衝突時の被害軽減のための船体構造への高延性鋼（HDS : Highly Ductile Steel）適用に関する研究

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Safe and Environment Friendly Hull Structures with Newly Developed Highly Ductile Steel and Collision Analysis

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ClassNK R&D PROJECT

This technology was developed with the support of ClassNK as part of the ClassNK Joint R&D for Industry Program.

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Outline

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3. Objectives
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Background

- Prevention of oil spill is one of important issues for maritime environment.
- D/H structure is effective to reduce risk of oil spill from tankers but is not sufficient to prevent oil spill accidents from tankers.
- Recently Highly Ductile Steel was newly developed by Nippon Steel and Sumitomo Metal and has been applied for actual ships to mitigate impact damages in collision.

Highly Ductile Steel (HDS)

- Comparing with the rule regulation of class or conventional steels,

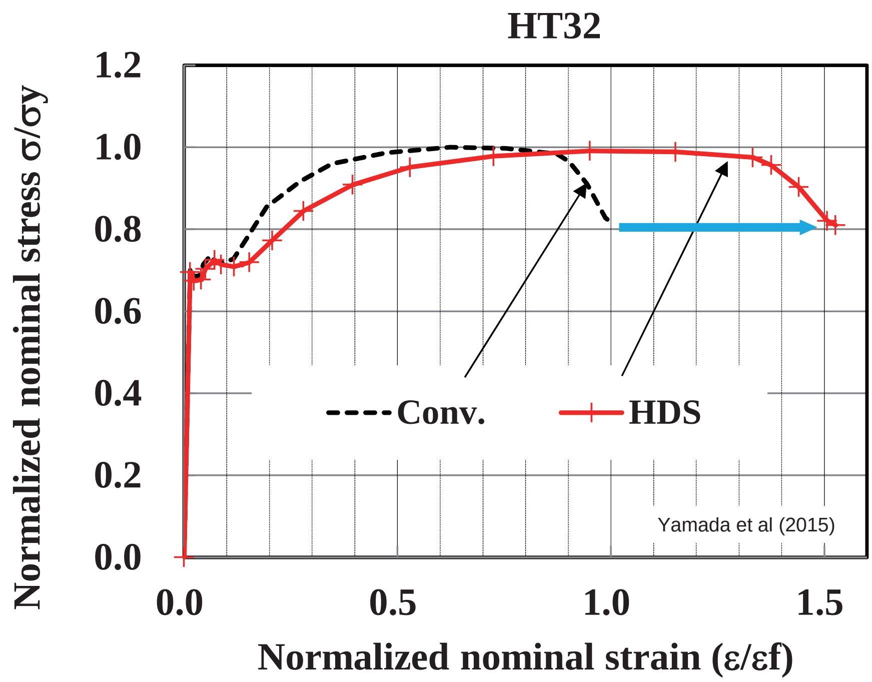
  Minimum Elongation : Almost 1.5 times larger than those in rule requirement

  Strength, Toughness and Workability (*e.g.*, Weldability): Same as conventional steels

- Comply with class rules and can be applied without change in structural design (with just substitute materials only).

Stress – Strain Curves

Same yield and tensile strength with larger elongation



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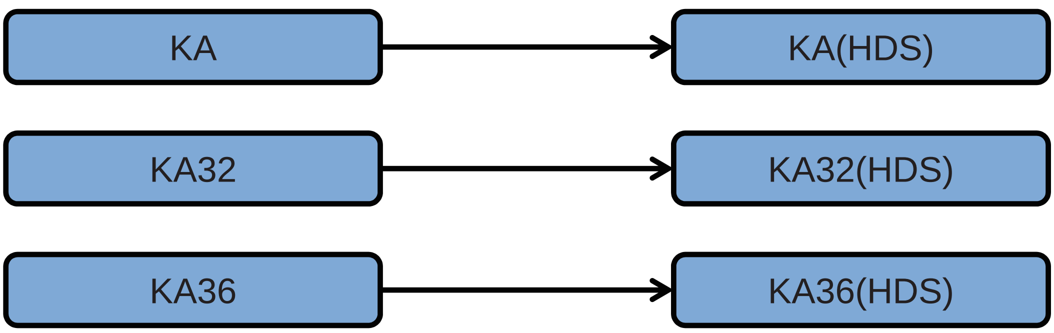
Kind of HDS



Each HDS are defined based on “stress –strain data” by mechanical test

Generally, Elongation is inversely proportional to strength and difficult to increase elongation of High tensile steel

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Advantage of HDS

Because of the large elongation of steel itself and expansion of plastic area caused by large elongation it self, absorbed energy of hull in collision is increased largely.

