Improve

Proceedings of IMPROVE Final Workshop

Design of Improved and Competitive Ships using an Integrated Decision Support System for Ship Production and Operation

17th - 19th of September 2009
Dubrovnik, Croatia

PowerPoint Presentations, Vol. II

Edited by
Vedran Žanić and Jerolim Andrić

University of Zagreb
Faculty of Mech. Eng. and Naval Architecture

Zagreb 2009

Proceedings of IMPROVE Final Workshop

Design of Improved and Competitive Ships using an Integrated Decision Support System for Ship Production and Operation

PowerPoint Presentations, Vol. II

Edited by

Vedran Žanić
vedran.zanic@fsb.hr
Faculty of Mechanical Engineering and Naval Architecture
University of Zagreb, Croatia

Jerolim Andrić
jerolim.andric@fsb.hr
Faculty of Mechanical Engineering and Naval Architecture
University of Zagreb, Croatia

Project co-ordinator:

Philippe Rigo
ph.rigo@ulg.ac.be
ANAST
University of Liege, Belgium

September 17-19, Dubrovnik, Croatia

IMPROVE Consortium Members

ANAST, University of Liege	Belgium
STX Europa	France
Uljanik shipyard (ULJANIK, USCS)	Croatia
Szczecin New Shipyard (SSN)	Poland
Grimaldi	Italy
Exmar	Belgium
Tankerska Plovidba Zadar (TPZ)	Croatia
Bureau Veritas (BV)	France
Design Naval & Transport (DN&T)	Belgium
Ship Design Group (SDG)	Romania
MEC	Estonia
Helsinki University of Technology (TKK)	Finland
University of Zagreb (UZ)	Croatia
NAME, Universities of Glasgow & Strathclyde	UK
Centre of Maritime Technologies (CMT)	Germany
BALance Technology Consulting GmbH (BAL)	Germany
WEGEMT	UK

The project is supported by the European Commission under the Growth Programme of the 6th Framework Programme. Contract No. FP6 – 031382

More information about the IMPROVE project can be found at the project website

http://www.improve-project.eu

Workshop is organised by:
Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia
Centre for Advanced Academic Studies (CAAS), Dubrovnik, Croatia
under requirements of:
Task 9.3 of IMPROVE Work Package 9.
Proceedings are in fullfilement of Deliverable D9.4:
'Synthetic report about conclusions of the workshop' with project and work package summaries and their conclusions presented and discussed at the workshop.
Additional CD with the conference papers and presentations is also prepared by UZ.

TABLE OF CONTENTS

APPLICATION CASES

Product Presentation: LNG Carrier (WP6)

Product Presentation: ROPAX Ship (WP7)

Product Presentation: Chemical Tanker (WP8)

IMPROVE PROJECT OVERVIEW

- DUBROVNIK WORKSHOP –

Design of Improved and Competitive Products
using
an Integrated Decision Support System
for
Ship Production and Operation

By Ph. Rigo, Improve Coordinator, ANAST, University of Liege

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

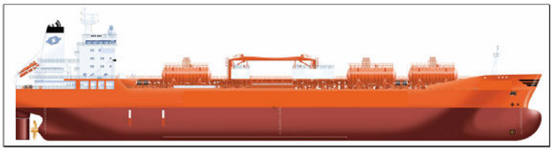
IMPROVE ➔ 17 PARTNERS & 10 Countries

No.	IMPROVE PARTNERS	Short name	Country
1	University of Liege (ULG), ANAST - Coordinator	ANAST	Belgium
2	STX France , St. Nazaire – (Shipyard)	STX	France
3	Uljanik Shipyard (with USCS Software division)	ULJ	Croatia
4	Szczecin New Shipyard (Stocznia Szczecinska Nowa)	SSN	Poland
5	GRIMALDI GROUP (Operator)	GRIM	Italy
6	EXMAR (Operator)	EXM	Belgium
7	Tankerska Plovidba Zadar – (Operator)	TPZ	Croatia
8	Bureau Veritas (Classification Society)	BV	France
9	Design Naval & Transport – Spin-off (Design)	DN&T	Belgium
10	Ship Design Group	SDG	Romania
11	MEC Insenerilahendused OÜ (Engineering)	MEC	Estonia
12	Helsinki University of Technology	TKK	Finland
13	University of Zagreb	UZ	Croatia
14	Universities of Glasgow and Strathclyde	NAME	UK
15	Center of Maritime Technologies	CMT	Germany
16	BALANCE (Engineering & Soft.)	BAL	Germany
17	WEGEMT (Inter Org.)	WEG	UK

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

1- Design of Improved and Competitive Products



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The IMPROVE challenge

The IMPROVE Challenge is the definition of a

- ❑ **multi-criteria,**
- ❑ **multi-stakeholder**

decision making procedure,

usable with the available software tools,

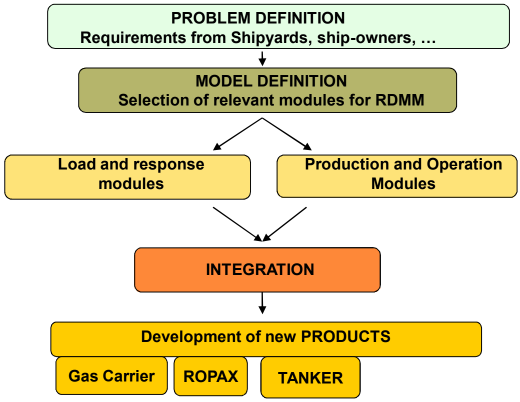
for the three different ships

and based on identified

- ❑ design variables,
- ❑ constraints, criteria,
- ❑ objectives.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Flowchart of the Project



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

2- Integrated Decision Support System

➔RDMM = Rational Decision Making Methods

➔DSP = Decision Support Problem

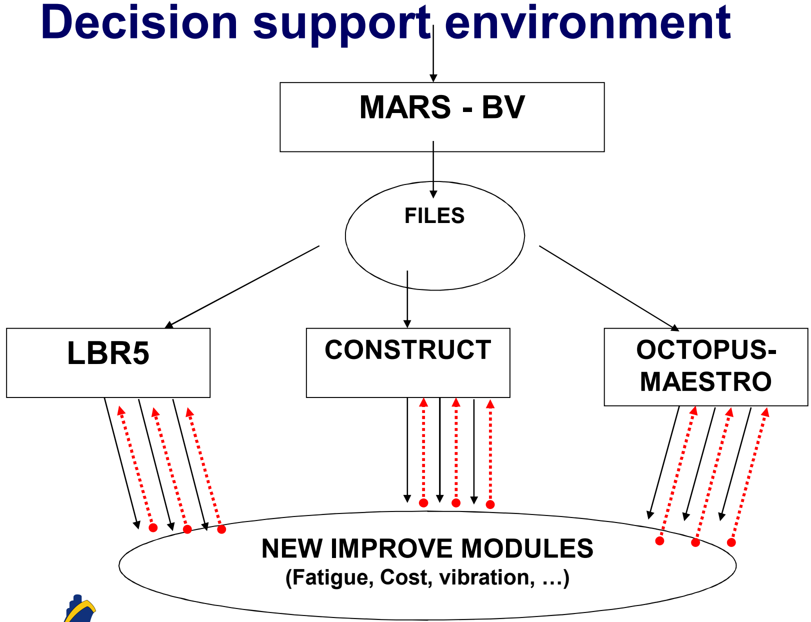
Three basic tasks are planned:

- (A) Procedure for generation of Pareto frontier for ship design and ship structural design,
- (B) Subjective decision making procedure and
- (C) Application of the procedure to three products.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

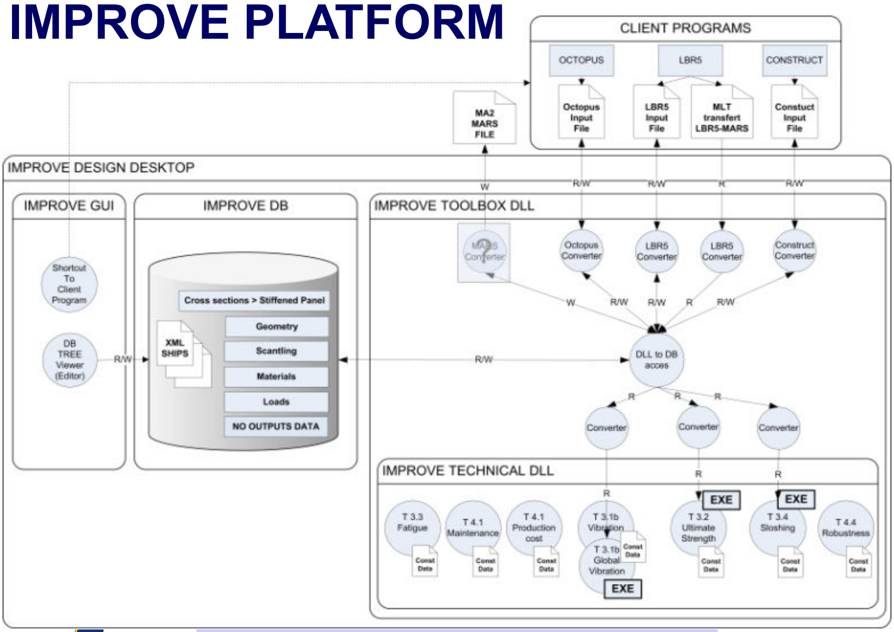
Decision support environment



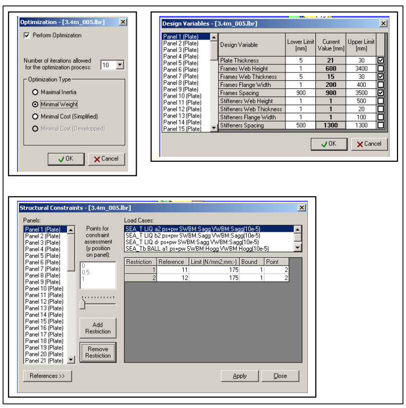
Improve

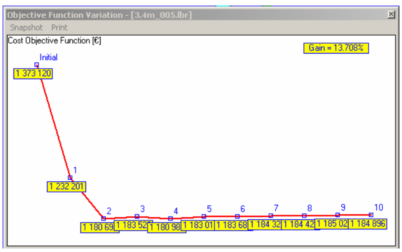
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE PLATFORM

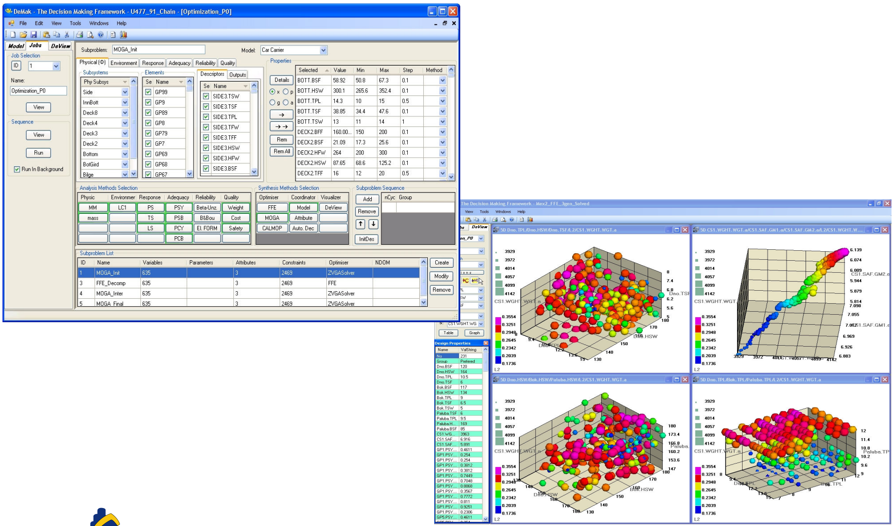


OPTIMISATION TOOLS
LBR5 (ANAST-ULG)





OPTIMISATION TOOLS
OCTOPUS/MAESTRO

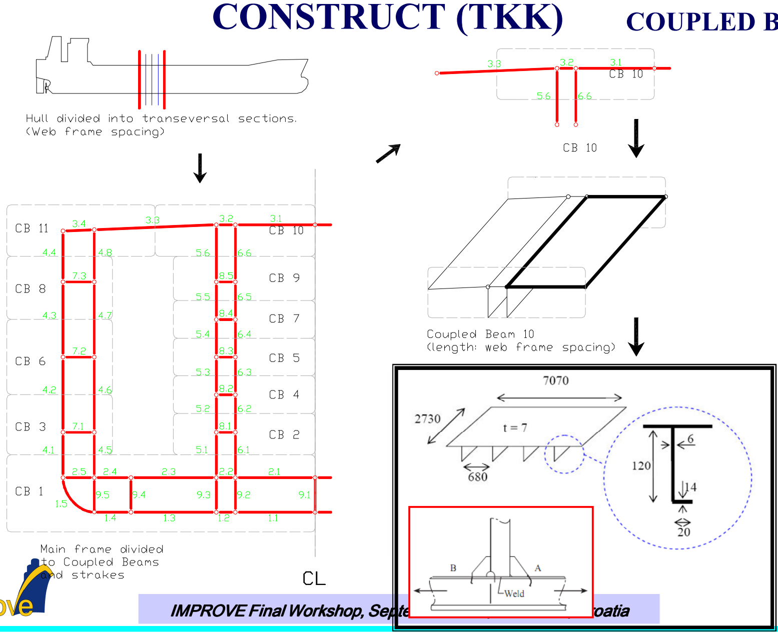


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMISATION TOOLS
CONSTRUCT (TKK)

COUPLED BEAMS

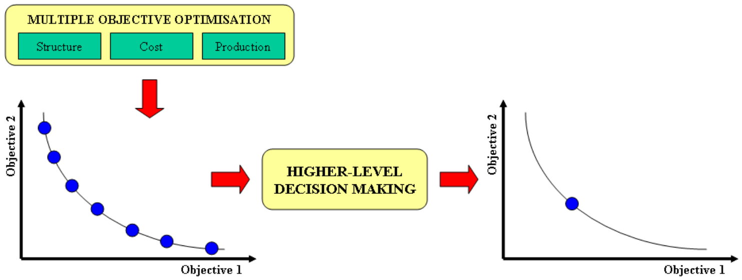


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE Framework for MCDM

Suggested methodology for design in IMPROVE



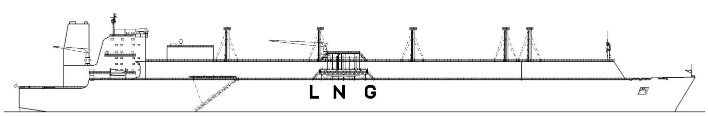
Two phase process:

- Conflicting Pareto designs generation
- Subjective decision making

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

3- Ship Production and Operation



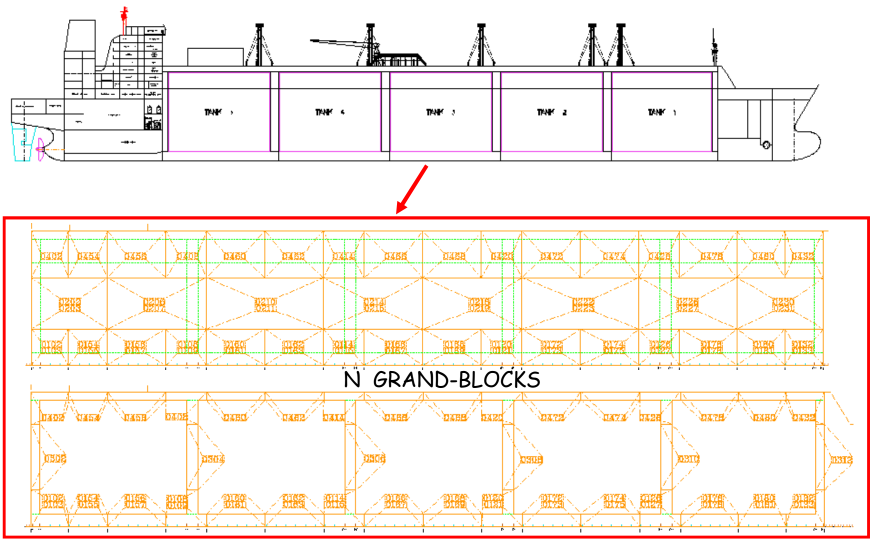
Assembling the grand blocks
➔ Building strategy

For the cargo part…

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

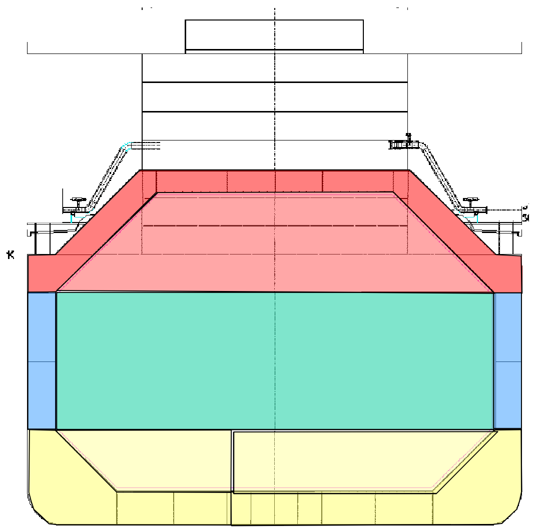
Distribution & numbering of grand blocks... General view...



