Numerical and analytical simulations of in-shore ship collisions within the scope of A.D.N. Regulations

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Motivations & Objectives

- Increase of inland water navigation ➔ Increase of ship collision events
- For the European inland waterway ➔ A.D.N. Regulations
- A.D.N. demands 36 F.E simulations ➔ takes lots of time ➔ 😞
- SHARP program ➔ Ship Hazardous Aggression Research Program
  ➔ simplified approach “Super-Element Method”

My Objective

- to validate SHARP program for inland ship collisions
  (Within the scope of A.D.N. Regulations)
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A.D.N. Regulations

- European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways

- Alternative Design Approach (Section 9.3.4)
  - Alternative design & Reference design
  - Risk of cargo tank rupture \( R = P \times C \)

\[
R : \text{risk [m}^2\text{];}
\]
\[
P : \text{probability of cargo tank rupture; and}
\]
\[
C : \text{consequence (measure of damage) of cargo tank rupture [m}^2\text{].}
\]
Define collision locations by A.D.N. Regulations

- 3 Vertical locations defined by minimum and maximum draughts of the colliding ships
- 3 Longitudinal locations
  - At bulkhead
  - Between webs
  - At web
A.D.N. Regulations (Cont.)

➢ Other important assumptions

- The struck ship is deformable ⇒ at rest
- Rigid striking ship ⇒ moving at 10 m/s (constant velocity)
- Scenario I: Push barge bow with 55 degree collision angle
- Scenario II: V-shape bow with 90 degree collision angle

Total = 2 * 9 * 2 = 36 calculations
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LS-DYNA/MCOL

Crushing forces

\[
[M + M_{\infty}] \ddot{x} + G \dot{x} = F_W(x) + F_H(x) + F_V(x) + F_C
\]

Internal mechanics such as yielding, buckling, rupture, etc. are solved by LS-DYNA

External dynamics such as the rigid body motion equations are solved by MCOL

New position, velocity, acceleration at the center of gravity

Figure available from (Le Sourne et al., 2003)
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SHARP/MCOL

Decompose the vessels into “Super-elements” ➔ Analytical Formula for each element ➔ Evaluate global Impact resistance ➔ Couple with MCOL

- Outputs
  - Crushing force and internal energy as a function of penetration
  - Graphical animation of the collision event

User-interface of SHARP

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Theories considered in LS-DYNA & SHARP (Cont.)

- How super-elements are considered in SHARP?
  - Right angle collision
  - Oblique angle collision

In general,

1. Hull super-element
2. Vertical bulkhead SE
3. Beam SE
4. Horizontal deck SE

Figure available from: (Buldgen et al., 2012)
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Collision Scenarios

- LS-DYNA/MCOL

- Among the 36 simulations suggested by A.D.N.,
- 5 scenarios are defined to compare the results with SHARP

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Bow Type</th>
<th>Collision Angle [deg]</th>
<th>Longitudinal Position</th>
<th>Vertical Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>V-shape</td>
<td>90</td>
<td>At web</td>
<td>Under deck</td>
</tr>
<tr>
<td>Case 2</td>
<td>V-shape</td>
<td>90</td>
<td>Between webs</td>
<td>Mid-depth</td>
</tr>
<tr>
<td>Case 3</td>
<td>Push barge</td>
<td>55</td>
<td>At web</td>
<td>Mid-depth</td>
</tr>
<tr>
<td>Case 4</td>
<td>Push barge</td>
<td>55</td>
<td>At bulkhead</td>
<td>Above deck</td>
</tr>
<tr>
<td>Case 5</td>
<td>V-shape</td>
<td>90</td>
<td>At web</td>
<td>Above deck</td>
</tr>
</tbody>
</table>
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Collision Scenarios (Cont.)

- Additional 8 impact locations need to be defined
- In order to take into account the variation inherent to the method

**SHARP/MCOL**

![Diagram](image)

Struck Ship’s Hull

where

- $s =$ stiffener spacing
- $l =$ web frame spacing

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Materials & Rupture Strain

- **LS-DYNA**
  - Elasto-plastic material
  - \[ \sigma = C \cdot \varepsilon^n \]

- **SHARP**
  - Perfectly rigid-plastic material

- **Rupture Strain**
  - Referring to A.D.N. Regulations
    \[ \varepsilon_f(l_e) = \varepsilon_g + \varepsilon_e \cdot \frac{t}{l_e} \] (Lehmann and Peschmann, 2002)

“20 % Rupture Strain”
Comparison & Analysis

- Comparison will be made according to:
  - Penetration into the struck ship
  - Struck ship deformation energy

- 3 categories of validation
  - Without rupture strain (striking ship speed 3 m/s)
  - Simulation with rupture strain (A.D.N. Regulations)
  - With modified rupture strain (in SHARP)

[10 FEM simulations & 135 SHARP simulations]
Some of the results without rupture strain

Some Observations

- Over-estimation of the deformation energy in SHARP
- The structures in SHARP are more rigid than LS-DYNA if failure strain is not considered

For Example;

Case 2 (V-shape/Bet. Webs/Mid-depth)
- Energy: 10%
- Penetration: 1%

Case 4 (Push-bridge/At bkh/Above deck)
- Energy and Penetration: 8% discrepancy
Some of the results with rupture strain (A.D.N. Regulations)***

- **Some Observations**
  - Under-estimation of the deformation energy in SHARP
  - The structures in SHARP (especially the side shell Super-element) needs more stiffness

**Case 2 (V-shape/Bet. Webs/Mid-depth)**
- 82% discrepancy

**Case 4 (Push- barge/At bhk/Above deck)**
- 64% discrepancy

% Difference = \( \frac{|LS-DYNA - SHARP|}{LS-DYNA} \) * 100.

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Comparison & Analysis (Cont.)

- **Improvements for the Solver**
  - ✔ **Coupling effect** ➔ Could change the boundary condition for the side shell

E.g. Case 1: V-shape bow : At web: Just under deck

The Coupling effect
Improvements for the User-face!!

- Geometrical simplifications → cannot exactly model the same push barge bow
Comparison & Analysis (Cont.)

- Failure modelling of super-element
- Post rupture Behavior of the side shell

- The side shell in LS-DYNA is still resisting the collision even after rupture
- The crushing resistance of the side shell in LS-DYNA is almost 6 times larger

E.g. Case3
At web Mid-depth
Conclusions & Recommendations

- Need some improvements
  - User-interface (striking ship modelling)
  - Solver (such as Boundary conditions, post-rupture behavior, etc.)
- Simulation time in SHARP ➔ a few seconds
- Simulation time in LS-DYNA ➔ a few days (sometimes, a few weeks)
- A complementary tool for FEM for the preliminary design stage

Thank you for your attention