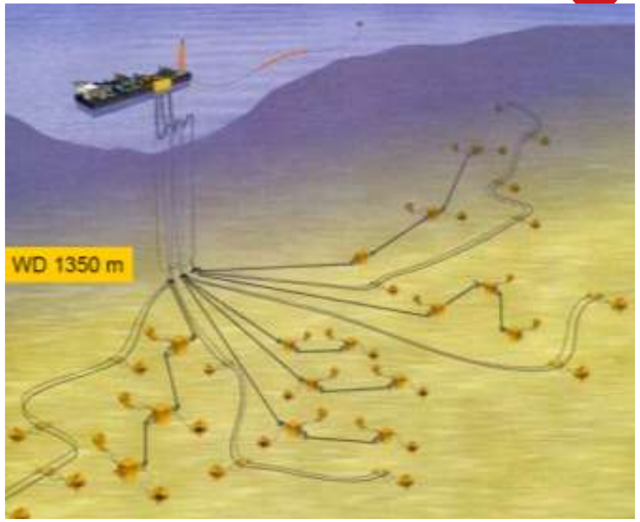
Use of CAE in energy offshore engineering

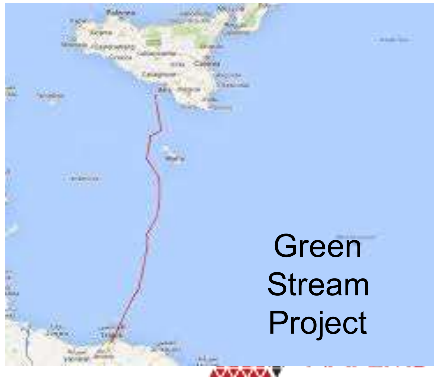
- Typical offshore oil & gas plants

Fixed Platform (w.d. < 150 m)

Floating Platforms (150 m < w.d. < 2000 m)



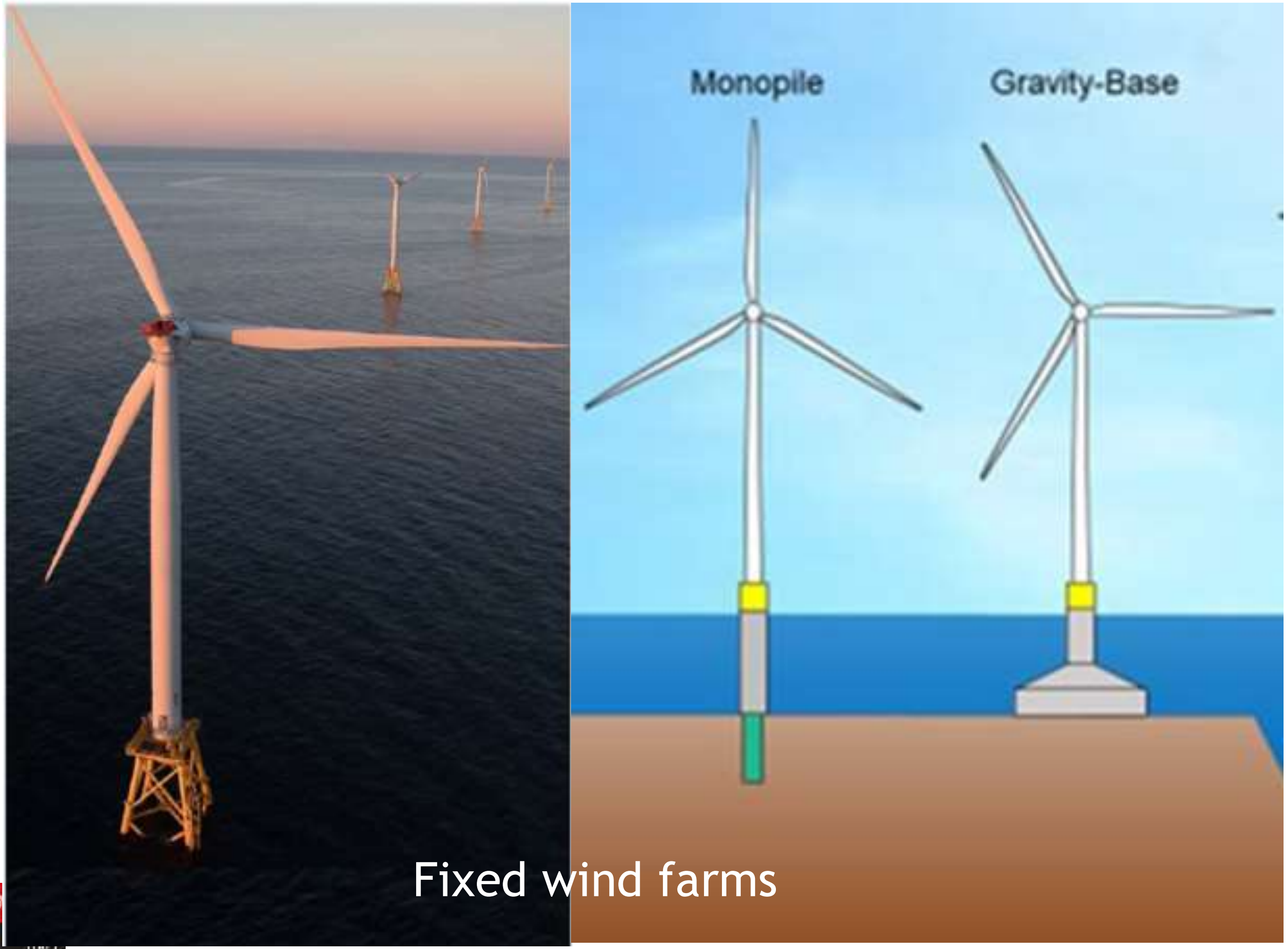
Subsea Production Systems
(150 m < w.d. < 2000 m)

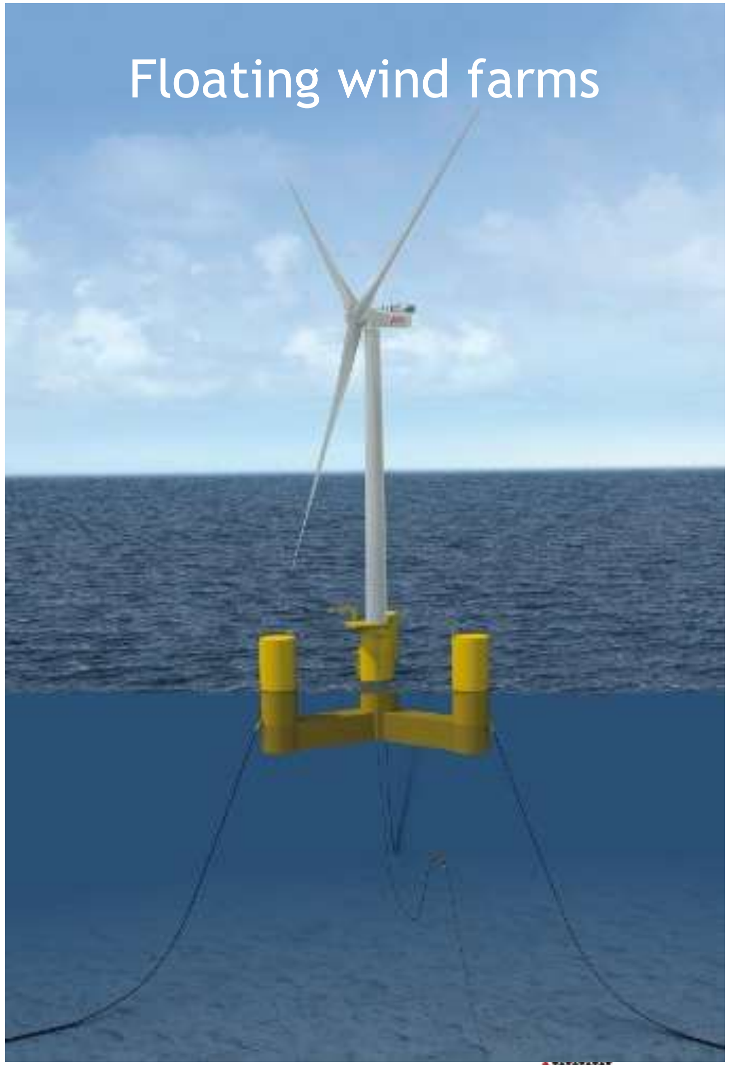


Submarine pipelines

Use of CAE in energy offshore engineering (cont'd)

- Typical offshore wind farms



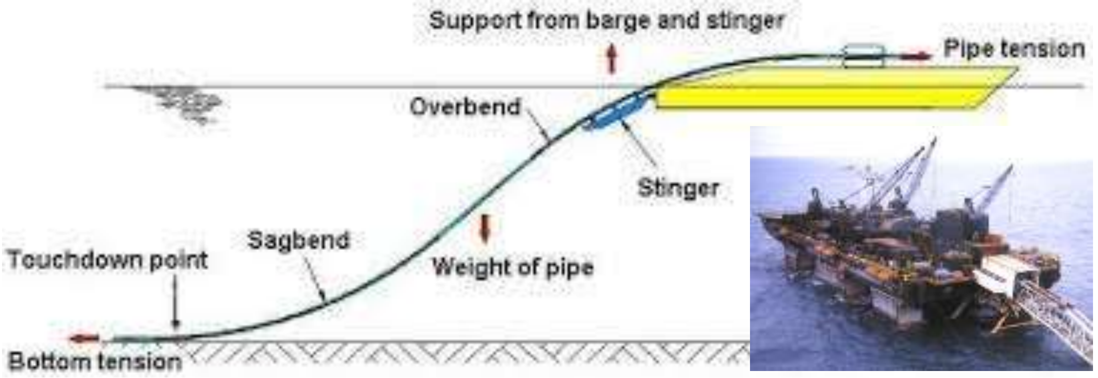


Use of CAE in energy offshore engineering (cont'd)

- Typical offshore operations

Installation of offshore plants

Laying of submarine pipelines



Drilling of offshore wells

Installation of wind turbines

Use of CAE in energy offshore engineering (cont'd)

- Numerical simulation within energy offshore engineering

  - Fundamental for the design and the installation of offshore energy systems, because these plants are becoming more and more complex, and their design is becoming more and more demanding.

  - Main numerical simulations
    - ➢ Structural analyses (static vs dynamic – linear elastic vs non linear – buckling)
    - ➢ Fatigue analysis
    - ➢ Seismic analysis
    - ➢ Vessel Motion analysis due to wind – wave – current loads
    - ➢ Fluid-structure interaction analysis
    - ➢ Thermal Analyses (steady & transient)
    - ➢ Computation Fluid Dynamic analysis
    - ➢ Single Phase vs Multiphase Fluid Analysis (definition of main operating parameters: pressure vs temperature vs fluid composition)

AGENDA

Introduction

- The use of the numerical simulation largely supports the engineering and design activities in many industrial areas, because of the availability of powerful software and high hardware capabilities
- The software currently available enable the simulation of complex physical problems, but nowadays there is a risk hidden in the use of the numerical simulation: an uncritical trust on the results of the numerical simulation, not adequately supported by a good physical and engineering comprehension of the problem under study
- This risk shows in different ways:
  - It is not given priority to the engineering and theoretical aspects of the problem under study
  - Limited attention is given to the time frame of the engineering activity and to the requested level of accuracy of the results
  - There is a tendency ” to “reproduce” as close as possible the reality, instead of “simulating” the main aspects impacting the design objectives and the requested results
  - The numerical simulation is not considered just as one of the tools available for an engineer, to design an equipment and/or to solve a problem
- Purpose of this presentation is to discuss all these risks, through some practical examples

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Firstly theory, then simulation

- It is mandatory for the engineer using the numerical simulation to maintain the full control of the engineering problem, and to avoid to delegate to the software the comprehension of the physical / engineering problem under study.
- The comprehension of the problem under study, necessary for the full control of the engineering activity, comes from the knowledge of the theoretical and engineering aspects that govern it; such knowledge has the same (or even more) importance of the capability of using the numerical tools.
- The full comprehension of the problem under study allows the selection of both the best simulation tool and the complexity of the model; moreover, it is essential to define simplified interpretative models, in order to:
  - Understand the problem
  - Understand the influence of various parameters
  - Identify the order of magnitude of the expected results: the result has to be (qualitatively) known a priori.

