WHEN TRUST MATTERS

N-005

Krav til ikke-lineære analyser av eksisterende konstruksjoner

Atle Johansen

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Atle Johansen

- Senior Principal Engineer in Department for Structures – Fixed Structures
  - DNV since 2007
  - Force Technology 2001-2007
  - SINTEF/MARINTEK 1993-2001
- Background:
  - Siv.Ing. Marine Structures NTH 1993
  - Research and software development (USFOS)
  - Laboratory testing; tubular joints, grouted connections
  - Reassessment and design verification of fixed and floating offshore structures
  - Experience with USFOS, ABAQUS, LS-DYNA, ANSYS
  - Co-author/Co-maintainer of DNV-RP-C208



Agenda

- Non-linear analyses
  - Categorisation
  - Benefits and challenges
- Requirements in N-001
- Requirements in N-005
- Available guidelines:
  - Ultiguide
  - EN 1993-1-14
  - DNV-RP-C208

Non-linear analyses

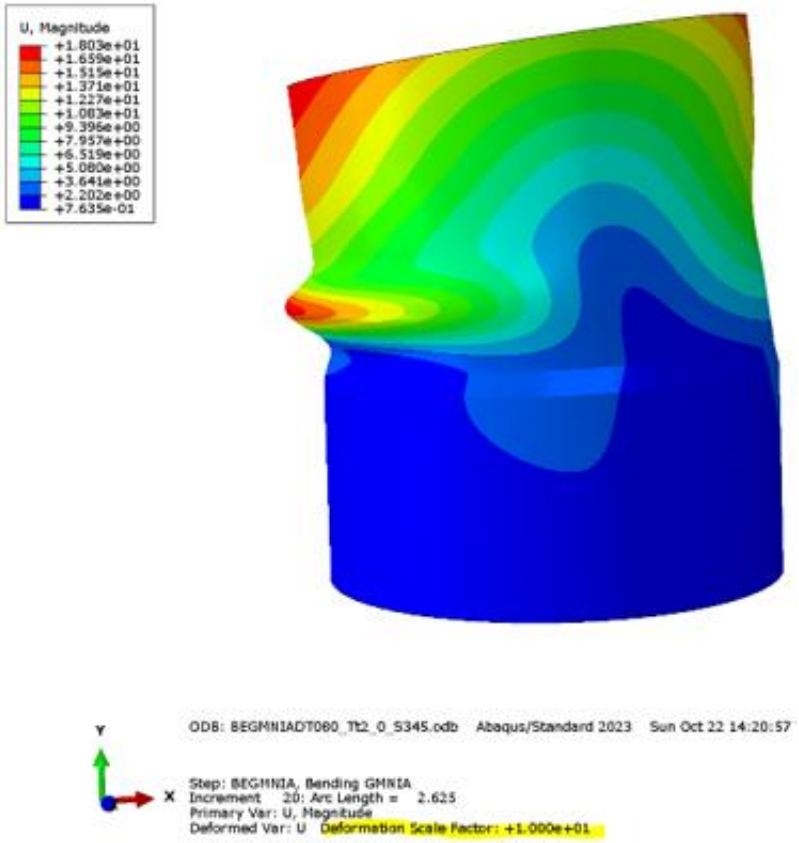
- Sources to non-linearity
  - Material – e.g. Plasticity
  - Geometry – e.g. Slender structures
  - Boundary – e.g. Contact
  - Load – e.g. Pressure

