Hasan Özgür Uzögüten

5th EMShip cycle: September 2014 – February 2016

Master Thesis

Application of super-element theory to crashworthiness evaluation within the scope of the A.D.N. Regulations

Supervisor: **Prof. Maciej Taczała, West Pomeranian University of Technology**, Szczecin, Poland
Eng. Nzengu Wa Nzengu, **Bureau Veritas Inland Navigation Management**, Antwerp, Belgium

Reviewer: **Prof. Hervé Le Sourne, L'Institut Catholique d'Arts et Métiers**, Nantes, France

Szczecin, January 2016

Contents:

Company: Bureau Veritas Inland Navigation Management (DNI)
Antwerp, Belgium

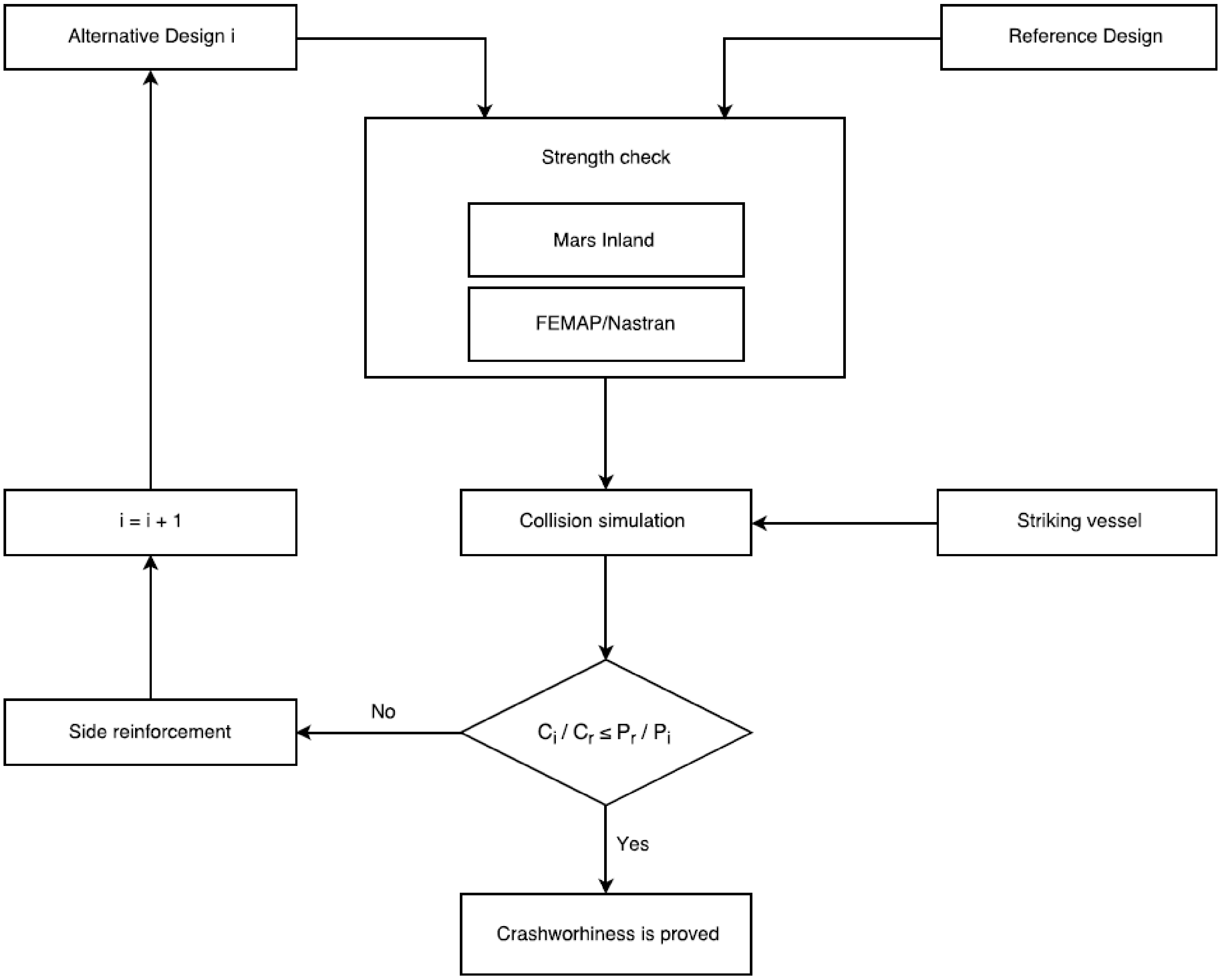
- Department of Rules, Development & Training
- Duration of 4 months
- Under the supervision of Eng. Nzengu Wa Nzengu
- Including 1-week training in Bureau Veritas Marine & Offshore Division, Nantes, France

- Crashworthiness evaluation of a Type C inland tanker will be carried out through the instrumentality of the SHARP Tool.

- The difference between the application of the super-element and the finite-element method will be presented in the light of Section 9.3.4. Alternative Constructions of A.D.N Regulations.

- The risk of cargo tank rupture of the alternative construction in the aftermath of the collision will be assessed in order to provide better crashworthy design by comparing the risk of cargo tank rupture with conventional (reference) construction.

- Checking structural scantling complying with the BV Rules of Inland Navigation NR 217 for the investigated vessel.
  - -Rule scantling check using Mars Inland software
  - -Direct calculations using FEMAP-Nastran software
- Determining necessary adaptations to utilize super-element method within Sec. 9.3.4 Alternative constructions of A.D.N. Regulations.
- Modelling the struck ship
- Choosing similar striking vessels from the database of BV and modelling in SHARP
- Creating the scenarios and running the simulations in SHARP as prescribed in the A.D.N. Regulations
- Conducting a comparative study between the different constructions


Alternative Design i
Reference Design
Strength check
Mars Inland
FEMAP/Nastran
i = i + 1
Collision simulation
Striking vessel
No
Side reinforcement
$C_i / C_r \leq P_r / P_i$
Yes
Crashworhiness is proved

According to Pedersen (1995) mechanics of ship collision are investigated under the two main parts:

- Internal Mechanics
  1. Experimental methods
  2. Empirical methods
  3. Simplified analytical methods
  4. Numerical methods

- External Dynamics

Methods	Analysis Efforts		Available results			
	Modeling efforts	Computation efforts	Stress	Loads	Penetration	Energy
Experimental Methods	Some	Difficulty of data acquisition	✓	✓	✓	✓
Empirical Methods	Fewest	Hand calculation				✓
Simplified Analytical Methods	Few	Hand calculation, simple tools		✓	✓	✓
Non-linear FEM	Extensive	Complex, sophisticated software	✓	✓	✓	✓

(The 16th International Ship And Offshore Structures Congress, 2006)

- The basic idea is to decompose the ship structure into macro-elements, so-called super-elements, to evaluate the individual strength of each super-element to collision.

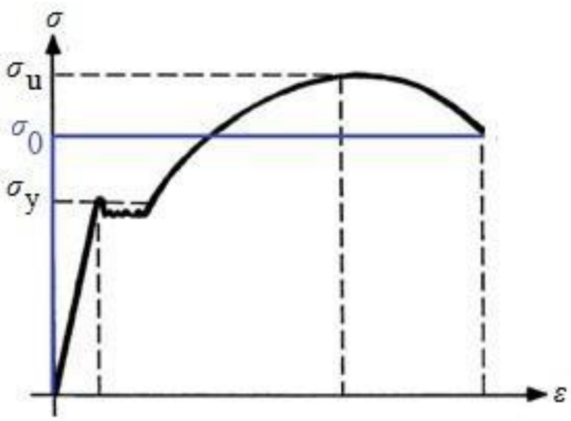
$$\dot{E}_{ext} = F \cdot \dot{\delta}$$

$$\dot{E}_{int} = \iiint_V \sigma_{ij} \cdot \dot{\epsilon}_{ij} \cdot dV$$

$$F \cdot \dot{\delta} = \iiint_V \sigma_{ij} \cdot \dot{\epsilon}_{ij} \cdot dV$$

Assumptions

- Material is considered perfect rigid plastic.