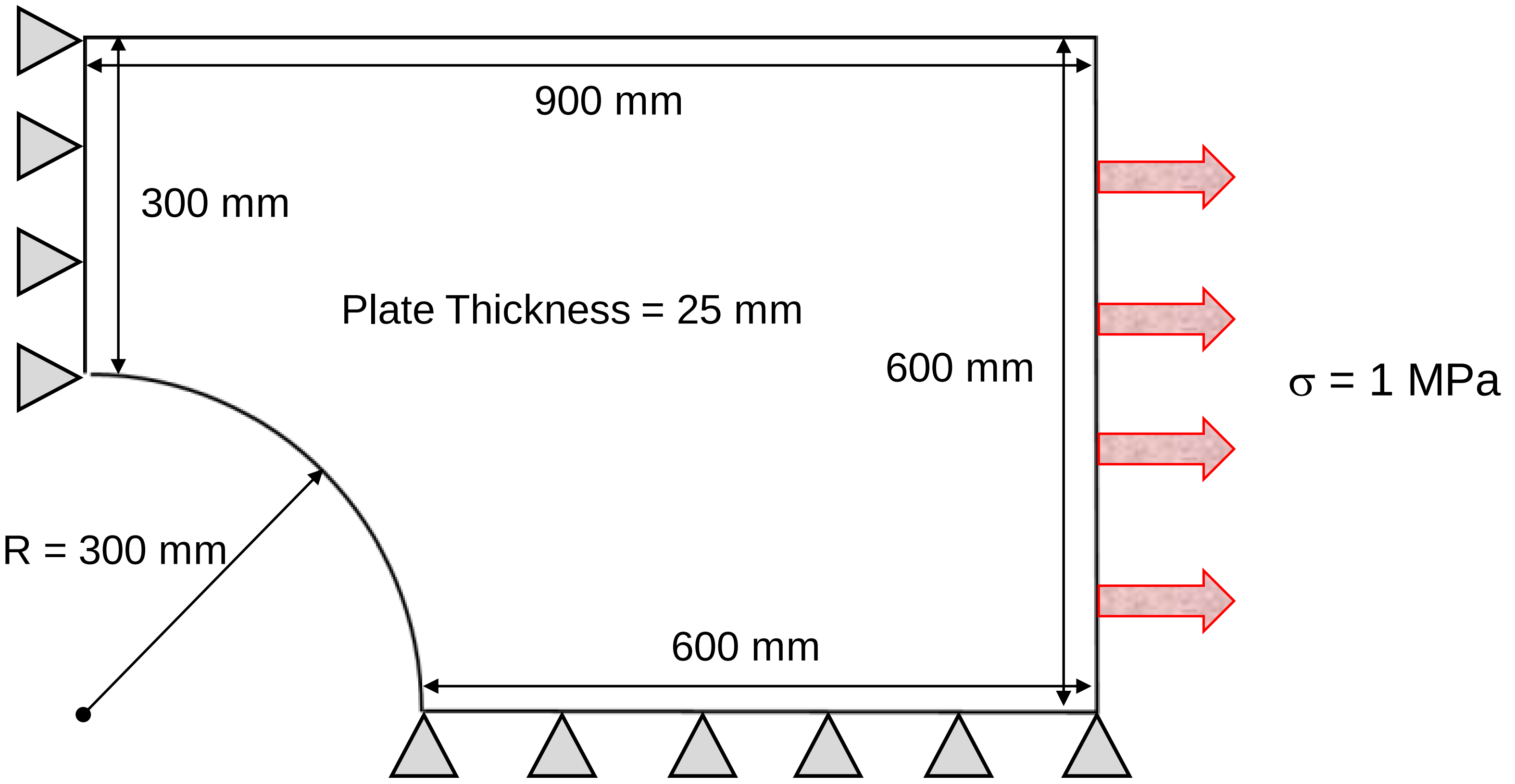
Every numerical result is wrong, until the comprehension of the problem convinces the engineer of its correctness.

Firstly theory, then simulation – An example (1)

STRESS CONVERGENCE VERSUS MESH REFINEMENT: IS IT ALWAYS TRUE?

- Typically, the accuracy in the stress prediction improves when a finer mesh is adopted

- Example in stress convergence with mesh refinement:



Firstly theory, then simulation – An example (1)

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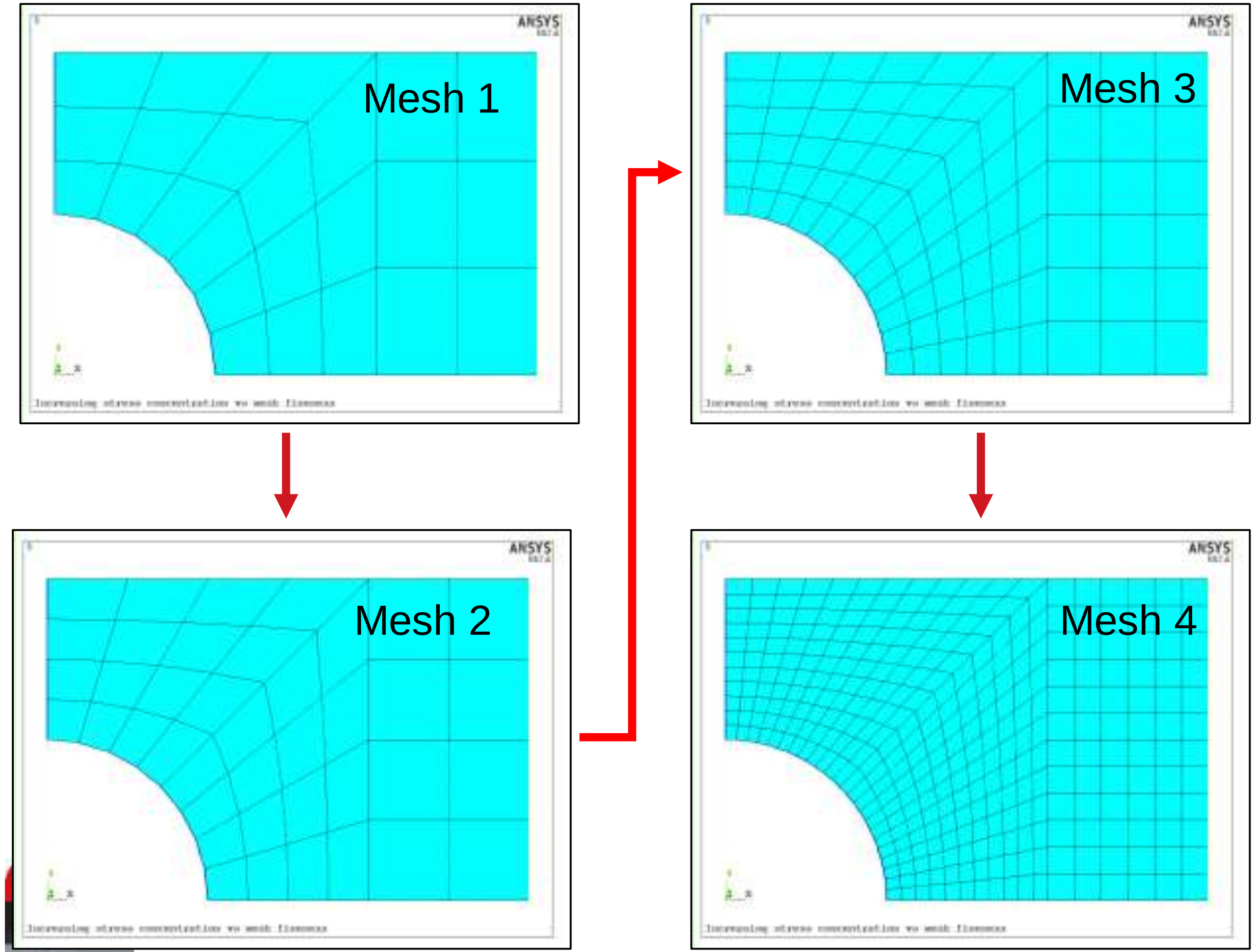
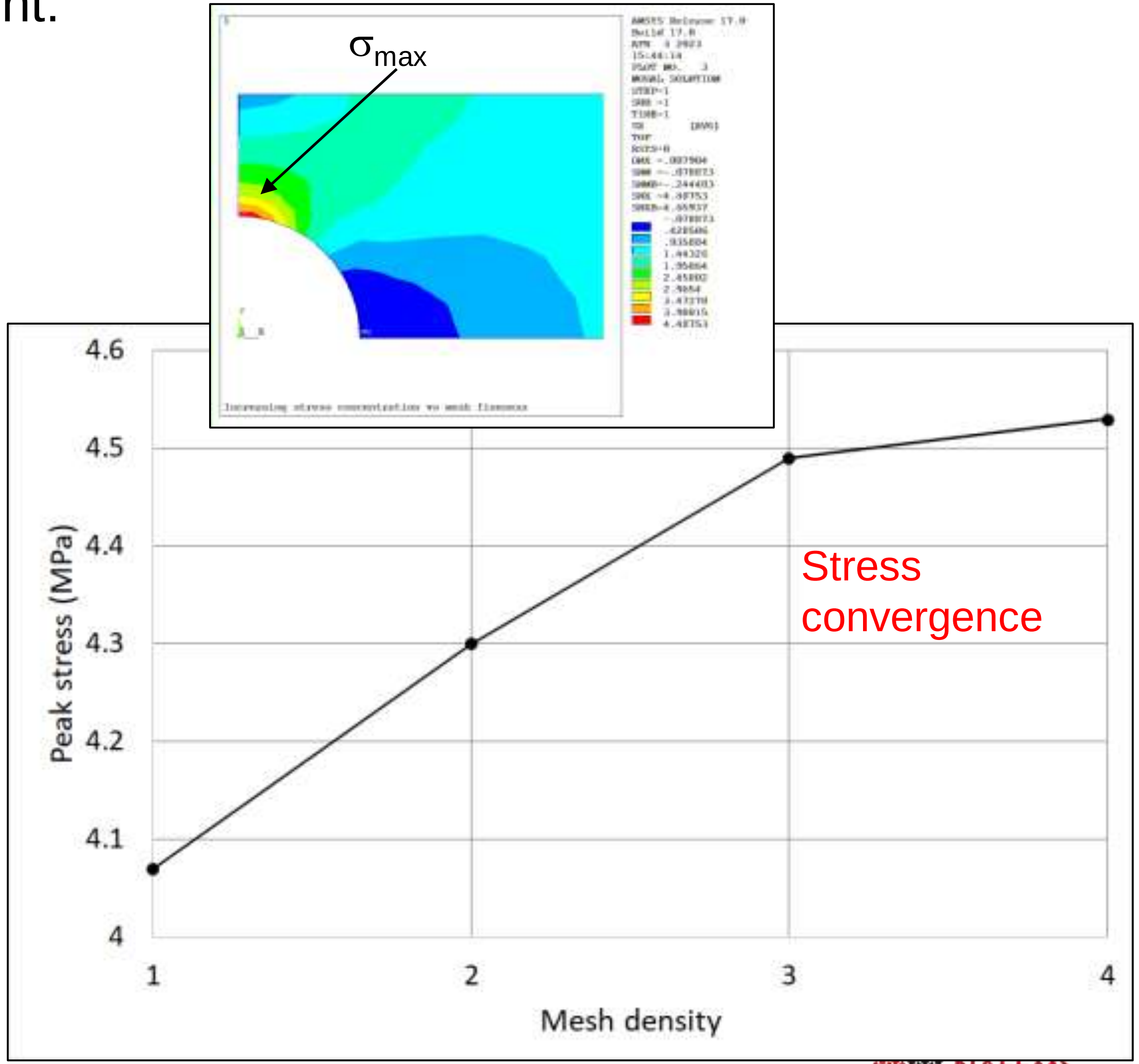
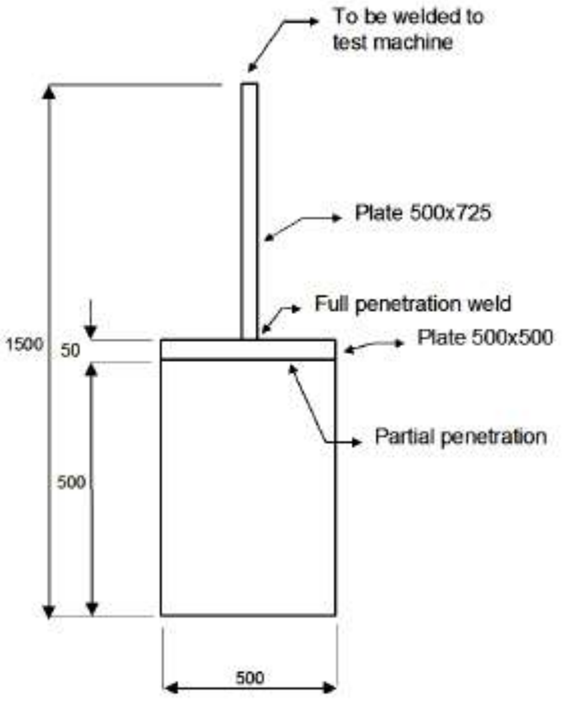


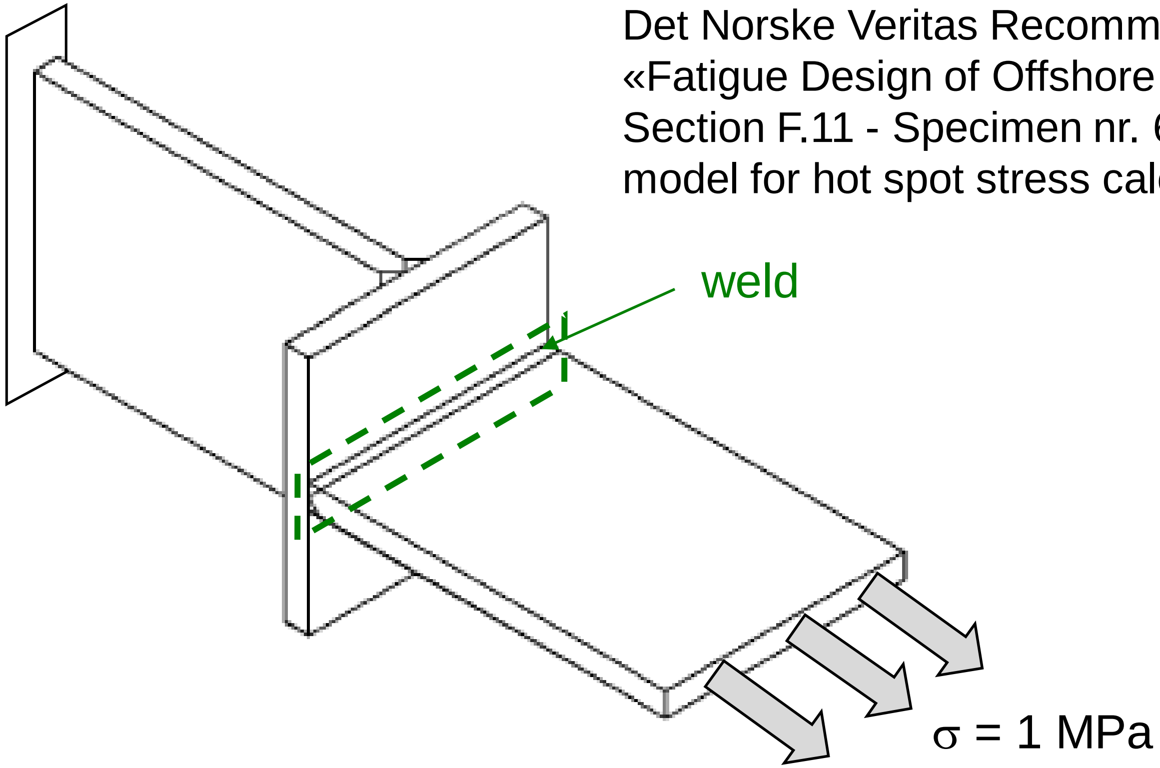


Firstly theory, then simulation – An example (1)

STRESS CONVERGENCE VERSUS MESH REFINEMENT: IS IT ALWAYS TRUE?