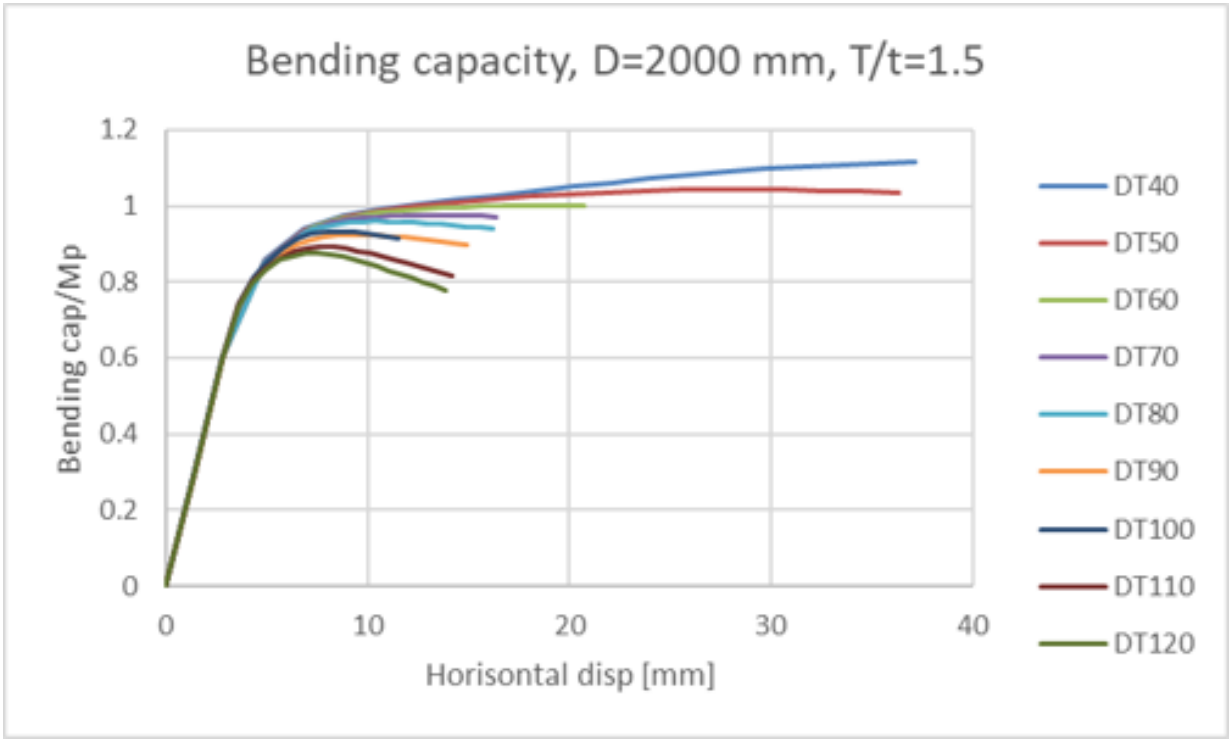
Type of analysis according to EN 1993-1-6 and EN 1993-1-14	Short name	Deformations	Material law	Geometry
Linear elastic analysis	LA	linear	linear elastic	perfect
Linear bifurcation (eigenvalue) analysis	LBA	bifurcation	linear elastic	perfect
Materially non-linear analysis	MNA	linear	elastic-plastic	perfect
Geometrically non-linear analysis	GNA	non-linear	linear elastic	perfect
Geometrically and materially non-linear analysis	GMNA	non-linear	non-linear	perfect
Geometrically non-linear elastic analysis with imperfections	GNIA	non-linear	linear elastic	imperfect
Geometrically and materially non-linear analysis with imperfections	GMNIA	non-linear	non-linear	imperfect

Non-linear analyses

- Why use non-linear analyses?
  - Can give results for complex structures not covered by analytical solutions/linear analyses
  - Can account for redistribution of forces locally and in larger structures
  - Some structures behave non-linear, and should be analysed accounting for non-linear geometric effects
  - Can give insight in capacity/structural response after first failure
- Failure modes that can be investigated using non-linear analyses
  - Buckling
  - Plasticity – tensile failure
  - Low cycle fatigue
- Challenges
  - Time consuming
  - Requires competent engineers and strict guidelines to ensure consistent and safe results

