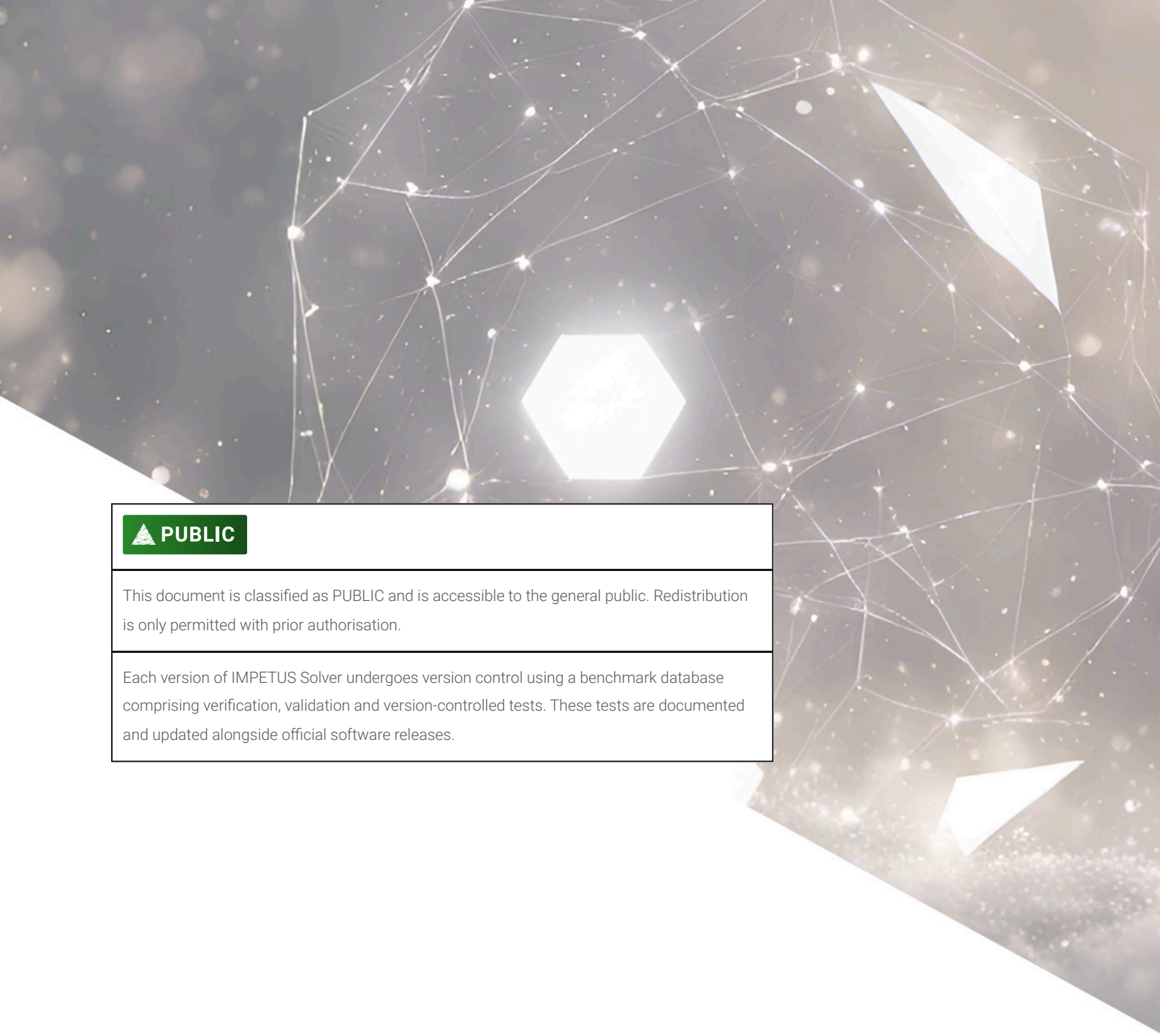


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Each version of IMPETUS Solver undergoes version control using a benchmark database comprising verification, validation and version-controlled tests. These tests are documented and updated alongside official software releases.

