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

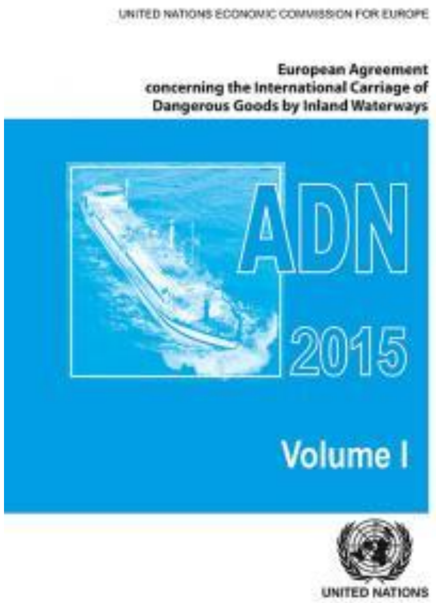
  (Within the scope of A.D.N. Regulations)

A.D.N. Regulations

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

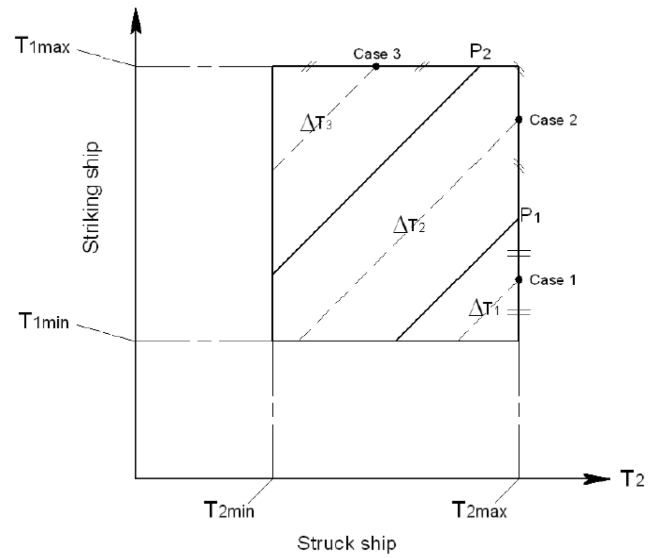
- Alternative Design Approach (Section 9.3.4)
  - Alternative design & Reference design
  - Risk of cargo tank rupture $R = P.C$

R : risk [m^2];
P : probability of cargo tank rupture; and
C : consequence (measure of damage) of cargo tank rupture [m^2].



A.D.N. Regulations (Cont.)

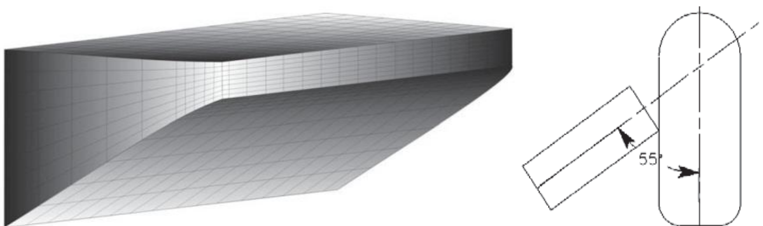
- Define collision locations by A.D.N. Regulations
  - 3 Vertical locations defined by minimum and maximum draughts of the colliding ships
  - 3 Longitudinal locations
    - ✓ At bulkhead
    - ✓ Between webs
    - ✓ At web



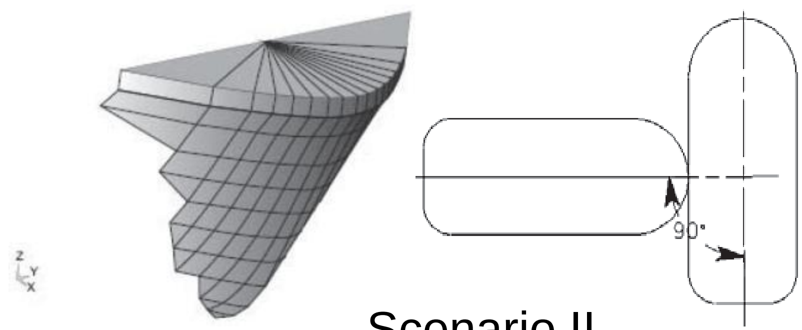
A.D.N. Regulations (Cont.)