1) Hollow depth is smaller than those in conventional steels applied.

   ⇒ Easy to repair

2) Hard to be pierced.

   ⇒ Decrease cargo / oil spill, escape sinking

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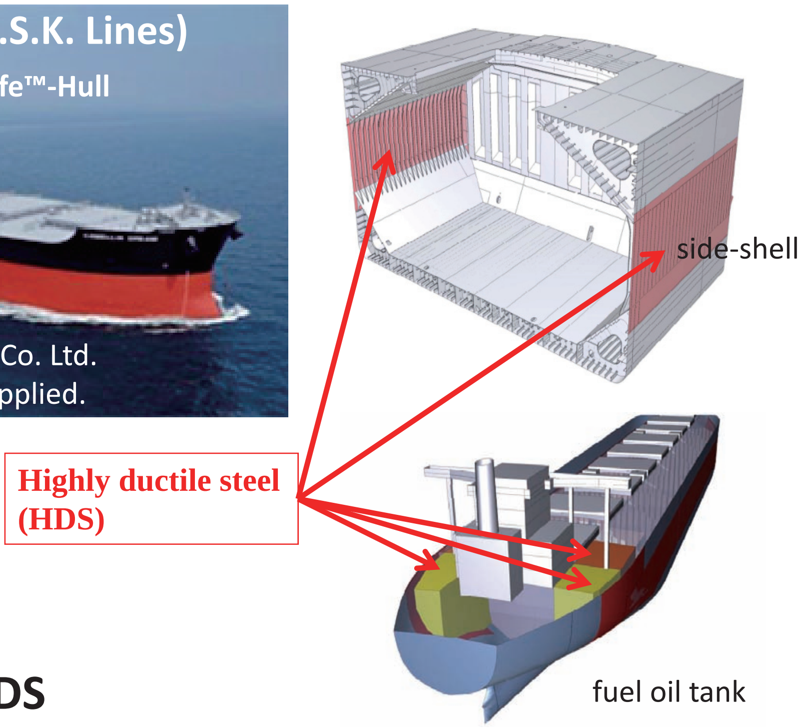
World First Application of HDS on Actual Ship

Loa	299.94 m
B	50m
D	24.7 m
DWT	206, 600 ton



Example of HDS
NSafe™-Hull (NSSMC)

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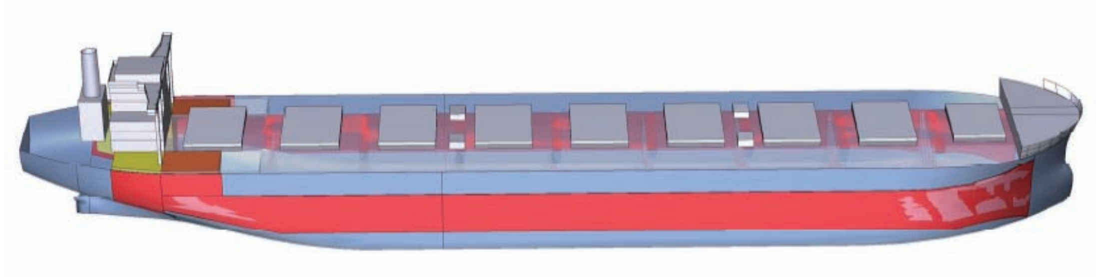
Used Parts and Purpose of HDS



Part	Material Name	Purpose
Ship's side of cargo hold	･Side shell ･Hold frame ･Side longitudinal stiffener	･Prevention for flood ･Protect for cargo ･Prevention for Mechanical damage (Grab damage)
Fuel oil tank (Top side tank)	･Side shell ･Top side tank bottom plate ･Longitudinal bulkhead plate of fuel oil tank ･Side longitudinal stiffener	･Prevention for oil spill ･Prevention for Mechanical damage (Grab damage)
Fuel oil tank (Engine room)	･Side shell ･Longitudinal bulkhead plate of fuel oil tank	･Prevention for oil spill