Non-linear analyses



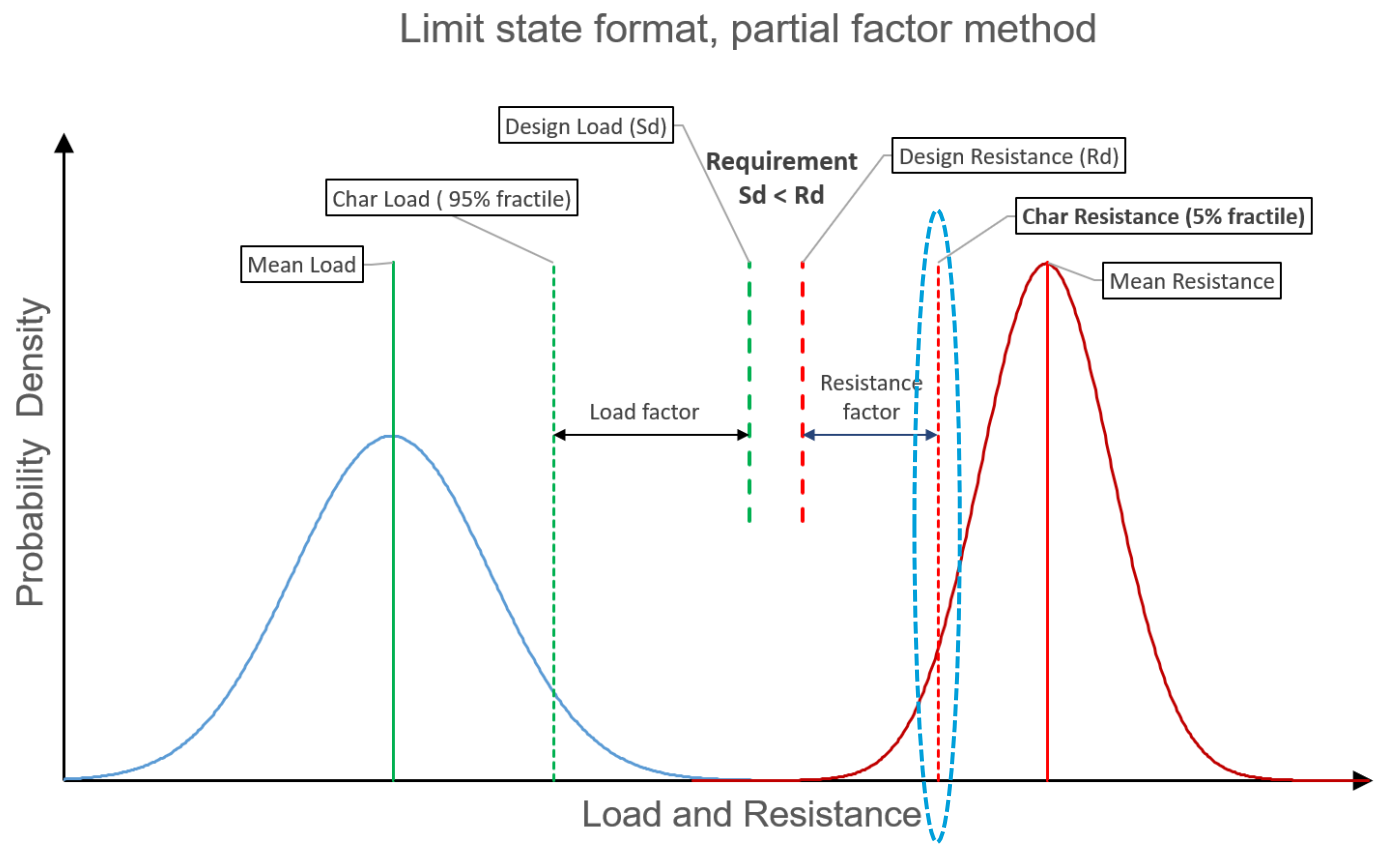


NORSOK N-001

- **Section 5.9 Non-linear analysis for design**
  - (..) Hence, a linear elastic model of the global structure should be used to establish action effects in the ultimate limit state (ULS) unless such model is non-conservative(..)
  - Non-linear methods are considered acceptable in design and capacity check of cross sections, welds, joints and local areas(..)
  - Global non-linear analyses may be used in ALS analysis(..)
  - Non-linear analysis may be used in assessment of ultimate limit state (ULS) for existing structures(..)