- Sometimes, a stress divergence happens when a finer mesh is adopted.
- Example in stress divergence with mesh refinement:



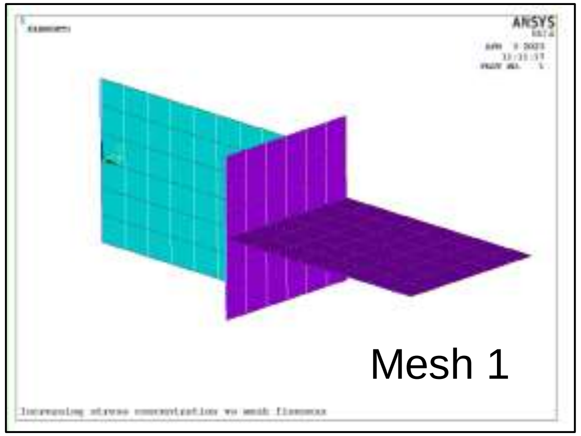


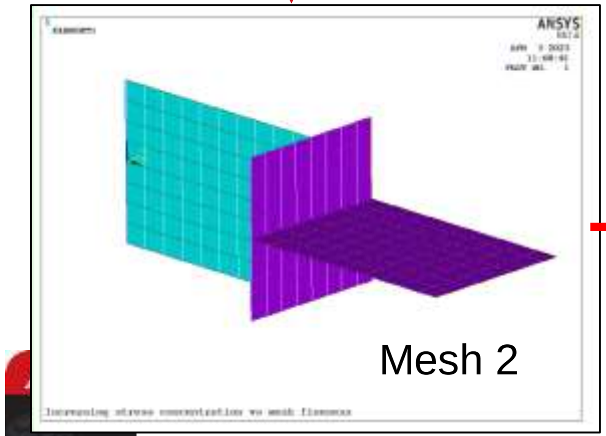
Det Norske Veritas Recommended Practice C203 «Fatigue Design of Offshore Steel Structure» Section F.11 - Specimen nr. 6 for validation of FE model for hot spot stress calculation

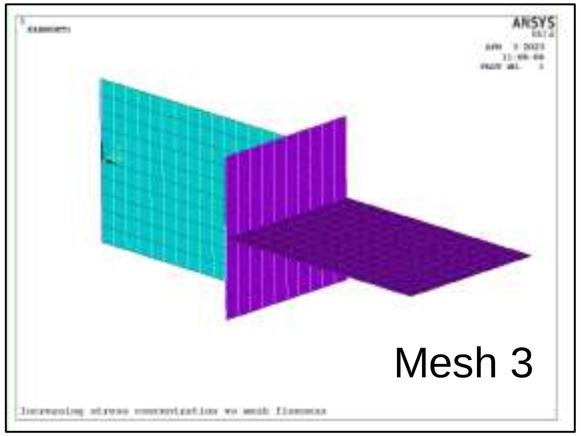
Firstly theory, then simulation – An example (1)

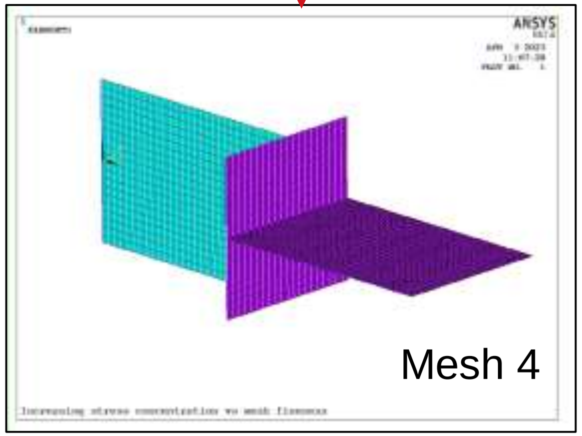
STRESS CONVERGENCE VERSUS MESH REFINEMENT: IS IT ALWAYS TRUE?

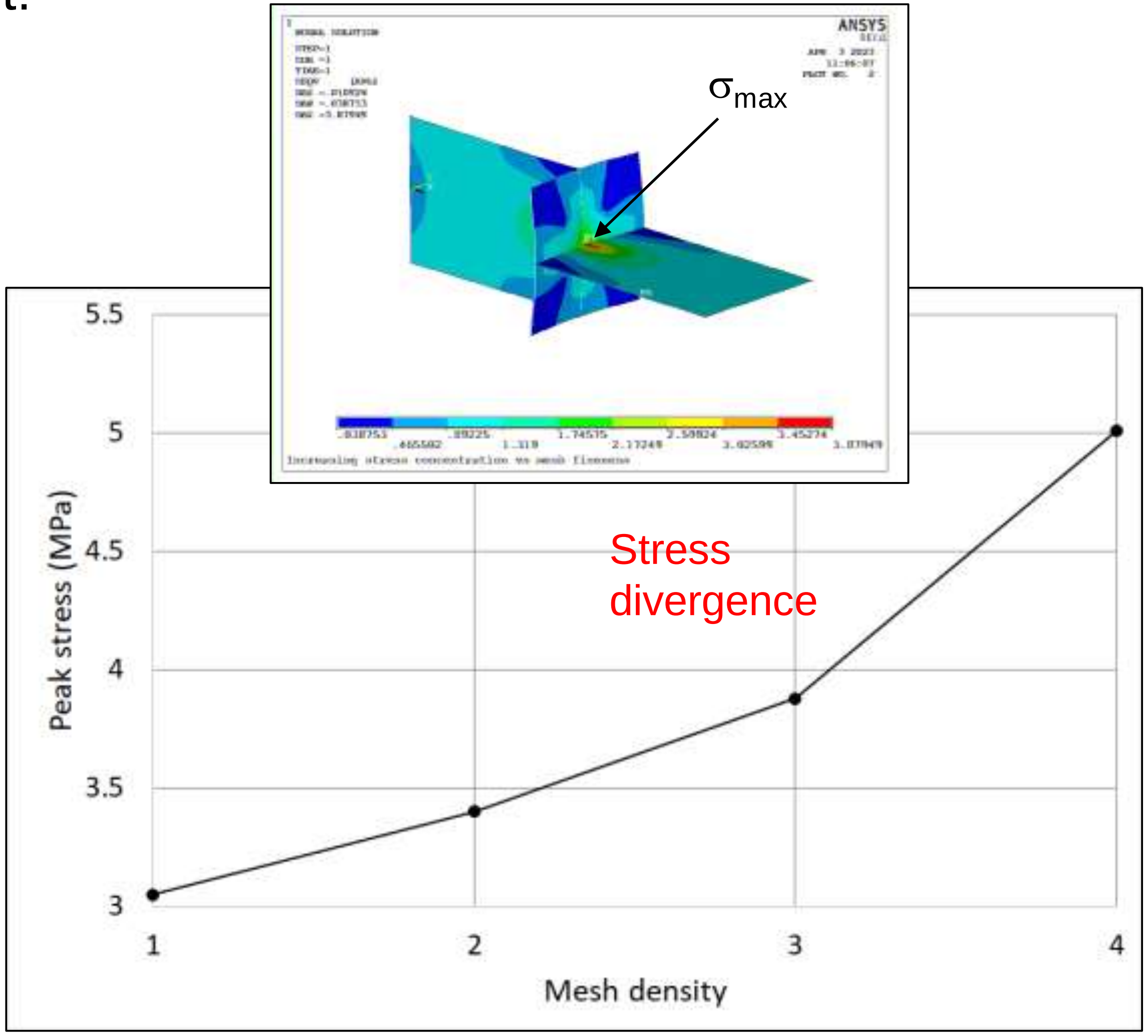
- Example in stress divergence with mesh refinement:











Firstly theory, then simulation – An example (1)

STRESS CONVERGENCE VERSUS MESH REFINEMENT: IS IT ALWAYS TRUE?

- Typically, the accuracy in the stress prediction improves when a finer mesh is adopted.
- This conclusion is valid for most of the finite element models; however, some local discontinuities into the geometry, such the connection of different plates, could introduce numerical discontinuities into the finite element solution, that result in a divergence of the prediction of the maximum stress.
- The full comprehension of the problem under study, including the full comprehension of its numerical simulation, allows to discriminate whether a mesh refinement produces a divergence of the stress prediction.

IT IS RISKY TO ACCEPT THE RESULTS AS THEY ARE

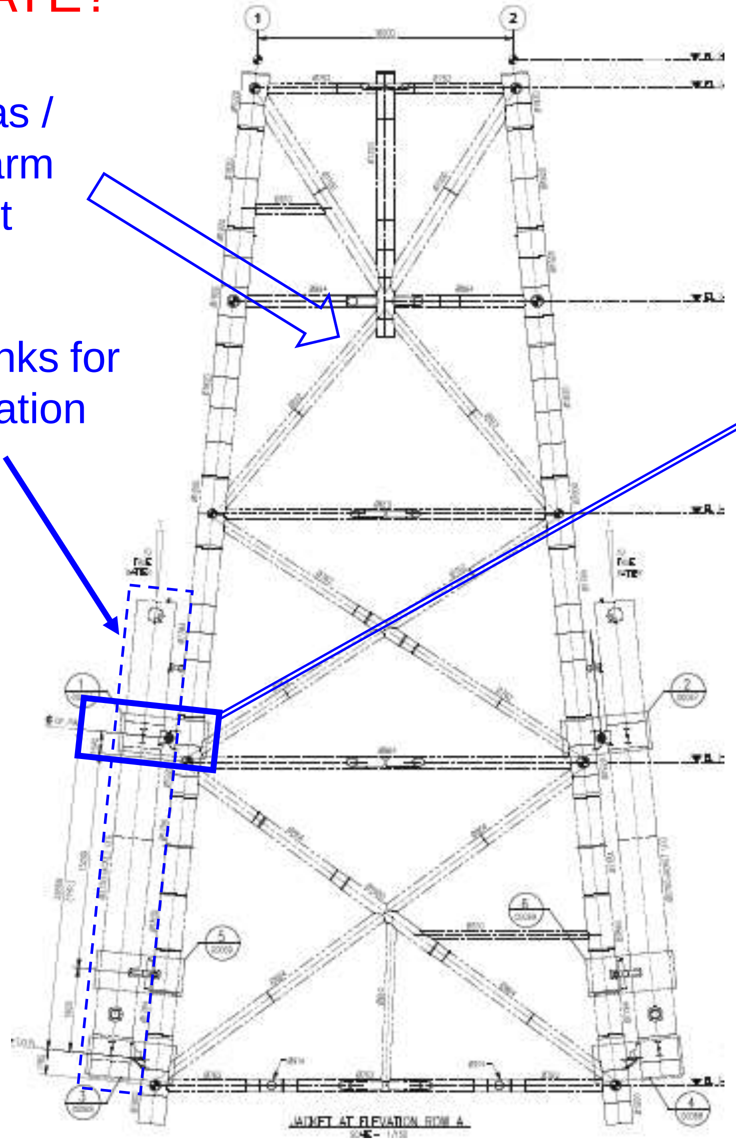
THE ENGINEERING AND THEORETICAL ASPECTS HAVE TO BE CAREFULLY CONSIDERED WHEN THE NUMERICAL RESULTS ARE EVALUATED

Firstly theory, then simulation – An example (2)

CONSISTENCY BETWEEN STRESS AND STRAIN RESULTS: IS THE MESH REFINEMENT ADEQUATE?