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Objectives

1. Investigate effect of HDS material on the decreasing structural damage of the struck tanker.

   By carring out a series of Non-linear finite element analysis (NL-FEA).
2. Estimate Critical Striking Velocity ($V_{B,cr}$) :

   Minimum striking ship speed to penetrate cargo oil tank (inner shell) in case of collision

   - Simulation 1 : Simple simulation / small deformation area
     Collision angle : Vertical
     Collision Speed : 12 knot
   - Simulation 2 : Practical, high accuracy, large deformation area
     Collision angle : Oblique – vertical
     Collision speed : 1 – 12 knot

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FE Analysis Simulation 1

Vertical Collision

(Simple Simulation)

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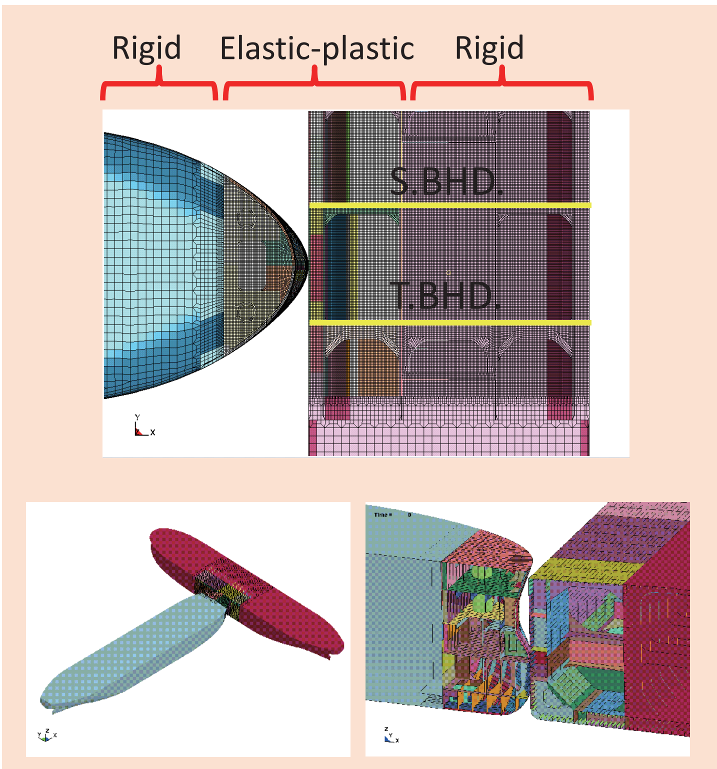
Simulation 1 : Collision Conditions

- VLCC collides with the midship part of another VLCC
- Both ships fully loaded
- Collision speed
  - striking (VB) : 12 knot
  - struck (VA) : still
- Collision angle : θ=90 deg.
- Motion of struck ship
  - : Considered
- Deformation area
  - : 1Tank length ,1/3withs