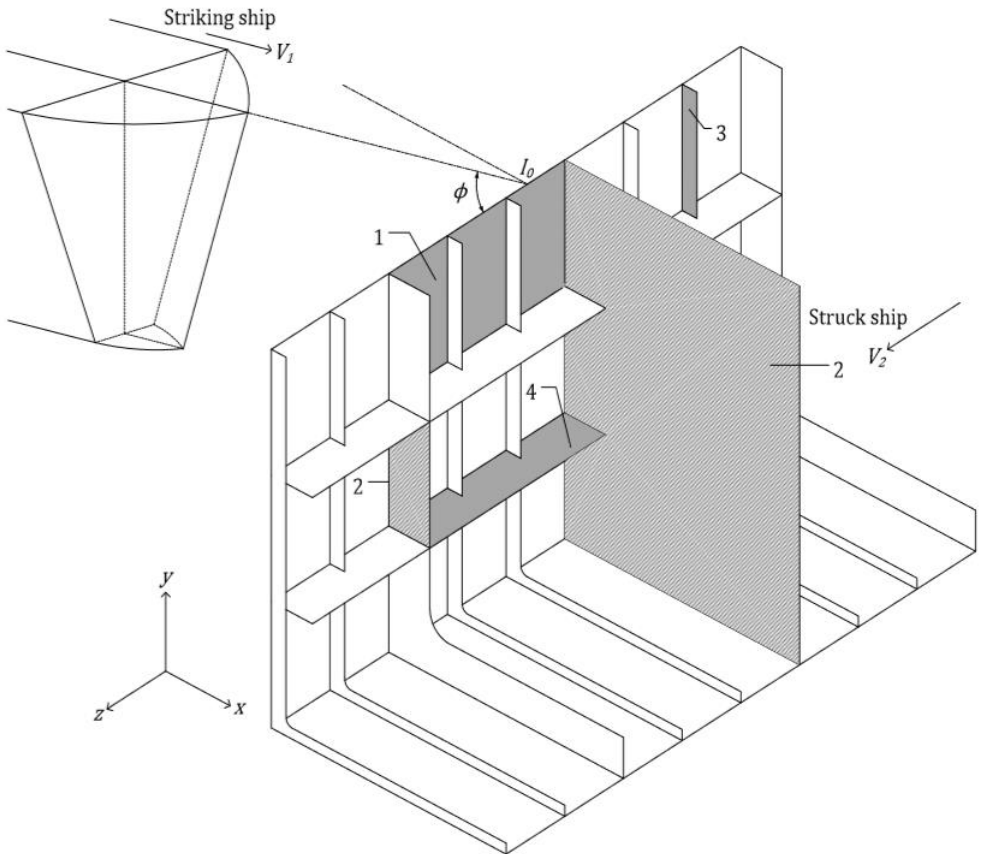


$$\sigma_0 = \frac{\sigma_u + \sigma_y}{2}$$

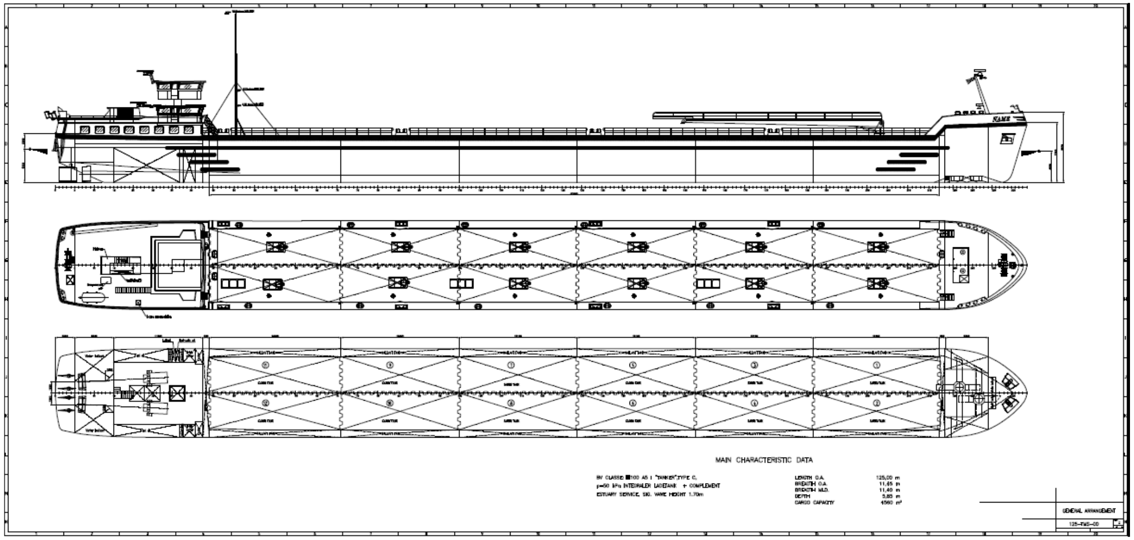
- Shear effects is neglected on the surface thus the internal energy is calculated by only bending and membrane effects uncoupled.

Types of super-elements

- Hull super-element (1)
- Vertical bulkhead super-element (2)
- Beam super-element (3)
- Horizontal deck super-element (4)



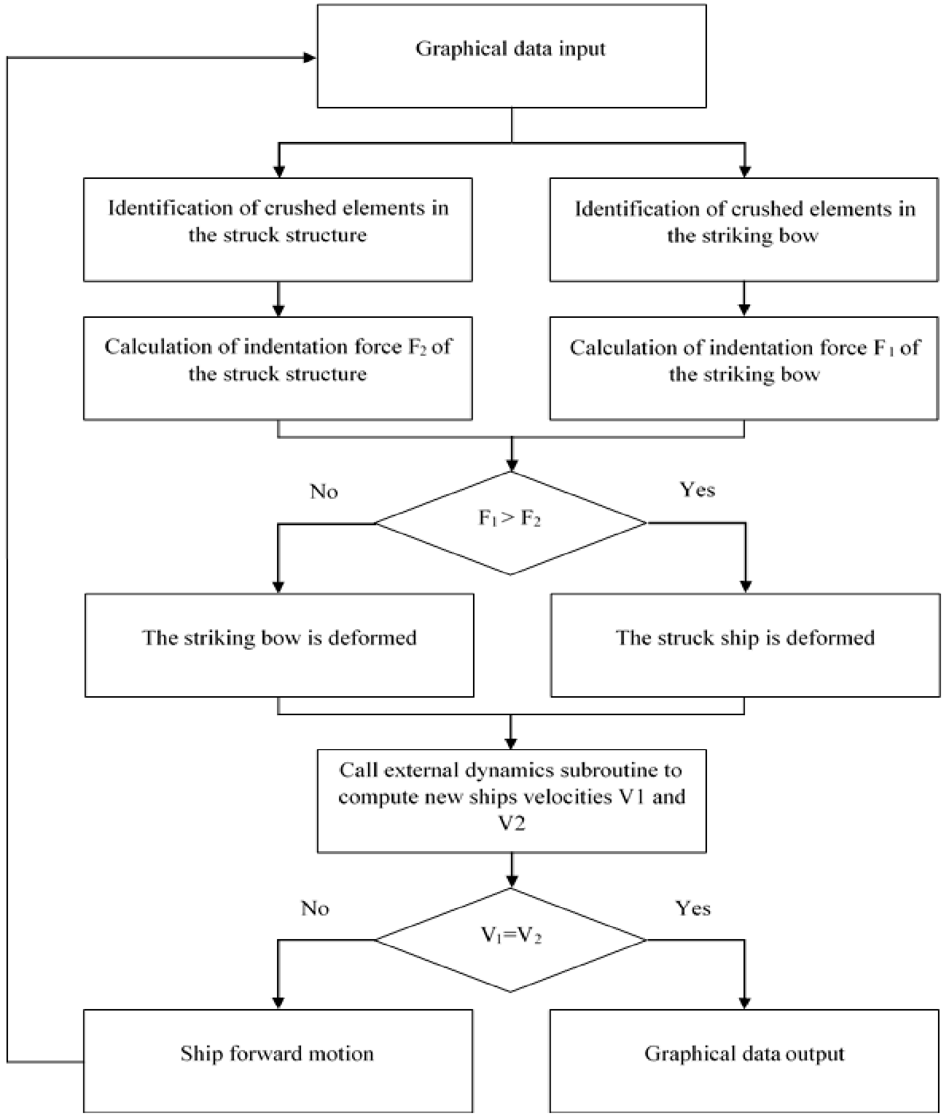
Investigated Vessel: Inland Tanker Type C