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

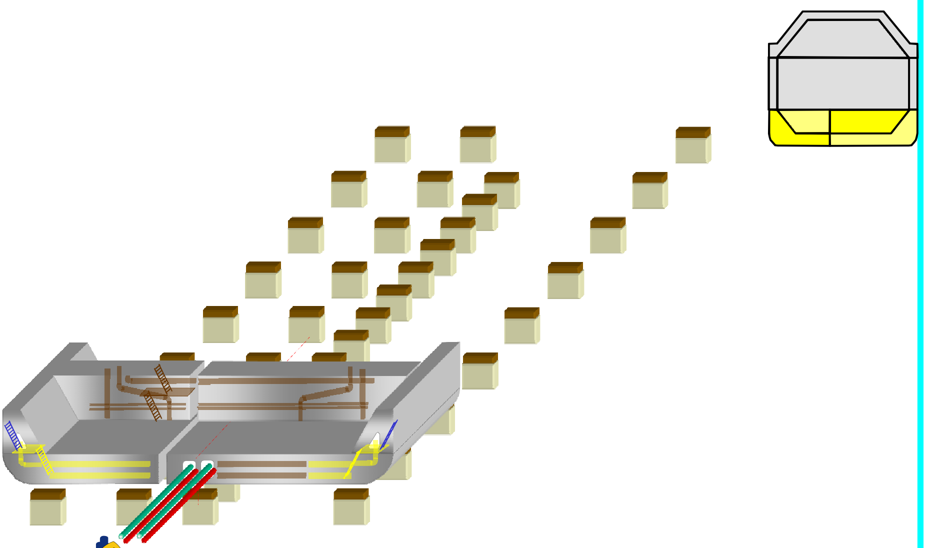
Distribution & numbering of grand blocks... Distribution principle... Trunk deck & upper cofferdam part...



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

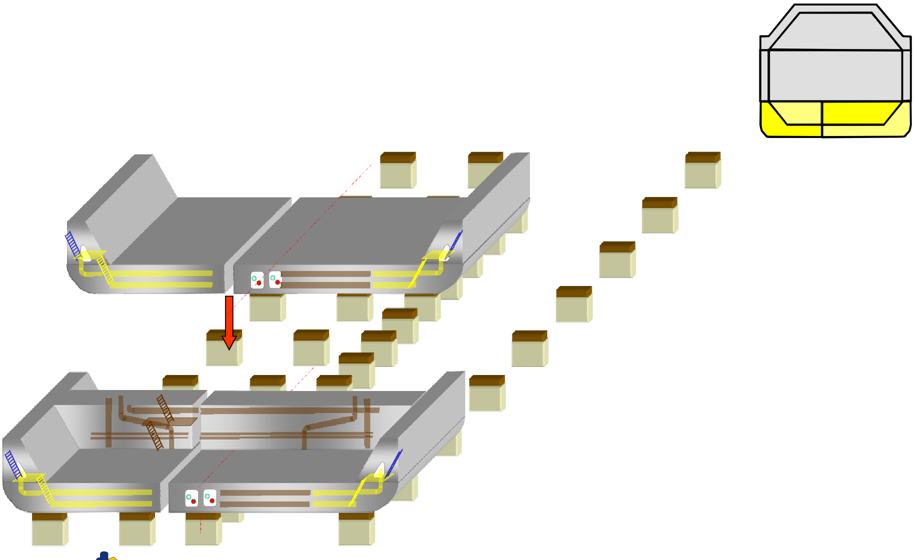
Distribution & numbering of grand blocks… Example of tanks erecting…



Improve

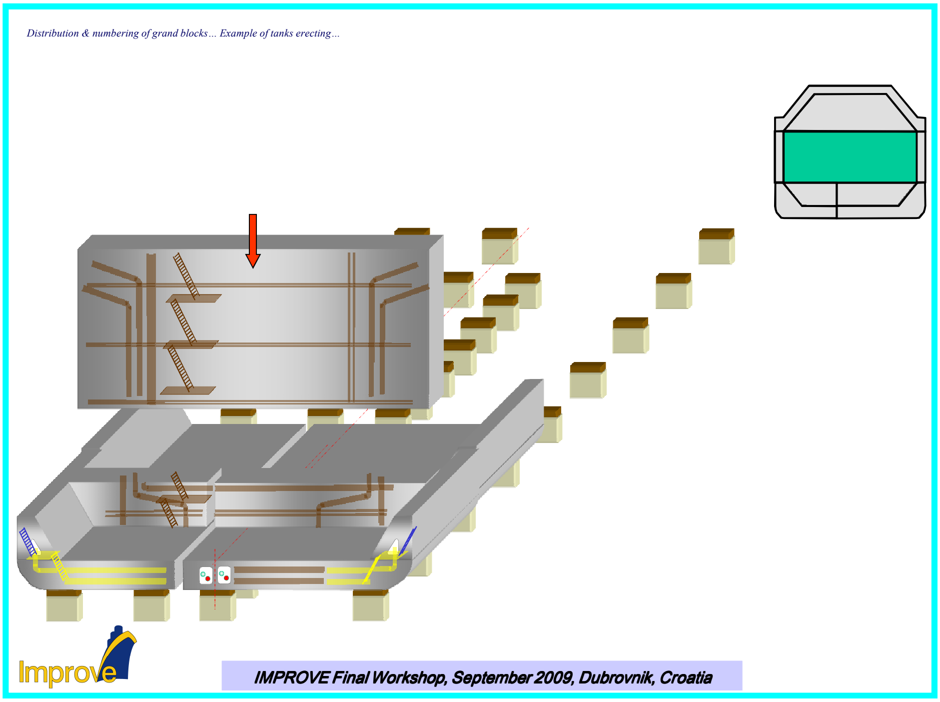
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

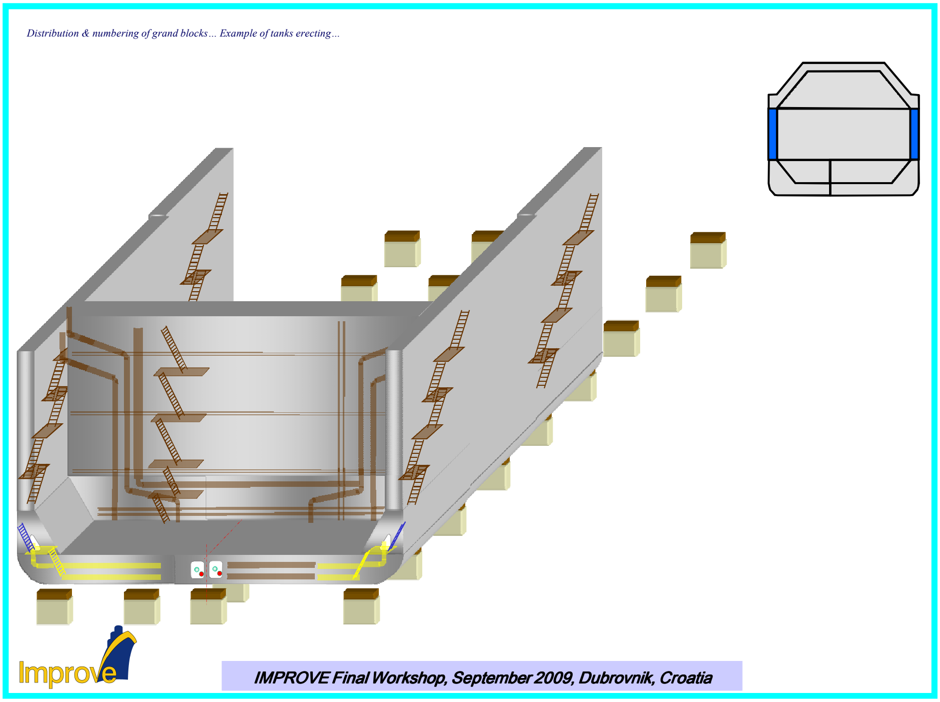
Distribution & numbering of grand blocks… Example of tanks erecting…

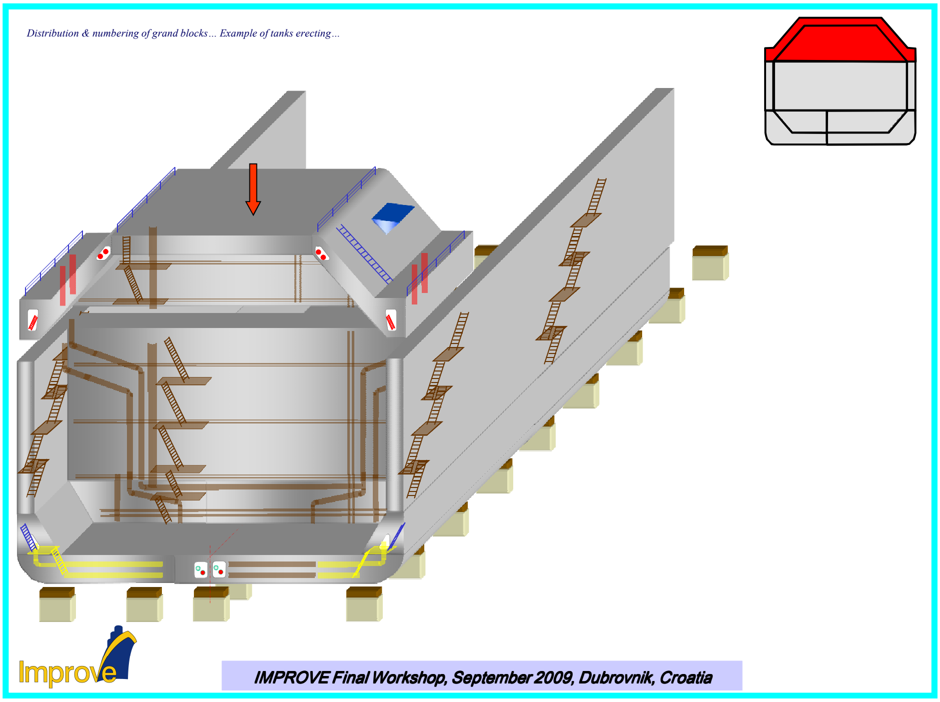


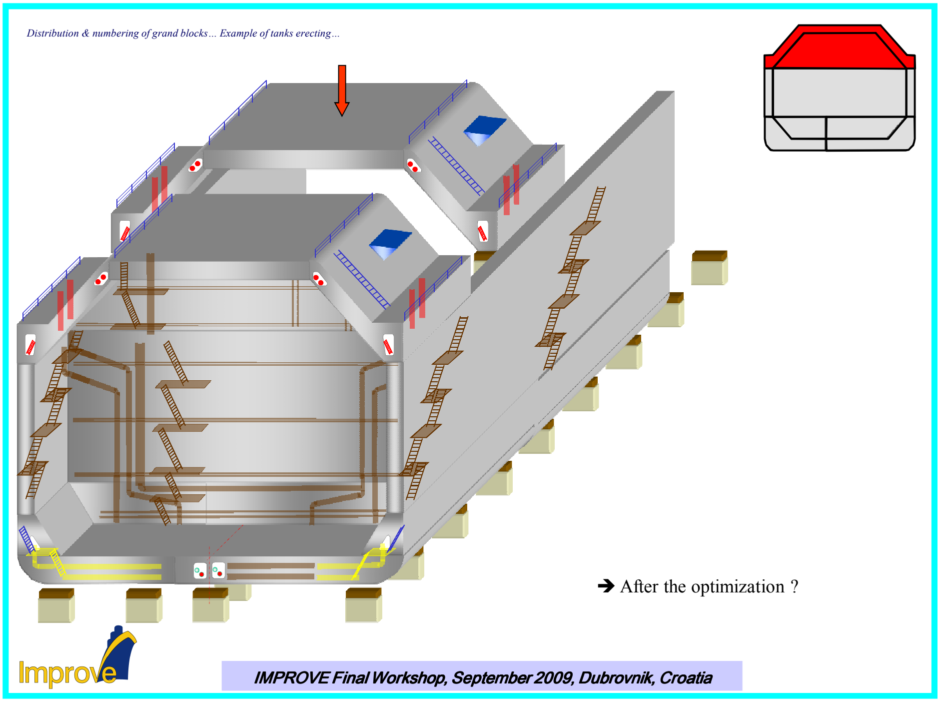
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia


Distribution & numbering of grand blocks… Example of tanks erecting…
Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia


Distribution & numbering of grand blocks… Example of tanks erecting…
Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia


Distribution & numbering of grand blocks… Example of tanks erecting…
Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia


Distribution & numbering of grand blocks… Example of tanks erecting…
➔ After the optimization ?
Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Ship Production and Operation

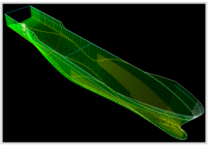
- **Production Cost model**
- **Maintenance and operational Cost Model**

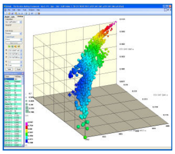
  in relation with the active design variables (structures)

  How to improve the ship structure to reduce unplanned operational breakdown (reparation, ….) ?