NORSOK N-001

- Section 7.2.3 Ultimate limit states (ULS) and Section 7.2.6 Accidental limit states (ALS):
  - *The characteristic value for resistance shall be determined based on the most unfavourable value for the different failure modes, e.g. use 95% vs. 5% fractile in cases where a high resistance is unfavourable.*



N-005:2026 Section 11.4.3 Requirements to assessment based on non-linear analysis methods

- **11.4.3.1 General**
  - Non-linear analysis shall be based on DNV-RP-C208.
  - The applicability of computer software for non-linear analysis shall be adequately validated and documented with respect to theory and use.
  - The combined qualifications of the group of engineers performing the analysis shall be appropriate for the task(..) Reference is made to NORSOK N-001:2020+AC:2021 clause 5.3.

  - Analysis based on non-linear methods shall:
    - be based on software that is tested for the actual purpose;
    - be calibrated against known cases;
    - account for all factors that influence the capacity, such as material non-linearity, imperfections, residual stresses and hydrostatic pressure;
    - be capable of representing redistribution of stresses, e.g. due to cracking of concrete structures;
    - consider all relevant failure modes, e.g. yielding, rupture, crushing, local and global buckling and soil failure.

N-005:2026 Section 11.4.3 Requirements to assessment based on non-linear analysis methods

- **11.4.3.2 Calibration of non-linear analysis**
  - Calibration of capacity of components in the non-linear analysis shall be performed against known cases, relevant laboratory test or analytical solution, following the principles in DNV-RP-C208.
  - The characteristic value of capacity implies a 5% fractile shall be used in cases where a low capacity is unfavourable and a 95% fractile shall be used in case where a high capacity is unfavourable.

  - The capacity shall be calibrated to the characteristic values given in NORSOK N-001:2020+AC:2021 and NORSOK N-004:2022+AC:2024, including referred standards, for cases provided in these standards. The characteristic capacity may also be based on calibration to high quality, publicly available and verified test data by the methods provided in DNV-RP-C208.

N-005:2026 Section 11.4.3 Requirements to assessment based on non-linear analysis methods

- **11.4.3.3 Special considerations for cyclic loading of steel structures**
  - Analysis based on non-linear methods shall document that the structure does not undergo deformations that weaken the ability to resist subsequent load-cycles, i.e., that the structure will shake-down without excessive plastic deformations or fracture due to repeated yielding.