- Length overall : 125.00 m
- Length between perpendiculars : 124.84 m
- Rule length : 122.40 m
- Breath : 11.42 m
- Displacement : 5774 tons
- Depth : 6.00 [m]
- Draught : 4.50 [m]
- Block coefficient : 0.90
- Service speed : 11.40 [kn] (= 20 km~h)

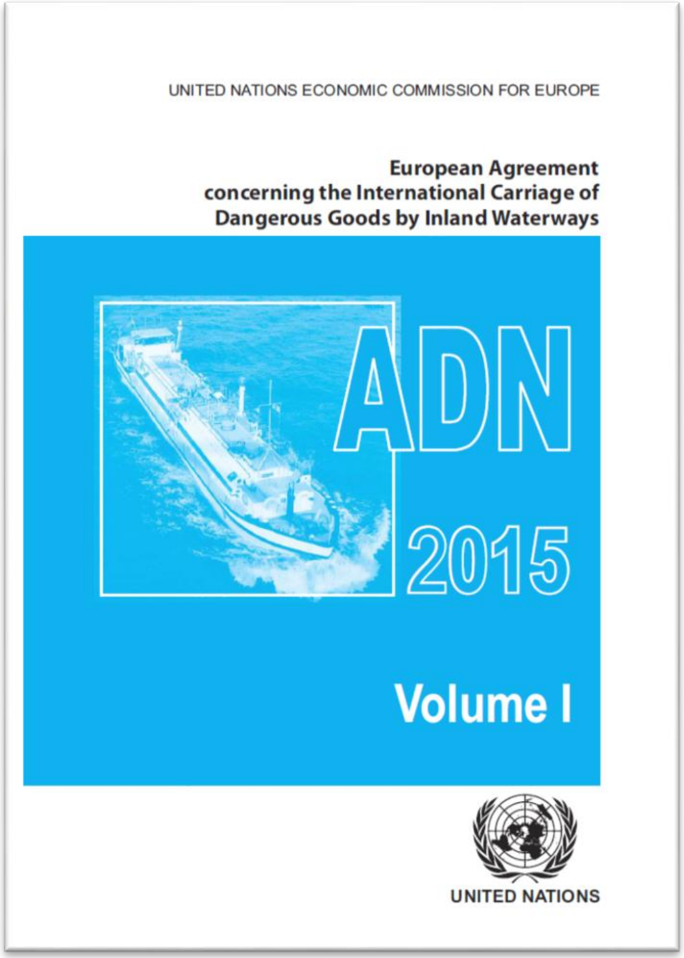
SHARP: Ship Hazardous Aggression Research Program

- A standalone software for evaluation of ship collisions
- Based on the super-element method for calculations of internal mechanics
- MCOL subroutine for the external dynamics
- Both rigid and deformable striking ships are able to be implemented.



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

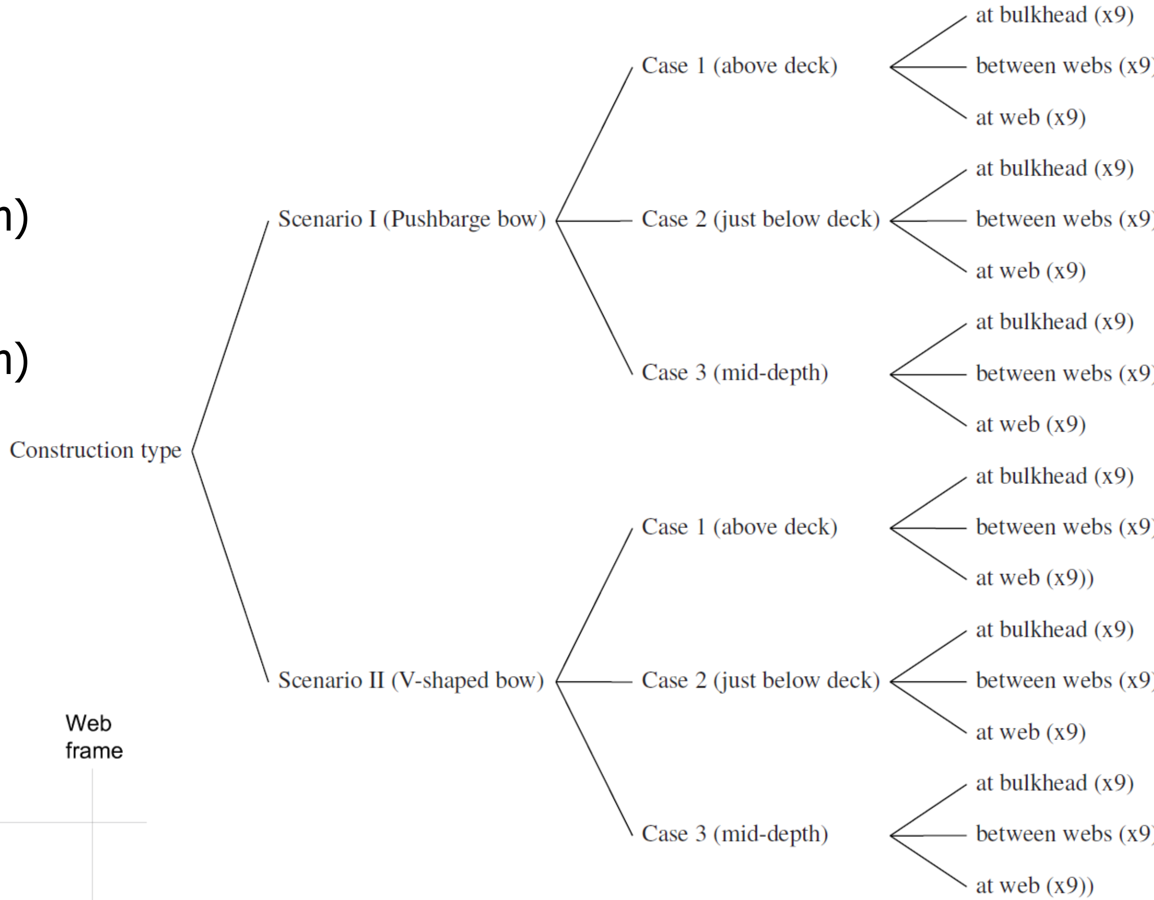
- *Section 9.3.4. Alternative Constructions* describes the procedure to prove crash-worthiness of an alternative construction
- 13 basic steps
- 2 scenarios involving 2 striking ships
- Each scenario has 3 vertical x 3 horizontal location, total 9 location is given.