Validation - Material Failure Prediction of Steel Structures

Documentation

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September 28, 2026

IMPETUS
driving precision

Document revisions:

Revision	Date	Comments
0	2015-11-02	First publication

Validation - Material Failure Prediction of Steel Structures

Introduction

This document presents validation tests on large deformation analysis involving plasticity and material failure of large-scale steel structures. The validation is done by building models of scientific studies reported in the literature. These studies are presented in the following.

An engineering approach to the modelling has been applied to all examples. That is, the material has been modelled to follow the exact minimum requirements of relevant design codes. The resulting capacities in terms of failure loads, deformation capacity and energy absorption should therefore be conservative. The examples presented herein quantifies this conservatism.

Version control

The tests presented in this document are subjected to version control, meaning that the models are run and evaluated prior to release of a new solver. This document is updated in conjunction with official releases of the software.

H. S. Alsos & J. Amdahl (2009)

On the resistance to penetration of stiffened plates

This is a test to validate the engineering failure prediction approach of stiffened steel plates subjected to loading from a cone shaped indenter. See Figure 1.

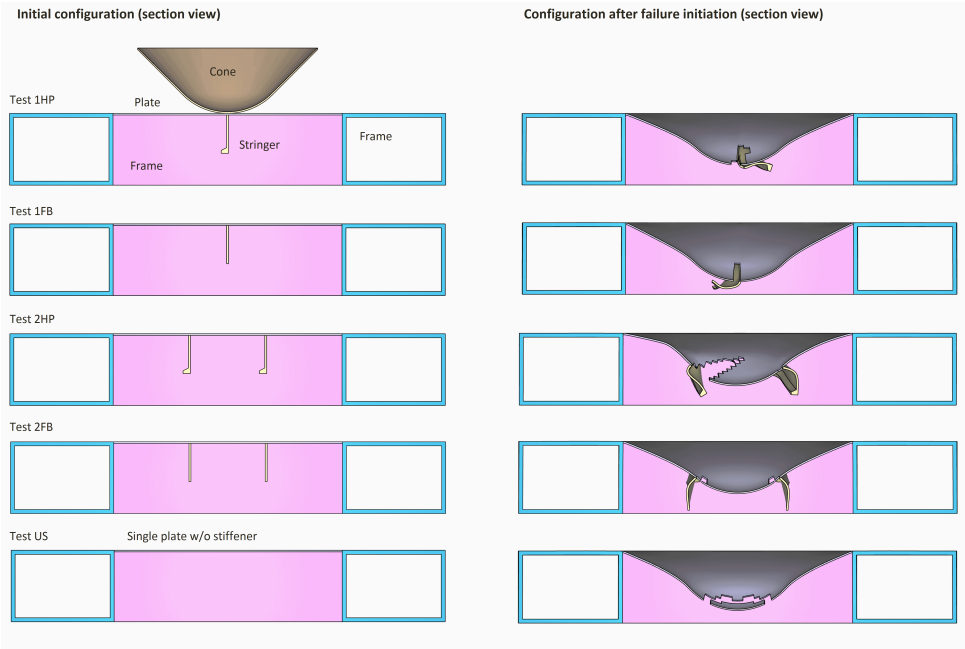


Figure 1. Overview of test set-up and FE model.

The materials used for the original investigation were S235 and S355 steels. The material calibration from the original investigation is not used. The following material objects were used:

- S235 (EN 10225)
- S355 (EN 10225)

For all models, cubic hexahedral elements with one element through the thickness of the plates are used. The nodal spacing is equal to the thickness of the plate.

The study consists of five tests. For each test the maximum force on the cone at failure and the corresponding cone displacement is checked. The experimental and numerical values of the maximum force on the cone and the corresponding cone displacements can be seen in Table 1 and 2. The top view of test us can be seen in Figure 2 and test results for the five tests can be seen in Figure 3 - 7.

Test	Experiment $[kN]$	Simulation $[kN]$	Error [%]
us	1500	980	-35
1fb	1420	1110	-22
1hp	1260	920	-27
2fb	1150	990	-14
2hp	970	780	-20

Table 1. Maximum force on cone at panel failure.