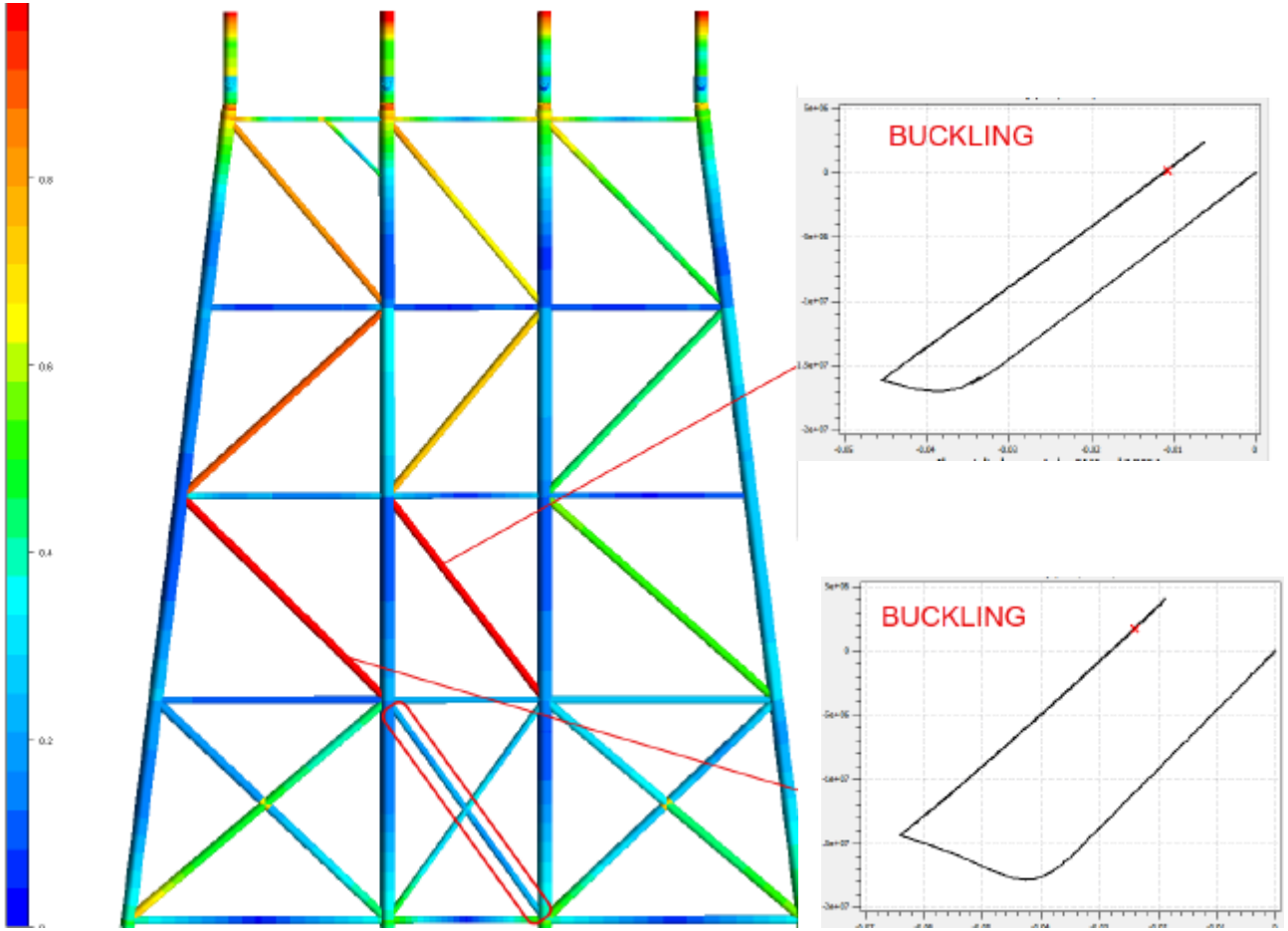
  - For jacket structures, one of the following methods shall be used to document that the structure has not experienced cyclic deformations that weaken its ability to resist subsequent load-cycles:
    a) Non-linear analysis with limited permanent deformation.
    b) Cyclic storm analysis according to Clause B.8, only applicable for jackets that are unmanned and shutdown in accordance with 13.3 to document the requirement given in Clause B.8.

  - For other types of offshore structures, the provisions in DNV-RP-C208 shall be used.

N-005:2026 Section 11.4.3 Requirements to assessment based on non-linear analysis methods

- **11.4.3.3 Special considerations for cyclic loading of steel structures**
  - Non-linear analysis with limited permanent deformation, as mentioned in 11.4.3.3, list item a), implies that:
    - the combined loading in structural components do not exceed local or global buckling according to NORSOK N-004:2022+AC:2024;
    - joints are not utilized above the capacity according to NORSOK N-004:2022+AC:2024;
    - no plastic mechanisms are formed;
    - maximum plastic elongation of tubular member do not exceed (..);
    - no part of the foundation has reached the ultimate soil capacity;
    - joints are, by inspection, proven to be free from fatigue cracks or the calculated fatigue loading is negligible.