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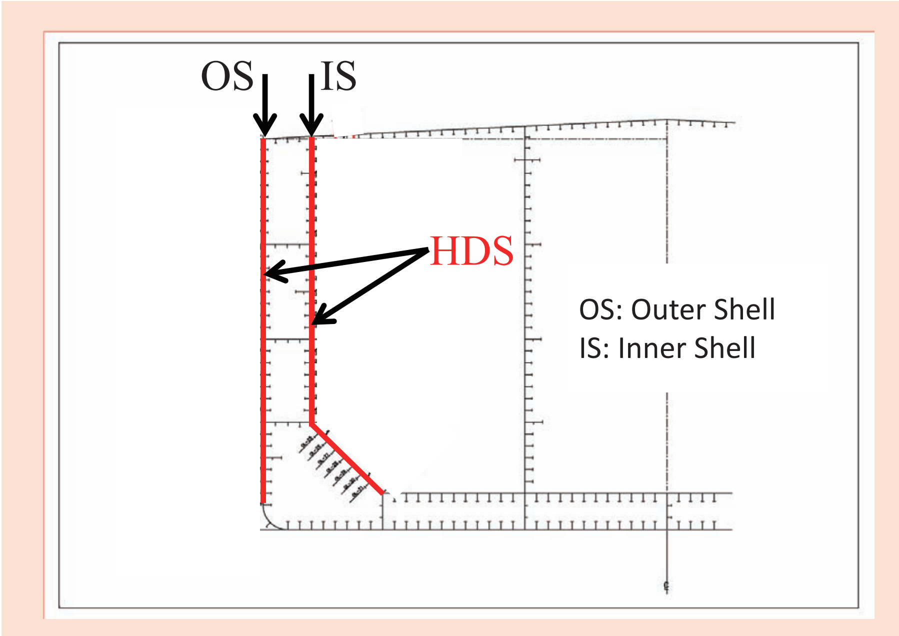
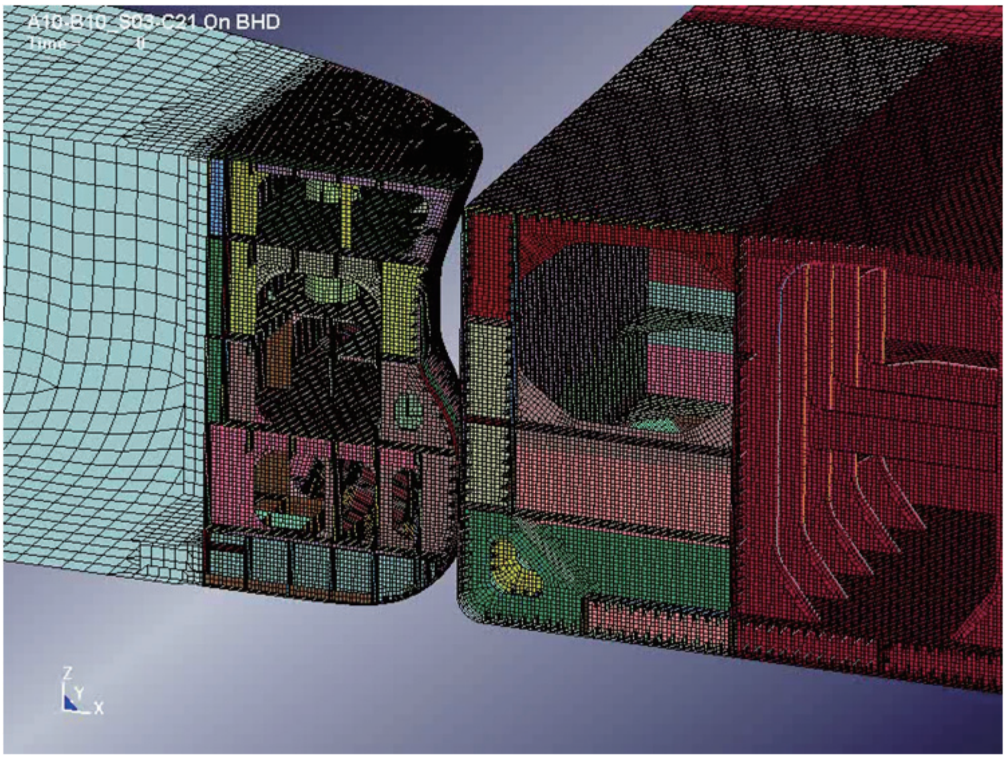
Simulation 1 : Application Members of HDS



