Survivability analysis of a struck ship with damage opening – influence from model and material properties uncertainties

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- **Associate Professor Carl-Erik Janson**
- **Professor Igor Rychlik**

Sea-state condition

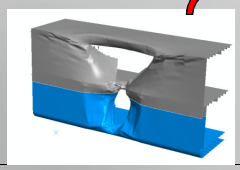
Wave direction relative damage opening

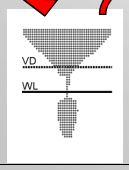
$T_{capsize}$

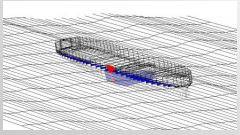
Position of damage opening

Shape of damage opening

Size of damage opening







$E[T_{capsize}]$
$V[T_{capsize}]$

Outline

- **Introduction**
- **Experiments and FE analyses**
  - Tensile tests
  - Forming limit tests
  - Bulb impact with a ship-like structure in small scale
- **Calculation of ship survivability, $T_{capsize}$**
- **Concluding remarks**

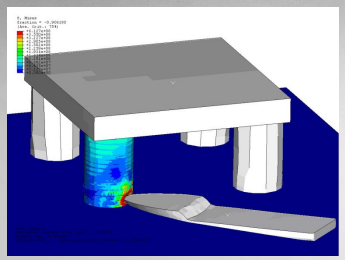
INTRODUCTION

The Titanic disaster

The Titanic is about to strike the iceberg, April 14, 1912

705 survivors, 1522 passengers and crew were lost

Collision …

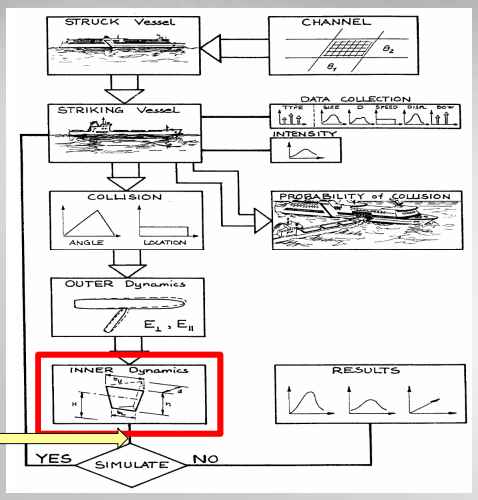


Grounding …

Exxon Valdez, Alaska, March 24, 1989

Selendang Ayu, Alaska, December 8, 2004

ISSC 2006 committee V.1 - collision and grounding

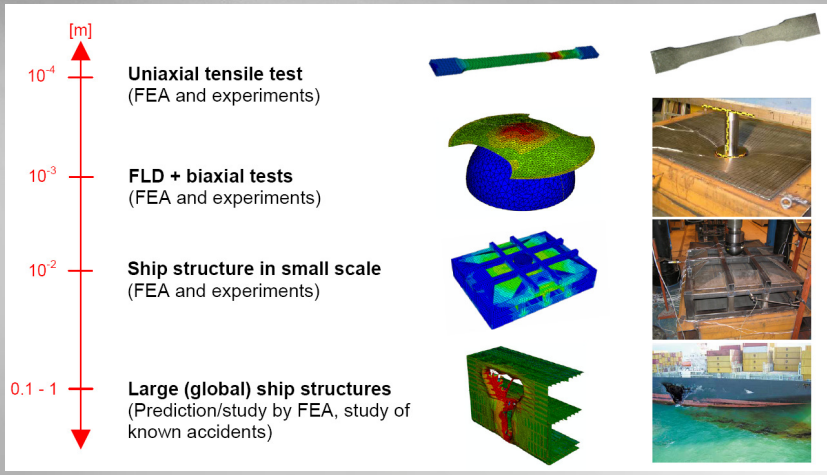


Dynamic damage stability analysis

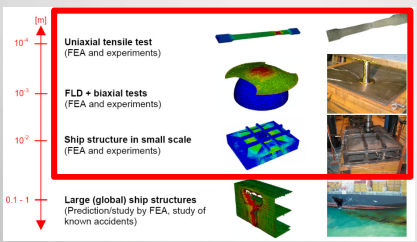
Main objectives of our research

- **Contribute to enhancement of survivability of ships struck/damaged by collision ($T_{capsize}$)**
- **Propose structural changes which lead to:**
  - larger energy absorption before fracture of the structure of the struck ship occurs
  - reduced damage openings and thereby longer $T_{capsize}$
- **Methodology and tools:**
  - experimental investigations,
  - structure analyses by means of the finite element method,
  - dynamic damage stability simulations, and
  - reliability of models and predictions made