N-005:2026 Section 11.4.3 Requirements to assessment based on non-linear analysis methods



- Not acceptable according to 11.4.3.3, list item a)

Requirements to non-linear analyses in N-005 vs N-006 - what is new ?

- The most important change is related to cyclic loading:
  - When establishing unmanning criteria, the analyses shall now be stopped at first failure to ensure cyclic capacity.
    - Recommended but not required in N-006
  - More detailed evaluations for cyclic capacity during the storm may still be used to document ULS for unmanned structures.
- A new failure criterion for tensile failure of tubular members is introduced (USFOS type analysis).
- References is given to DNV-RP-C208.

Available guidelines for how to perform non-linear analyses

- Ultiguide (DNV-SINTEF-BOMEL) 1999
  - “USFOS” type of analysis guideline. Outdated in some areas (e.g. tubular joint modelling)

- SN-EN 1993-1-14:2025 (pre-standard) Design assisted by finite element analysis
  - Covers also linear analyses. Overlap with DNV-RP-C208 in some areas. Less specific in some areas.

- DNV-RP-C208:2022 Determination of structural capacity by non-linear finite element analysis methods

Guidelines: DNV-RP-C208

- The development of the RP was funded by the industry:
  - JIP-I (2011-2013): Initial publication of the RP in 2013
  - JIP-II (2013-2016): Major revision in 2016
  - Since 2016, only minor amendments have been made
- Intended use:
  - Structural capacity evaluations of large offshore steel structures (shell and beam elements) documented according to codes for offshore structures (NORSOK, ISO, DNV)
  - Yield strength up to 500 MPa
- The RP gives modelling and analysis guidelines for non-linear analyses of failure modes such as:
  - Tensile failure
  - Buckling
  - Failure due to repeated yielding (low cycle fatigue)

Downloads of DNV-RP-C208 since 01-01-2022

Publication Title	Total Download (Contact)	Unique Download (Contact)
RP-C203 Fatigue design of offshore steel structures	34 464	9 610
RP-C205 Environmental conditions and environmental loads	27 461	8 178
RP-B401 Cathodic protection design	15 586	5 605
RP-N103 Modelling and analysis of marine operations	14 012	4 855
RP-C208 Determination of structural capacity by non-linear finite element analysis methods	12 890	4 460
RP-C204 Structural design against accidental loads	8 518	3 632
RP-F109 On-bottom stability design of submarine pipelines, cables and umbilicals	8 461	2 876
RP-A203 Technology qualification	7 606	3 580
RP-F112 Duplex stainless steel - design against hydrogen induced stress cracking	7 292	2 765
RP-0034 Steel forgings for subsea applications - technical requirements	7 154	2 654
RP-C212 Offshore soil mechanics and geotechnical engineering	6 990	2 670
RP-C202 Buckling strength of shells	6 950	2 900
RP-F105 Free spanning pipelines	6 780	2 582
RP-C205 Environmental conditions and loads	6 696	2 885
RP-N201 Lifting appliances used in subsea operations	6 220	3 046
RP-C201 Buckling strength of plated structures	6 199	2 561
RP-F107 Risk assessment of pipeline protection	6 129	2 612
RP-0360 Subsea power cables in shallow water	6 121	2 526
RP-0416 Corrosion protection for wind turbines	5 838	2 386
RP-F114 Pipe-soil interaction for submarine pipelines	5 669	2 131
RP-0591 Redundant dynamic positioning systems with closed bus-ties	5 451	1 764
RP-B204 Welding of subsea production system equipment	5 445	2 155
RP-F104 Design and operation of carbon dioxide pipelines	5 168	2 244
RP-E306 Dynamic positioning vessel design philosophy guidelines	4 858	2 106
RP-F110 Global buckling of submarine pipelines	4 461	1 754
RP-0286 Coupled analysis of floating wind turbines	4 431	1 837
RP-0005 RP-C203: Fatigue design of offshore steel structures	4 363	2 866
RP-D101 Structural analysis of piping systems	4 362	2 042
Totalt	**445 540**	**46 073**