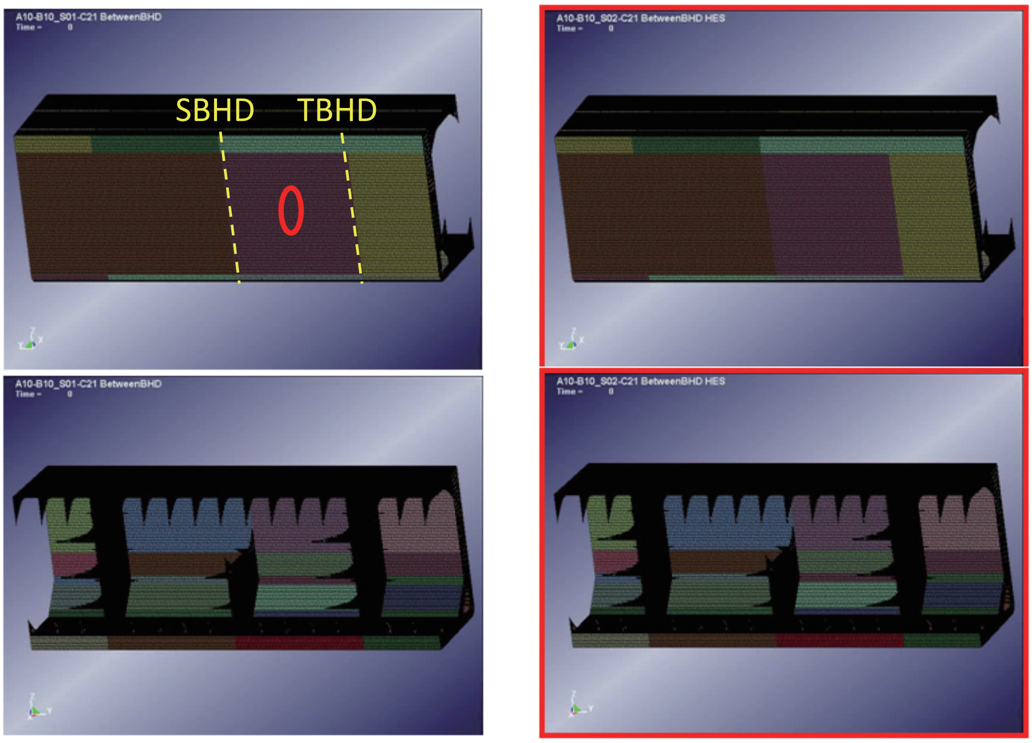
HDS is only applied to OS and IS of the struck ship.

Analysis conditions other than material are same.