➢ 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



Scenario I

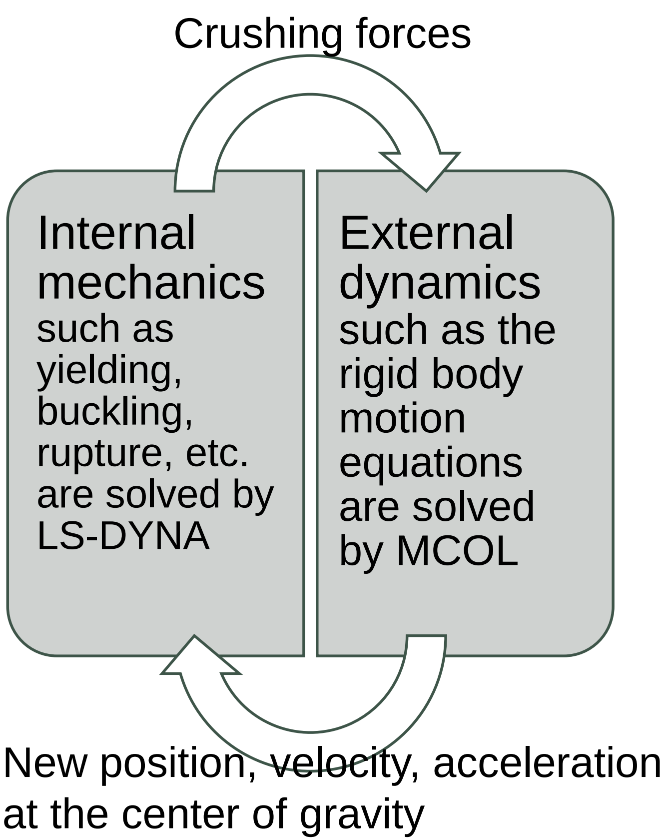


Scenario II

Total = 2 * 9 * 2 = 36 calculations

LS-DYNA/MCOL

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



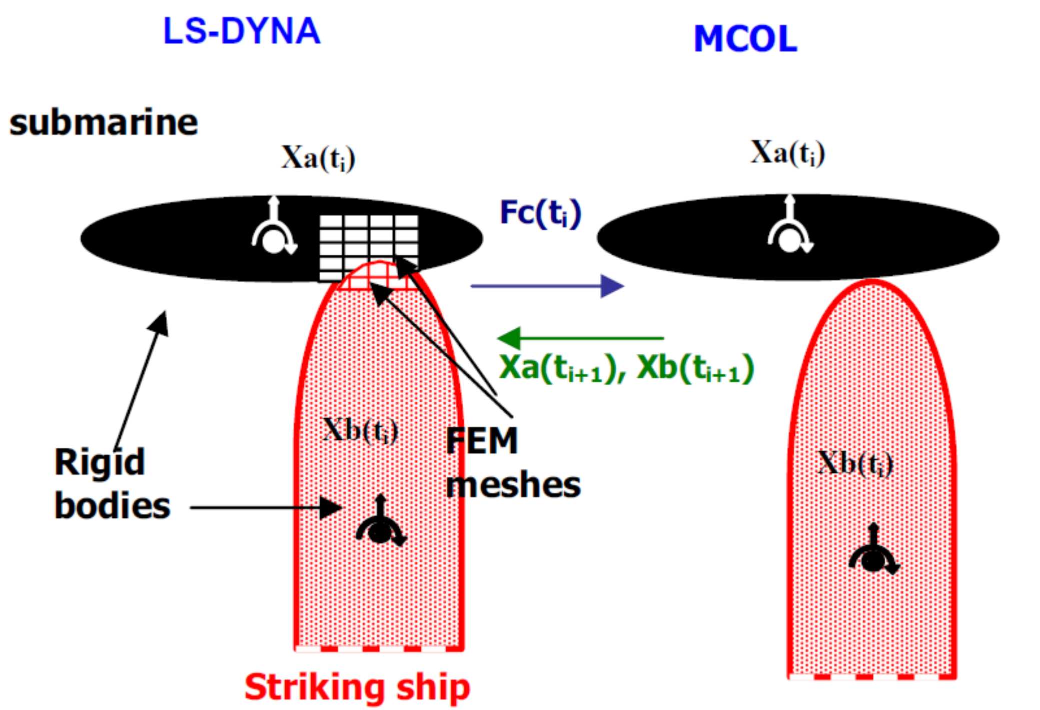


Figure available from (Le Sourne et al., 2003)