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

4- IMPROVE Design procedure(s)

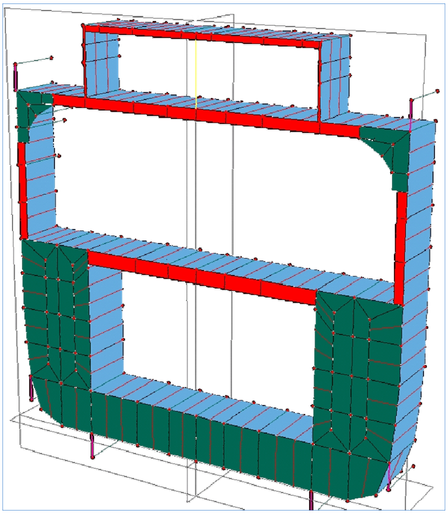




Updates of analysis modules

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

SHIP → SHIP MODEL(s)

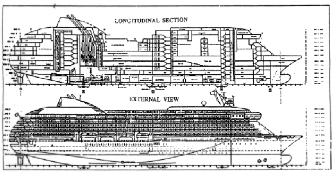


L_{OA} / L_{PP}	154.5/1 47.0 m
Breadth moulded	17.50 m
Depth to accommodation deck	13.35 m
Draught	4.50 m
Deadweight	5000 t
Tank-cars	52

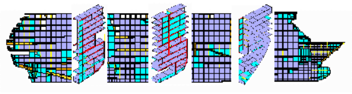
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

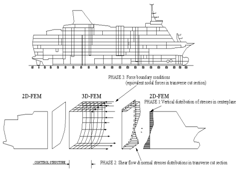
MODELLING

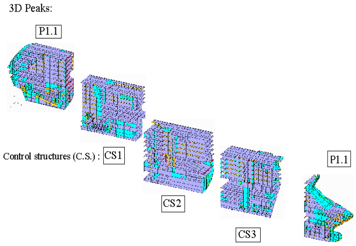


MAIN PARTICULARS:
L_{OA} =189.70 m
L_{PP} =168.05 m
Bmax = 29.20 m
T = 6.70 m
$T_{SCANT.}$ =7.00 m
GT= 40000 GRT
DWT =3900 t
v =20 Kn



Overall Design Procedure (2D & 3D models)

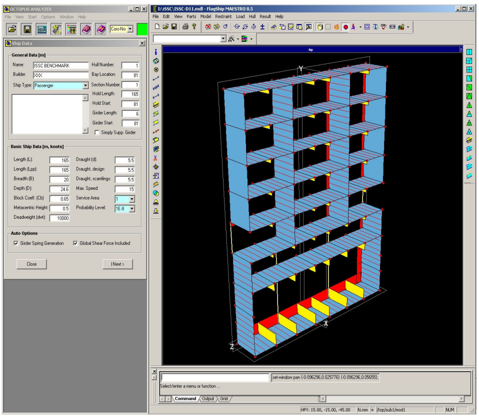


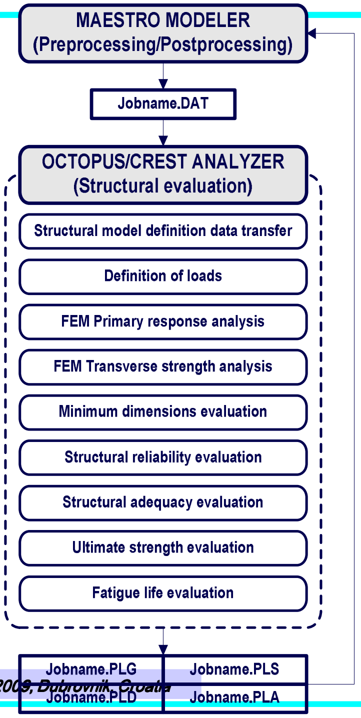


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Working environment and flowchart





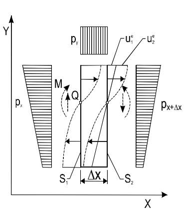
Improve

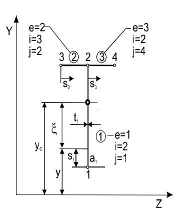
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

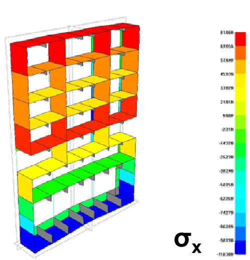
RESPONSE

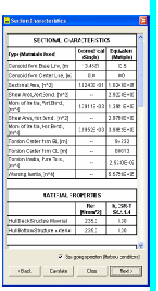
Primary response analysis

- Calculation of shear stress flow caused by horizontal and vertical bending moments, torsion …
- Calculation of normal stresses due to horizontal and vertical bending moments.
- Calculation of normal stress correction caused by shear stresses.
- Calculation of sectional characteristics.









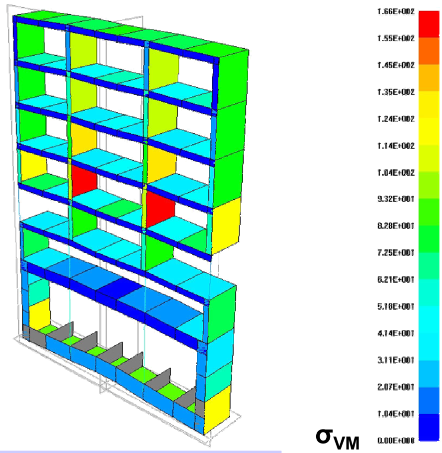
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

RESPONSE

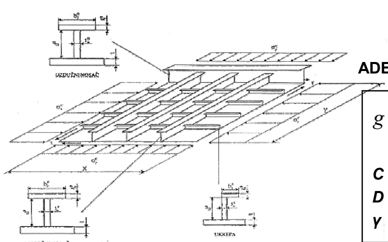
Transverse strength analysis

Calculation of displacements and stresses.



ADEQUACY

Library of structural adequacy criteria



ADEQUACY PARAMETER:

$$g = \frac{C - \gamma \cdot D}{C + \gamma \cdot D} \quad (1)$$

***C* - Capability;**
***D* - Demand;**
***γ* - Safety Factor.**

Definition range:

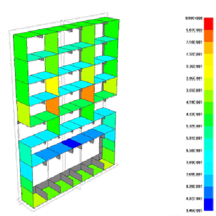
$$-1 \leq g \leq 1$$

$$g = \frac{FL - DL}{FL + DL} \quad (2)$$

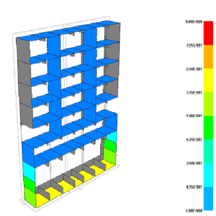
***FL* – Calculated Fatigue Life**

***DL* – Design Life**

VISUALIZATION OF RESULTS:



CRITERIA:
Panel Collapse Membrane Yield (PCMY)

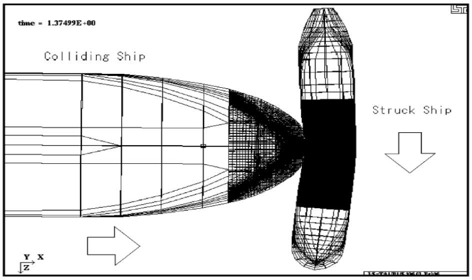


CRITERIA:
Panel Collapse Stiffener Buckling (PCSB)

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

NEW MODULES

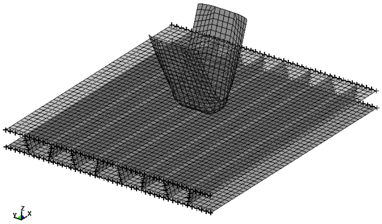
a) Accidental load assessment

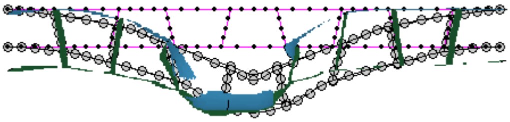


Inner mechanics

2D+ method

- Tool allowing fast assessment of structural resistance under impact loading
- validated with experimental tests





b) The Sloshing module

Inputs: Sloshing pressure for each panel

Given by Bureau Veritas

Outputs: Three new constraints for each panel

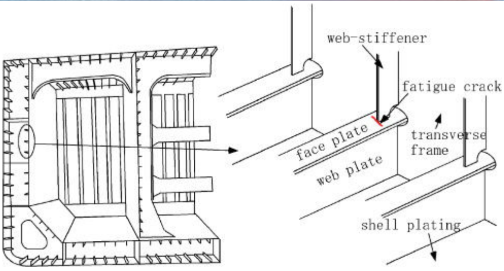
- Constraint on the net minimum thickness (**plate**)

- Constraint on the net minimum section modulus (**stiffeners**)

- Constraint on the net minimum shear sectional area (**stiffeners**)

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

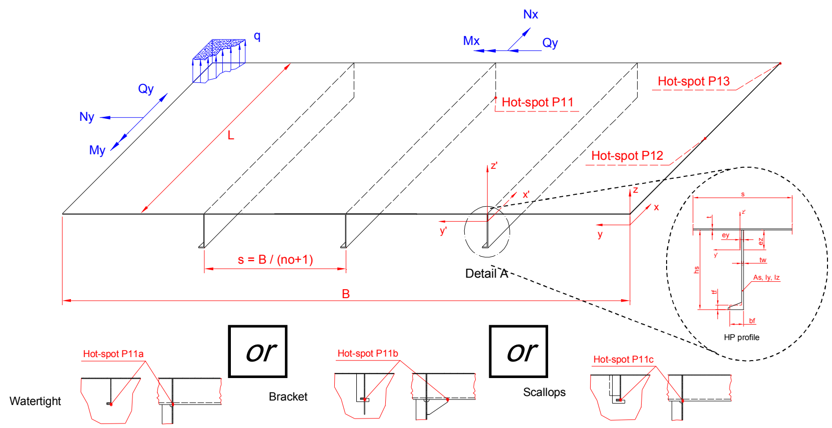
c- Fatigue assessment at early design stage



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

c) The Fatigue module

Inputs: For the plate: choice of Hot-spot and brackets



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

d) The Vibration module

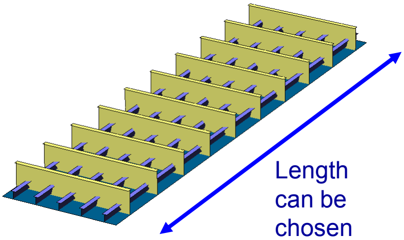
- Gives frequency for each panel selected
- Uses only as a check at the end of the process because:
  - One panel takes about 1 minute to be evaluated (to much !!)
  - One model can have 300 design variables (9 by panel) ➔ Time consuming !!

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The Vibration module

"Vibration" panel could be:

- A simple panel with
  – Primary stiffeners
  – Secondary stiffeners
  – Primary frames
  – Secondary frames
  – Girders



For each extremity: boundary condition must be chosen!

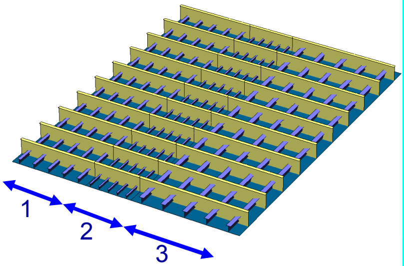
• The Vibration module

"Vibration" panel could be:

- A set of panels (deck study)

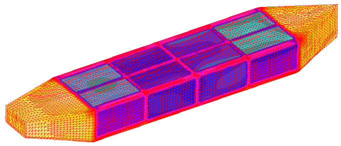
Rem.:

- Frames must be identical
- Panels must be aligned
- Material must be the same
- Vibration length must be equal
- Panels thicknesses must be equal
- Same boundaries condition for each panel

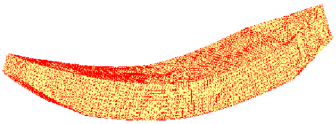


Global vibration

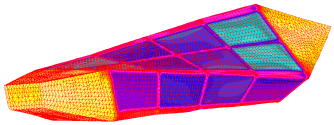
Mode No.	Vibrations in water (freq. Hz)		
	VIBHULL	COSMOS/M	Diff.(%)
1-vert.bend.	0.86	0.75	12.79
2-vert.bend.	1.94	1.68	13.40
3-vert.bend.	3.26	2.88	11.65
1-horiz.bend.	2.56	2.41	5.85
2-horiz.bend.	6.42	6.01	6.38
3-horiz.bend.	12.36	11.02	10.84
1-torsion	-	-	-



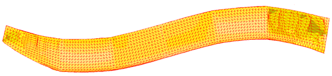
FEM 3D model (COSMOS)



First vertical modal shape (COSMOS)



First torsional modal shape (COSMOS)



Second vertical modal shape (COSMOS)

Improve

e) The Life Cycle Cost module

= New objective function

I

Inputs: Lightweight – Deadweight – Scenario – indCorrosion

Displacement constant | *Deadweight constant*

Outputs: four different cost/revenue

- Cost of periodic maintenance (2)
- Cost of oil consumption (3)
- Operational revenues (4)
- Dismantling revenues (5)

0 → "Classic" LCC module

1 → With corrosion scenario

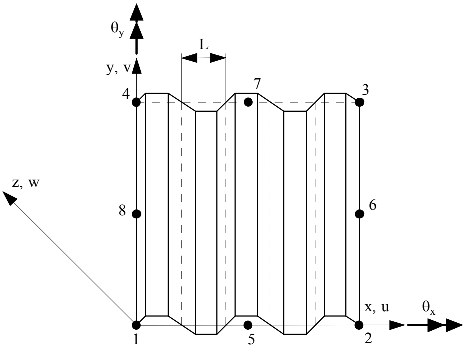
Life Cycle Cost = (2) + (3) – (4) – (5)

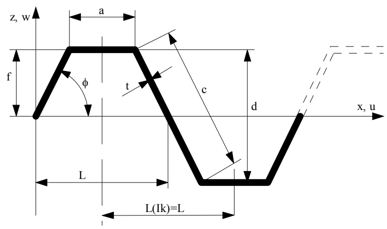
(possibility to add production cost)

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

F) CORRUGATED BULKHEADS

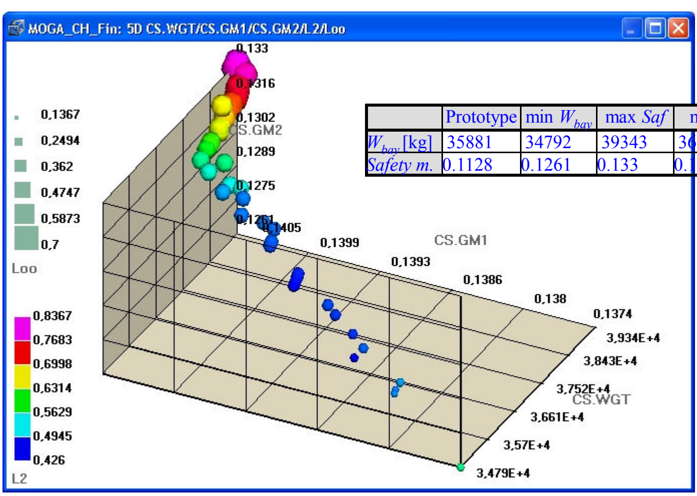




Scantlings of the corrugation one half-wave shown in the xz plane.

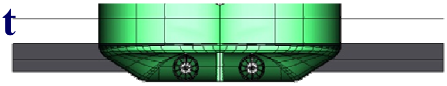
- Developed trough introduction of anisotropy into plane shell isoparametric finite element.
- Constant thickness property equal to the bulkhead sheet thickness, while the influence of the corrugation is introduced trough Young's module in both directions.

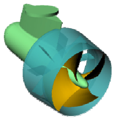
Optimisation → Pareto Frontier



	Prototype	min W_{bay}	max *Saf*	min L_2
W_{bay} [kg]	35881	34792	39343	36230
Safety m.	0.1128	0.1261	0.133	0.1281

New LNG Concept





V-shape → Unloaded draft ↗
Unloaded trim → Unloaded aft draft ↗
Smaller propellers → Required unloaded draft ↘

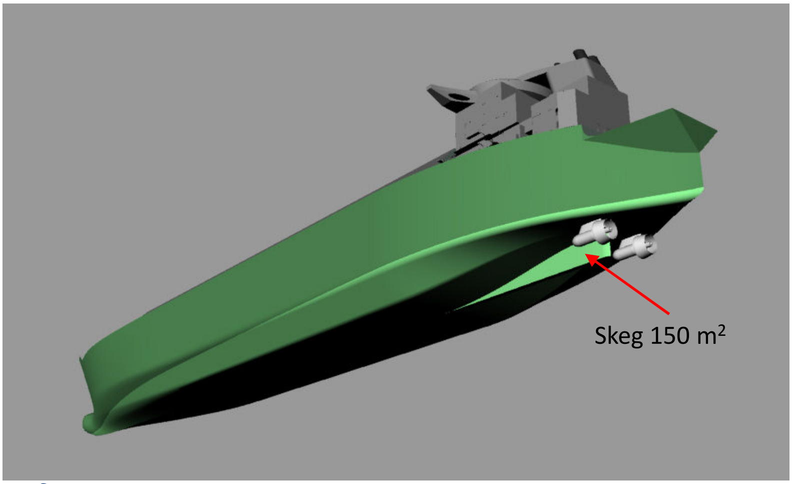
→ Immersion of the propellers without ballasts

→ No invasion of non-indigenous marine species
→ No sediment transfer
→ LNG savings = 9%

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

New LNG Concept



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG designs – optimization

LBR-5 least cost optimization results

Design	Standard		Free ballast	
	Initial scantling			
Mass [tons]	1840.44		1845.70	
Cost [M€]	3.16		3.13	
	Optimized scantling (only sloshing constraints)			
Mass [tons] / Gain	1694.98	**7.90%**	1714.55	**7.10%**
Cost [M€] / Gain	3.00	**5.25%**	3.04	**3.06%**
	Normalized scantling (sloshing and fatigue constraints)			
Mass [tons] / Gain	1709.76	**7.10%**	1724.73	**6.55%**
Cost [M€] / Gain	3.06	**3.14%**	3.07	**2.09%**