Simulation 1 : Results of FEA



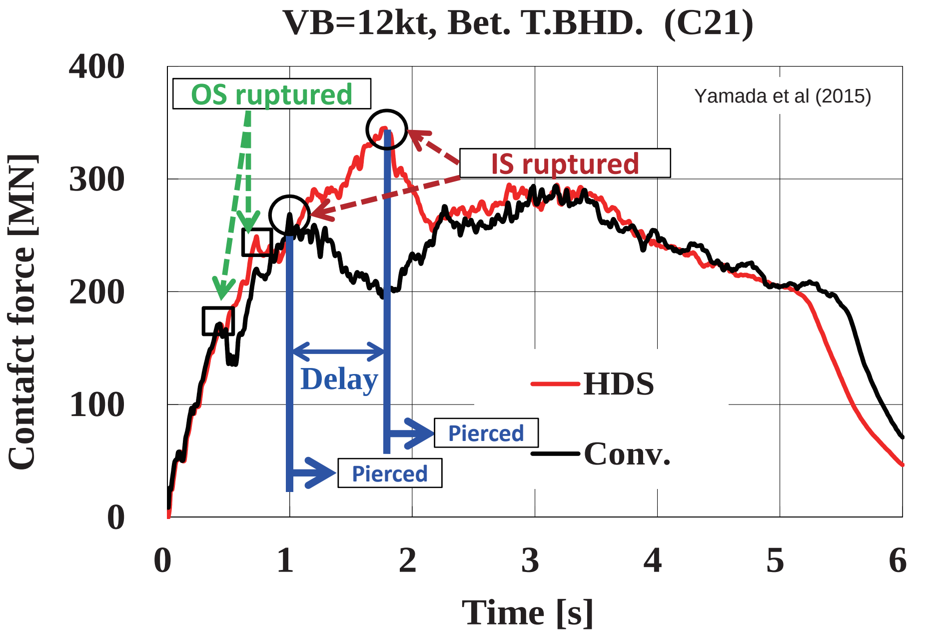
Simulation 1 : Results of FEA



Conventional | Trupture:0.87

HDS | Trupture:1.81

Comparison of Histories of Contact Force

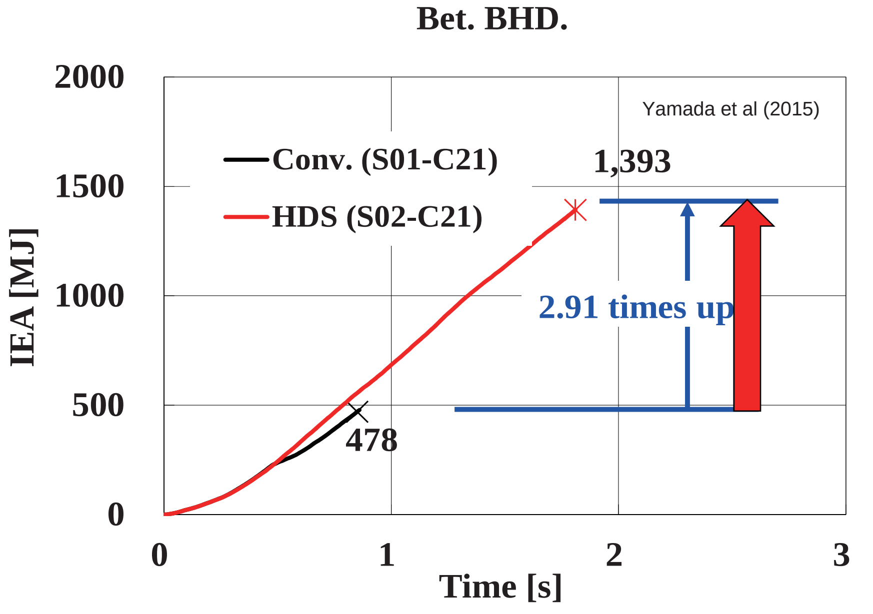


Black: Conventional, Red: HDS

Contact force significantly decrease after IS rupture.

Due to application of HDS, delay of IS rupture can be seen
($T_{rupture}$; 0.87s →1.81s, 2 times later).

Effect of HDS on Energy Absorption



Energy absorption by the struck ship until oil tank (inner shell) rupture becomes 3 times larger than that of conv.

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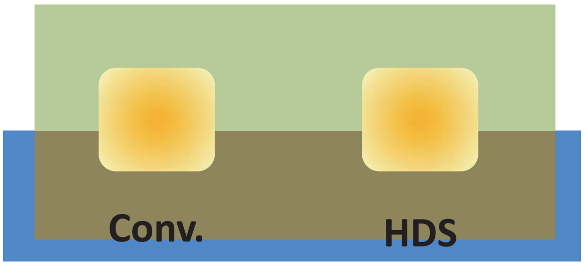
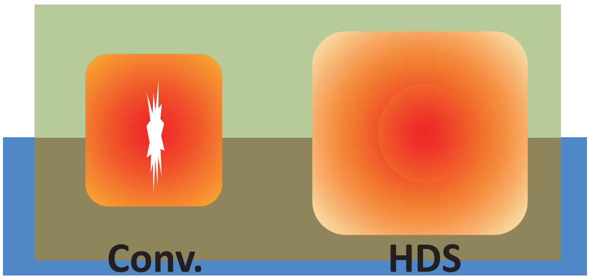
Conceptual Drawing of Deformation

Large elongation of steel and expansion of plastic area increase energy absorption of hull in collision.
Hull structures HDS applied is hard to be pierced.

Small deformation
(Low speed collision)



Large deformation
(High speed collision)



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FE Analysis Simulation 2

Oblique - Vertical Collision

(Practical and High Accuracy Simulation)

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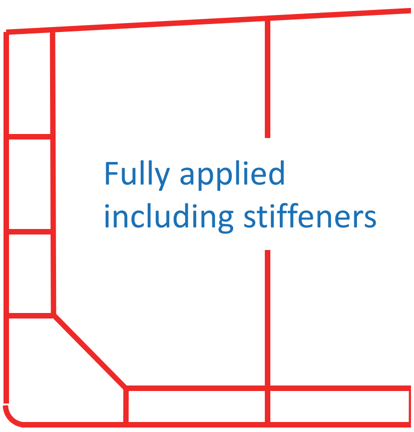
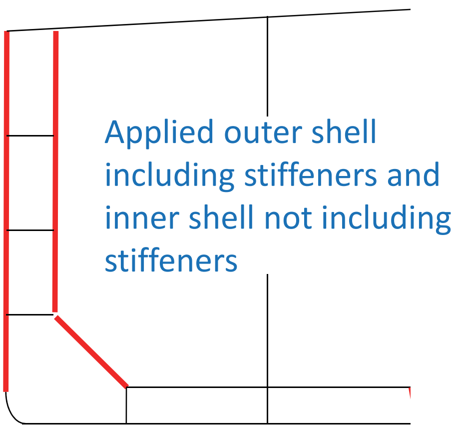
Simulation 2 : Application Members of HDS