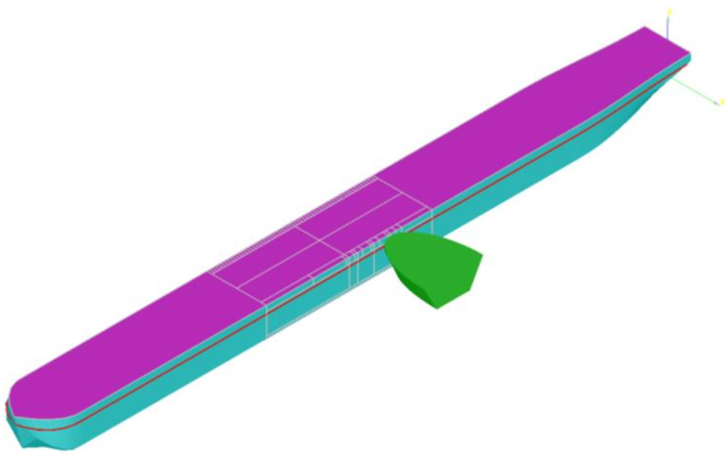
SHARP/MCOL

Upper-bound theorem

Rigid-body Movement

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

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

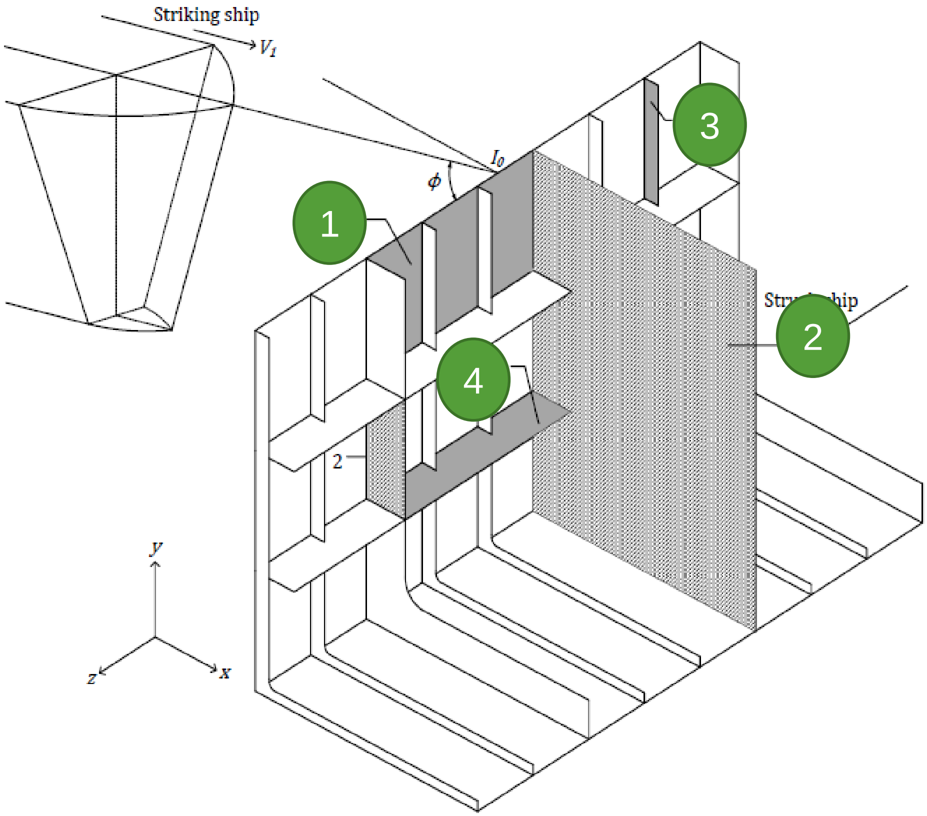