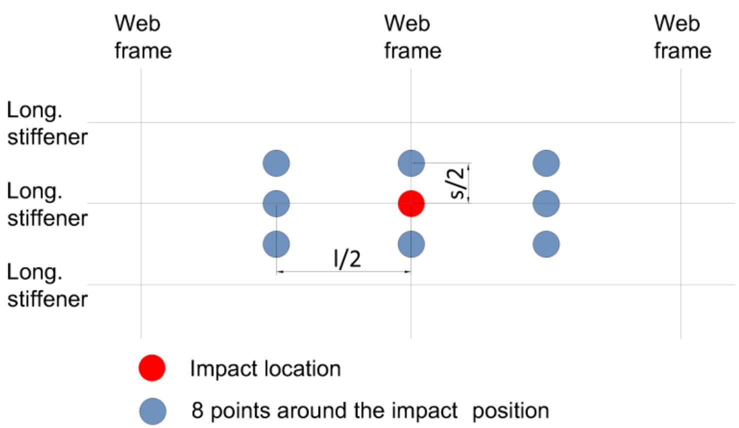


3 struck ship designs:

- Reference construction

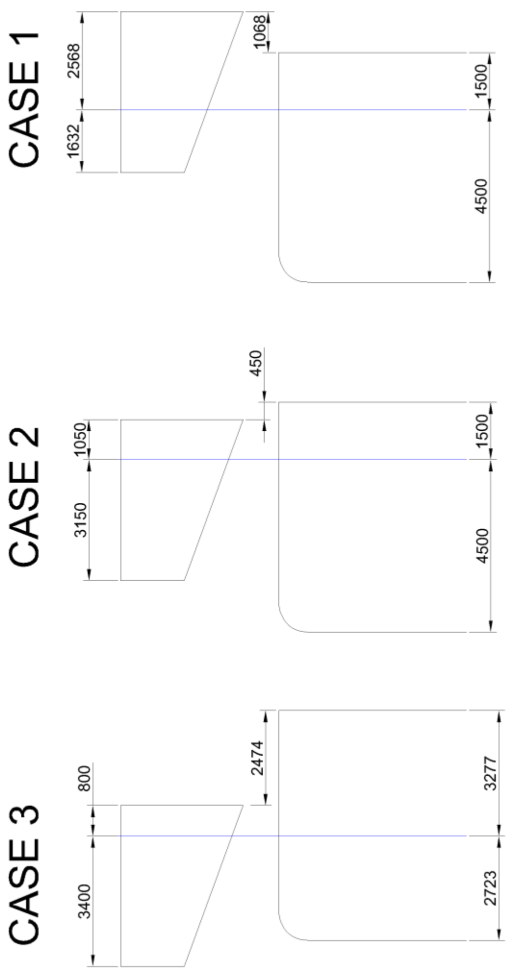
- Alternative construction 1
- reduced double hull spacing (0.8 m) without any reinforcements
- Alternative construction 2
- reduced double hull spacing (0.8 m) with reinforcements



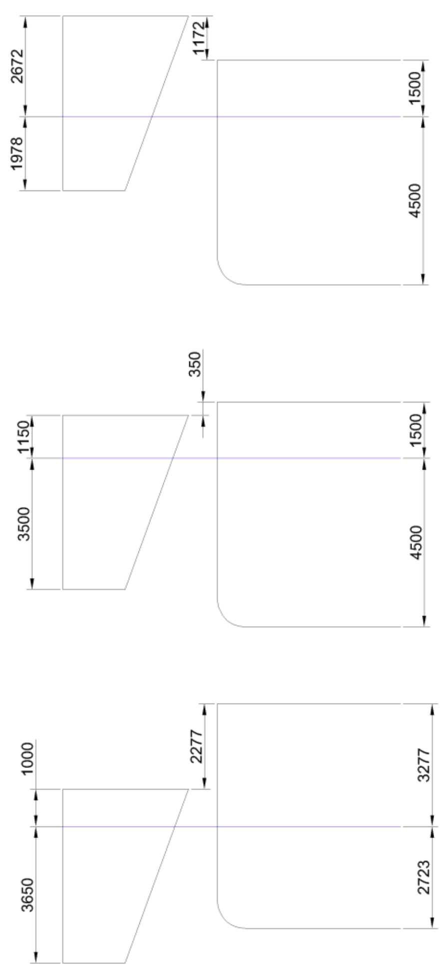


162 for each, total number of 486 simulations

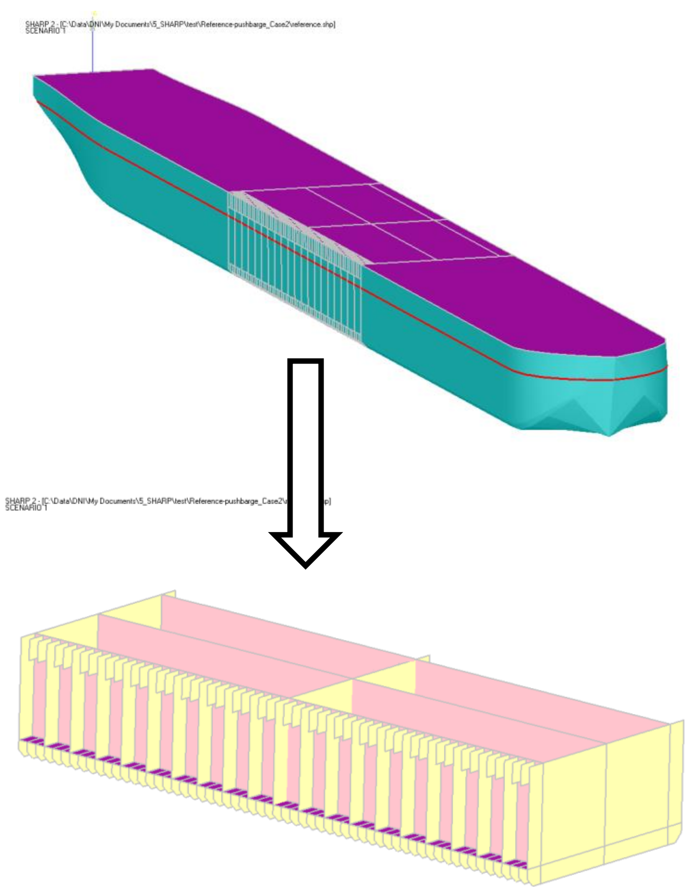
Scenario I (Push barge bow)



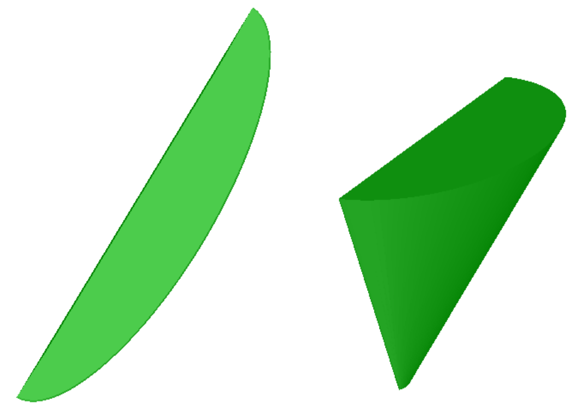
Scenario II (V-shaped bow)



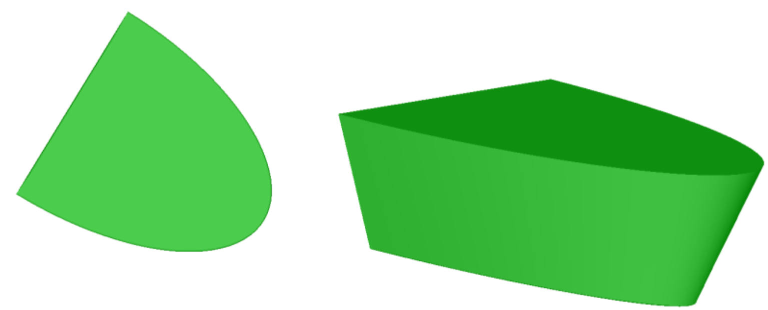
Struck ship



Striking ships



Push barge bow



V-shaped bow

Limitations

- Brackets cannot be modelled
- Lightening, sloshing holes or manholes cannot be modelled
- Corrugated plates cannot be modelled
- If there is more then one type of stiffeners on a single plate, only one of the stiffener property can be chosen
- It is not possible to define the rupture strain of the beam elements individually.