Full application



Partial application



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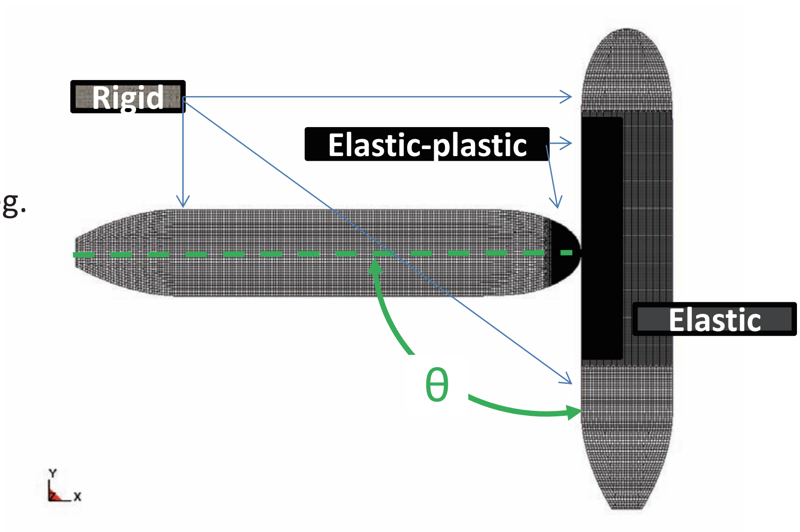
Simulation 2 : Collision Conditions

- VLCC collides with the midship part of another VLCC
- Both ships fully loaded
- Collision speed
  striking (VB) : 1-12 knot
  struck (VA) : still
- Collision angle : θ=60-150 deg.
- Motion of struck ship
  : Considered
- Deformation area
  : 3 Tanks ×1/2withs



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Simulation 2 : Analysis matrix

Velocity(kt) / Angle(deg)	15	12	10	9	8	7	6	5	4	3	2	1
60						N	N	N	N			
75		F,P,N					N	N	N			
90		F,P,N	N		N		N	N	N	N		
105		F,P,N				N	N	N	N		N	
120		N				N	N	N	N			
135		N	N	N	N		N	N	N			
150		N				N	N	N				

F : HDS Full applied
P : HDS Partial applied
N : HDS Not applied

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Critical Striking Velocity ($V_{B,cr}$)

Critical Striking Velocity（$V_{B,cr}$）:

Minimum striking ship speed to penetrate cargo oil tank (inner shell) in case of collision

Kinetic energy of striking ship =

Translational kinetic energy after collision + Rotational kinetic energy after collision + Absorbed energy other than ship motion (mainly deformation and sliding energy) by the time of IS rupture

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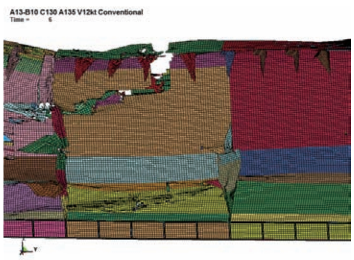
Simulation 2 : Results of FEA