Test	Experiment $[\mu s]$	Simulation $[\mu s]$	Error [%]
us	200	173	-14
1fb	175	171	-2
1hp	145	148	2
2fb	130	151	16

Test	Experiment μs	Simulation μs	Error [%]
2hp	125	110	-12

Table 2. Displacement of cone at panel failure.

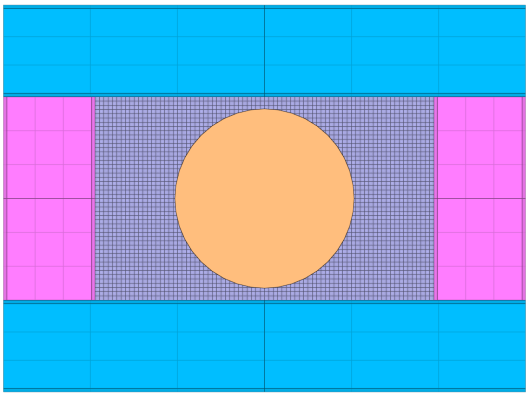


Figure 2. Test us - top view.

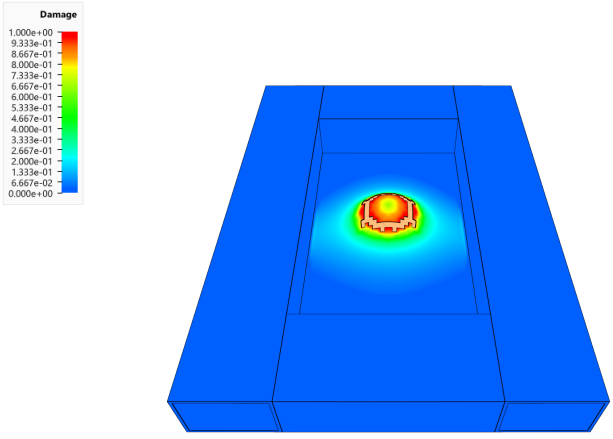


Figure 3. Test us - damage at last state.

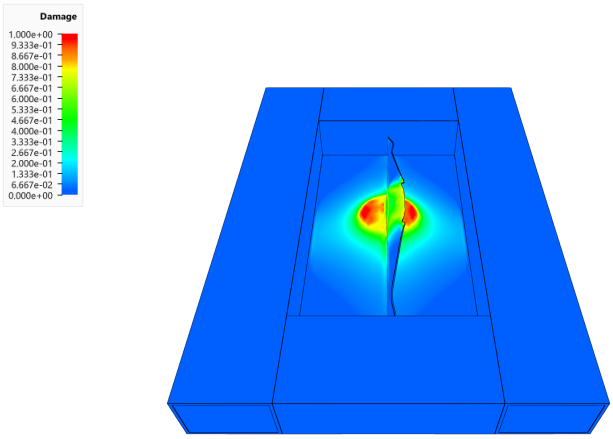


Figure 4. Test 1fb - damage at last state.

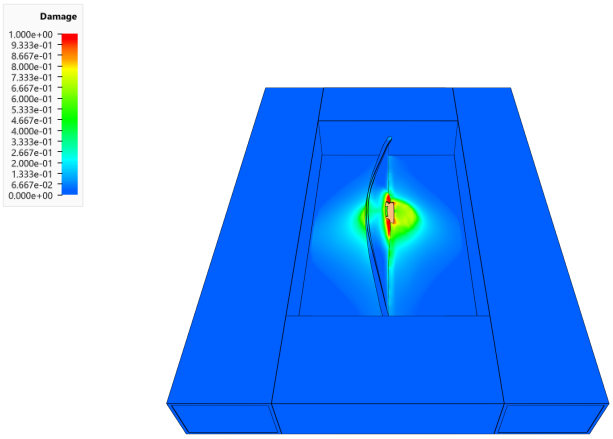


Figure 5. Test 1hp - damage at last state.