Procedure for explicit nonlinear FEA



EXPERIMENTS AND FE ANALYSES

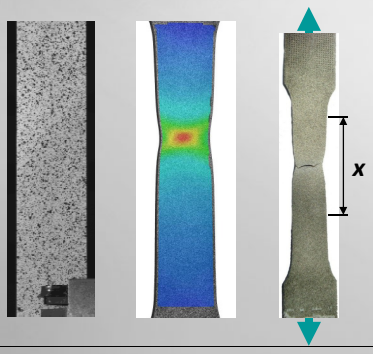


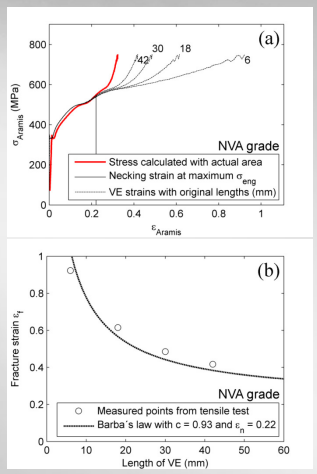
Experimental investigations

- **Uniaxial tensile tests**
  - Establishment of nonlinear constitutive material model for the material in use
  - Establishment of (uniaxial) material properties for failure/fracture criteria
  - Scaling/tuning of experimentally obtained material data
- **Forming limit diagram tests**
  - Establishment of (multiaxial) material properties for failure/fracture criteria
- **Bulb impact with ship-like structure in small scale**
  - Verification of FE models, constitutive material models and failure/fracture criteria

Uniaxial tensile tests

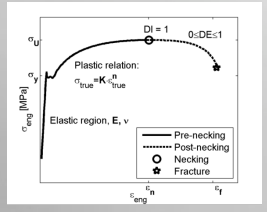
- **Digital image correlation technique**
  - ARAMIS optical strain measuring system
- **Allows for measurement of length-scale dependent local strains (ε_{Aramis})**





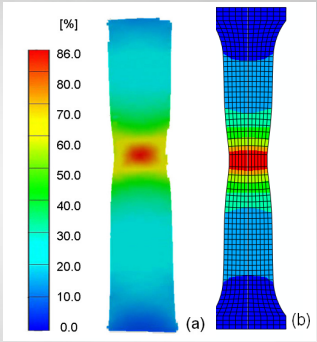
Uniaxial tensile tests

- **Finite element software: Abaqus/Explicit**
- **Nonlinear isotropic hardening plasticity model**
- **Shell elements (S4R)**
  - Barba's rule is used to fit material properties to element size
- **Initiation and evolution of damage**
  - Damage initiation (DI) - at necking, ε_n
  - Damage evolution (DE) - governing the behaviour from DI up to fracture , ε_f

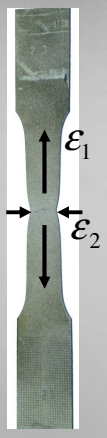


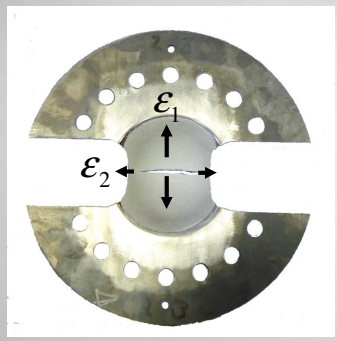
- ✓ **DI:** ductile criterion in Abaqus/Explicit
- ✓ **DE:** bilinear damage evolution law in Abaqus/Explicit