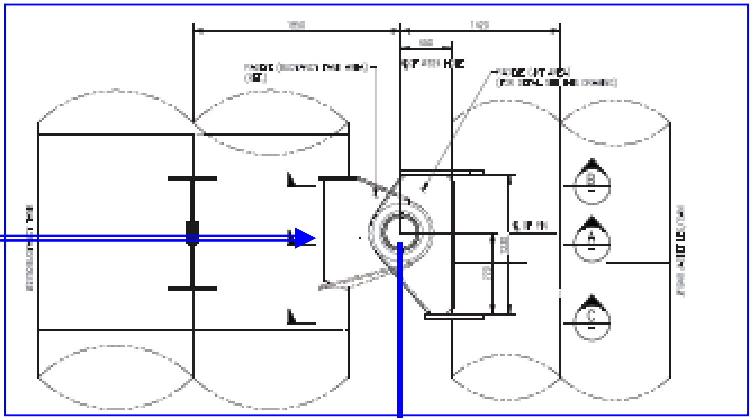
Oil & Gas / Wind Farm Jacket

Bouyancy Tanks for Jacket installation

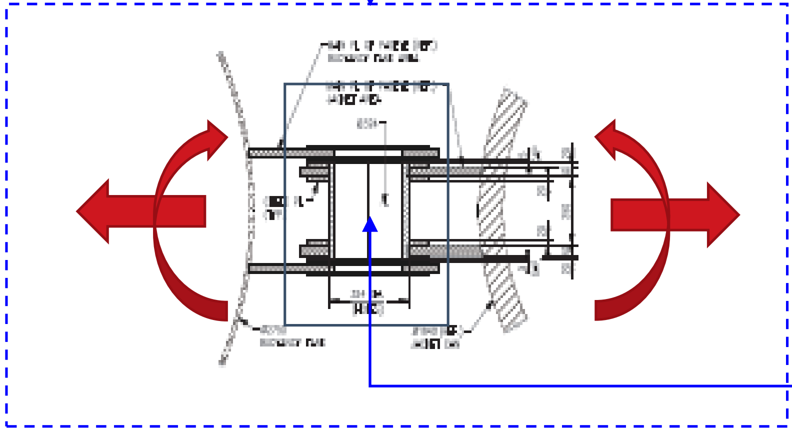


Bouyancy Tank

Jacket Tubular



Connection between Buoyancy Tank and Jacket

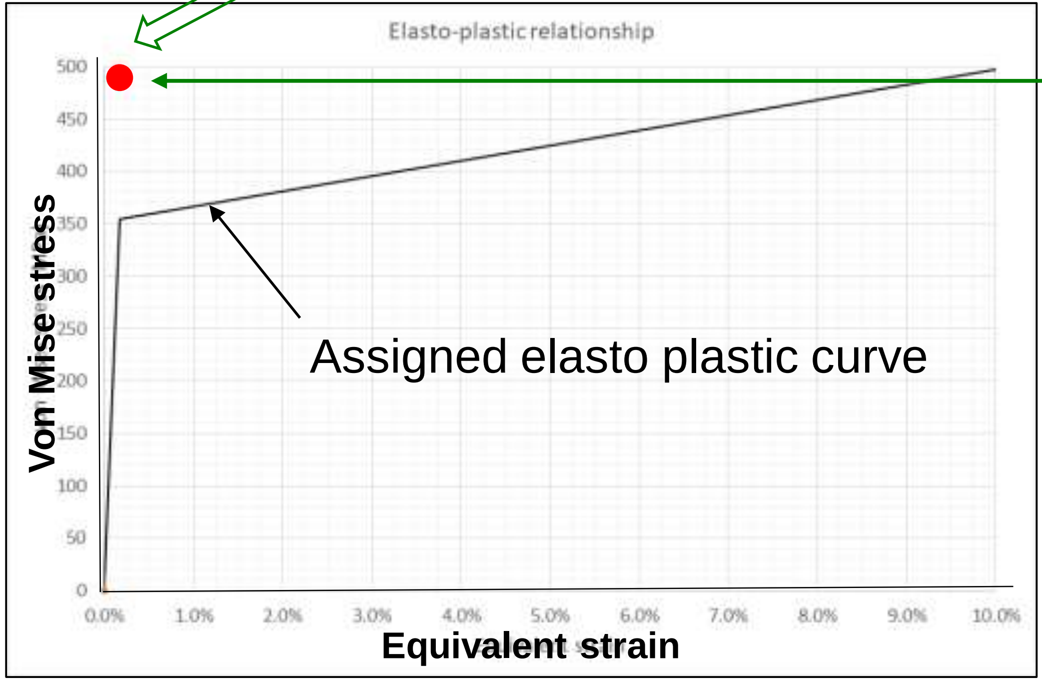


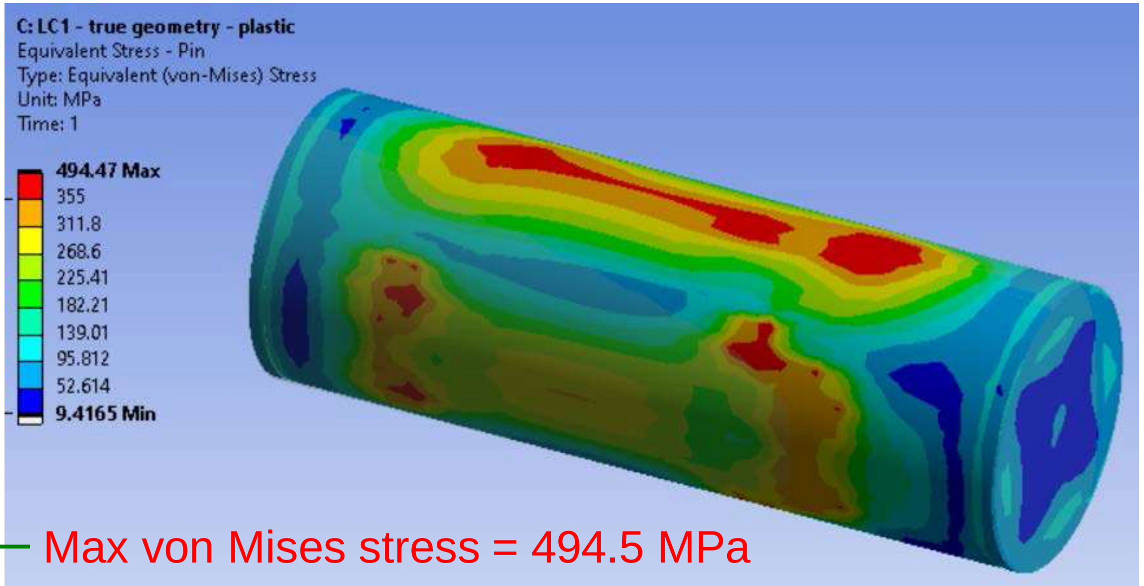
Internal Pin

Firstly theory, then simulation – An example (2)

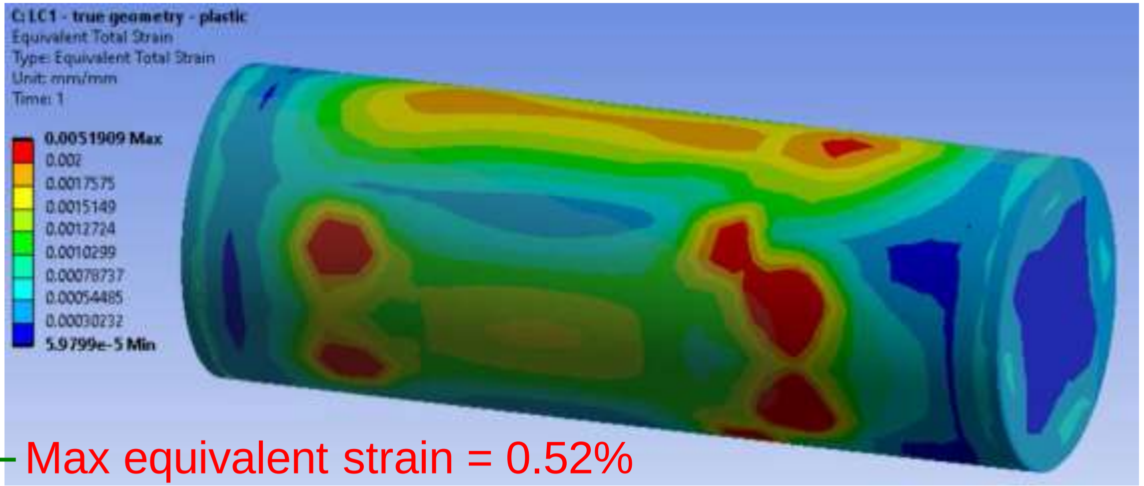
CONSISTENCY BETWEEN STRESS AND STRAIN RESULTS: IS THE MESH REFINEMENT ADEQUATE?

FE result: combination of max von Mises stress & max equivalent strain





Max von Mises stress = 494.5 MPa



Max equivalent strain = 0.52%

- Plotted results not in line with material model => numerical reason: a very coarse mesh

AGENDA

The different design phases

- The design of offshore energy plants and systems is characterized by three different phases:
  - Conceptual Design and/or Feasibility Study
  - Basic Design
  - Detailed Design
- During the Conceptual Design various alternatives are analyzed and compared, and the best technical & economic configuration is identified, together with a preliminary characterization of its main components and an estimate of the overall investment cost.
- The Basic Design further develops the selected configuration, in order to identify a more accurate estimate of the investment costs (± 15%).
- The Detailed Design is aimed at the construction, installation and start-up of the Energy Production System.

The different design phases (cont'd)

- Each design phase results in different requirements for the numerical simulation, in terms of both required level of accuracy and time available to complete the design.
    - The Conceptual Design usually takes a short time (few weeks); therefore, the analysis and the comparison of the various alternatives should be carried out quickly, and the requested accuracy of the results is not high.
    - Viceversa, the Detailed Design has totally different requirements: there is generally only one configuration to be analyzed, but with a high degree of accuracy; however, it takes longer time (at least a few months).
- Numerical analyst is requested to adapt his activity to the design phase requirements, using the most suitable numerical tool, according to the required accuracy and the available time frame

AGENDA

Possible analysis tools

- Two alternatives are available to perform calculations:
  - Numerical simulations (i.e. FE / CFD analysis)
  - Analytical methods (i.e. hand made checks and/or simplified formulas)

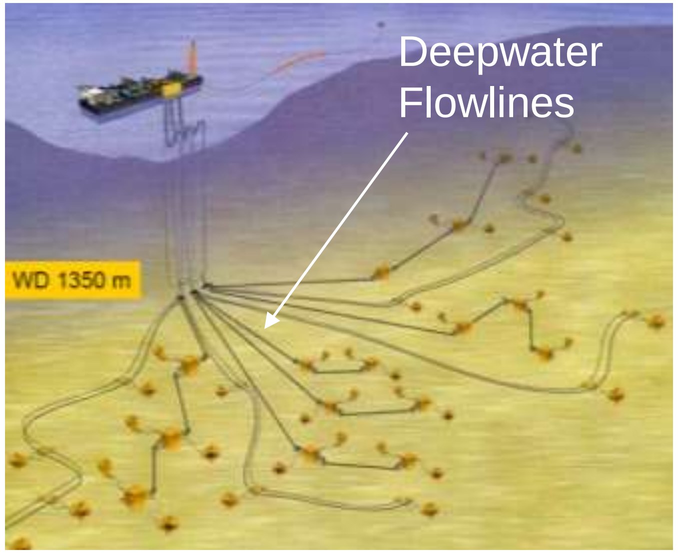
	Pro's	Con's
Analytical Methods	✓ Easy & quick use ✓ Qualitative description of the phenomenon ✓ Quick development of sensitivity analyses	✓ Lower accuracy in the results ✓ Conservatism in the prediction of the phisical / structural behavior
Numerical (FEM / CFD) Methods	✓ High accuracy in the results	✓ High simulation time ✓ Difficult development of sensitivity analyses

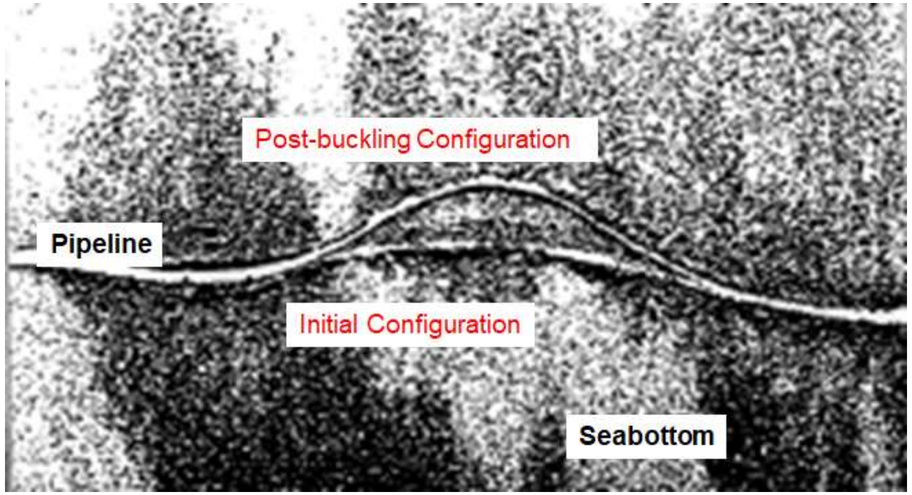
- Numerical simulations are more accurate and result in a less conservative design; analytical models are more useful in initial studies and sensitivity analyses

Analytical vs Numerical Tools – An example (1)