Experience with DNV-RP-C208 since 2013

- We regularly receive technical inquiries to the RP from the industry (rules@dnv.com)
- Experience through our advisory and 3rd party verification
- Training:
  - DNV-RP-C208: Determination of structural capacity by non-linear finite element analysis methods
  - 208 engineers have attended our course since 2022





DNV

CERTIFICATE OF TRAINING

Certificate No.: __CERTIFICATE_NUMBER__

This is to certify that

__NAME__

has attended the course on:

DNV-RP-C208
DETERMINATION OF STRUCTURAL CAPACITY BY NON-LINEAR FINITE ELEMENT ANALYSIS METHODS

on 28 – 30 of October 2025

Tutors: Atle Johansen, Jacob Dybwad, Anders Kleven, Arne Fjeldstad, Marius Clausen

Course content was as follows:

Non-linear analysis methods in offshore design codes
Objective and content of DNV-RP-C208
Selection of software and analysis methods (explicit and implicit solvers)
Material modelling (material models, proposed material curves in the RP)
Geometry modelling, element types, contact modelling
Application of loads and safety factors
How to analyze buckling failure
How to analyze tensile failure
How to determine weld capacity
How to assess low cycle fatigue
Code requirements to structures exposed to accidental loads
How to perform explicit analyses, i.e. modelling and selection of control parameters
Important aspects of impact analyses, e.g. collision and dropped objects
Important aspects of explosion analyses

Date 30.10.2025 Signed on behalf of DNV AS:

Atle Johansen
Senior Principal Engineer
Fixed Structures Technology

Jacob Dybwad
Principal Engineer
Fixed Structures Technology

Head office: DNV Headquarters , Veritasveien 1, 1322 Høvik, Norway. Tel: +47 67 57 99 00

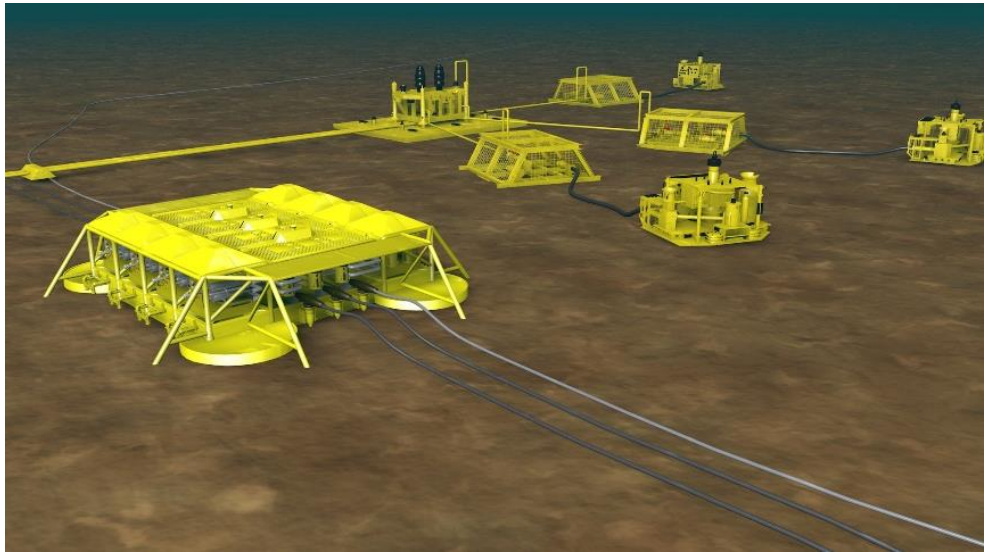
DNV

Experience with DNV-RP-C208 since 2013

- We are observing a growing application of the RP beyond its original scope, including:
  - Structures within the renewable sector, naval industry (e.g. war ships), fish farms and subsea structures
  - Structures with complex and detailed geometries which requires solid elements, rather than beam and shell elements originally envisioned for large offshore structures and ships