- indirect weight gain
- the values correspond to a half of tank
- more severe loading conditions imposed to "Free ballast" design

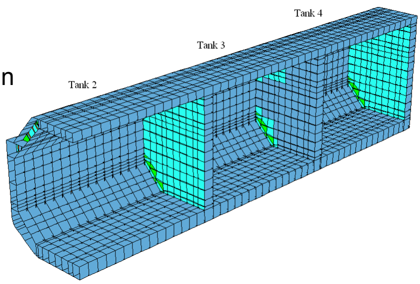
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG carrier – optimization

OCTOPUS/Maestro modeling

- FE modeling – "Free ballast" design
- 3 tanks
- 17 load cases
- sloshing pressure

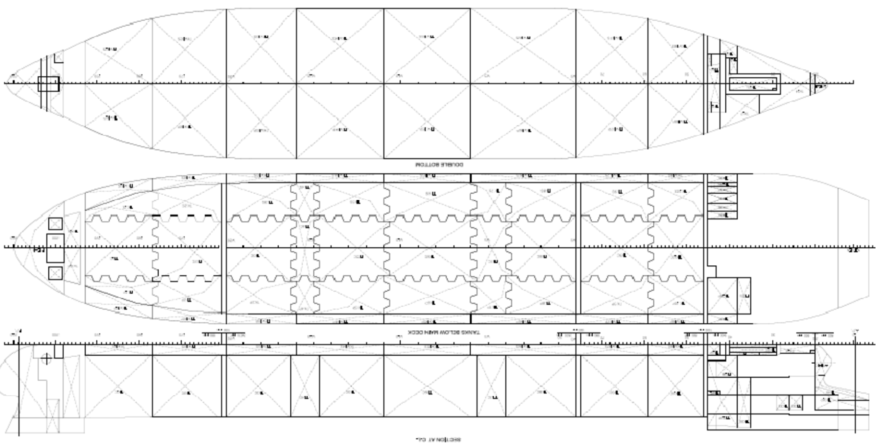


1) Prototype structure analysis
   - to assess the adequacy of the initial model of LNG
   - library of failure criteria (inbuilt MAESTRO software)
   - allow to establish the starting point of the design problem
2) Preliminary design phase
   - optimization of the remodeled LNG ship structure

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

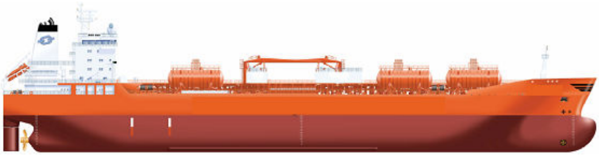
CHEMICAL TANKER – General Arrangement

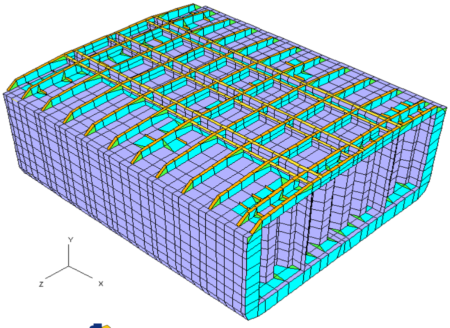


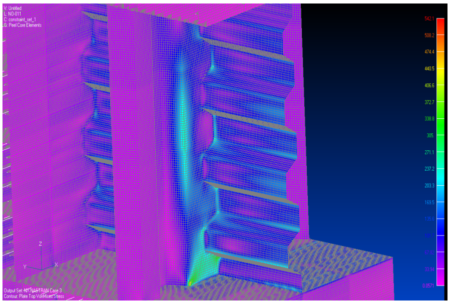
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

TANKER design – optimization



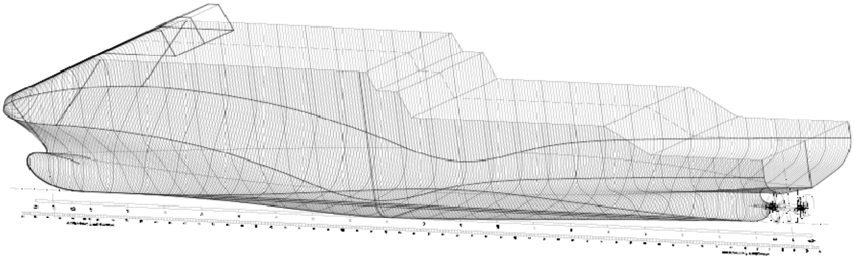




Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

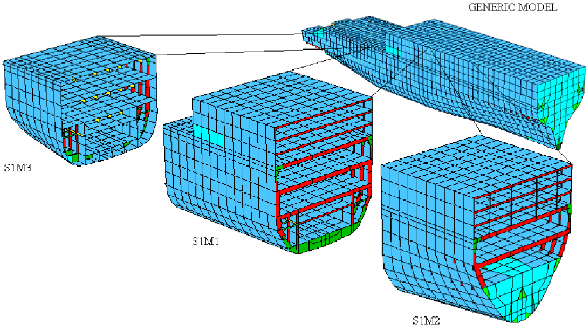
ROPAX – optimization



Body Lines of New ROPAX Ship

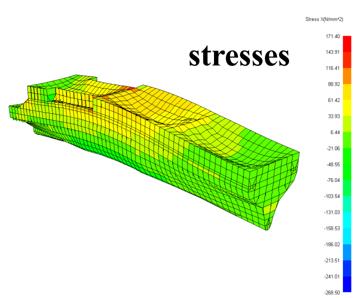
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

NEW ROPAX



σ_x

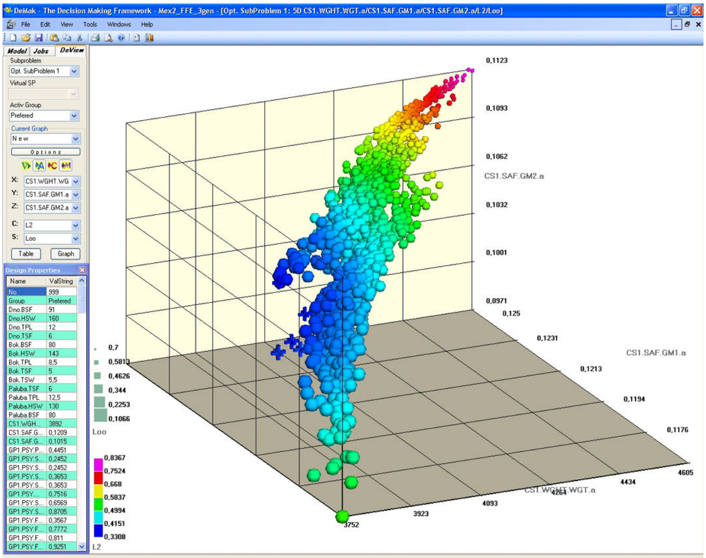
stresses



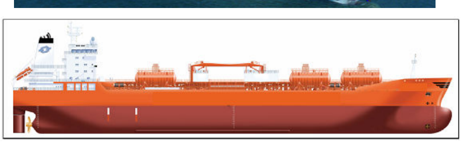
Selected ship zone for structural optim

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

ROPAX – optimization



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia



Improve

THANK YOU!

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

INVITED LECTURERS

IMPROVE Final Workshop
Invited Lecture

Next Generation Ship Structural Design

Dr. Owen F. Hughes
Virginia Tech
Blacksburg, Virginia USA

September 17, 2009

IMPROVE Project/Team Acknowledgement

- Appreciate the opportunity to speak to this gathering
- IMPROVE represents the very best in ship design innovation
- Technology advances are very evident in IMPROVE technical results

Overview

- Historical Perspective
- Ship Structural Design Evolution
- ‘Next Generation Ship Structural Design’ Requirements
- Improved Integration with Overall Ship Design Process
- Design of Higher Performance Structures
- Summary

Historical Perspective

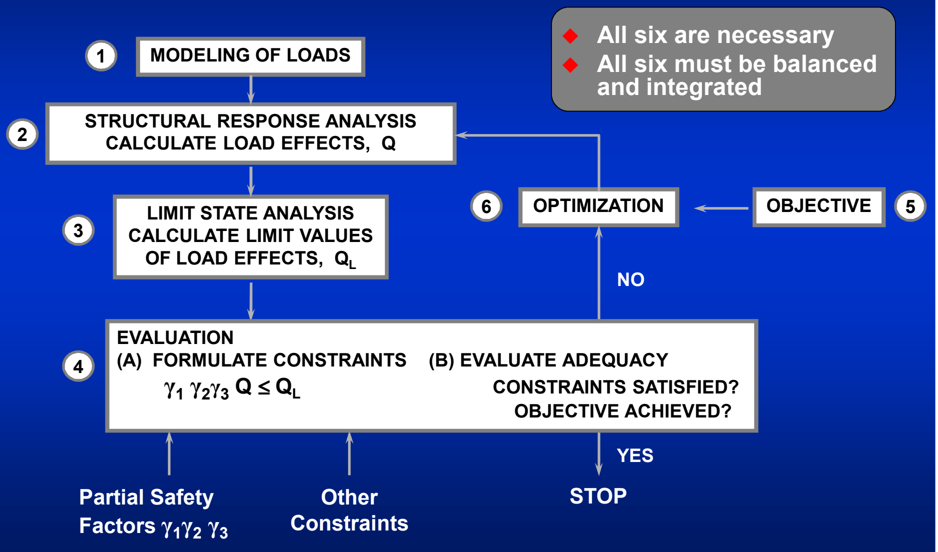
- Today’s approaches have roots in 1970’s
- Technologies emerged to support improved design process
- Finite Element Analysis
- Structural Limit State Evaluation
- Optimization Methods
- Computers

Historical Perspective

- Today's approaches have roots in 1970's
- Technologies emerged to support improved design process
- Finite Element Analysis
- Structural Limit State Evaluation
- Optimization Methods
- Computers

} Unified Approach for *Rationally-Based Ship Structural Design*

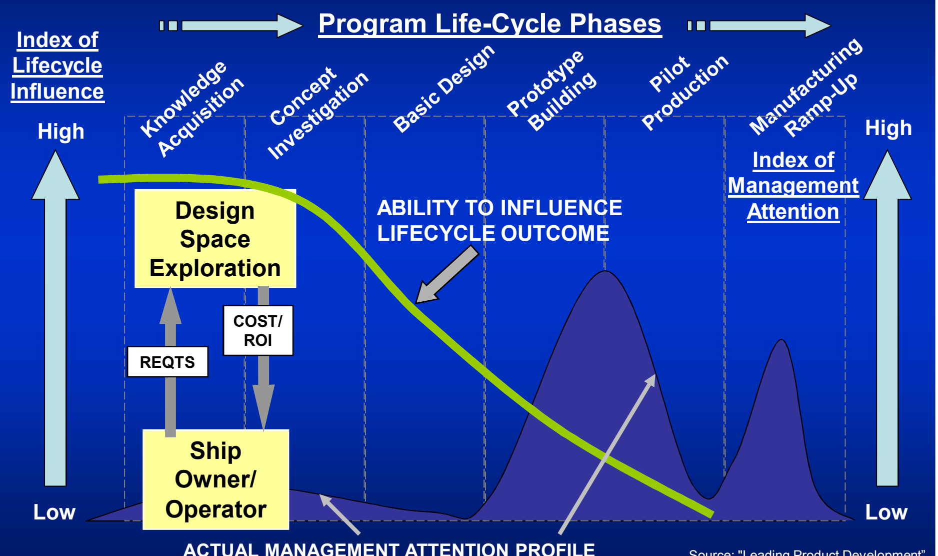
Six Elements of Rationally-Based Ship Structural Design



Key Structural Performance Parameters:

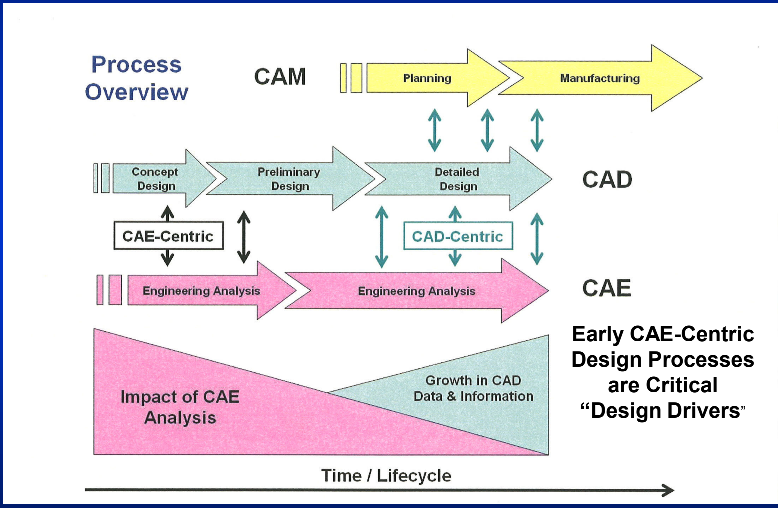
- Higher performance structures – reduced weight with higher degrees of safety and reliability
- Lower fabrication costs
- Better economic performance in terms of lower contribution to light ship and hence larger payload fractions
- Reduced structural maintenance costs over the life-cycle
- Recognition of social responsibility in terms of environmental protection, collision/damage tolerance, reduced risk of failure, etc.

Design Space Exploration Strategy



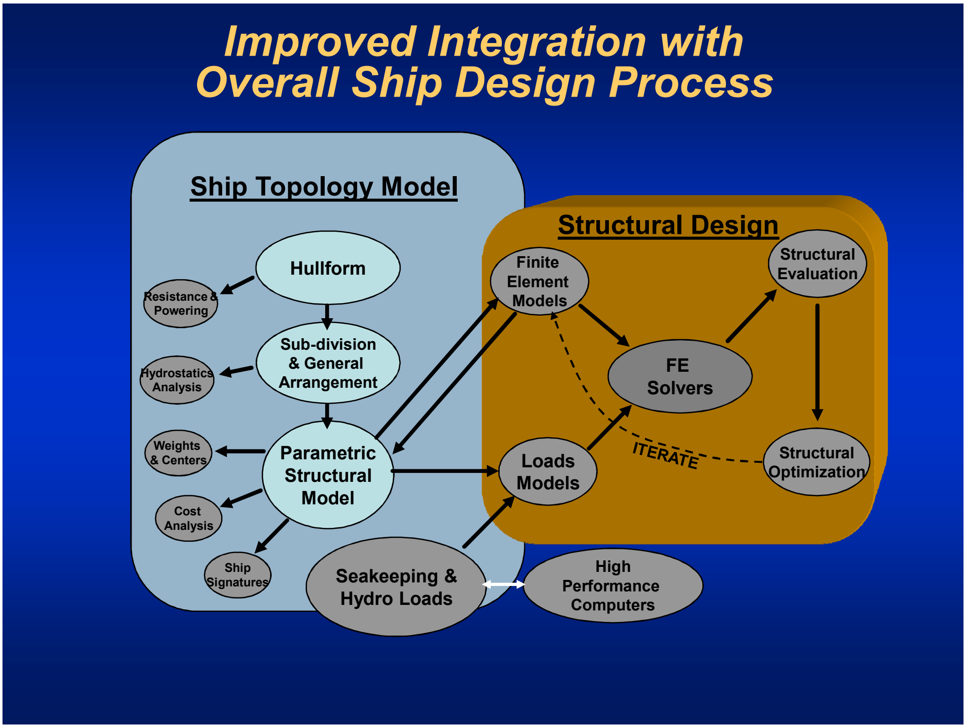
Source: "Leading Product Development"
Wheelwright & Clark
Harvard Business School