External tools

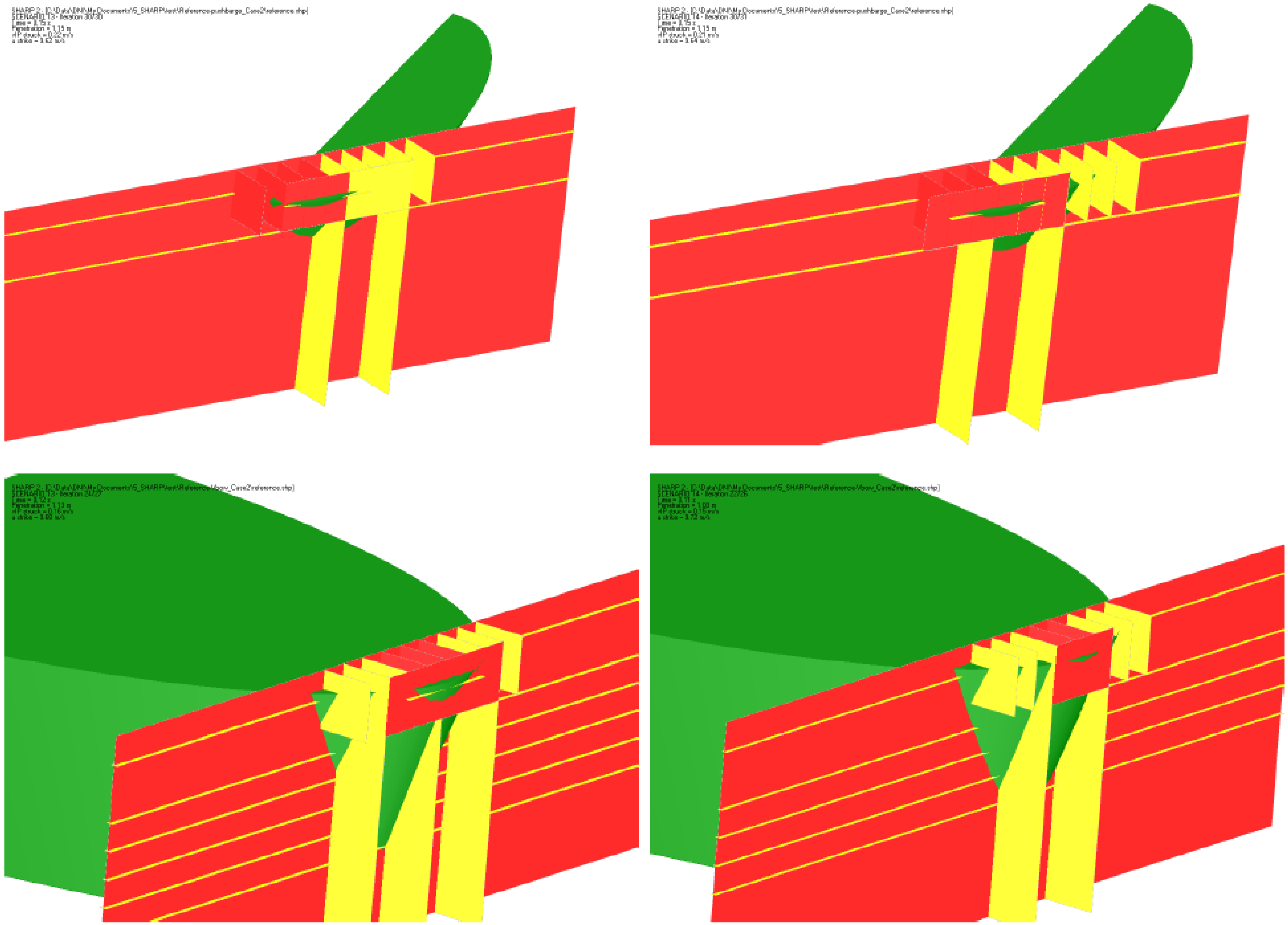
- MARS Inland and SIEMENS FEMAP with NASTRAN, to check the strength of the structure in compliance with the *BV Rules for Classification of Inland Navigation Vessels NR 217.*

- HydroSTAR, to obtain the matrices of hydrodynamics coefficients such as added mass, damping, restoring stiffness.

- ARGOS, to obtain hydrostatic data of the struck and striking ships.