Figure available from: (Buldgen et al., 2012)

Collision Scenarios

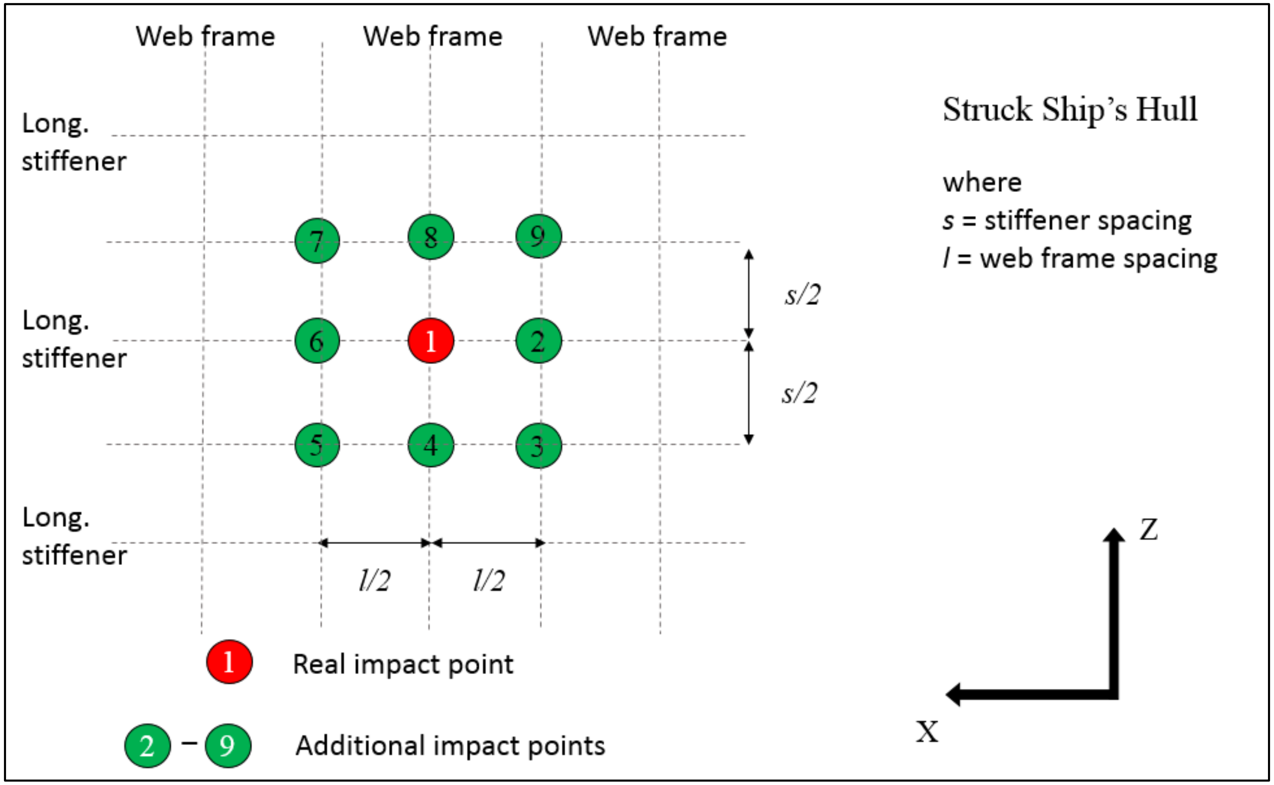
- LS-DYNA/MCOL
  - ✓ Among the 36 simulations suggested by A.D.N.,
  - ✓ 5 scenarios are defined to compare the results with SHARP