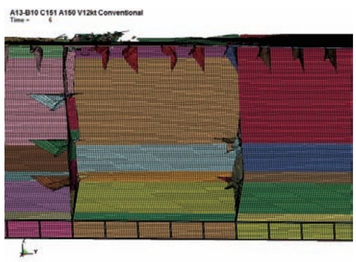
Full-applied, 90deg.
（B02-C122）

Partial-applied, 90deg.
（B05-C126）

Conventional, 90deg
（B09b-C116e）



Conventional, 135deg.
（C130）



Conventional, 150deg.
（C151）

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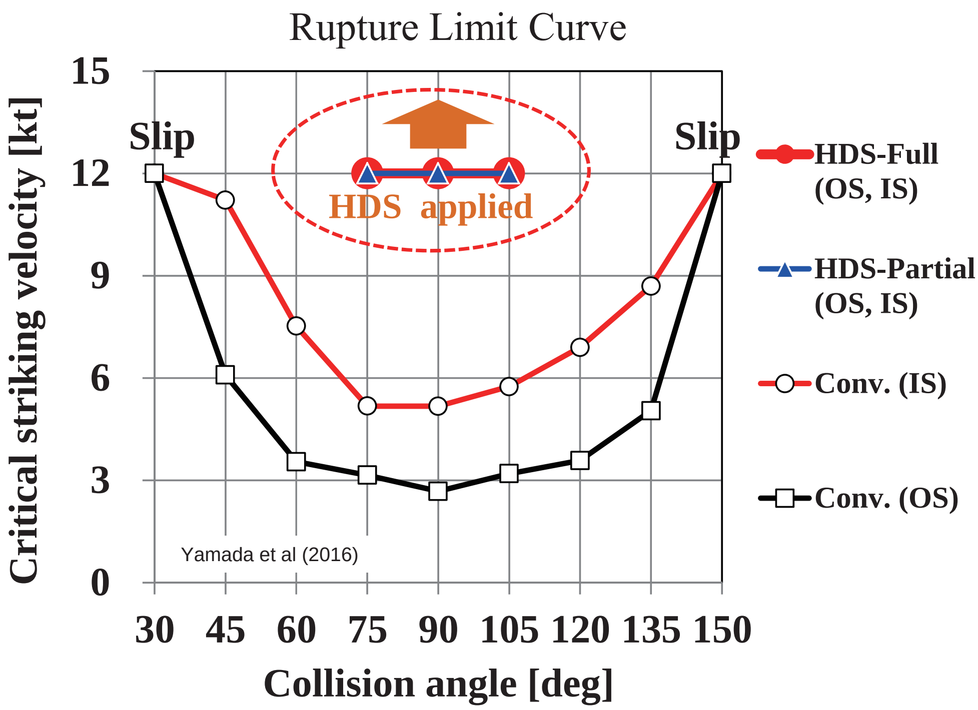
Critical Striking Velocity



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ClassNK Notation and Descriptive Note

ClassNK Notation

"Hull Protection by Highly Ductile Steel" (HP-HDS)

Notation is assigned to ships using ClassNK approved HDS effectively to increase the energy absorbed by the hull in the case of collision or grounding.

Descriptive Note

Specifies the grades and application areas of the HDS used.

e.g. : KA32-HD XX applied to side shell plate and side longitudinal within Fr. XX-XX (or No. X-X WBT)

Material grade of HDS

Approved HDS is indicated by "HD XX"

"XX" shows the increased percentage of elongation of HDS against the rule required minimum specified elongation of the corresponding normal steel.

e.g. : KA32-HD50 for $15 < t \leqq 20$

KA32-HD50 is Highly Ductile Steel with minimum specified elongation 27%, where the minimum specified elongation of KA32 is 18%. (18 x 1.5 = 27)

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Conclusions (1)

- HDS is developed by Nippon Steel & Sumitomo Metal. HDS possess larger elongation.
- HDS can increase energy absorption of hull structures in collision about 3 times larger than that of ordinary steel.
- HDS is applied on the actual ships already by Imabari Shipbuilding to prevent / mitigate cargo and fuel oil spill.
- ClassNK prepared for class notation “HP-HDS”.

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Conclusions (2)

Advantage of HDS are

1) Hollow depth is smaller than the hull conventional steel applied.

   ⇒ Easy to repair

2) Hard to be pierced by striking ship.

   ⇒ Decrease cargo spill, escape sinking

Imabari Shipbuilding will apply HDS as standard for safety of ships and global environment conservation.

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Thank you for your attention

NIPPON STEEL & SUMITOMO METAL

IMABARI SHIPBUILDING CO., LTD.

ClassNK

National Maritime Research Institute

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Reference

- Yamada, Y., Ichikawa, K. Kamita, K., Tozawa, S., Inami, A., Suga, H., Fujita, H., Senga, Y., Arima T., Murakoshi, S. (2015). "Effects of Highly Ductile Steel on the Crashworthiness of Hull Structures in Ship to Ship Collision", Proceedings of International Conference on Ocean, Offshore and Arctic Engineering (OMAE-2015).

- Yamada, Y., Ichikawa, K. Kamita, K., Tozawa, Suga, H., Arima, T. (2016). "Effects of Highly Ductile Steel on the Crashworthiness of Hull Structure in Oblique Collision", Proceedings of International Conference of Collision and Grounding of Ships (ICCGS-2016).

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