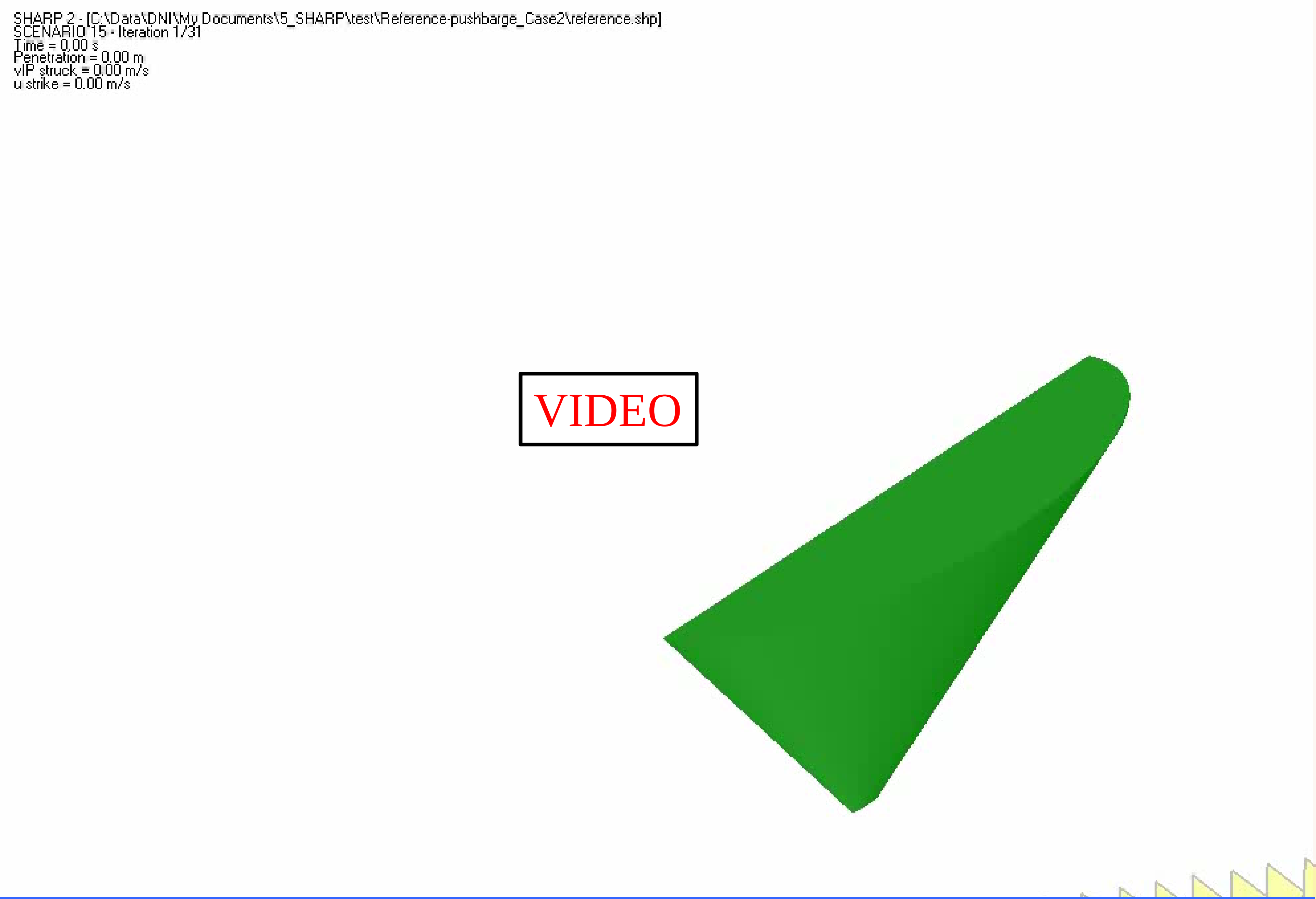
Scenario I

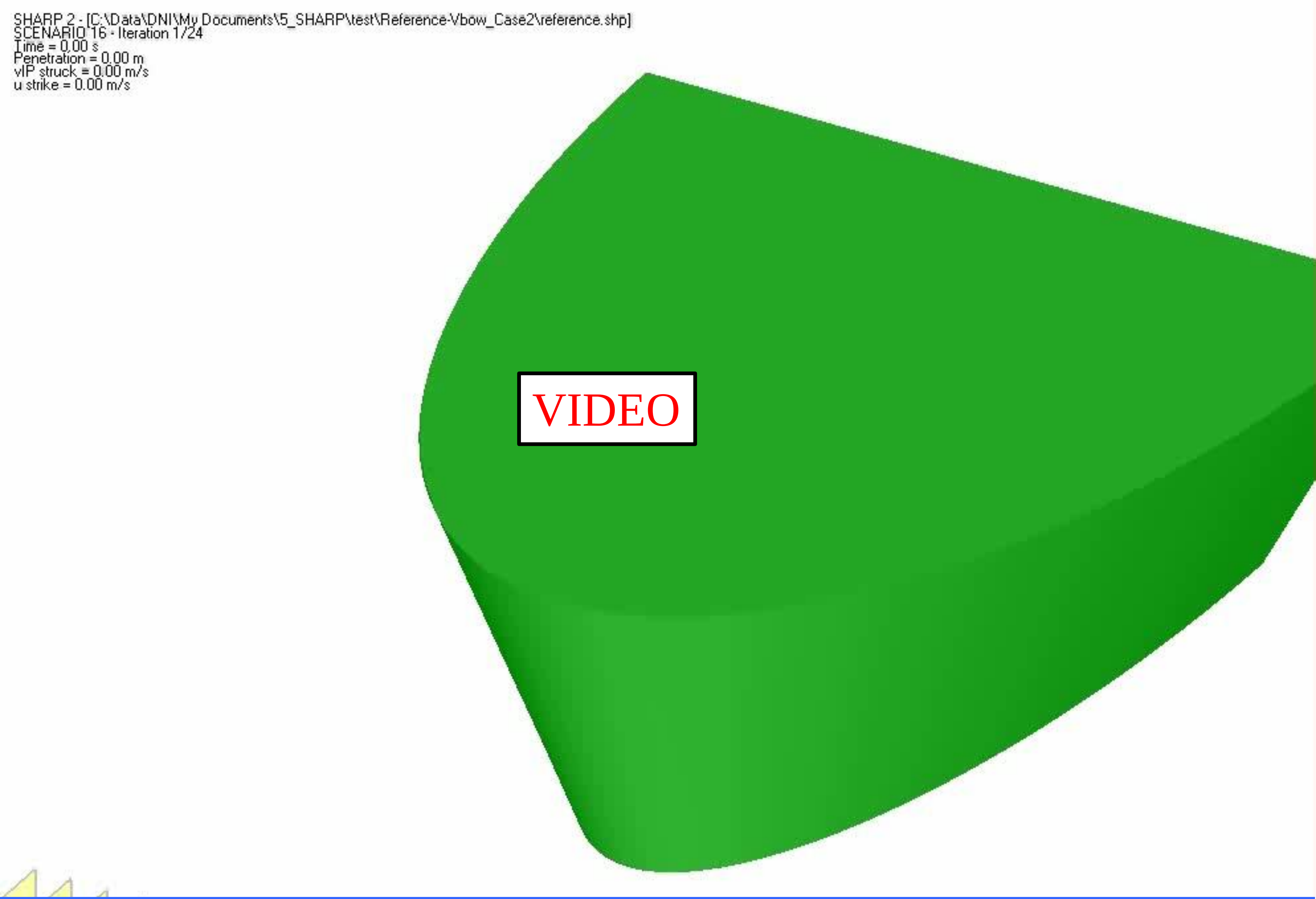
Scenario II

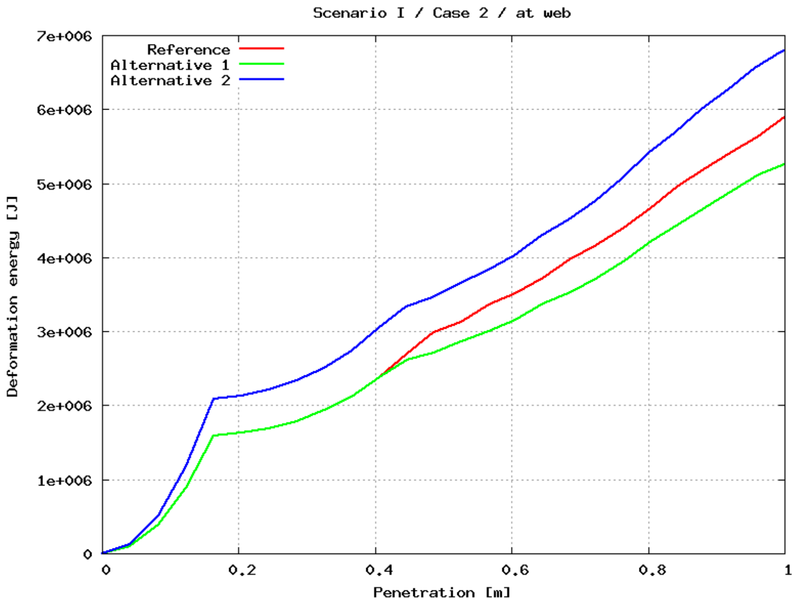


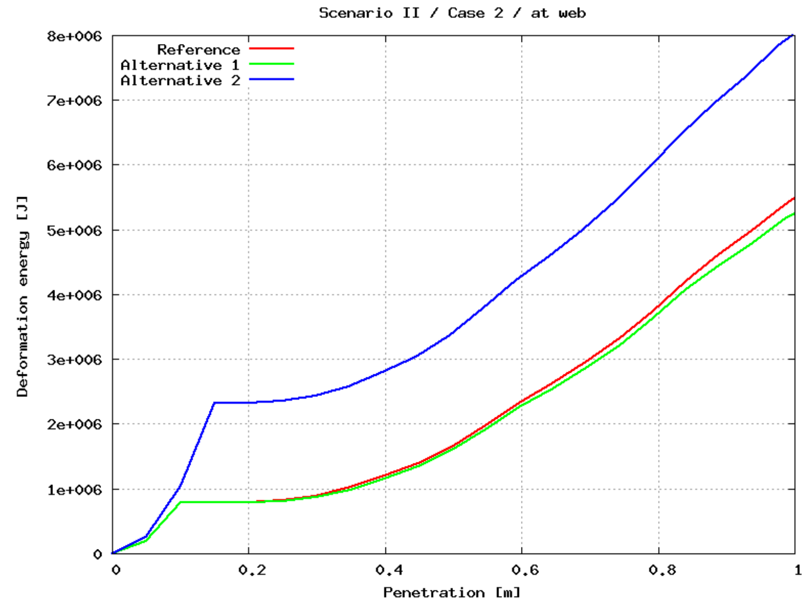
(a) Collision at web

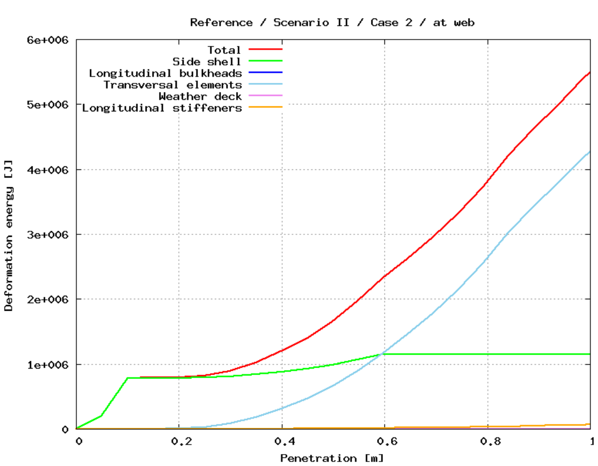
(b) Collision between webs

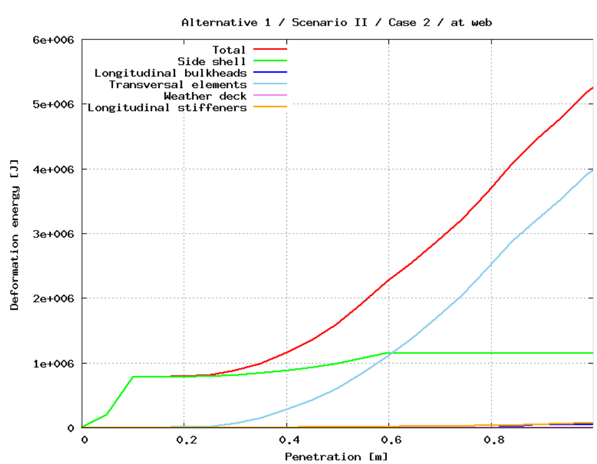

SHARP 2 - [C:\Data\DNI\My Documents\5_SHARP\test\Reference-pushbarge_Case2\reference.shp]
SCENARIO 15 - Iteration 1/31
Time = 0.00 s
Penetration = 0.00 m
vIP struck = 0.00 m/s
u strike = 0.00 m/s
VIDEO