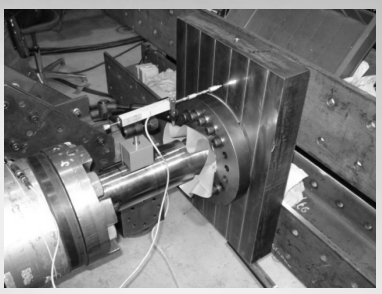
Uniaxial experiment **FEA**



Forming limit diagram tests

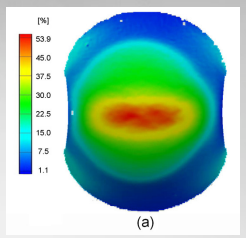


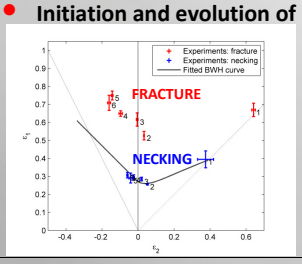




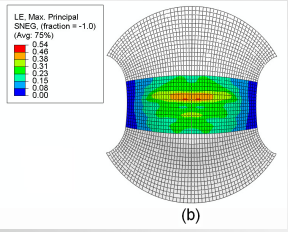
Forming limit diagram tests

- **Finite element software: Abaqus/Explicit**
- **Nonlinear isotropic hardening plasticity model**
- **Shell elements (S4R)**
  - Barba's rule is used to fit material properties to element size
- **"General contact conditions" criterion**
  - Zero friction (according to test conditions!)
- **Initiation and evolution of damage: DI+DE**



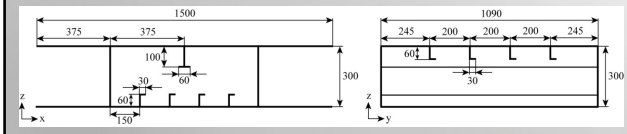


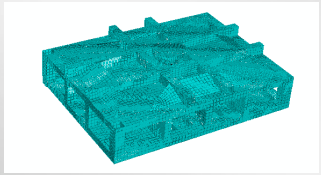
- ✓ **DI:** FLD criterion in Abaqus/Explicit
- ✓ **DE:** bilinear damage evolution law in Abaqus/Explicit



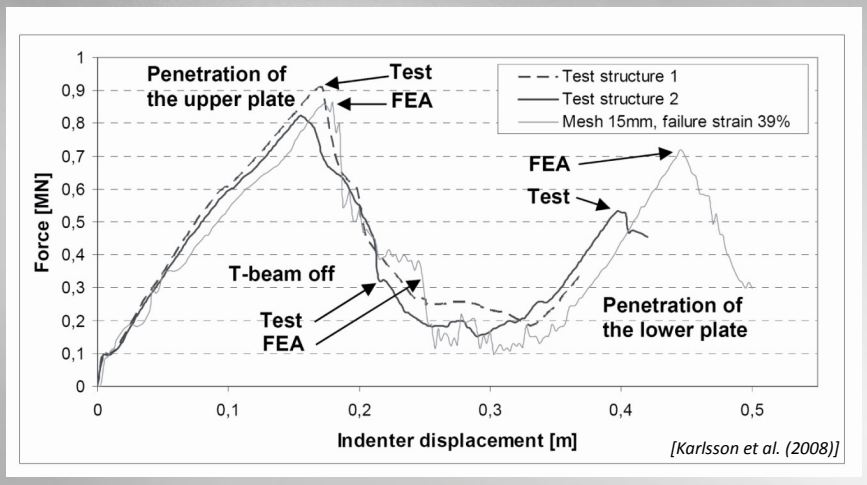
Bulb impact with a ship-like structure in small scale

- **Solid half-sphere acting as the indenter**
- **Displacement-controlled conditions**
- **Fixed boundary conditions around the edges**
- **Finite element software: Abaqus/Explicit**
- **Nonlinear isotropic hardening plasticity model**
- **Shell elements (S4R)**
- **"General contact conditions" criterion**
- **Shear failure criterion**
  - Relationship between fracture strain and appropriate element size was obtained by iteration procedure using experimental results