Scenarios	Bow Type	Collision Angle [deg]	Longitudinal Position	Vertical Position
Case 1	V-shape	90	At web	Under deck
Case 2	V-shape	90	Between webs	Mid-depth
Case 3	Push barge	55	At web	Mid-depth
Case 4	Push barge	55	At bulkhead	Above deck
Case 5	V-shape	90	At web	Above deck

Collision Scenarios (Cont.)

- SHARP/MCOL

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



Materials & Rupture Strain

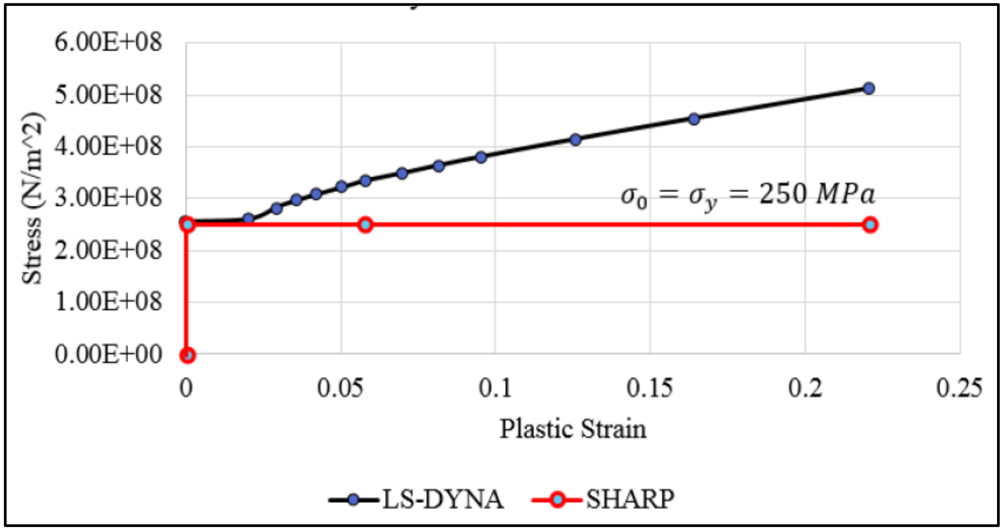
❑ **LS-DYNA**

✓ Elasto-plastic material

$$\sigma = C.\varepsilon^{n}$$

❑ **SHARP**

✓ Perfectly rigid-plastic material



➢ Rupture Strain

✓ Referring to A.D.N. Regulations

$\varepsilon_f(l_e) = \varepsilon_g + \varepsilon_e.\frac{t}{l_e}$ (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 [10 FEM simulations & 135 SHARP simulations]