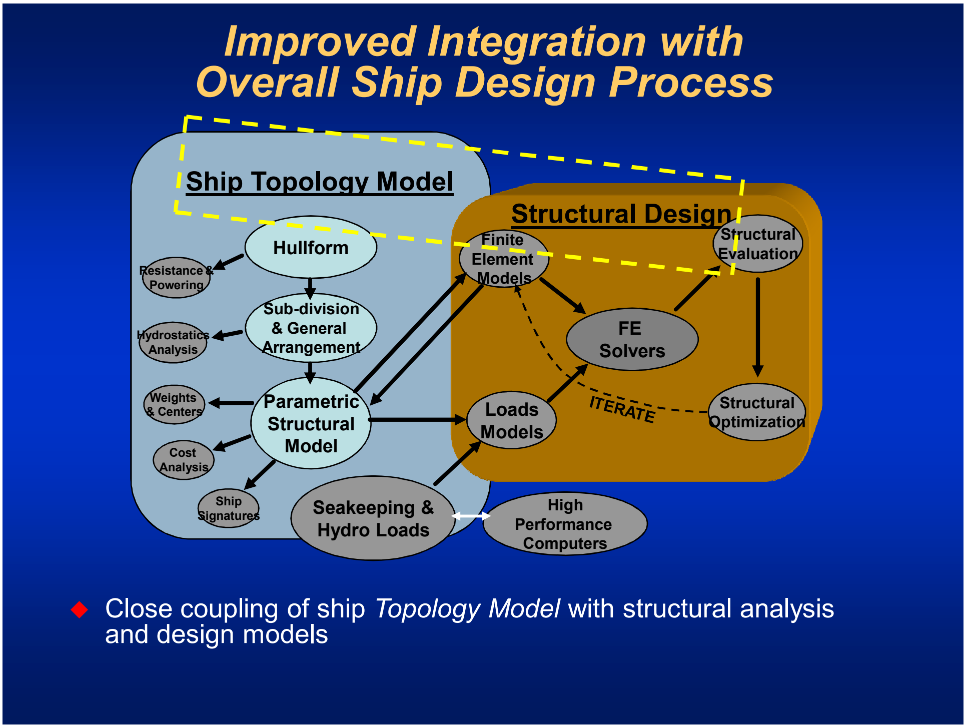
Physics-Based Computer-Aided Engineering Needs to Occur Early in the Design Process



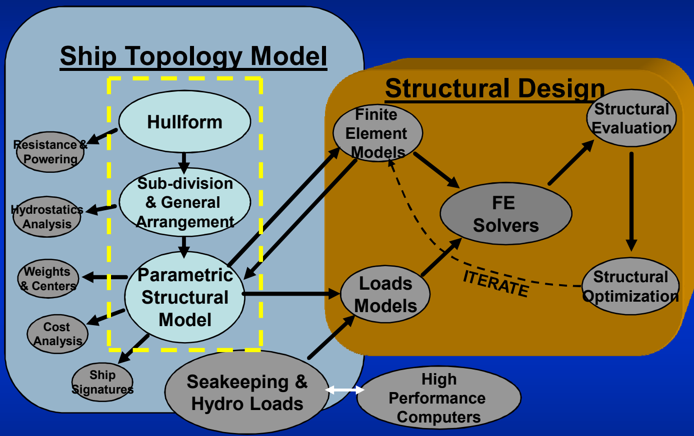
Improved Integration with Overall Ship Design Process

- A ship design is now routinely developed using a surface model
- The surfaces represent hull and major decks and bulkheads
- The surface model also serves as a *Topology Model* that organizes the three dimensional spaces of the ship
- The surface model defines the purposes of the spaces and the relationships between the spaces
- This advanced *Topology Model* becomes the master 'organizer' of a ship design
- A challenge for CAE models and analyses is to have a functional linkage or relationship with the master *Topology Model*


Improved Integration with
Overall Ship Design Process
Ship Topology Model
Hullform
Resistance & Powering
Sub-division & General Arrangement
Hydrostatics Analysis
Weights & Centers
Parametric Structural Model
Cost Analysis
Ship Signatures
Seakeeping & Hydro Loads
High Performance Computers
Structural Design
Finite Element Models
Structural Evaluation
FE Solvers
Loads Models
ITERATE
Structural Optimization

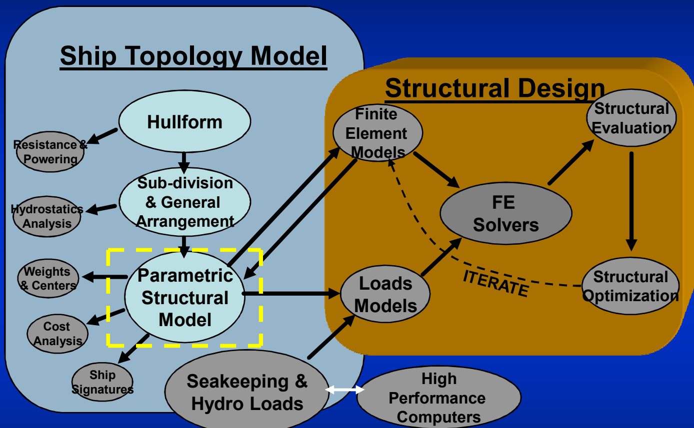

Improved Integration with
Overall Ship Design Process
Ship Topology Model
Hullform
Resistance & Powering
Sub-division & General Arrangement
Hydrostatics Analysis
Weights & Centers
Parametric Structural Model
Cost Analysis
Ship Signatures
Seakeeping & Hydro Loads
High Performance Computers
Structural Design
Finite Element Models
Structural Evaluation
FE Solvers
Loads Models
ITERATE
Structural Optimization
Close coupling of ship *Topology Model* with structural analysis and design models

Improved Integration with Overall Ship Design Process



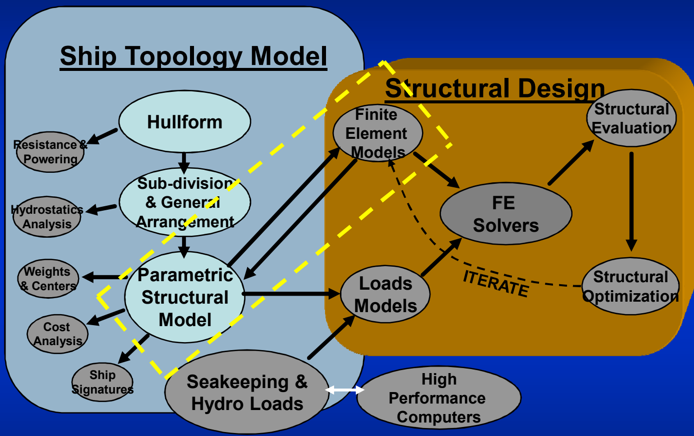
- Automated generation and updating of structural models in response to changes in ship hull form, and deck and bulkhead arrangements

Improved Integration with Overall Ship Design Process



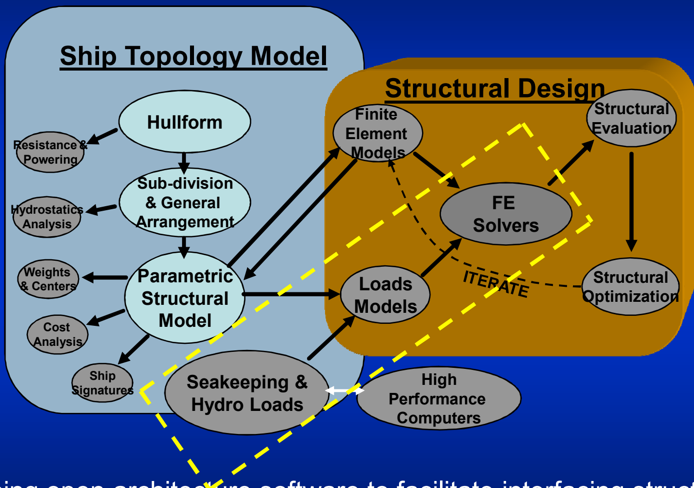
- Creating a parametric parent ship structural object model by defining structural attributions for the *Topology Model*

Improved Integration with Overall Ship Design Process



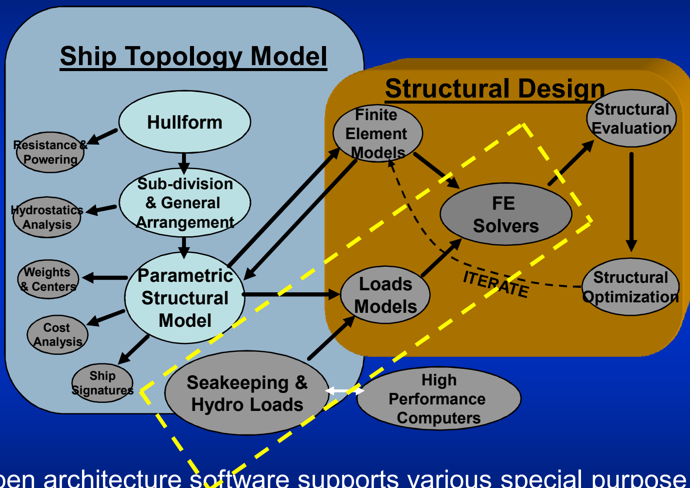
- Spawning/automating multiple structural analysis models (including different detail levels of finite element models) from the parent structural object model

Improved Integration with Overall Ship Design Process



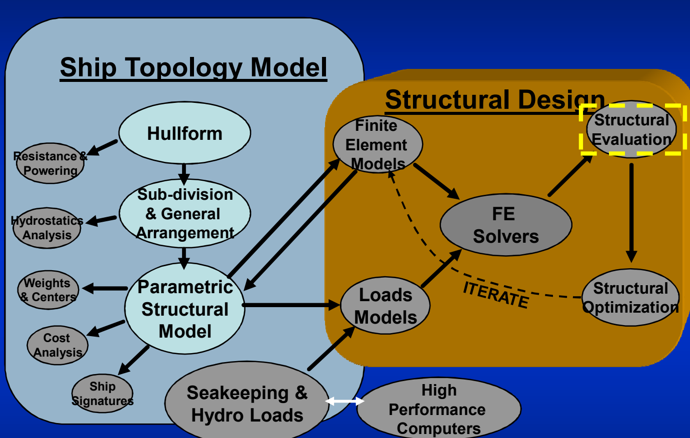
- Using open architecture software to facilitate interfacing structural analysis models with various load prediction analyses and tools, such as 2D/3D time/frequency domain hydrodynamic analyses

Improved Integration with Overall Ship Design Process



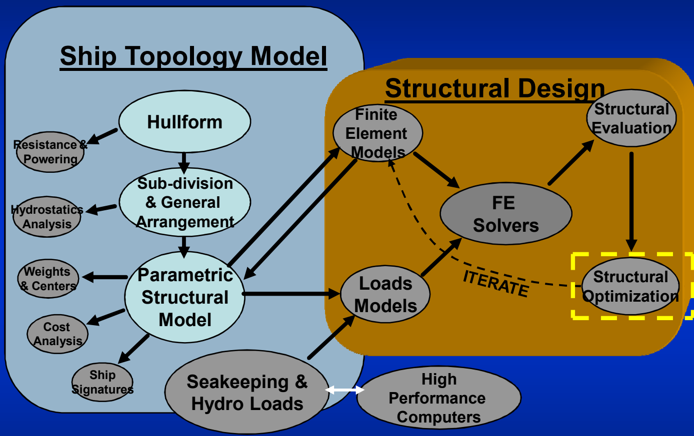
- Open architecture software supports various special purpose analyses and different tools, such as Dynamic Load Approach, Spectral Fatigue Analysis, Underwater Shock, and forced vibration

Improved Integration with Overall Ship Design Process



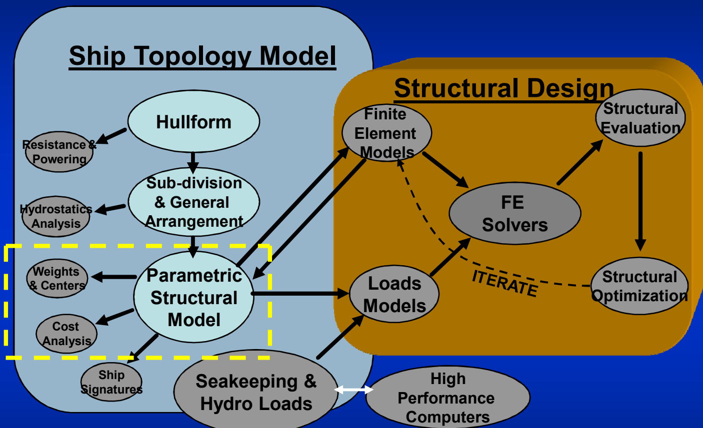
- Automated structural panel evaluations (MAESTRO limit state sets; ALPS/ULSAP; ALPS/Hull; Naval Vessel Rules; High Speed Naval Craft, etc.)

Improved Integration with Overall Ship Design Process



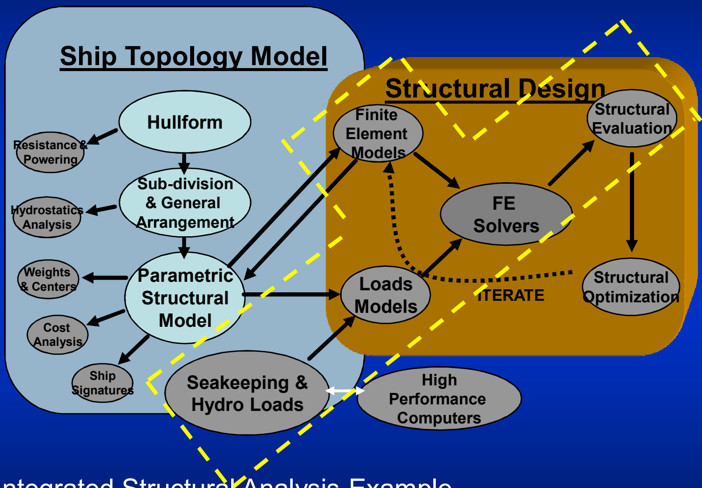
- Structural optimization to refine and improve the structural performance and meet design requirements and objectives

Improved Integration with Overall Ship Design Process



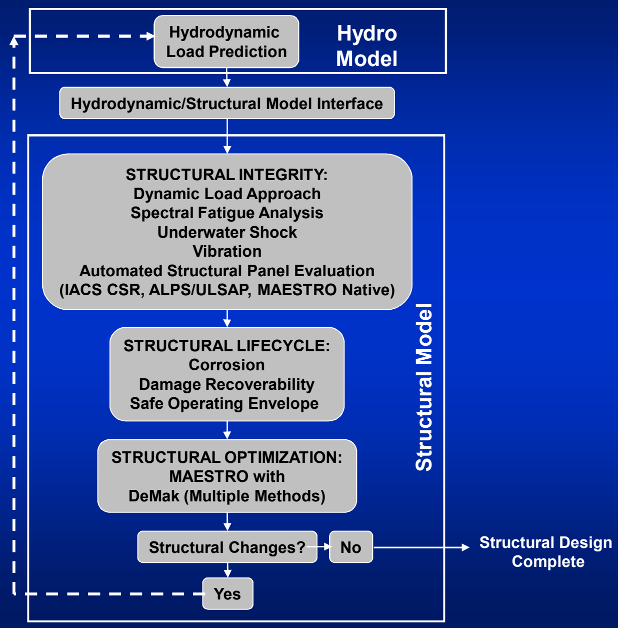
- Coupling between the structure and the ship's weight/centers and cost estimation models

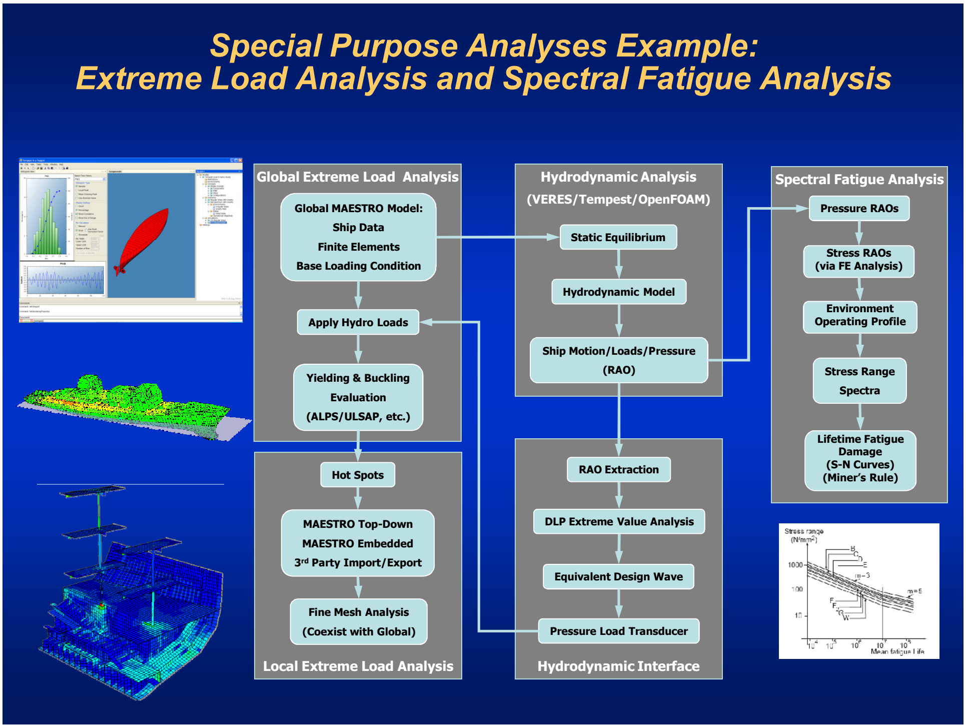
Improved Integration with Overall Ship Design Process