Experience with DNV-RP-C208 since 2013

- Technical queries from the industry to the RP mainly relates to:
  - **Tensile strain criteria for shell elements**
    - How to establish and use the current strain criteria
    - The basis for the current strain criteria
  - **Solid elements**
    - The need for an assessment procedure
  - **Material curves**
    - Higher strength steels (e.g. S690)
    - Thicker plate thicknesses for the steel grades currently covered in the RP (S235, S275, S355, S420, S460)

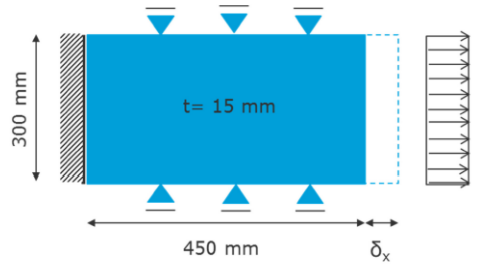
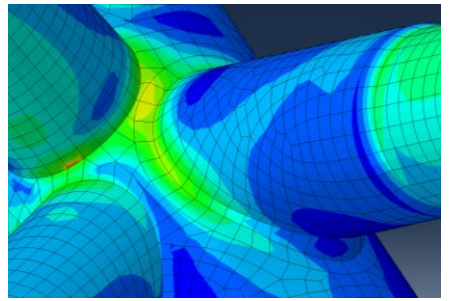
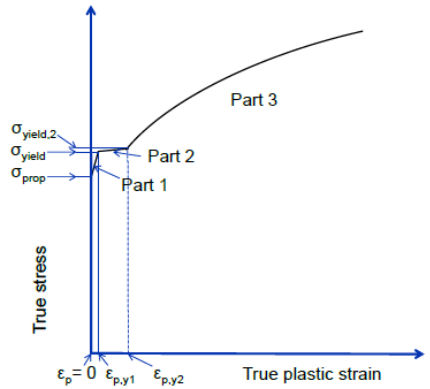


Figure 5-1 Calibration case CC01, steel plate under uniaxial load plane strain conditions





DNV have prepared a JIP proposal to further develop DNV-RP-C208

- Status:
  - So far, we have not been able to secure sufficient funding to start the project
  - We continue to be in dialog with the industry regarding a potential JIP

- **Material curves for high strength steel and thick plates:** Establish material curves and tensile failure criteria for higher strength steels and larger plate thicknesses than those currently covered in the RP, see Section 3.1
- **Verification of tensile failure criteria for shell elements:** Reassess the existing tensile failure criteria for shell elements in the RP, identify recent testing relevant to verify these criteria and reproduce such tests by finite element analysis (FEA), see Section 3.2
- **Laboratory testing:** Conduct a dedicated test program at DNV's Materials Laboratory to support the two objectives above, see Section 3.3
- **Assessment procedure and tensile failure criteria for solid elements:** Develop an assessment procedure and define tensile failure criteria for solid elements, as the current method in the RP applies only to shell elements, see Section 3.4
- **Expand FE model library for ship impact analyses:** Expand FE model library for ship impact analyses, see Section 3.5
- **Alignment with the upcoming standard EN 1993-1-14:** Alignment with the upcoming standard EN 1993-1-14 "Design assisted by finite element method", see Section 3.6
- **Element type guidance:** Develop more detailed guidelines for selecting appropriate element types and mesh density in structural analyses, see Section 3.7
- **Weld assessment guidance:** Develop more detailed guidelines for assessing welds within FE models, see Section 3.8
- **'Upper shelf theory' review:** Conduct a review of existing and ongoing research on 'upper shelf theory' —specifically, how material toughness influences tensile strain-based failure criteria—and explore its application to both shell and solid elements, see Section 3.9
- **High-temperature analysis guidance:** Develop a guideline for analyses involving high temperatures (e.g. fire analyses), see Section 3.10

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