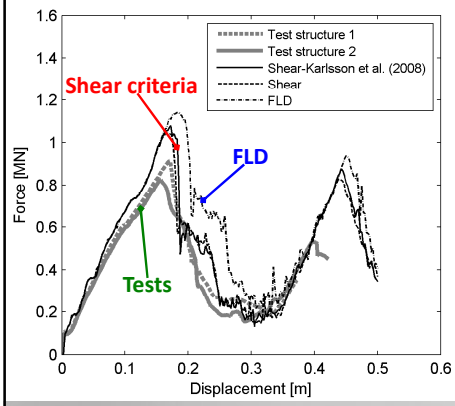


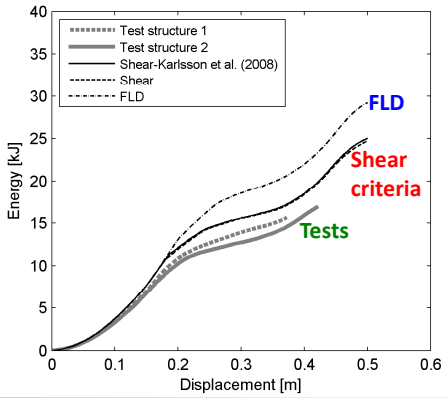
Bulb impact with a ship-like structure in small scale



[Karlsson et al. (2008)]

Bulb impact with a ship-like structure in small scale





CALCULATION OF SHIP SURVIVABILITY, $T_{capsize}$

Factors considered and the approach

Sea-state condition

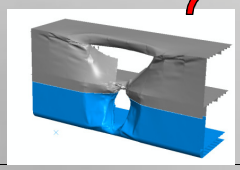
Wave direction relative damage opening

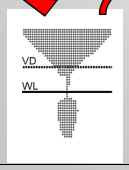
$T_{capsize}$

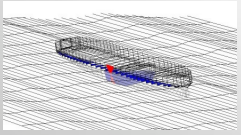
Position of damage opening

Shape of damage opening

Size of damage opening



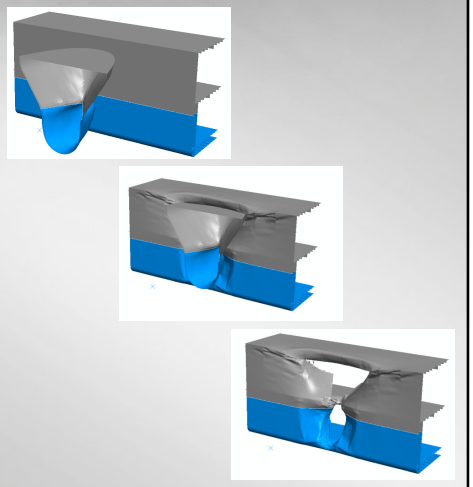




$E[T_{capsize}]$
$V[T_{capsize}]$

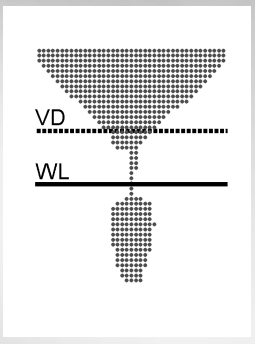
Nonlinear FE analyses

- **ABAQUS/Explicit**
- **Shell elements (S4R)**
- **Nonlinear isotropic hardening plasticity model**
- **"General contact conditions"**
- **External dynamics disregarded**
  - Struck ship fixed
- **Rigid bow section indenting the side-shell structure**
  - Right angle



Damage opening – shape and size from FEA

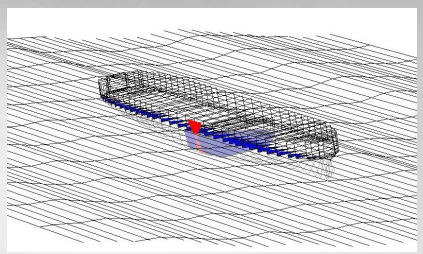
- **Damage opening:**
  - Projected area represented by grid of points
- **Each point represents an area and an inflow or outflow**
  - Bernoulli equation in SIMCAP tool

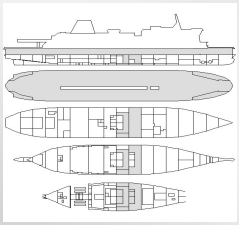


VD – Vehicle deck
WL – Waterline

Dynamic damage stability simulations

- **In-house code, SIMCAP**
  - Potential flow
  - Strip theory
- **Wave model**
  - Spectrum
  - Heading direction relative to waves
- **Application case**
  - RoPax ship
  - SOLAS damage case
- **Interruption criterion**
  - Simulation $T_{capsize}$ > 30 minutes
  - Capsize of ship within 30 minutes