THE FLOWLINE LATERAL BUCKLING PHENOMENON

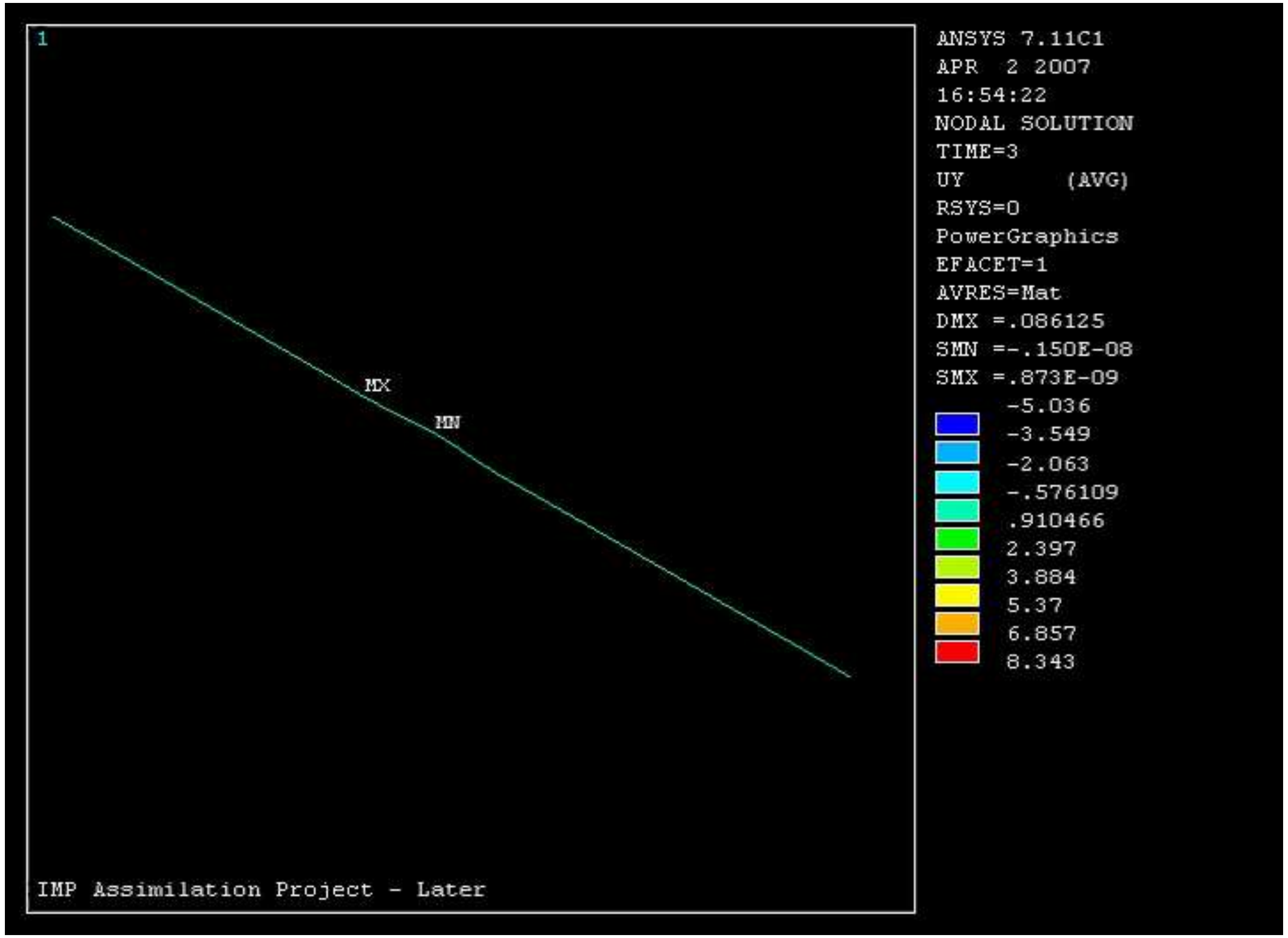
- The flowline tends to expand, because of the action of hydrocarbon temperature & pressure.
- Demanding operating conditions are usually expected for hydrocarbon transportation in deepwaters:
  - hydrocarbon temperature: up to 110 – 130 °C
  - hydrocarbon pressure : up to 30 – 40 MPa
- The axial friction between pipe and soil restraints the axial expansion associated to the pressure and temperature loads.
  - A compressive force develops along the route, and it can become larger than the Euler Buckling Load. The consequence is the lateral (horizontal) buckling





Analytical vs Numerical Tools – An example (1)

THE FLOWLINE LATERAL BUCKLING PHENOMENON

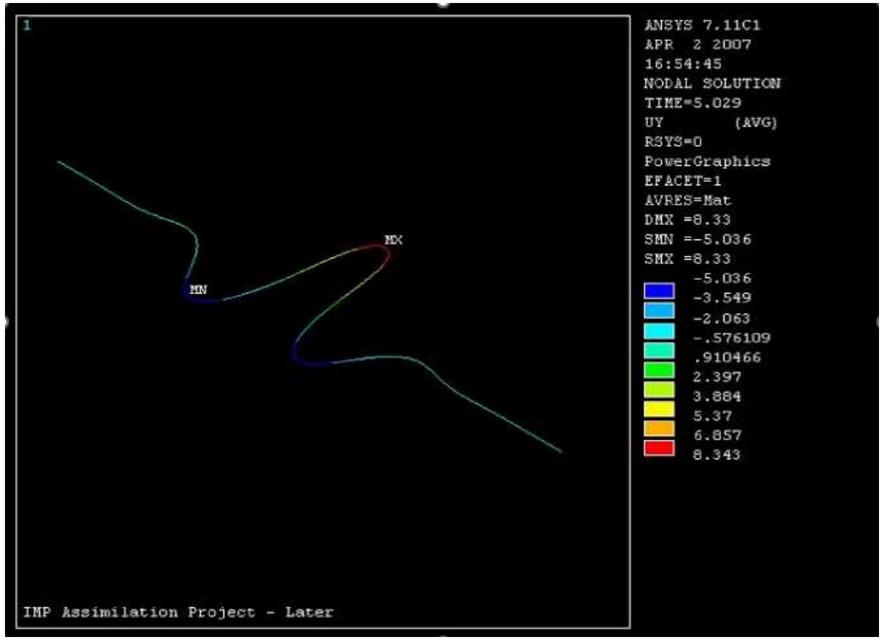


Hydrocarbon Temperature & Pressure progressively increasing during system start-up, remains constant during operationg, and then reducing during system shut-down

Analytical vs Numerical Tools – An example (1)

THE FLOWLINE LATERAL BUCKLING PHENOMENON

- Pipeline Structural Integrity is deeply affected by the buckling phenomenon.
- Strategy in the past => buckling prevention: no development of large compressive force (many location along the route for pipeline expansion) and/or no buckling development (pipeline burying)
- Strategy not practical and/or economical at present (particularly in deepwaters)

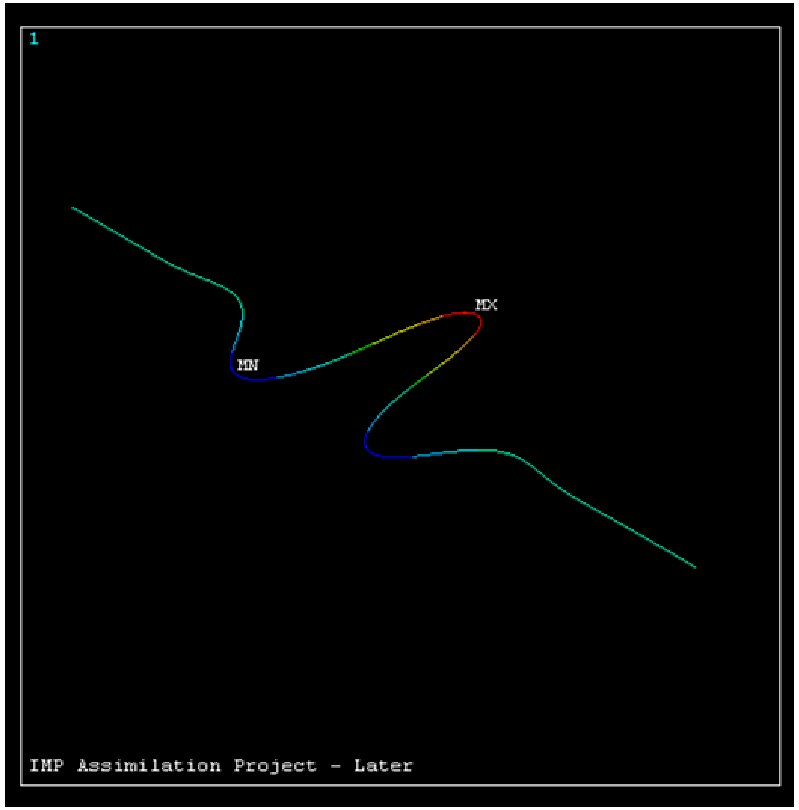


- Present strategy, based on advances analysis tool => Buckling control
  - Buckling development is allowed, but controlled
  - Both analytical & numerical methods are used:
    - Analytical Methods into the initial design phases (and during detailed design phases, as validation of numerical results)
    - Numerical (FEM) Methods into the detailed design phases

Analytical vs Numerical Tools – An example (1)

THE FLOWLINE LATERAL BUCKLING PHENOMENON: NUMERICAL (FE) METHODS

- FEM results are considered representative of the actual pipeline behaviour.
- The preparation of the FEM does not present difficulties; the following aspects can be included in the global FE model:
  - Elasto-plastic behaviour of the pipe steel;
  - Soil-pipe interaction.
  - Large displacement (and finite strain) theory;
- Difficulties are mainly associated to the management of the numerical convergence:
  - Management of the existing non-linearities (pipe-soil contact & friction, elasto-plasticity, etc)
  - Management of the onset of the global instability (the lateral buckling)

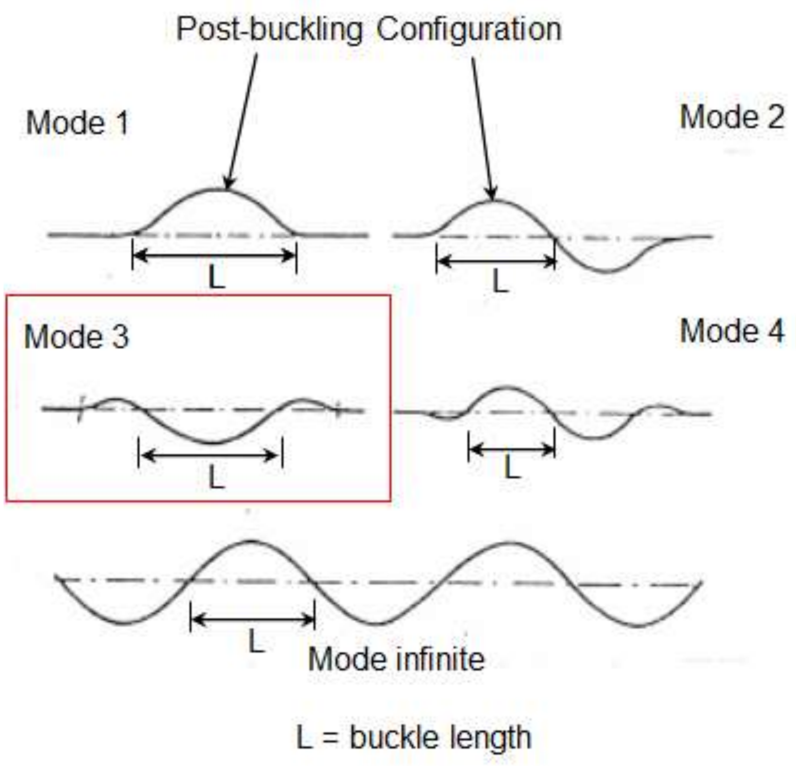


Analytical vs Numerical Tools – An example (1)

THE FLOWLINE LATERAL BUCKLING PHENOMENON: ANALYTICAL METHODS

- Coming from the study of the thermal buckling of the railroad track.