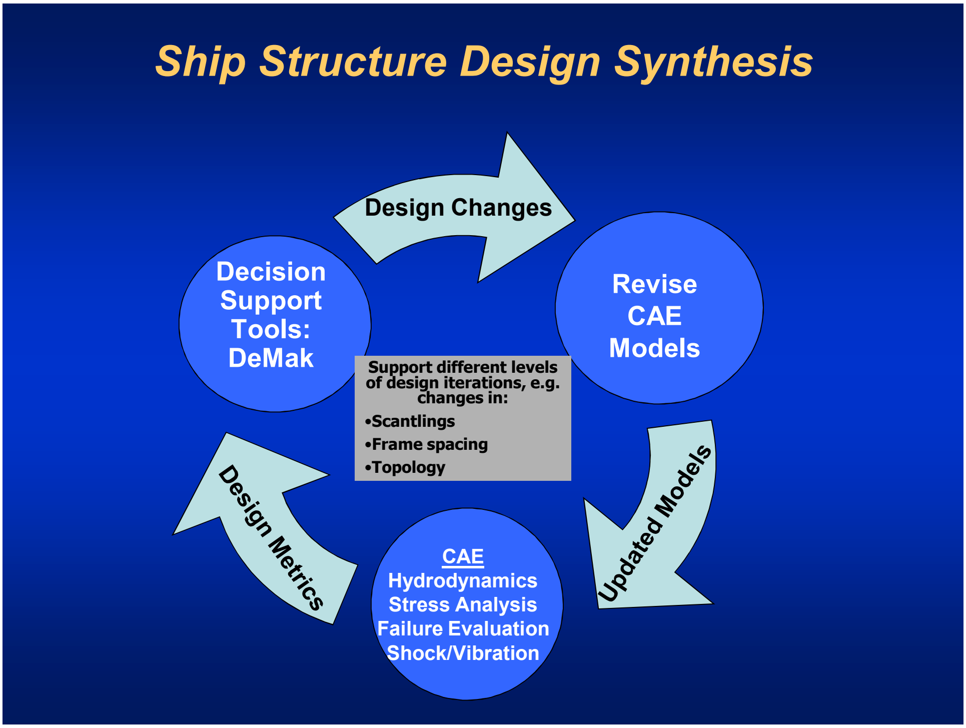


- Integrated Structural Analysis Example

Flowchart of Integrated Structural Analysis




Special Purpose Analyses Example:
Extreme Load Analysis and Spectral Fatigue Analysis
Global Extreme Load Analysis
Global MAESTRO Model:
Ship Data
Finite Elements
Base Loading Condition
Apply Hydro Loads
Yielding & Buckling
Evaluation
(ALPS/ULSAP, etc.)
Hydrodynamic Analysis
(VERES/Tempest/OpenFOAM)
Static Equilibrium
Hydrodynamic Model
Ship Motion/Loads/Pressure
(RAO)
Spectral Fatigue Analysis
Pressure RAOs
Stress RAOs
(via FE Analysis)
Environment
Operating Profile
Stress Range
Spectra
Lifetime Fatigue
Damage
(S-N Curves)
(Miner's Rule)
Hot Spots
MAESTRO Top-Down
MAESTRO Embedded
3rd Party Import/Export
Fine Mesh Analysis
(Coexist with Global)
Local Extreme Load Analysis
RAO Extraction
DLP Extreme Value Analysis
Equivalent Design Wave
Pressure Load Transducer
Hydrodynamic Interface
Stress range
(N/mm²)
1000
100
10
Mean fatigue life


Ship Structure Design Synthesis
Design Changes
Decision
Support
Tools:
DeMak
Revise
CAE
Models
Support different levels
of design iterations, e.g.
changes in:
•Scantlings
•Frame spacing
•Topology
Design Metrics
Updated Models
CAE
Hydrodynamics
Stress Analysis
Failure Evaluation
Shock/Vibration

Summary and Conclusions

- Next generation ship structural design tools and methods must further unify structural design process sub-elements into a more efficient and higher fidelity process
- Goal is to achieve both engineering integrity and optimized performance for the owner/operator
- Advances in design tool architecture, geometry and topology modeling, loads analysis, and structural evaluation must be better unified
- The degree of complexity of ship structural design continues to grow, driven by the results of scientific development coupled with the ever-competitive environment of ship owners and operators

Summary and Conclusions

- The vision of next generation ship structural design requires more complete unification with both the basic ship topology design and with the multiple aspects of ship loading and structural design
- Decision support technologies and methods are here to stay and are becoming more widely applied and accepted. Next generation structural design will depend more on these technologies to effectively explore the design space and generate the best designs for ships of tomorrow.

GOALS by which ship structural design can Improve

Improve has achieved many of these GOALS

Design for Performance

Kai Levander

SeaKey Naval Architecture

Kai Levander

SVP Naval Architecture
Aker Yards Cruise & Ferries

Professor II
NTNU Marine Technology
Dr.H.C.
Helsinki University of Technology

stx Europe

Cruise & Ferries

Helsinki | Turku | Rauma
St. Nazaire | Lorient

Offshore & Specialized Vessels

Langsten | Brattvaag | Aukra | Søviknes
Brevik | Promar | Tulcea | Braila

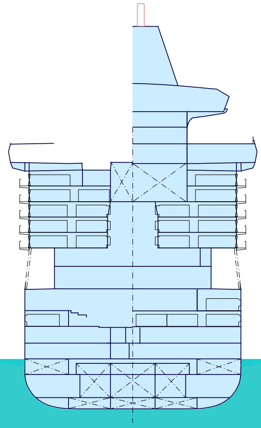
Kai Levander 2009-09-18 SeaKey Naval Architecture 2

System Based Ship Design

- Initial sizing of the ship
  - • Capacity carriers, like container vessels, ferries and cruise ships, where size is determined by the volume of the cargo
  - - Deadweight carriers, like oil tankers and bulk carriers, where size is determined by the weight of the cargo
- Parametric exploration
  - • Variation of main dimensions, hull form and lay out
- Engineering synthesis
  - •Ship performance, speed, endurance and sea-keeping
- Evaluation of the design
  - • Building cost and operating economics

Mission > Function > Form > Performance > Economics

The Ship Design Task

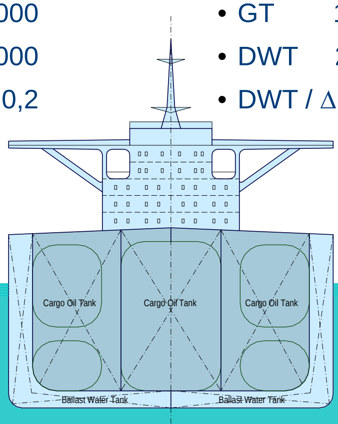


Cruise Ship

- GT 140 000
- DWT 10 000
- DWT / Δ 0,2

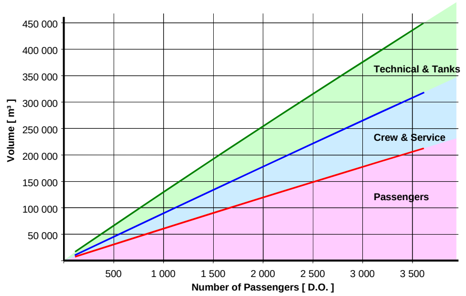
Tanker

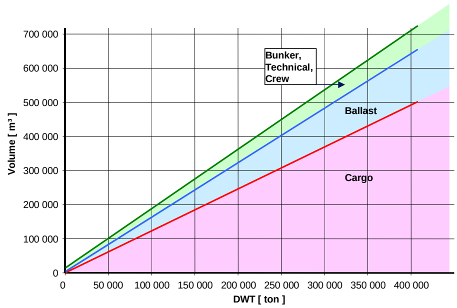
- GT 140 000
- DWT 260 000
- DWT / Δ 0,8



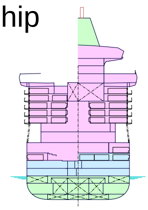
Capacity and deadweight carriers

Estimating the space needed in the ship

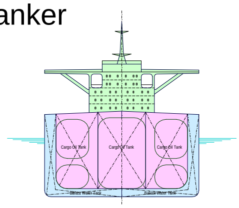




Cruise Ship

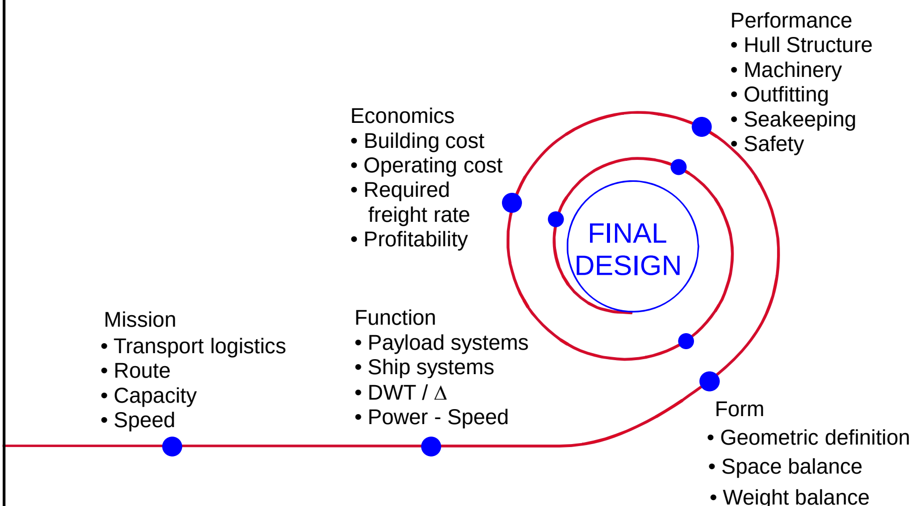


Tanker



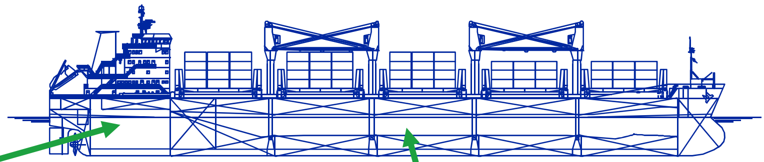
Kai Levander 2009-09-18 SeaKey Naval Architecture 5

System Based Ship Design



Kai Levander 2009-09-18 SeaKey Naval Architecture 6

Cargo Ship System



Ship Function

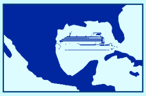
Structure	Hull, poop, forecastle Superstructures
Crew Facilities	Crew spaces Service spaces Stairs and corridors
Machinery	Engine and pump rooms Engine casing, funnel Steering and thrusters
Tanks	Fuel & lub oil Water and sewage Ballast and voids
Comfort Systems	Air conditioning Water and sewage
Outdoor Decks	Mooring, lifeboats, etc.

Payload Function

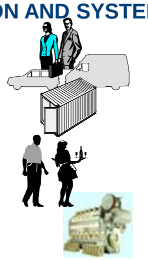
Cargo Units	Containers Trailers Cassettes Pallets Bulk / Break Bulk
Cargo Spaces	Holds Deck cargo spaces Cell guides Tanks
Cargo Handling	Hatches & ramps Cranes Cargo pumps Lashing
Cargo Treatment	Ventilation Heating and cooling Pressurizing

SeaKey - System Based Design /1

MISSION ROUTE, CAPACITY, SPEED, RESTRICTIONS

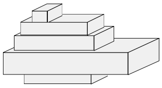


FUNCTION AND SYSTEM DESCRIPTION



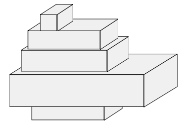
Payload	CARGO CARGO HANDLING CARGO TREATMENT	⇨	AREAS VOLUMES
Service	CREW SERVICE SPACES	⇨	AREAS, VOLUMES
Machinery	ENGINE ROOM TECHNICAL SPACES	⇨	AREAS, VOLUMES
Tanks, Voids		⇨	VOLUMES

$\Sigma =$ **GROSS TONNAGE**

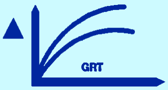


SeaKey - System Based Design / 2

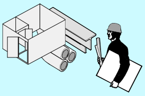
$\Sigma =$ GROSS TONNAGE



WEIGHT
- Lightweight
- Deadweight

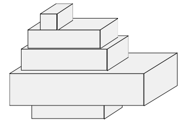


BUILDING COST
- Design
- Material
- Labour



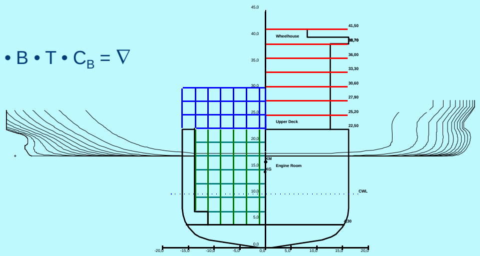
SeaKey - System Based Design / 3

$\Sigma =$ GROSS TONNAGE

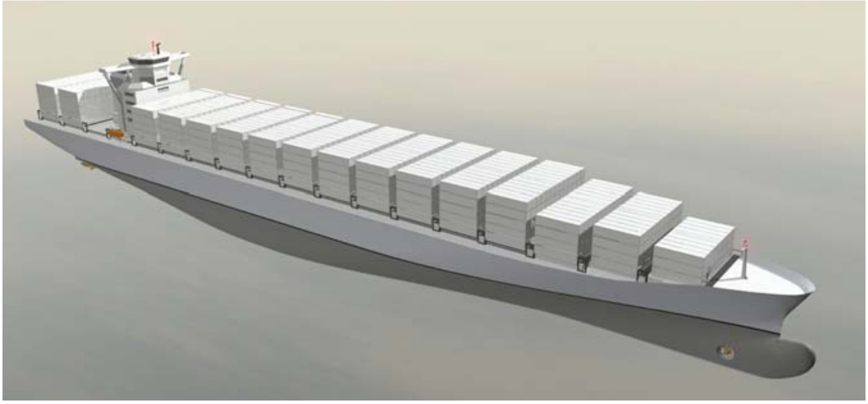


FORM AND PERFORMANCE
- Main Dimensions
- Hull Generation
- Space balance
- Weight balance
- Speed & power
- Hydrostatics

$$L \cdot B \cdot T \cdot C_B = \nabla$$



Space Balance

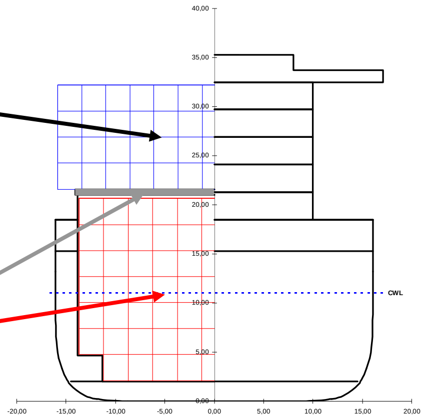


Kai Levander 2009-09-18 SeaKey Naval Architecture 11

Cargo Holds and Deck Cargo Space

Deck Cargo Space
- Open space, not included in the Gross Tonnage

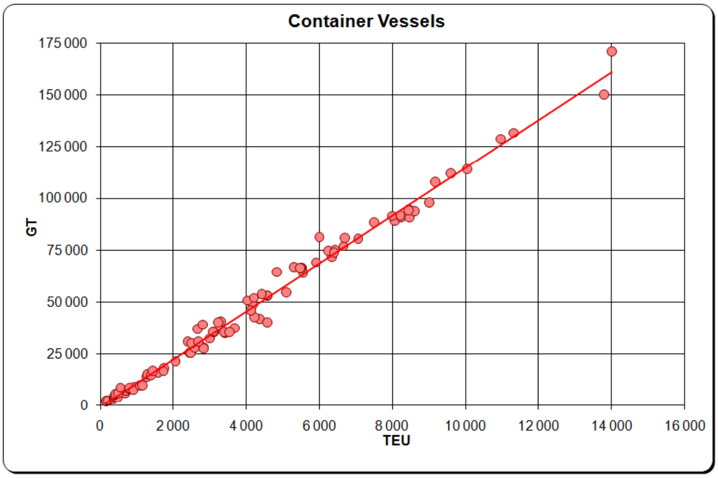
Cargo Holds with Hatches
- Closed space, included in the Gross Tonnage