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

➢ Some of the results without rupture strain

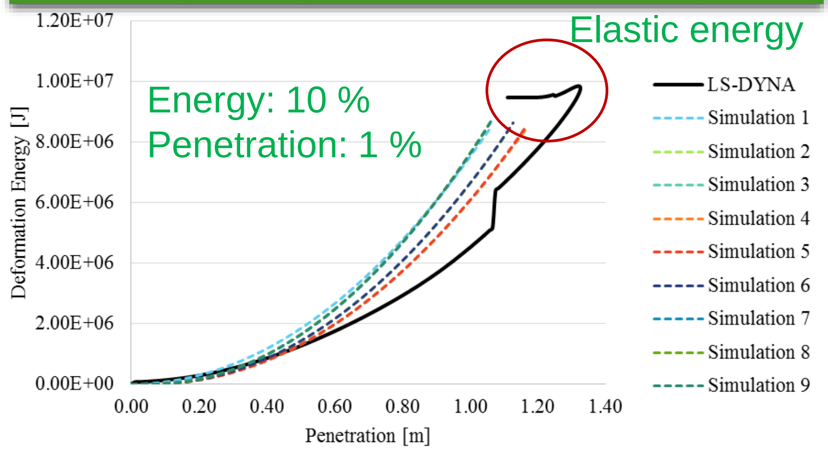
❑ Some Observations

✓ Over-estimation of the deformation energy in SHARP

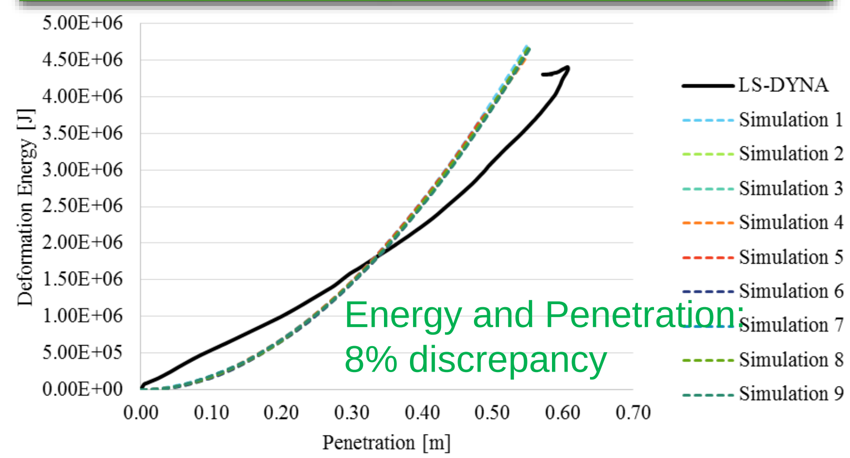
✓ The structures in SHARP are more rigid than LS-DYNA if failure strain is not considered

For Example;

Case 2 (V-shape/Bet. Webs/Mid-depth



Case 4 (Push-barge/At bhk/Above deck)

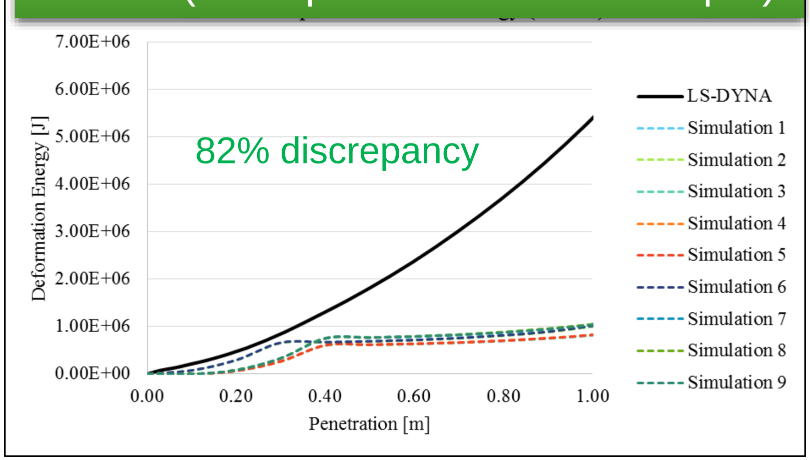


➢ Some of the results with rupture strain (A.D.N. Regulations)***

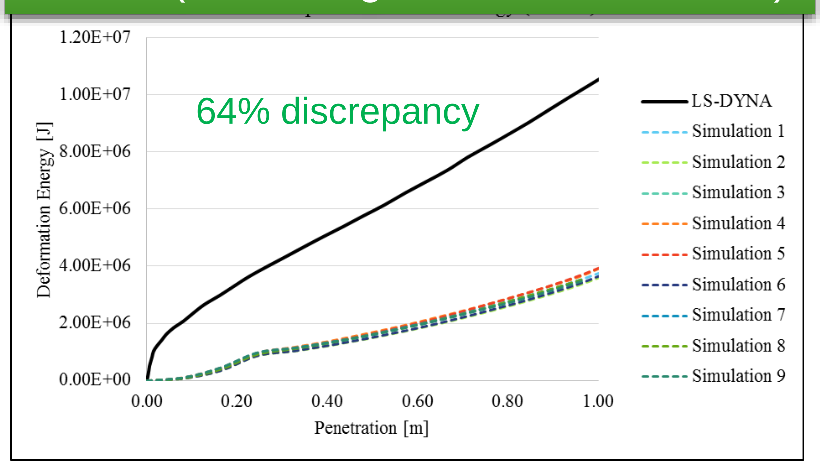
❑ Some Observations

- ✓ 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)