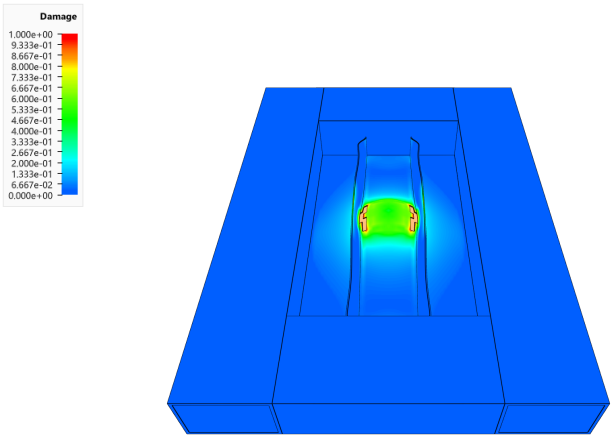


Figure 6. Test 2fb - damage at last state.

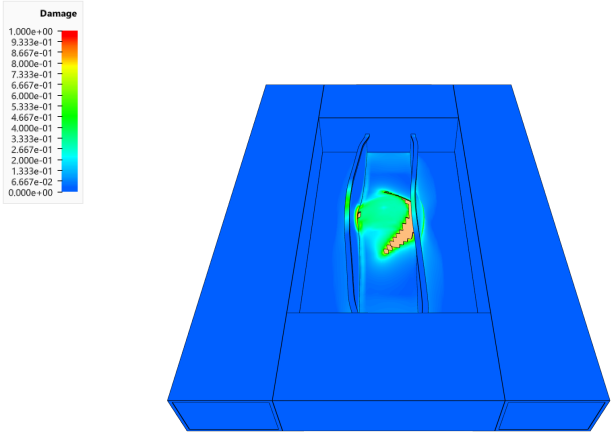


Figure 7. Test 2hp - damage at last state.

For version control the maximum value of the contact force between the plate and the cone is checked.

References

[1] - EN 10225 - Weldable structural steels for fixed offshore structures.

[2] - Hagbart S. Alsos, Jørgen Amdahl: On the resistance to penetration of stiffened plates, Part I - Experiments, International Journal of Impact Engineering, Volume 36, Issue 6, June 2009, Pages 799-807.

TESTS

This benchmark is associated with 5 tests.

M. Langseth (1988)

Plugging Capacity of Steel Plates

This is a test to validate the engineering prediction approach for plugging resistance of steel plates. We use a 1/4 model with symmetry conditions as shown in the figures below. The set-up is a projectile with a mass of 49.59 kg and initial velocity v_0 impacting a St-52 steel plate with thickness h. The diameter of the impacting rod d is 36.5 mm. Four levels of the thickness h of the steel plates have been investigated. For all models we use cubic hexahedral elements with one element over the thickness. In the impact region, the element side length is 1/6 of the punch diameter.

The following material object was used:

- S355 (EN 10225)

An overview of the test set-up can be seen in Figure 1.

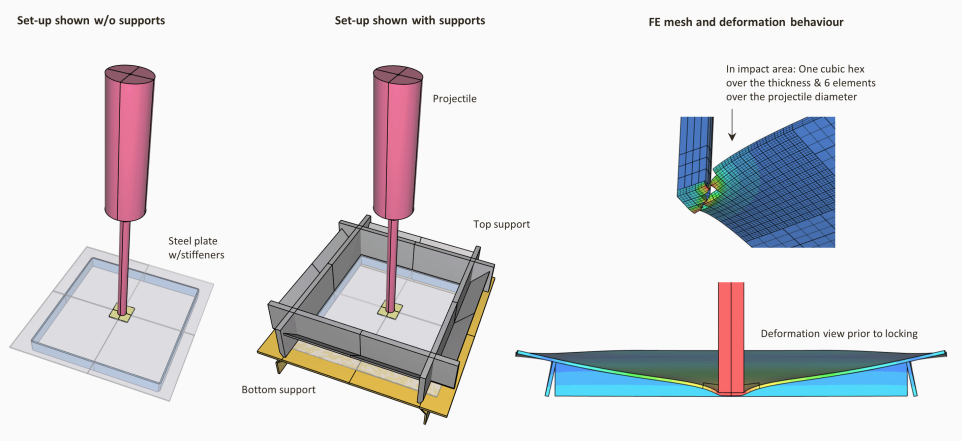


Figure 1. Overview of test set-up and FE model.