GT=(0,2 + 0,02 x log GV) x GV

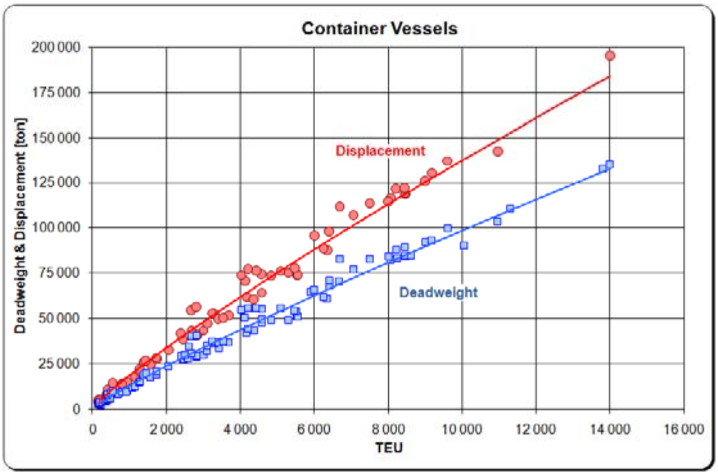
Kai Levander 2009-09-18 SeaKey Naval Architecture 12

Space Balance



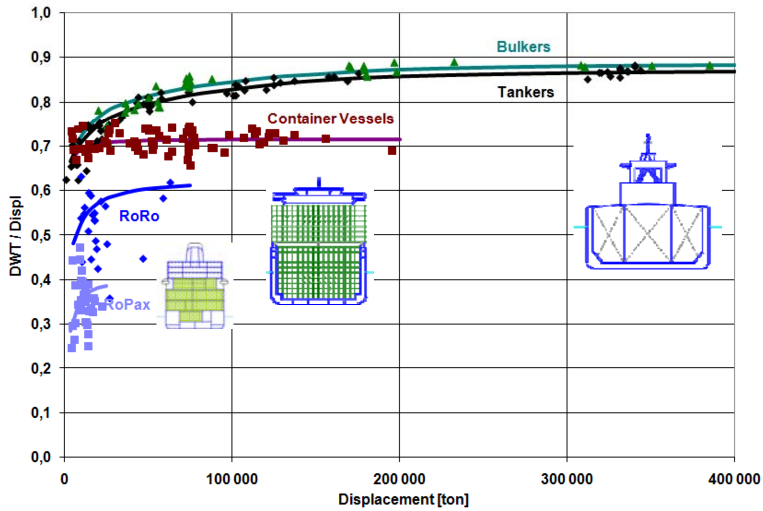
GT=(0,2 + 0,02 x log GV) x GV

Weight Balance



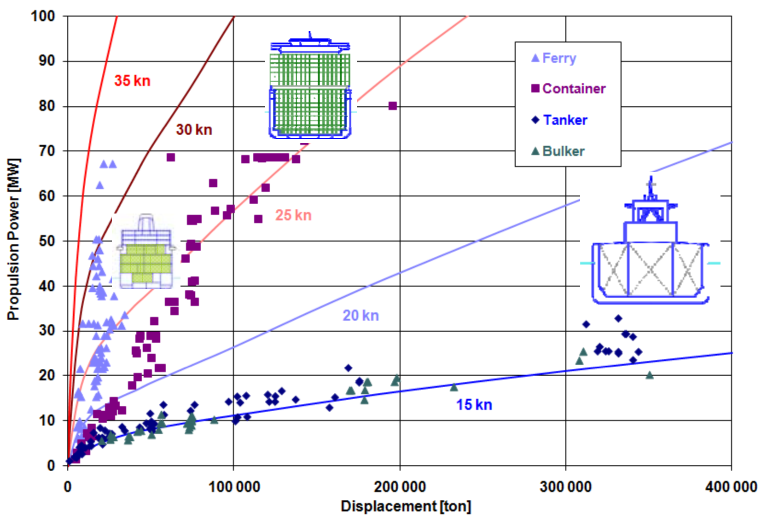
Displacement = LWT + DWT =1,025 x L x B x T x C_B

Design Criteria No 1
Deadweight / Displacement



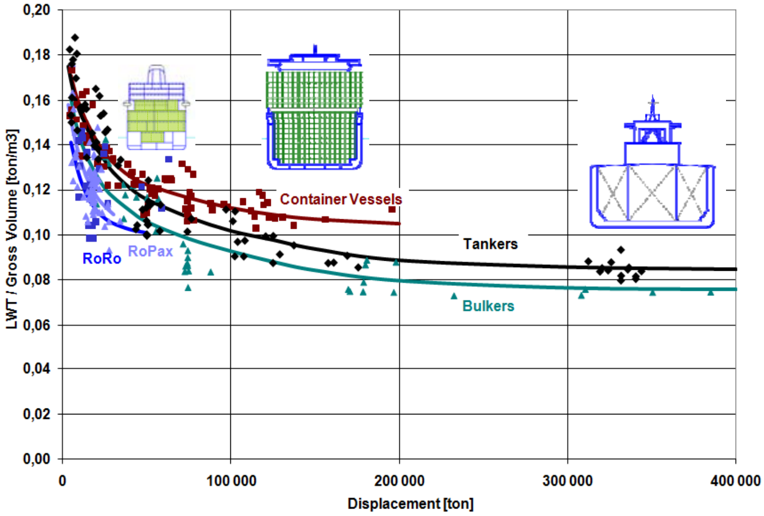
Kai Levander 2009-09-18 SeaKey Naval Architecture 15

Design Criteria No 2
Power Demand



Kai Levander 2009-09-18 SeaKey Naval Architecture 16

Design Criteria No 3
Lightweight Density



Kai Levander 2009-09-18 SeaKey Naval Architecture 17

Ship Key Performance Indicators

Impact Area	Technology Drivers	Goal	Indicator
Construction	Design Concept Standard Solutions Modular Construction Supplier Networking	Construction Efficiency	Building cost [USD / Payload unit]
Payload Functions	Payload Capacity Speed & Power Cargo Units Cargo Handling	Transport Capacity	Money making potential [RFR]
Ship Functions	Hull Form Propulsion Solution Fuel Type & Consumption Heat Recovery	Propulsion Efficiency	Bunker cost [USD / Year] Carbon Footprint [CO2 / ton• nm]
	Navigation Machinery Operation Docking & Mooring	Automation	Crew cost [USD / Year]
	Planned Maintenance Preventive Maintenance Condition Monitoring	Reliability	Keep schedule Time saving
IMO Flag States	Fire prevention Grounding prevention Collision Prevention	Safety	Casualties Insurance cost Repair & replacement cost
Social Values	Smoke, NOX, SOX Waste, Sewage, Ballast Wake & Noise Recycling & Scrapping	Environmental Friendliness	Health Risk Environment fees & fines Disposal cost

IMO Energy Efficiency Design Index

$$\text{EEDI} = \text{Energy Efficiency Design Index} = \frac{\sum C_F \cdot SFC \cdot P}{\text{Capacity} \cdot V_{ref}}$$

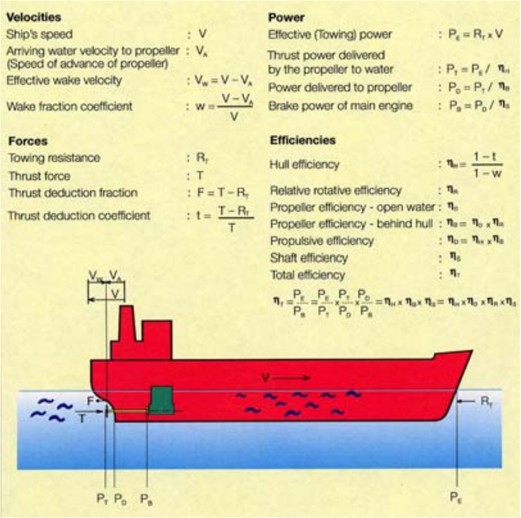
C_F =	Non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content (C_F = approximately 3.1).
SFC =	Specific fuel oil consumption for the engine in g per kW per hour.
Vref =	Ship speed, measured in nautical miles per hour (knot), on deep water in the maximum design load condition (scantling condition) at 75 % of the maximum output of the engine(s) and assuming the weather is calm with no wind and no waves..
Capacity =	Deadweight in tonnes for container ships, bulk carriers, tankers, gas tankers, and general cargo ships. For passenger ships capacity is defined as the ships Gross Tonnage, GT, as such ships are more 'volume carriers' instead of 'deadweight carriers'.
P =	Engine power in kW which shall include both the main engine power for propulsion (75 per cent MCR) and the auxiliary engine power for other purposes. The latter is interpreted as the power used on a daily basis and shall be estimated as 3 to 5 per cent of the main engine power, no matter how much auxiliary engine power is actually installed. For main engine power of 10 000 kW or above the auxiliary power is defined as: $0.025\ P_{prop} + 250$ kW For main engine power of less than 10 000 kW the auxiliary power is defined as: $0.050\ P_{prop}$
P_{prop}	Total installed main engine propulsive power in kW.

Propulsion Power

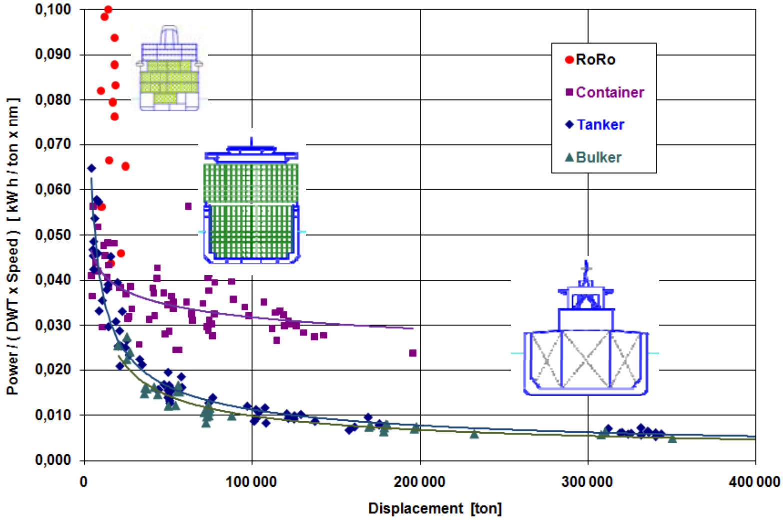
$$EEDI = \frac{\sum C_F \cdot SFC \cdot P}{Capacity \cdot V_{ref}}$$

Power Factor

$$PF = \frac{Propulsion\ power}{DWT \times Speed} \left[\frac{kWh}{ton \times nm}\right]$$



Design Criteria for CO2 Emissions
Power Factor



Kai Levander 2009-09-18 SeaKey Naval Architecture 21

Reducing CO2 Emissions from Ships

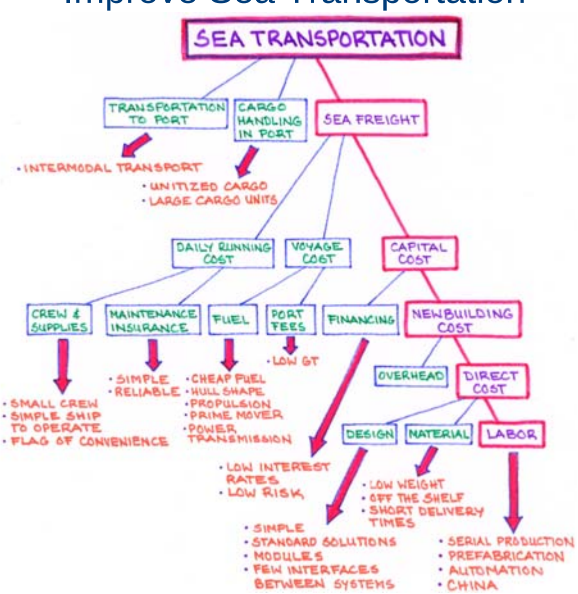
- Economy of Scale - Increased Ship Size
- Reduced Speed at Sea - Shorter time in Port
- Lower Hull Resistance
- Better Propulsion
- High-Efficient Power Plant
- Environmental Friendly Energy
- Wild Cards