- Analytical method is based on simplified assumptions:
  - Single buckling within an infinite & straight pipeline
  - Constant compressive load along the pipeline
  - Pre-defined post-buckling configuration (typical mode: Mode 3)
  - Perfectly elastic pipe material behavior
  - Large displacement & small strains
  - Rigid-Coulomb pipe-soil friction



Analytical vs Numerical Tools – An example (1)

THE FLOWLINE LATERAL BUCKLING PHENOMENON: ANALYTICAL METHODS

Hobbs' Equation

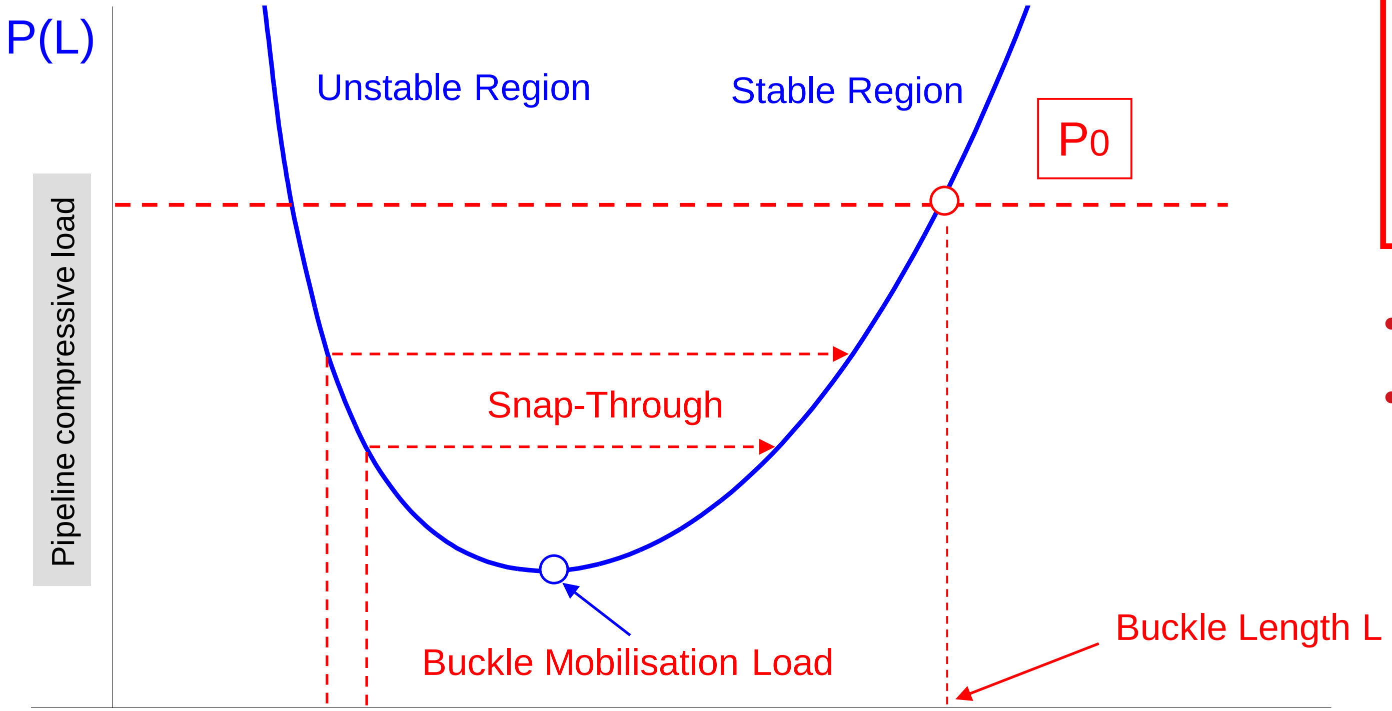
$$P_o = P(L) = k_1 \frac{EI}{L^2} + k_3\, \mu_{long}\, q_s\, L \left[\sqrt{1 + k_2 \frac{E\,A\,\mu_{lat}^2\, q_s\, L^5}{\mu_{long}\,(E\,I)^2}} - 1 \right]$$

→ Buckle Length $L(P_0)$

P0 = compressive load inducing buckling

$$M_{max} = k_5 \mu_{lat} q_s L^2$$

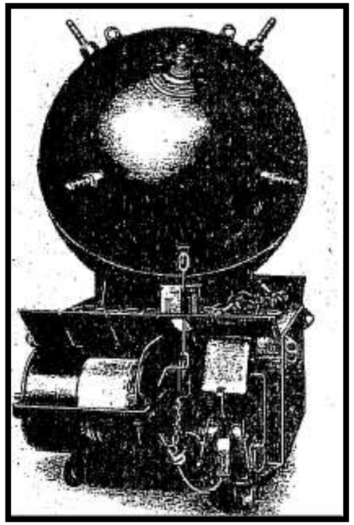
$$y_{max} = k_4 \frac{\mu_{lat} q_s}{EI} L^4$$



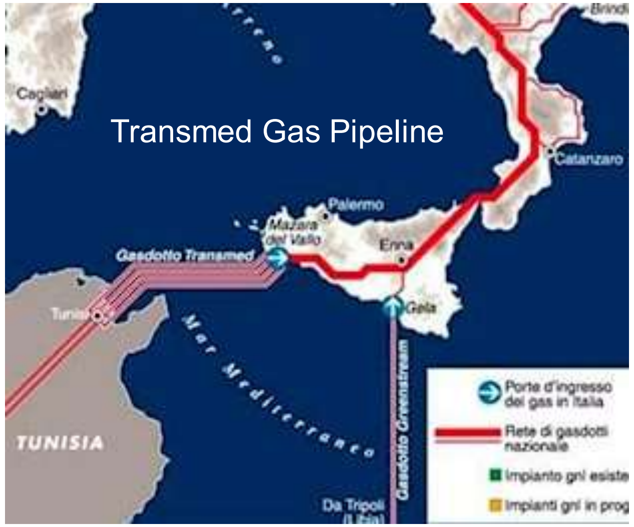
- Conservative Predictions
- Error on M_{max} prediction (vs FE results) < 10%

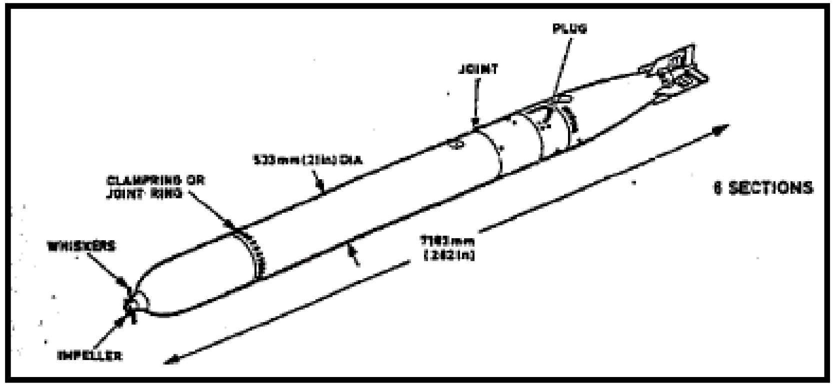
Analytical vs Numerical Tools – An example (2)

STRUCTURAL INTEGRITY ASSESSMENT OF A PIPELINE SUBJECTED TO AN ACCIDENTAL UNDERWATER EXPLOSION



- Some existing or future submarine gas pipelines cross seabed areas which in the recent past were war theatre, or dumping areas used for burying weapons after the last war.
- In this case there is the need to prepare an initial clearance corridor around the pipeline route, free of explosives; moreover, during operating life unexploded charges can be dragged close to the pipeline, for instance by fishing gears.
- The assessment of the structural integrity of a submarine pipeline subjected to underwater explosions is mandatory, to define the initial clearance corridor and/or to decide whether a dragged charge needs to be removed or not.





Analytical vs Numerical Tools – An example (2)

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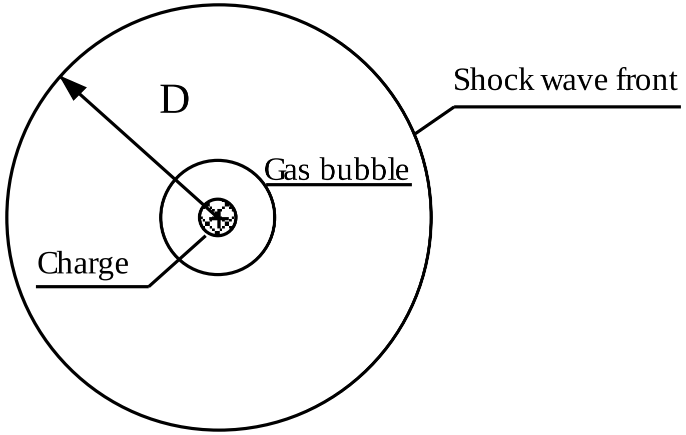
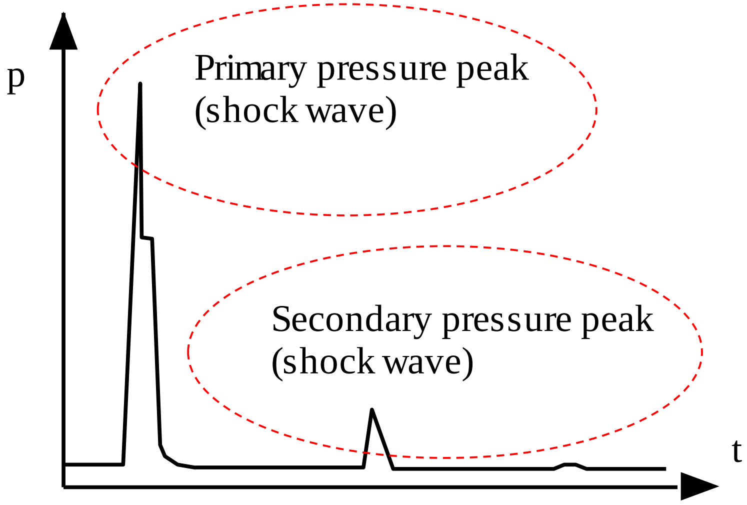


- Explosion: chemical reaction which converts the explosive material into a gas characterized by very high temperature (~3000°C) and peak pressure (~15-25 GPa).
- The pipeline is suddenly invested by the primary shock wave pressure, few msec after the explosion
- Firstly, a local (shell) response of the pipe wall develops: a significant local damage can develop up to a wall tearing inducing a gas leakage => most critical event. If the pipe wall does not collapse, the pipeline could develop a global (beam) response: the pipeline could move laterally => not critical event
- After few seconds, that pipeline is invested by the secondary pressure peak, associated to the expansion of a gas bubble, but this pressure is smaller than the primary one => no consequences for the pipeline



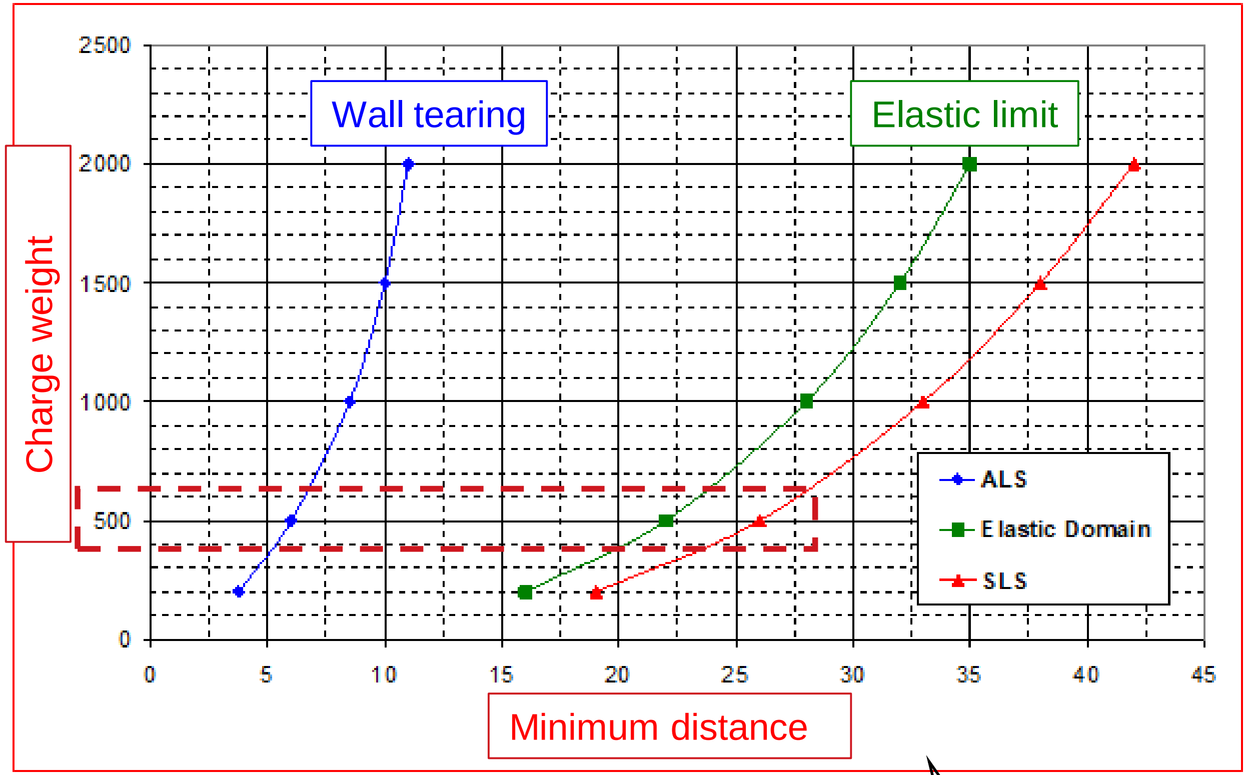
Analytical vs Numerical Tools – An example (2)

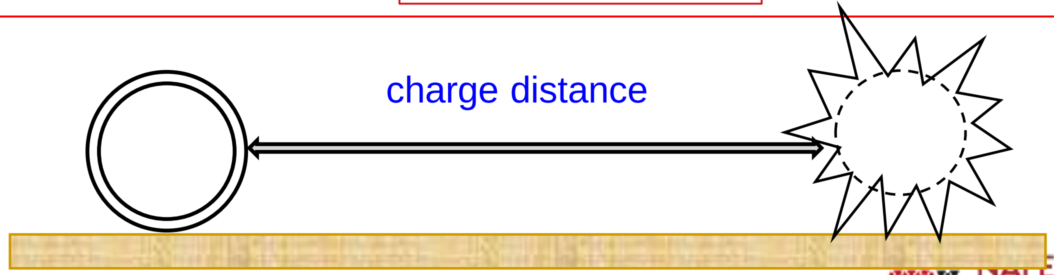
STRUCTURAL INTEGRITY ASSESSMENT OF A PIPELINE SUBJECTED TO AN ACCIDENTAL UNDERWATER EXPLOSION

- Curves relating the charge weight versus the corresponding minimum distance shall be identified; they depend on allowed limit state for the pipeline.

- Charge weight = 500 kg
  - Elastic limit distance (no plastic strains) ≈ 24 m
  - Wall tearing distance (gas leakage) ≈ 6.5 m

- Analytical approaches are available to characterize the pipeline loading and to perform preliminary studies, as well as numerical methods to develop a full 3D non-linear study.