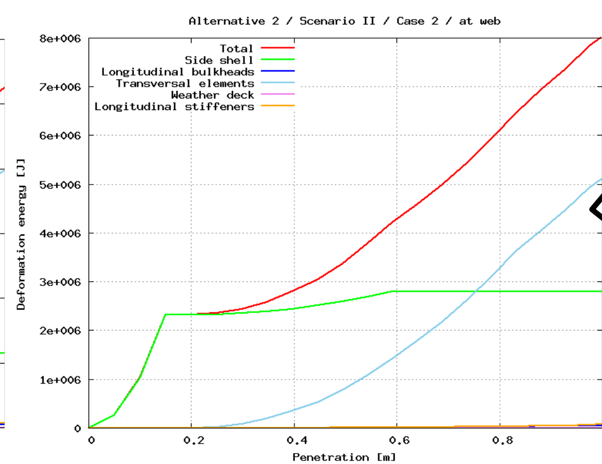

SHARP 2 - [C:\Data\DNI\My Documents\5_SHARP\test\Reference-Vbow_Case2\reference.shp]
SCENARIO 16 - Iteration 1/24
Time = 0.00 s
Penetration = 0.00 m
vIP struck = 0.00 m/s
u strike = 0.00 m/s
VIDEO


Scenario I / Case 2 / at web
Reference
Alternative 1
Alternative 2
Deformation energy [J]
Penetration [m]
0
1e+006
2e+006
3e+006
4e+006
5e+006
6e+006
7e+006
0
0.2
0.4
0.6
0.8
1


Scenario II / Case 2 / at web
Reference
Alternative 1
Alternative 2
Deformation energy [J]
Penetration [m]
0
1e+006
2e+006
3e+006
4e+006
5e+006
6e+006
7e+006
8e+006
0
0.2
0.4
0.6
0.8
1


Reference / Scenario II / Case 2 / at web
Total
Side shell
Longitudinal bulkheads
Transversal elements
Weather deck
Longitudinal stiffeners
Deformation energy [J]
Penetration [m]


Alternative 1 / Scenario II / Case 2 / at web
Total
Side shell
Longitudinal bulkheads
Transversal elements
Weather deck
Longitudinal stiffeners
Deformation energy [J]
Penetration [m]


Alternative 2 / Scenario II / Case 2 / at web
Total
Side shell
Longitudinal bulkheads
Transversal elements
Weather deck
Longitudinal stiffeners
Deformation energy [J]
Penetration [m]

Reinforcements	Conventional [mm]	Reinforced [mm]	Increase %
deck stringer plate thickness	11.0	15.0	36%
side plating thickness	11.0	15.0	36%
web frame thickness	8.0	10.0	25%
brackets at ordinary frame	8.0	10.0	25%
sheerstrake thickness	25.0	32.5	30%

Reference design	
P_r	0.8813
V_{tank}	377.740 m^3

$$\frac{C_n}{C_r} \leq \frac{P_r}{P_n}$$

Alternative design-1	
P_{n1}	0.9025
V_{tank}	393.203 m^3

Check		
1.0409	$\leq$	**0.9766**
	(FALSE)	

Result:
Reinforcements are required.

Alternative design-2	
P_{n2}	0.8429
V_{tank}	393.203 m^3

Check		
1.0409	$\leq$	**1.0457**
	(TRUE)	

Result:
Alternative design is provided.

P : probability of cargo tank rupture
C : consequence (measure of damage) of cargo tank rupture [m^2]

Conclusions

- The super-element method is applicable to the A.D.N. procedure considering the necessity of the adaptations such as the definition of the rupture criteria and some structural simplifications.

- The alternative construction-2 with reinforcements is proved to possess a lower risk than the reference design by using super-elements within the A.D.N. Procedure.

- SHARP enables the designer to test many structural arrangement solutions and to select the most efficient crashworthy design without excessive investment

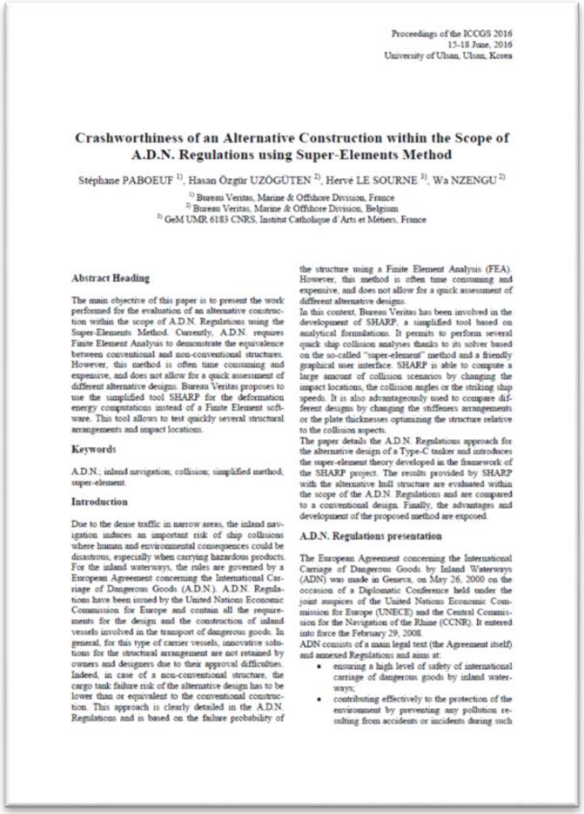
- Indeed, the super-element method preserves a potential, and within the further development of the SHARP Tool, it might be an effective substitution for the finite-element method in terms of rapidity and simplicity in the evaluation of the crash-worthiness within the procedure of the A.D.N. Section 9.3.4 Alternative Constructions.

Recommendations and Future Work

- Same assessment to be performed using FEM in order to validate applicability of super-element theory in the A.D.N procedure
- Implementation of inland vessel lines/bow shapes in SHARP library
- Development of new super-elements to allow better/more realistic modelling of inland vessel hull structure (e.g. corrugated bulkheads)

A paper based on this study is accepted to be presented in the ICCGS 2016, Ulsan, Korea

Headline in Bureau Veritas October 2015 Newsletter



Proceedings of the ICCGS 2016
15-18 June, 2016
University of Ulsan, Ulsan, Korea

Crashworthiness of an Alternative Construction within the Scope of A.D.N. Regulations using Super-Elements Method

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Abstract Heading

The main objective of this paper is to present the work performed for the evaluation of an alternative construction within the scope of A.D.N. Regulations using the Super-Elements Method. Currently, A.D.N. requires Finite Element Analysis to demonstrate the equivalence between conventional and non-conventional structures. However, this method is often time consuming and expensive, and does not allow for a quick assessment of different alternative designs. Bureau Veritas proposes to use the simplified tool SHARP for the deformation energy computations instead of a Finite Element software. This tool allows to test quickly several structural arrangements and impact locations.

Keywords

A.D.N.; inland navigation; collision; simplified method; super-element.