The tests referenced in Table 1, did not give plugging, but were the tests closest to plugging. Hence, the true plugging velocity is a bit higher. All simulations give plugging. The results show that the recommended engineering modelling practice gives conservative results and underestimate the energy absorption by about 20%. The test results can be seen in Figure 2 - 5.

Test	Plate thickness $[mm]$	Impact velocity $[m/s]$	Impact energy $[J]$	Residual kinetic energy $[J]$	Error [%]
A1-4-5	4.54	11.49	3273	767	-23
A1-6-3	6.30	14.07	4910	813	-17
A1-8-6	7.94	17.82	7874	1604	-20
A1-10-4	9.82	21.29	11239	2767	-25

Table 1. Original test definition, experimental & numerical results.

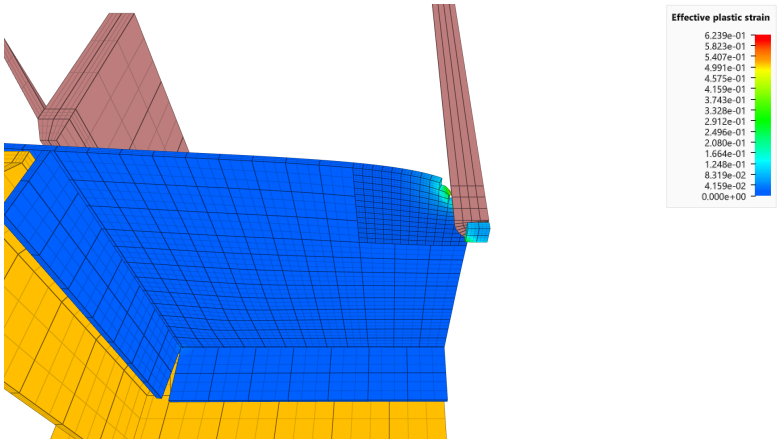


Figure 2. Effective plastic strain at last state, A1-4-5.

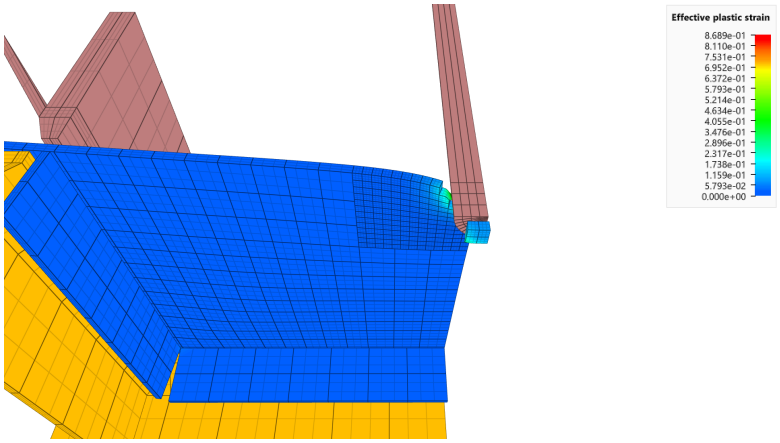


Figure 3. Effective plastic strain at last state, A1-6-3.

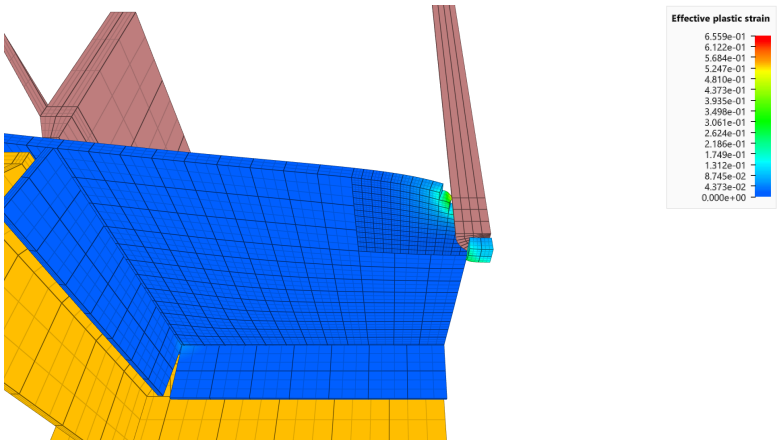


Figure 4. Effective plastic strain at last state, A1-8-6.