Case 4 (Push-barge/At bhk/Above deck)



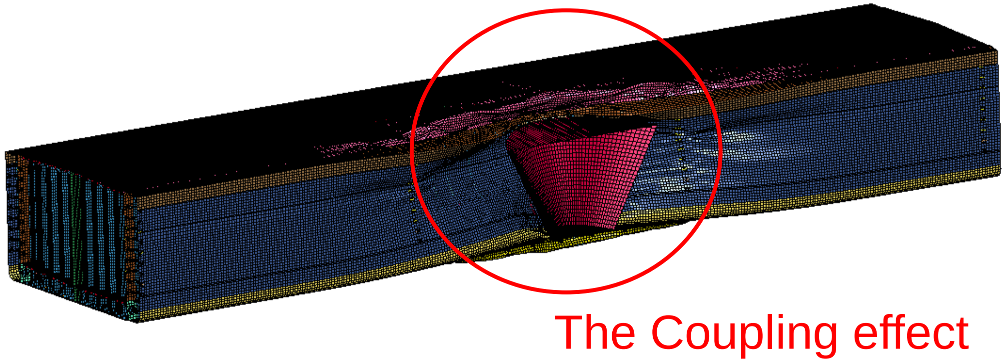
$$\%\ Difference = \frac{|LSDYNA - SHARP|}{LSDYNA} * 100.$$

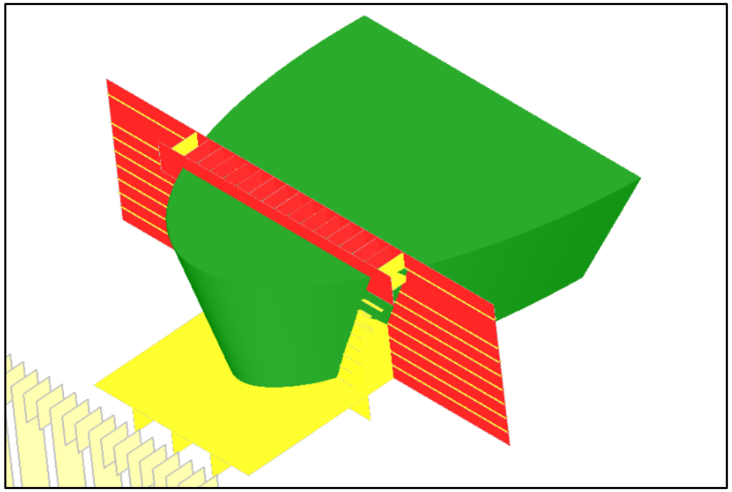
Comparison & Analysis (Cont.)

❑ 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

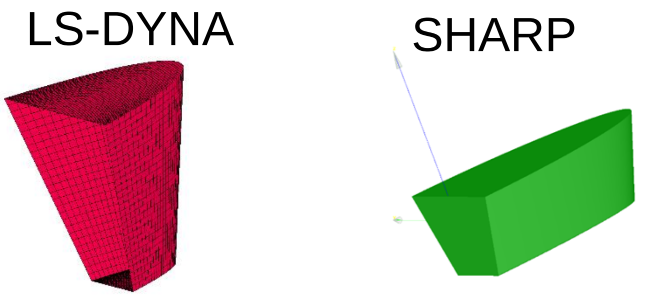




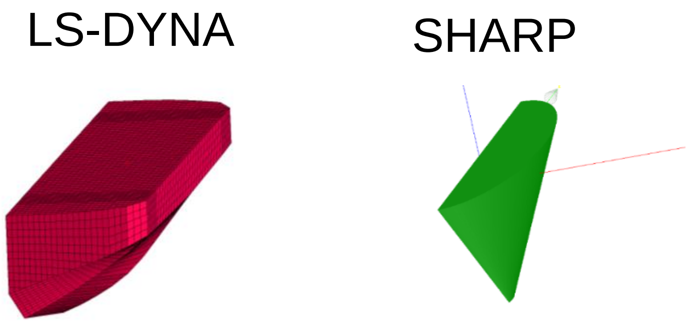
Comparison & Analysis (Cont.)