Influence of "uncertainties" on $T_{capsize}$

Model uncertainties

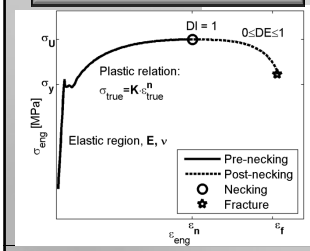
- Different models for DI represents different failure phenomena
  - **Shear** – traditionally used due to its simplicity
  - **FLD** – accounts for multiaxial behaviour
- The same DE model for both

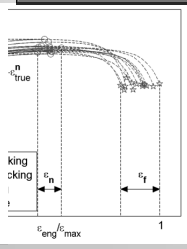
Material properties uncertainties

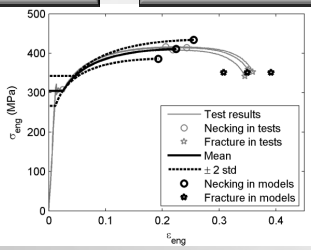
- Scatter of material properties within a material class
- Three sets of material properties represent this scatter
  - The mean value
  - ±2 standard deviations

Natural variation in sea-state

- Significant wave height, H_s, between 3 and 7 m
  - Below 3m – all survive
  - Above 7m – capsize in intact condition
- Phase shift between wave components, wave seeds
  - 8 wave seeds for every H_s

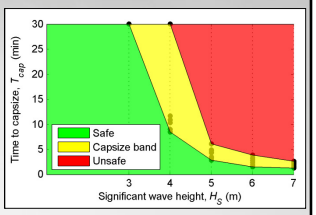


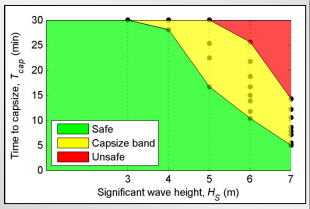




Example of results

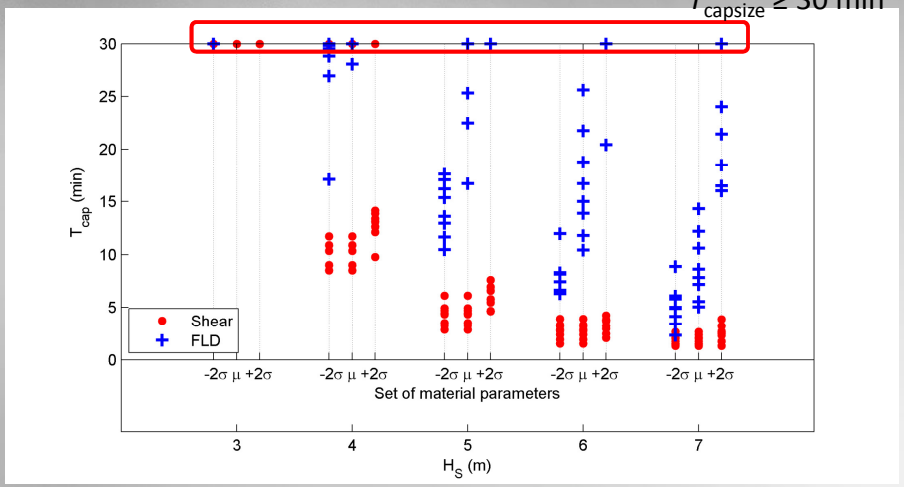
Failure model	Set of material parameters: -2 std	Mean	+2 std
Shear	A_{tot} = 47 m²	A_{tot} = 40 m²	A_{tot} = 33 m²
FLD	A_{tot} = 17 m²	A_{tot} = 11 m²	A_{tot} = 7 m²





Example of results

$T_{capsize} \geq 30$ min



CONCLUDING REMARKS

- **Methodology and strategy in structure analysis of ship collision and grounding**
  - Need for systematic numerical procedures which are verified by experimental investigations
  - Selection of/comparison of failure model and criteria
  - Uncertainty analysis is crucial (model, material, “other sources”)
- **Future safer structures against collision/grounding damages**
  - Modelling guidelines?
  - Lightweight design and multi-objective optimisation procedures
- **Risk analyses (e.g. $T_{capsize}$)**
  - “Shape and size of damage”
  - Uncertainty in numerical predictions
  - Reliability of models and calculated results
  - Application case driven investigations

ATLANTICA outside Christiansö, Denmark (Jonas Ringsberg, 1986)