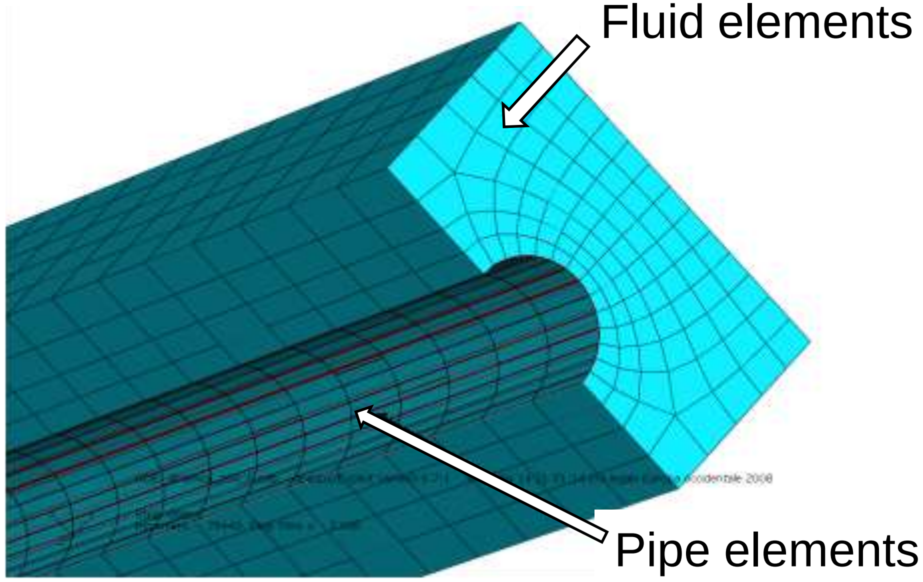
Analytical vs Numerical Tools – An example (2)

STRUCTURAL INTEGRITY ASSESSMENT OF A PIPELINE SUBJECTED TO AN ACCIDENTAL UNDERWATER EXPLOSION – NUMERICAL APPROACH

- Main requirements of the detailed (FEM) structural analysis
  - Coupling between structural response and propagation of acoustic shock wave pressure
  - Elasto-plastic, strain rate - dependent steel behavior
  - Very large strains (larger than 5-10%)
  - Non-linear time-domain dynamic analysis

⇨ FEM Explicit Code

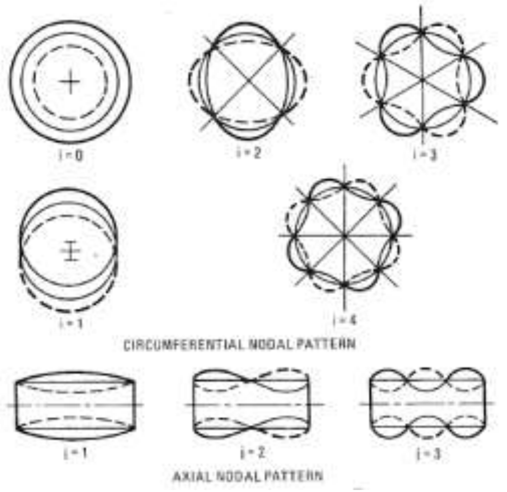
- FEM Model shall include:
  - Pipeline
  - Fluid surrounding pipeline
  - Charge and explosion: two possibilities
    1. 3D FEM charge model, incapsulated within the fluid zone
    2. Generator of shock wave pressure



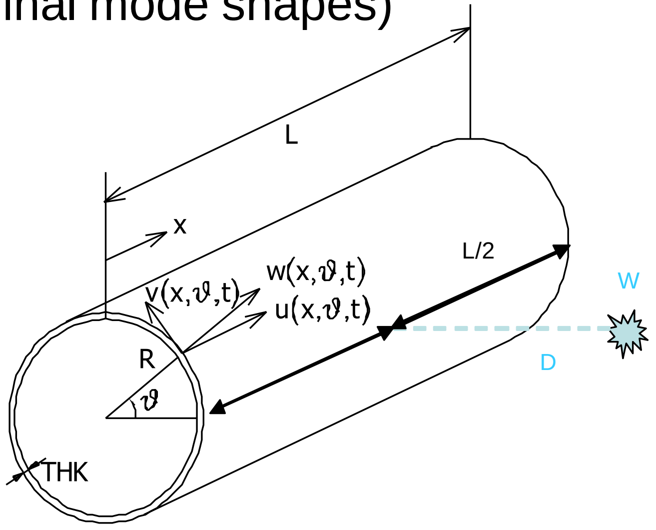
Analytical vs Numerical Tools – An example (2)

STRUCTURAL INTEGRITY ASSESSMENT OF A PIPELINE SUBJECTED TO AN ACCIDENTAL UNDERWATER EXPLOSION – ANALYTICAL APPROACH

- Simplified assessment of the pipeline structural response
- Analytical method is based on simplified assumptions:
  - Only the pipe wall is included in the model (surrounding water is excluded)
  - Perfectly elastic behavior of steel
  - Interaction between shock wave pressure and pipe included only in terms of pressure loading
  - Modal superposition approach (combination or circumferential and longitudinal mode shapes)



$$
\begin{cases}
u(x,\vartheta,t)=\sum_{i=0}^{N}\sum_{j=1}^{M}\left(q_{i,j}(t)\,u_{i,j}(x,\vartheta)\right)\\
v(x,\vartheta,t)=\sum_{i=0}^{N}\sum_{j=1}^{M}\left(q_{i,j}(t)\,v_{i,j}(x,\vartheta)\right)\\
w(x,\vartheta,t)=\sum_{i=0}^{N}\sum_{j=1}^{M}\left(q_{i,j}(t)\,w_{i,j}(x,\vartheta)\right)
\end{cases}
$$



Possible analysis tools - Conclusions

INTEGRATION OF ANALYTICAL & NUMERICAL METHODS

Design Phase	Design Requirements	Adopted Methods
Conceptual/ Feasibility (Initial) Phase	✓ Stringent time frame (few weeks) ✓ Assessment & comparison of different alternatives ✓ Sensitivity analyses (influnce of parameters on post-buckling config.) ✓ Limited accuracy of results	✓ Wide use of analytical methods ✓ Use of numerical methods aimed mainly at confirming the analytical results, and removing (large) conservatism in the stress prediction
Detailed Design Phase	✓ Longer time frame (many months) ✓ Detailed assessment of few alternatives ✓ Very high accuracy of results	✓ Wide use of numerical methods ✓ Use of analytical methods as guidance to the FEM simulations

Possible analysis tools – Conclusions (cont’d)

- The numerical analyst is requested to perform numerical simulations in all the design phases. Therefore, the following criteria should drive the simulation activity:
  - A suitable set of computational tools, ranging from simplified calculation models to the FE software, should be available, so that the most appropriate tool can be selected time-by-time
  - The analyst should be able to choose at each stage the most effective tool, among all the available ones, with respect to the degree of accuracy required in the numerical simulation and the time available for its execution.
  - The analyst should be able to move easily from the simplified calculation to the complex model, while keeping the same efficiency and quality.
  - However, a simplified approach to the simulation is fundamental even in the detailed phase, during the development of a complex numerical simulation, because it enables validation of the accuracy of the results obtained through a detailed model;

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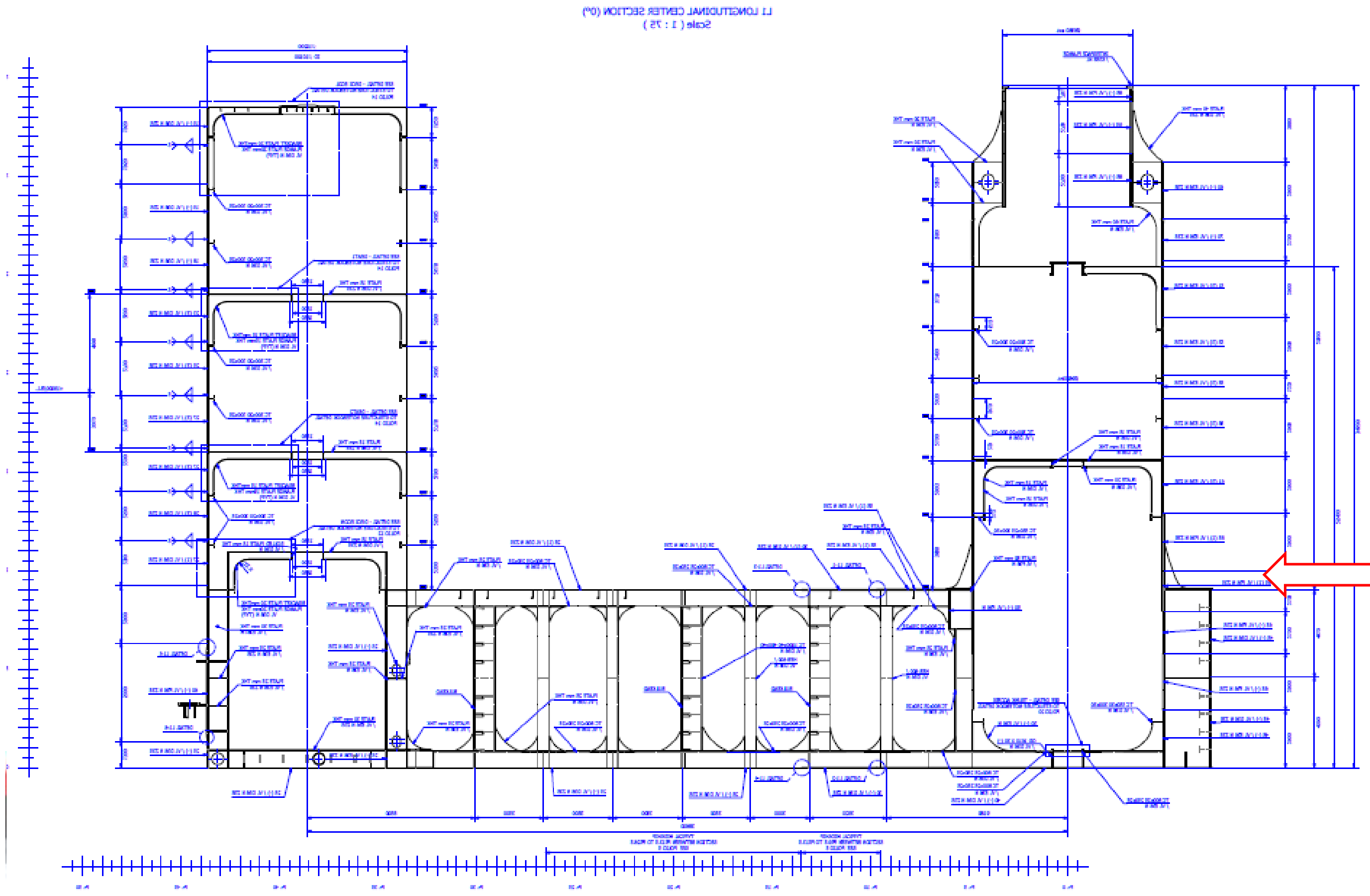
“Reproduction” vs “Simulation”

- Numerical simulation may be used both to "reproduce" and "simulate" the reality.
- "Reproduction" means the accurate modelling of all the aspects of the problem under study (i.e. geometry, material behavior, loading conditions), while "Simulation‘’ means the preparation of a model and a numerical analysis procedure which not exactly reproduces the problem (because includes some simplifications), but is able to identify its main aspects.
- A "simulation“ produces results that are less detailed than the "reproduction“ (but still acceptable engineering-wise), but it makes numerical simulation less complex and requires significantly less computational efforts.
- Consequently, the analyst performing a numerical simulation within a design activity should be able to appraise whether the “simulation” is acceptable, or it is required to “reproduce” the reality
- The preliminary engineering and theoretical assessment of the problem under study is fundamental:
    - to select between “simulation” and “reproduction”
    - in case of “simulation“, to include in the numerical simulation those simplifications which will provide the required information, with acceptable accuracy and within the time frame required by the project.
    - In case of “reproduction”, to maintain the full control of the problem under study

“Reproduction” vs “Simulation” – An example (1)

FLOATING FOUNDATION OF A WIND TURBINE

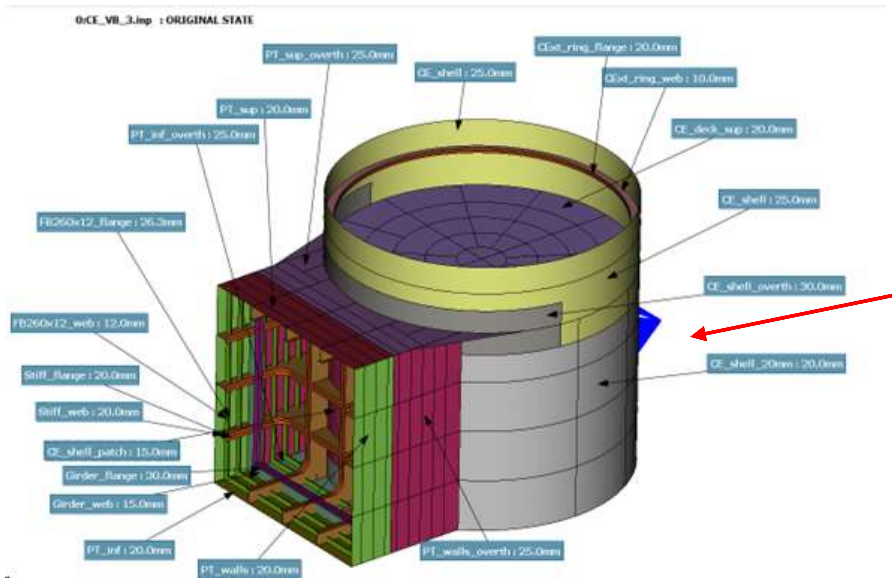
- Typical hull structure, with primary, secondary, and tertiary structure