Introduction

Due to the dense traffic in narrow areas, the inland navigation induces an important risk of ship collisions where human and environmental consequences could be disastrous, especially when carrying hazardous products. For the inland waterways, the rules are governed by a European Agreement concerning the International Carriage of Dangerous Goods (A.D.N.). A.D.N. Regulations have been issued by the United Nations Economic Commission for Europe and contain all the requirements for the design and the construction of inland vessels involved in the transport of dangerous goods. In general, for this type of carrier vessels, innovative solutions for the structural arrangement are not retained by owners and designers due to their approval difficulties. Indeed, in case of a non-conventional structure, the cargo tank failure risk of the alternative design has to be lower than or equivalent to the conventional construction. This approach is clearly detailed in the A.D.N. Regulations and is based on the failure probability of the structure using a Finite Element Analysis (FEA). However, this method is often time consuming and expensive, and does not allow for a quick assessment of different alternative designs.

In this context, Bureau Veritas has been involved in the development of SHARP, a simplified tool based on analytical formulations. It permits to perform several quick ship collision analyses thanks to its solver based on the so-called "super-element" method and a friendly graphical user interface. SHARP is able to compute a large amount of collision scenarios by changing the impact locations, the collision angles or the striking ship speeds. It is also advantageously used to compare different designs by changing the stiffeners arrangements or the plate thicknesses optimizing the structure relative to the collision aspects.

The paper details the A.D.N. Regulations approach for the alternative design of a Type-C tanker and introduces the super-element theory developed in the framework of the SHARP project. The results provided by SHARP with the alternative hull structure are evaluated within the scope of the A.D.N. Regulations and are compared to a conventional design. Finally, the advantages and development of the proposed method are exposed.

A.D.N. Regulations presentation

The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) was made in Geneva, on May 26, 2000 on the occasion of a Diplomatic Conference held under the joint auspices of the United Nations Economic Commission for Europe (UNECE) and the Central Commission for the Navigation of the Rhine (CCNR). It entered into force the February 29, 2008.

ADN consists of a main legal text (the Agreement itself) and annexed Regulations and aims at:

- ensuring a high level of safety of international carriage of dangerous goods by inland waterways;
- contributing effectively to the protection of the environment by preventing any pollution resulting from accidents or incidents during such

BUREAU VERITAS
Move Forward with Confidence

Inland Navigation News Letter

Editorial

Dear readers,

As we enter the last quarter of this year, the Inland Navigation teams are gearing up to achieve important technical development goals. Current economic and regulatory constraints motivate our teams to focus on practical solutions and innovative services for our customers. We are involved daily in new design, new materials, new fuels, new types of cargo, extended range of operation and other queries all aimed at getting better performance. Our specialised engineers and experienced surveyors are committed to serving our clients efficiently – shipowners, shipyards, designers – and assisting administrations – flag authorities, national and regional offices, safety committees, institutions – helping them all reach the right decisions on unusual requests. Our established business in Europe, South America and Africa, where BV activities are expanding, is now in demand for new projects in South Asia. Contact us at DNI or e mail our Singapore office for information and advice:
office.singapore@bureauveritas.com

Truly Yours,
Eric Lallemand / Jean Michel Chatelier
Director / Deputy Director

Tanker alternative design

The design and equipment of tankers intended for the carriage of dangerous goods by inland waterways in Europe has to comply with the applicable provisions of the A.D.N. regulations. These provisions aim to anticipate the risks of transporting and handling of hazardous substances and to minimize the consequences of accidents if they occur, notably:

- Cargo tanks are required to be protected from penetration in the event of minor damage to the vessel, and also have a degree of protection from damage in the event of collision,
- Limitations are imposed on cargo tank size, intended to restrict the amount of cargo which may escape in the event of accidental breaching.

Tank vessels which are not in compliance with either of the two above-mentioned requirements for double-side distance and cargo tank volume must be protected through a more crashworthy side structure. This alternative design approach has to be proven by comparing the risk level of a conventional construction, complying with the A.D.N. regulations, with the risk level of a crashworthy alternative construction. The risk level of an alternative construction depends strongly on the collision energy absorption capacity without cargo tank rupture.

The determination of the collision absorption energy capacity is traditionally carried out by means of a finite element analysis (e.g. LS-DYNA, ABAQUS, etc.), which is quite time-consuming, especially when a large number of required collision scenarios are simulated. Furthermore, before an optimal alternative design is reached, different alternative designs need to be examined, leading to a huge amount of time for modelling and computation by use of a finite element software program.

To reduce this time there is now a simplified tool based on analytical formulations aimed at prediction of the collision energy absorption capacity of the design. This approach decomposes the ship structure into macro-elements, widely known as super-element, then evaluates the individual strength of each super-element to collision. This simplified method delivers a quick and efficient procedure for rapid ship collision analysis.

From an economic point of view, this new tool will help ship owners have a better insight into how to maximize the tank capacity of their vessels by decreasing the distance between the cargo tank wall and the outer shell while respecting fully the criteria related to crashworthiness. This is good news not only for new constructions but also for conversions from a single hull vessel to a double hull one in which the best compromise between the cargo tank volume and the structure arrangement is reached as a result of rapid iterations of alternative designs.

The Rules, Development and Training team of DNI is committed to sharing the know-how of this efficient tool with ship owners and designers. Please feel free to contact us at:
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www.veristar.com

Summary

- Editorial
- Tanker alternative design
- ADN News
- New class notation «Gas-Prepared»
- Composite materials in inland vessels' structures
- 12th Benelux Committee meeting of Bureau Veritas in Luxembourg
- Brazilian and Chinese government officers visited BV inland vessel PÃO DE AÇÚCAR
- Newcomers

NEWS

ADN News

The ADN Safety Committee held its twenty-seventh session in Geneva during the last week of August. Bureau Veritas presented several requests for interpretation and proposals for amendments with a view to improve the comprehension of the rules and the safety of vessels. ADN rules do not currently permit the use of membrane tanks, but for the first time this technology has been accepted within the scope of a derogation by the Safety Committee.

The Informal Working Group "Explosion Protection" explained a proposed amendment for introducing new Explosion Safety measures. Basic safety measures have to be met by all vessels, dry cargo vessels as well as tank vessels having an ADN certificate of approval, if a vessel stays in an assigned zone, for example terminals and locks, in pushed convoys or in side-by-side formations.

Extended and modified safety measures, in addition to the basic safety measures, for tank vessels, pushed convoys and side-by-side formations of type G, C, N have been foreseen.

The use of construction materials like wood, aluminium alloys, plastic materials and rubber (as regulated in the 9.3.x.0.2) was discussed and a proposal to extend the existing requirements to the reality of today was issued in the document 2015/19 (see www.unece.org). Further analysis and discussions will be necessary during the session of January 2016

New class notation «Gas-Prepared»

As inland navigation restrictions on air emissions get tougher, one of the most attractive long term investments for an inland navigation fleet owner is to use natural gas as fuel. However not all owners want to operate the vessels using gas fuel initially. The challenge is to build vessels which can easily be converted to gas fuel at a later date.

Bureau Veritas has stepped up to provide the new notation "Gas-Prepared" that applies to vessels which during the new building phase are designed with specific arrangements to accommodate future LNG fuel installation, in accordance with the requirements of BV Rule note NR627. This enables shipowners to be certain that future gas fuel conversion of their vessels will fulfil the relevant requirements and also helps to optimize the investment level they are willing to make.

The "Gas-Prepared" notation may also be extended to cover specific arrangements for the vessel: structure - "S"; piping - "P"; or dual fuel engine - "ME-DF", for engines designed to be converted to Dual Fuel in the future-"AEB".

- Gas-Prepared
- Gas-Prepared (P)
- Gas-Prepared (P,ME-DF)

The documents to be submitted for examination are clearly indicated in Rule note NR627, and owners and the shipyards should also consider that a HAZID analysis must be conducted in advance to ensure that risks arising from the use of gas fuel are properly considered and analysed. When the vessel is eventually converted to Dual Fuel operation, the additional class notation "Gas-Prepared" will be replaced by the additional service feature "Dualfuel" or "Gasfuel", provided that all the applicable requirements are met

THANK YOU.