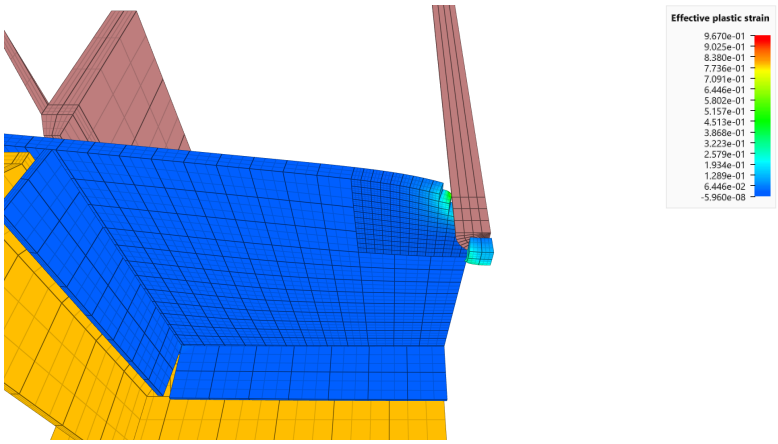


Figure 5. Effective plastic strain at last state, A1-10-4.

References

[1] - EN 10225 - Weldable structural steels for fixed offshore structures.

[2] - M. Langseth: Dropped Objects. Plugging Capacity of Steel Plates. Doktor ingeniøravhandling 1988:25, Institutt for Konstruksjonsteknikk, Norges Tekniske Høgskole, Trondheim (1988).

[3] - M. Langseth, P.K. Larsen, Dropped objects' plugging capacity of steel plates: An experimental investigation, International Journal of Impact Engineering, Volume 9, Issue 3, 1990, Pages 289-316.

TESTS

This benchmark is associated with 4 tests.

R. Törnqvist (2008)

Failure of Pressure Loaded Plates

This is a test to validate the engineering failure prediction approach of steel plates subjected to uniform pressure loading. The material used for the original investigation was S275 steel. We do not use the material calibration from the original investigation. The following material was used:

- S275 (EN 10225)

For the model, cubic hexahedral elements with one element through the thickness of the plates is used. The nodal spacing is equal to the thickness of the plate. See Figure 1.

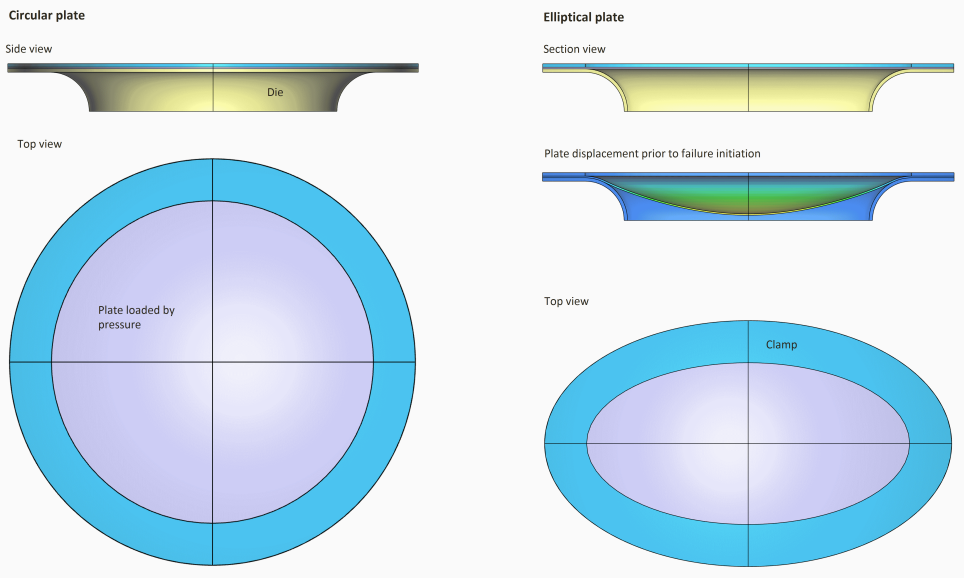


Figure 1. Overview of test set-up and FE model.