- **Improvements for the User-face!!**

✓ Geometrical simplifications ➔ cannot exactly model the same push barge bow



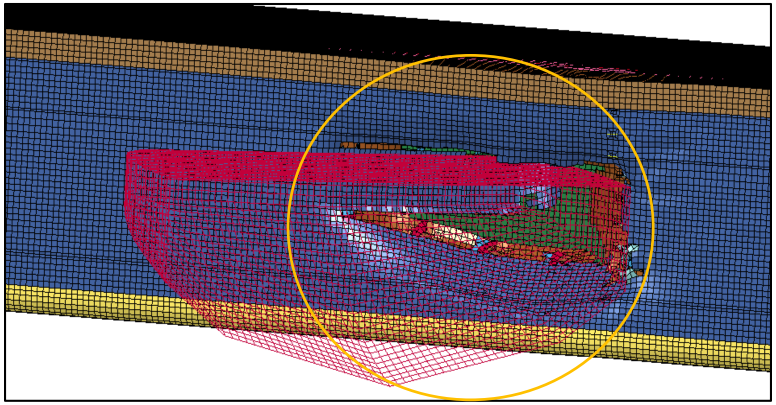
V-shape bow

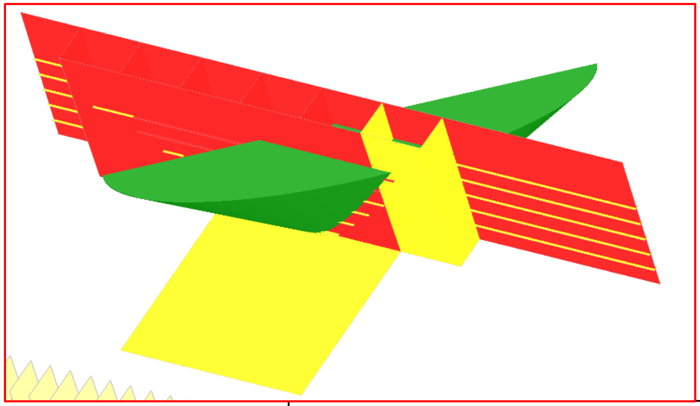


Push-barge bow

Comparison & Analysis (Cont.)

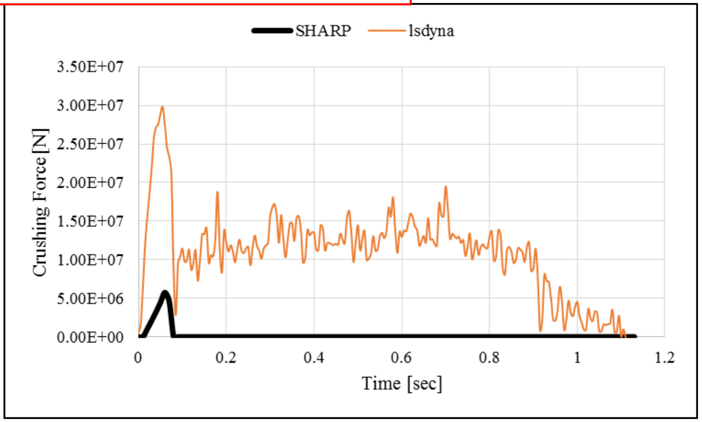
- ✓ Failure modelling of super-element
- ✓ Post rupture Behavior of the side shell





E.g. Case3
At web
Mid-depth

- 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



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