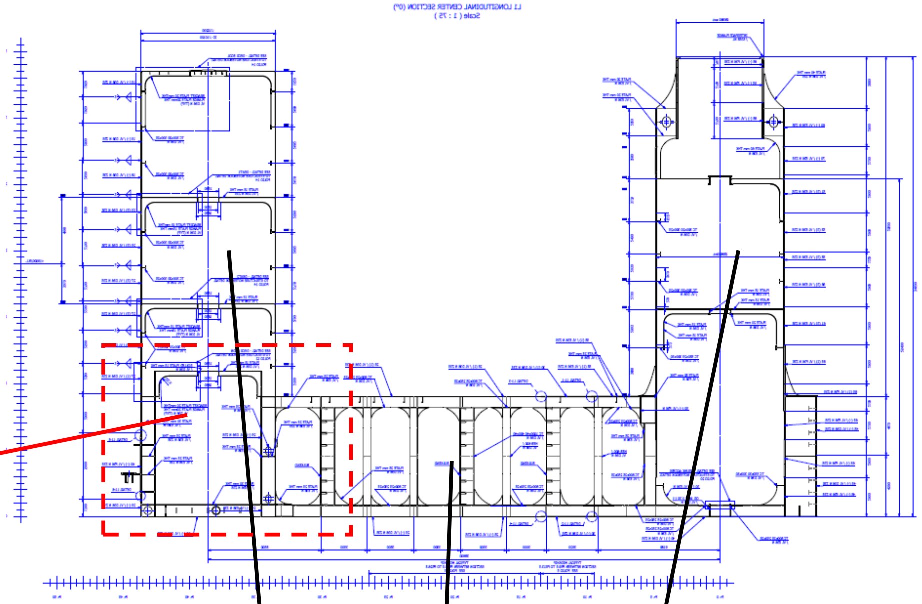


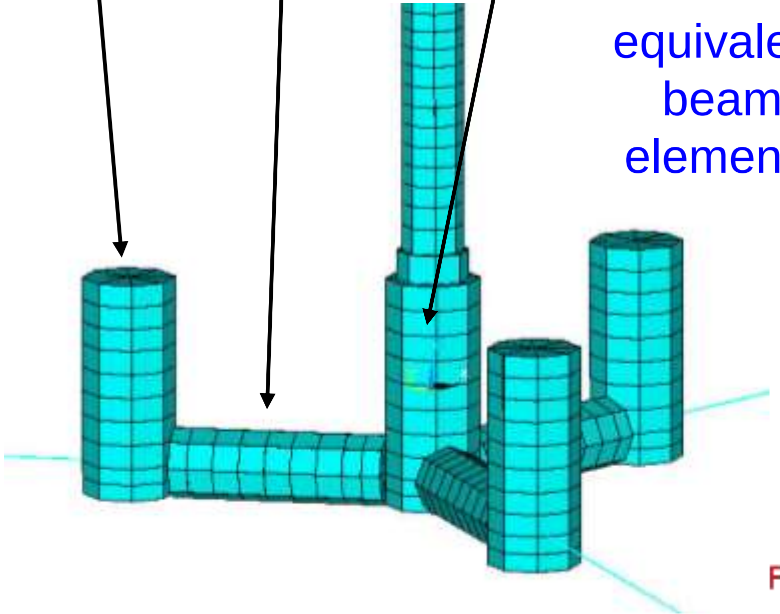
“Reproduction” vs “Simulation” – An example (1)

FLOATING FOUNDATION OF A WIND TURBINE

- “Reproduction”: full 3D model of the hull structure.







- “Simulation”: equivalent beam model, with beam elements reproducing as correctly as possible hydrostatic and hydrodynamic properties of the 3D structure
  - The simulation through an equivalent model is adequate for some design steps and structural calculations

AGENDA

Numerical simulation as a tool

- The current capability in terms of software and hardware may encourage the numerical analyst to concentrate his activity on the preparation of a good numerical model, rather than to focus his activity on the supply of useful information and engineering solutions & answers to the project team.
- The preparation of both the numerical model and analysis strategy should be fully aligned with the expectation of the project team in terms of numerical results
- A numerical simulation is effective and valid support to the design activities when it is fully integrates with the other design activities, both as time frame and accuracy of the results.

An approximate (but reliable) numerical result, provided in the due time, is more useful than an accurate numerical result provided late in time!

AGENDA

Uncertainties in the numerical simulation

- Any numerical simulation, even in case of "reproduction" of the reality, includes uncertainties; some examples are:
    - The geometry of the problem is not fully known (or available), and/or if completely known, it could be too complex and/or numerical demanding its precise modeling
    - The loading condition could not be fully known, and/or it could be based on assumptions;
    - Sometimes, the applied loads are characterized by a statistical distribution, so any load value applied to a numerical model is not an "absolute" value, but has associated a probability of occurrence (or vice versa, a probability of not-occurrence)
    - The material properties are not exactly known, because dedicated material test results could not be available or, if available, these results cannot be assumed "exactly" valid for all the geometry under study
    - The adopted numerical solution could introduce additional uncertainties (i.e. mesh density, time step adopted for non-linear or time-domain analyses, numerical approach for time-domain analyses, etc.)
- Consequently, any numerical results cannot be assumed as "fully exact": some safety factors have to be superimposed to the results, in particular if the numerical simulation is aimed at identifying limiting conditions.
    - Code and regulations usually take into account these uncertainties, and define specific safety factors to be used within the numerical simulations, mainly for loads and material properties

AGENDA

Risks associated to powerful software and hardware

- Today numerical analysts have access, at relatively limited cost, to high computational capacities. Therefore, large models and complex problems can be nowadays developed easily, quickly and cheaply.
- But this possibility could invite the analyst to avoid an engineering assessment of the problem to be solved, necessary to optimize the computational model and the problem-solving method, while maintaining a good quality in the prediction of the result to be obtained.
- If the engineering judgement of the problems is maintained at high levels, numerical simulations can be made more complex only where necessary, to save computational time even if high computational capacities are available.
- For instance, a good engineering judgement of the problem allows to refine the FE mesh only where high strain / stress gradients and / or significant non linearities are expected, and allows also to move from initially less complex models to subsequent more complex models, only if and when necessary.
  - This approach requires more time in the preparation of the computational model and approach, but the advantage gained in simulation simplicity, engineering control of the problem, and overall computational time is certainly larger

Risks associated to software and hardware (cont’d)

- Current releases of numerical codes tend to make analysts free from defining analysis parameters, through the introduction of many default parameters.
- Sometimes concepts like "analyses can be carried out with no experience in finite elements analysis“ are proposed.
- However, the possibility to develop numerical simulations even in the absence of adequate engineering expertise, may increase the risk of making design errors, but without the awareness of it.
- Any software includes a disclaimer: the software provider is not responsible of the results obtained from the (wrong) use of the software
- This risk is minimized if the engineering assessment of the problem come first (and it is considered more important than) the development of the numerical simulation.

Conclusions

The engineer is the crucial element (not the software)

Every numerical result is wrong, until the comprehension of the problem convinces the engineer of its correctness.

An approximate (but reliable) numerical result, provided in the due time, is more useful than an accurate numerical result provided late in time!

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What is NAFEMS

- NAFEMS is the International Association of the Engineering Modelling, Analysis and Simulation Community (www.nafems.org)
- NAFEMS is not-for-profit organization, joined by more than 1,500 organizations (both industrial and academic) in more than 50 countries, having the following main objectives:
  - Improve the professional status of people involved in the use of engineering simulation
  - Establish best practices in engineering simulation
  - Provide a focal point for the dissemination and exchange of information and knowledge relating to engineering simulation
  - Continuously improve the education and training in the use of simulation techniques
  - Be recognized as a valued independent authority that operates with neutrality and integrity
  - Provide recognized Certification in Numerical Simulation
- NAFEMS is organized through:
  - International Technical Working Groups, working in areas of interest where the simulation community requires educational materials
  - Regional Groups, aimed at pursuing NAFEMS objectives at regional / national level

What is NAFEMS (cont'd)

- NAFEMS membership

What is NAFEMS (cont'd)

- NAFEMS Technical Working Groups
  - Composites
  - Computational Electromagnetics
  - Computational Fluid Dynamics
  - Computational Structural Mechanics
  - Education and Training
  - Engineering Data Science
  - Geotechnics
  - High Performance Computing
  - Impact, Shock & Crash
  - Manufacturing Process Simulation
  - Multibody Dynamics
  - Multiphysics
  - Optimisation
  - Simulation Data Management
  - Simulation Governance & Management
  - Stochastics
  - Systems Modeling & Simulation

- NAFEMS Regional Groups
  - Americas
  - ASEAN
  - DACH
  - Eastern Europe
  - France
  - Iberia
  - India
  - ITALY
  - Japan
  - Nordic
  - UK

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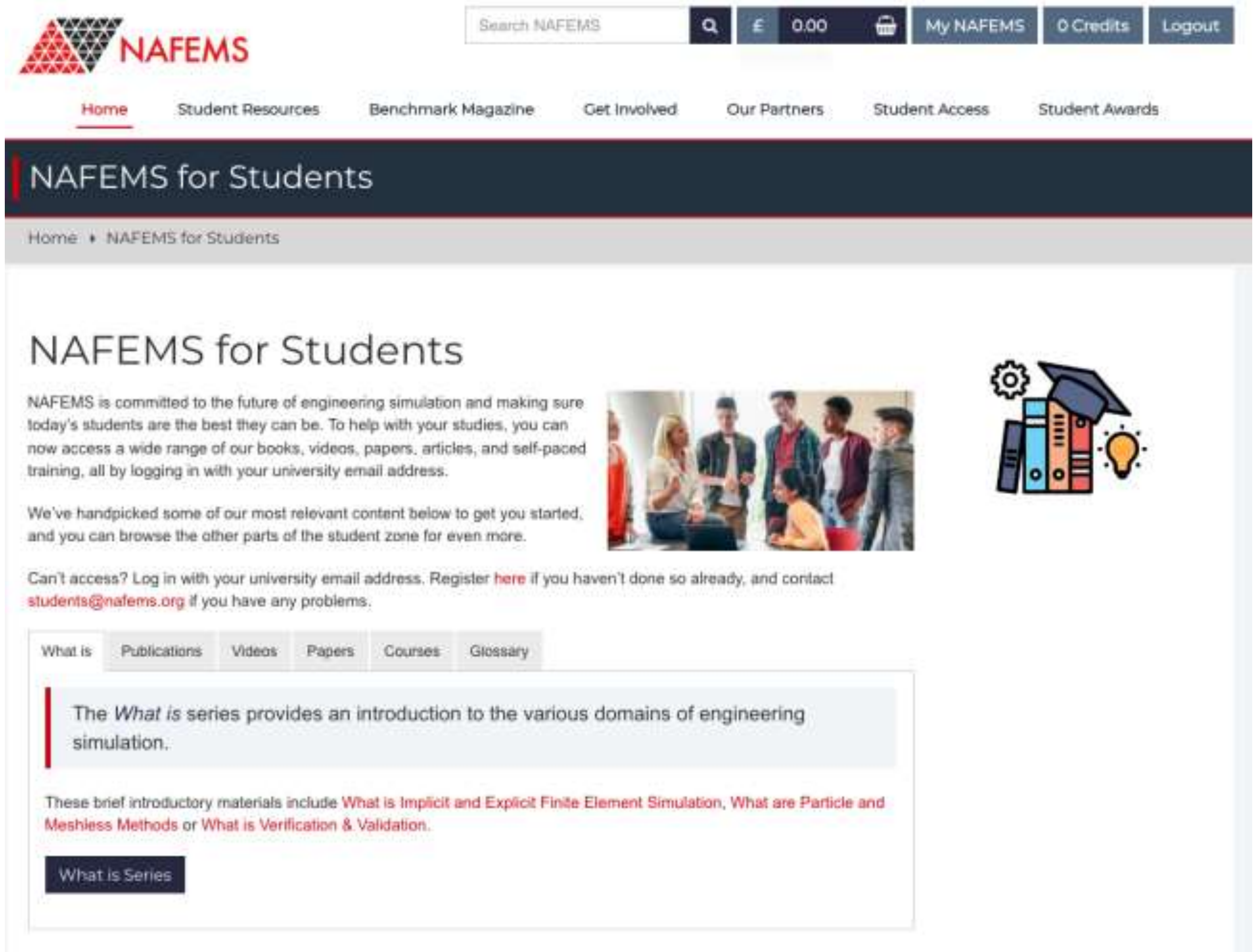
What is NAFEMS (cont’d)

- NAFEMS for students
  - Initiative launched by NAFEMS in early October 2023
  - Free registration to NAFEMS for university students, having an official university e-mail.
  - NAFEMS Students allows the access to a selection of publications, videos, papers, on-line courses.
  - Further details in the Linkedin page: https://www.linkedin.com/pulse/nafems-students-m%25C3%25A1rton-gr%25C3%25B3za-lyhuf/?trackingId=lYCtxKEzjRrzKk35l2vl5w%3D%3D



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