The benchmark consists of two tests. One test is pressure loading of a circular plate. The span width is 960 mm. The second test is pressure loading of an elliptical steel plate where the main axes are 480 mm and 960 mm. Both plates have a thickness of 5 mm. 1/4 of the model with symmetry conditions is used. Using our approach for the material modelling we arrive at the following results for the maximum pressure. The experimental compared with numerical values can be seen in Table 1 and test results can be seen in Figure 2 & 3.

Test	**Experiment** $[MPa]$	**Simulation** $[MPa]$	**Error** **[%]**
Circular	8.91	7.3	-18
Elliptic	13.2	14.0	6

Table 1. Pressure at plate failure.

The results are not strictly conservative, but the maximum overestimation of the applied pressure at burst is only 6%.

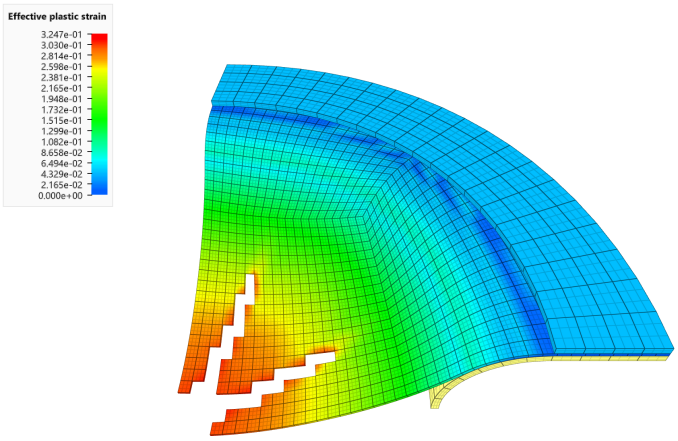


Figure 2. Effective plastic strain at last state, circular plate.

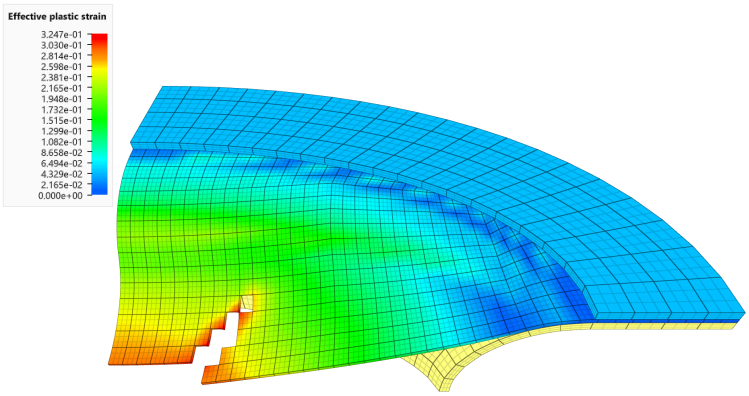


Figure 3. Effective plastic strain at last state, elliptic plate.

For version control, maximum value of the contact force between the plate and the die is checked.

References

[1] - EN 10225 - Weldable structural steels for fixed offshore structures.

[2] - Hagbart S. Alsos, Odd S. Hopperstad, Rikard Törnqvist, Jørgen Amdahl: Analytical and numerical analysis of sheet metal instability using a stress based criterion, International Journal of Solids and Structures, Volume 45, Issues 7-8, April 2008, Pages 2042-2055.

[3] - Rikard Törnqvist: Design of Crashworthy Ship structures, PhD thesis, Technical University of Denmark, Department of Mechanical Engineering. Maritime Engineering. June 2003.

TESTS

This benchmark is associated with 2 tests.