Kai Levander 2009-09-18 SeaKey Naval Architecture 22

Improve Sea Transportation

Kai Levander 2009-09-18 SeaKey Naval Architecture 23

Improve Sea Transportation



Kai Levander 2009-09-18 SeaKey Naval Architecture 24

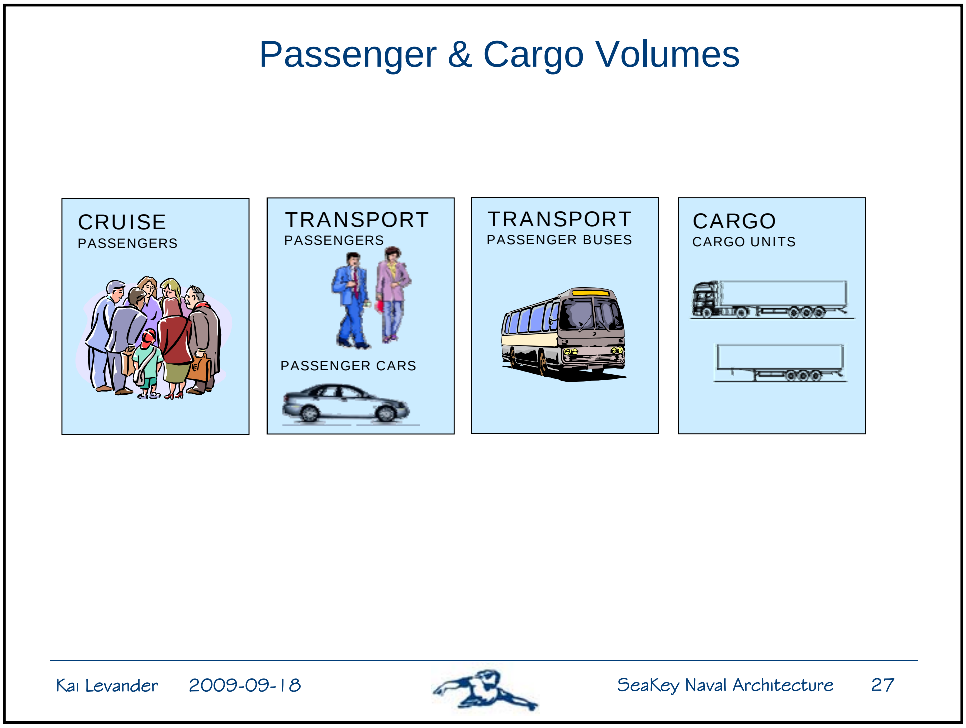
Ferry Business

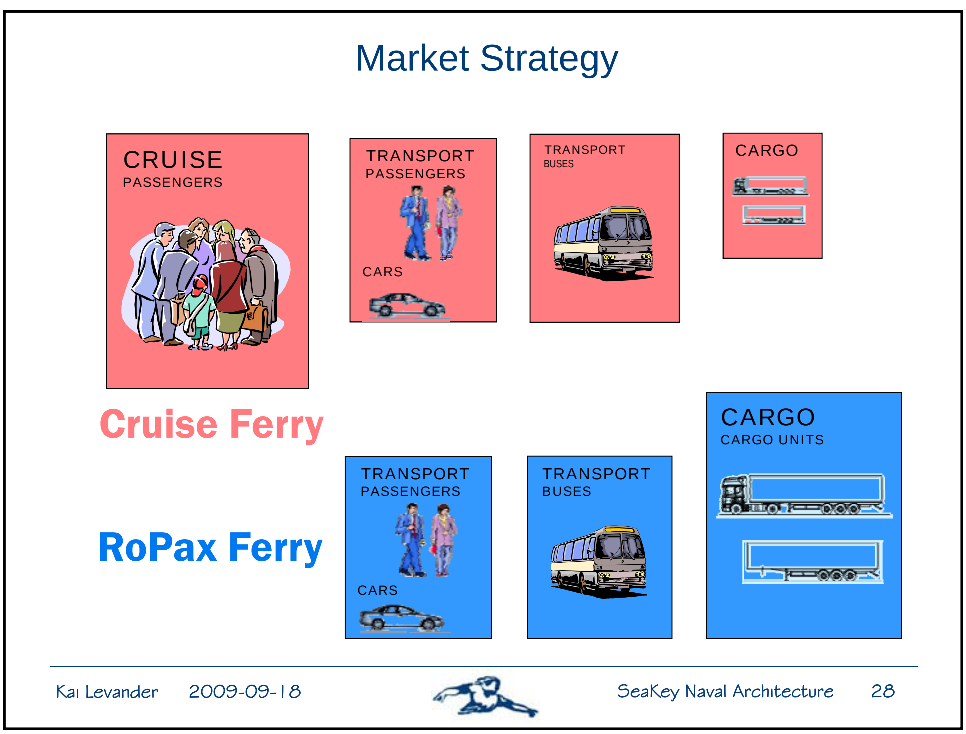
What are the Success Factors

Kai Levander 2009-09-18 SeaKey Naval Architecture 25

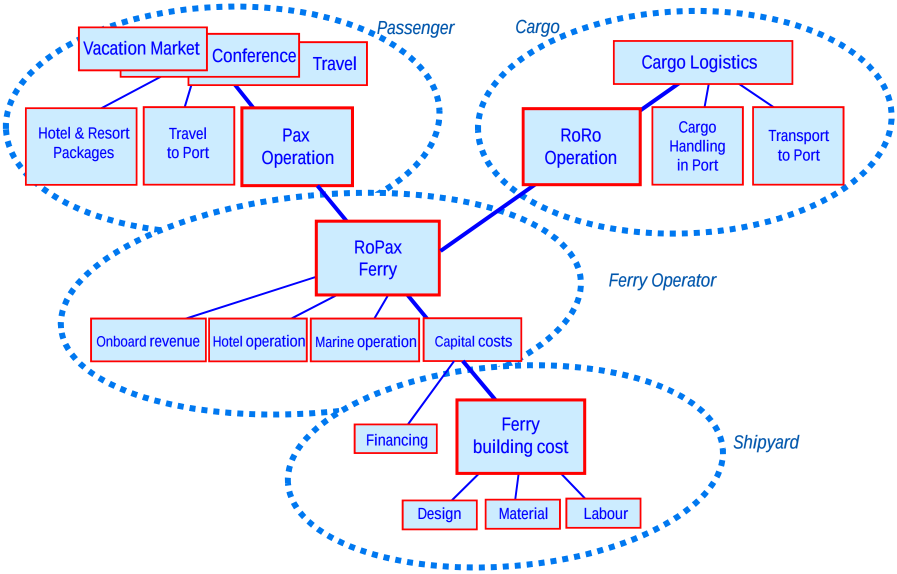
RoPax Ferry - Key Performance Indicators

Impact Area	Technology Drivers	Goal	Indicator
Construction	Design Concept Standard Solutions Modular Construction Supplier Networking	Construction Efficiency	Building price [EUR / GT] Building cost [EUR / LWT]
Payload Functions	Passenger Capacity Cabins and Public Spaces RoRo Cargo Capacity	Ticket Revenue Onboard Revenue Freigh Revenue	Money making potential [EUR / day]
Onboard Service	Food & Beverage Shopping Entertainment	Pax Satisfaction	Pax / Crew ratio Hotel crew cost [$ / Year]
Ship Service	Machinery Hull Form & Propulsion Fuel Type & Consumption	Energy Saving	Bunker cost [$ / Year]
	Navigation Machinery Operation Manuevering & Docking	Automation	D & E crew cost [$ / Year]
	Planned Maintenance Condition Monitoring	Reliability	Keep operating schedule
	Fire prevention Grounding prevention Collision Prevention	Safety	Casualties Insurance cost Repair & replacement cost
Social Values	Smoke & Emissions Waste, Sewage, Ballast Wake & Noise Recycling & Scrapping	Environmental Friendliness	Health Risk Environment fees & fines Disposal cost

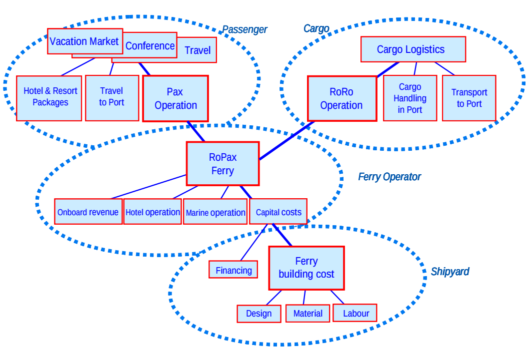

Passenger & Cargo Volumes
CRUISE
PASSENGERS
TRANSPORT
PASSENGERS
PASSENGER CARS
TRANSPORT
PASSENGER BUSES
CARGO
CARGO UNITS
Kai Levander
2009-09-18
SeaKey Naval Architecture
27


Market Strategy
CRUISE
PASSENGERS
TRANSPORT
PASSENGERS
CARS
TRANSPORT
BUSES
CARGO
Cruise Ferry
RoPax Ferry
TRANSPORT
PASSENGERS
CARS
TRANSPORT
BUSES
CARGO
CARGO UNITS
Kai Levander
2009-09-18
SeaKey Naval Architecture
28

RoPax Ferry Shipping - Success Factors



Value Added – Impact of 10 % improvement



	EUR / 12 hour trip
Higher RoRo Freight Rate	*5000*
Higher Pax Ticket Price	*2500*
Higher Pax Car Rate	*800*
Higher onboard revenue	*1800*
Reduced bunker consumption	*1000*
Reduced hotel crew cost	*520*
Reduced D&E crew cost	*350*
Reduced maintenance cost	*150*
Shipbuilding cost	*3600*

METHODS and TOOLS

Tools for Early Design Stage - Modules for the Structural Response and Load Calculations (WP3)

IMPROVE

WP3: LOAD & RESPONSE MODULES

*(**UZ**)University of Zagreb, Zagreb, Croatia (WP leader)*

*(**ANAST**) University of Liège, Liège, Belgium*

***DN&T**, Liège, Belgium*

***MEC**-Insenerilahendused , Talin, Estonia*

*(**TKK**)Helsinki University of Technology, Helsinki, Finland*

*(**BV**) Bureau Veritas, Neuilly-Sur-Seine, France*

*(**NAME**) Universities of Glasgow and Strathclyde, Glasgow, Scotland, UK*

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

WP 3: The overall objective

•To **develop, update and validate missing calculation modules** that will be integrated with the core design tools (LBR5, OCTOPUS, CONSTRUCT) through integration tasks.

•**The load and response calculation modules**, corresponding to the design problem and design methods previously identified, form the core of the design feasibility control of the entire IMPROVE approach.

•They must be streamlined **to fit the synthesis methods** with specific requirements (fast execution for multiple optimizations runs).

•They may also be relaxed to fit tolerances of the **concept design phase.**

•Testing of the fulfillment of tolerances for the fast optimization process to **be used for the application cases** (in WP6 to WP8).

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

WP3 tasks:

TASK 3-1: Modules to perform **stress and strength analysis** at

Task 3.1a Modules for stress analysis modules

Task 3.1b Vibration modules

TASK 3-2: Modules to assess **ultimate strength**

TASK 3-3: Modules to assess **fatigue**

TASK 3-4: Models to assess **design loads** (hydrodynamic loads, sloshing, …) and accidental loads (crashworthiness)

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE (WP3 T3.1a)

New and Updated Modules to Performed Stress and Strength Analysis

V. Zanic, T. Jancijev, J. Andric, M. Grgic, S. Kitarovic, P. Prebeg

(UZ)University of Zagreb, Zagreb, Croatia

P. Rigo, C.Toderan, D. Desmidts, A. Amrane, T. Richir, E. Pircalabu,

(ANAST) University of Liège, Liège, Belgium

M. Lappy

DN&T, Liège, Belgium

4

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Deliverable contains three groups of activities:

A) **D**evelopment of fast and **efficient equivalent modeling** modules for the concept design. **Modules developed enable efficient calculations of: 1) corrugated bulkhead, 2) cofferdam and 3) double bottom structures.**

B) Verification and validation of the existing response modules, including their improvements. New design procedure for multi-deck ships, based on generic ship models was introduced. Structural feasibility module according to BV Rules was developed.

C) Development and improvements in the optimization modules

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

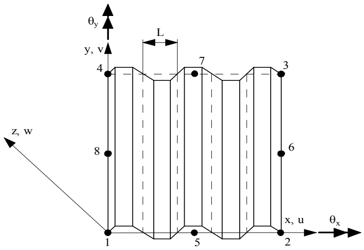
A) EFFICIENT EQUIVALENT MODELING MODULES FOR THE CONCEPT DESIGN

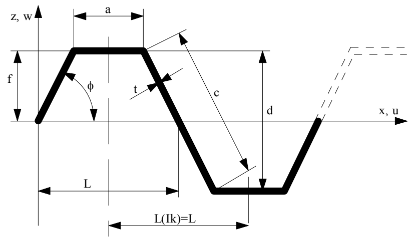
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

A1) FE modeling of equivalent corrugated bulkhead

•Through this sub-task the development and validation of **eight-node isoparametric shell finite element** for corrugated bulkhead was carried out by UZ and was incorporated into OCTOPUS software.





Developed through introduction of anisotropy into plane shell isoparametric FE. Anisotropy for membrane and plate stress state is discussed separately.

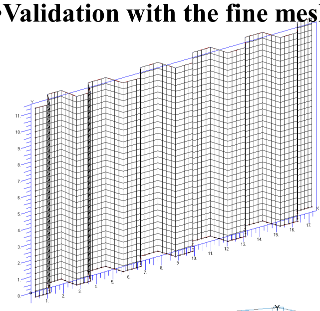
Constant thickness property equal to the bulkhead thickness, while the influence of the corrugation is taken through Young's modules in both directions (considering sectional scantlings of the half wave of corrugation).

Improve

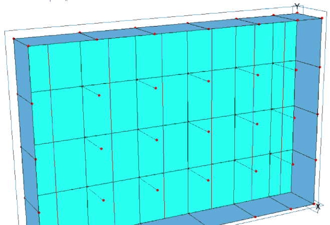
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

VALIDATION OF THE EQUIVALENT CORRUGATED BULKHEAD FE

•**Validation with the fine mesh NASTRAN FE** model was carried out.

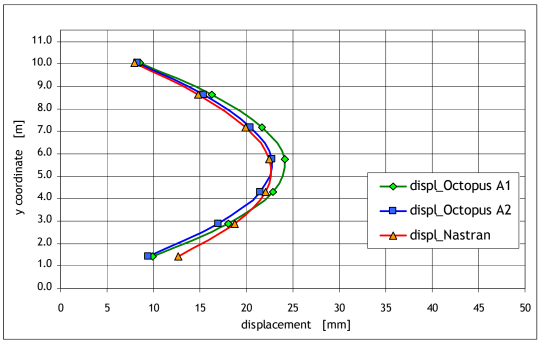


NASTRAN model



OCTOPUS model

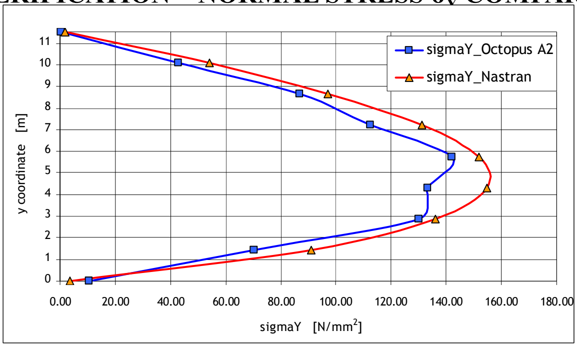
DISPLACEMENT COMPARISON



Improve

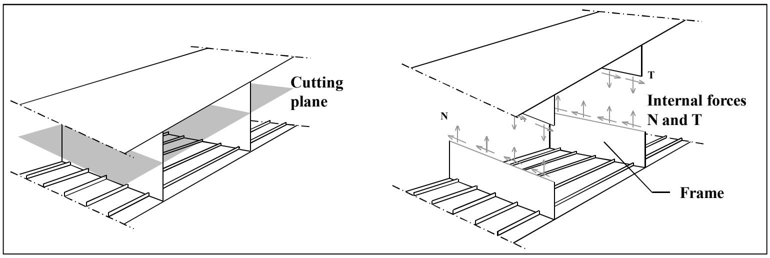
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

VERIFICATION – NORMAL STRESS σ_Y COMPARISON



Comparison of OCTOPUS model with NASTRAN fine mesh FE model shows very good agreement of displacements and normal stress. **The normal membrane stresses vary up to 15%.**

A2) Development of a equivalent double bottom element for the LBR-5 software



Through this sub-task the development and validation of the double-hull element was preformed taking into account the **additional stiffness brought by the double-hull web frames as well as the link they constitute between these web frames and the double-hull plating** (inner hull and outer hull).

A2) Development of a equivalent double bottom element

➢Analytical formulation is based on differential equations of "stiffened panel"

➢The methodology is validated with respect to FEM.

➢The optimization using "double-hull" element requires significant computation time. It's necessary to reduce this computation time. This topic will be the main goal of future work.

➢The development of an additional constraints on web frame thickness in order to prevent their buckling will be also one of the future tasks.

Improve

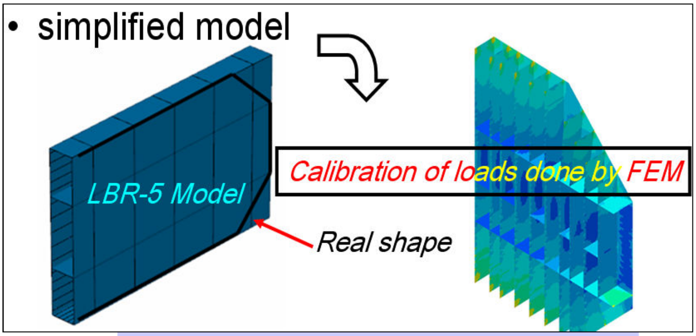
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

A3) Development of Equivalent Modeling of cofferdams for LBR-5

Through this sub-task the development and validation of **modeling of cofferdams using LBR-5** software is presented.

It enables better coordination's between longitudinal and transverse structure optimization.

Development done in this chapter is only focusing on the problem of LNG cofferdam structure.



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

A3) Development of Equivalent Modeling of cofferdams

CONCLUSIONS:

- The stresses obtained in the symmetry axis with **LBR5 are in average 15-20% higher than the FEM solution** for the two load cases.
- The differences are due to several reasons, including the LBR5 geometry and scantlings approximations and the differences between the two considered methods for the analysis.
- **The differences at the extremities are influenced by the boundary conditions and the rectangular shape** used by the LBR5 model.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

B) VERIFICATION AND VALIDATION of the existing response modules

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

B1) Modules for **the longitudinal strength** calculation have been examined and improved.

Method is based on the **extended beam theory with shear flow calculations**.

The **comparison** between 2D OCTOPUS/LBR-5 and 3D FE models was carried out on the RoPax and LNG structure as an examples.

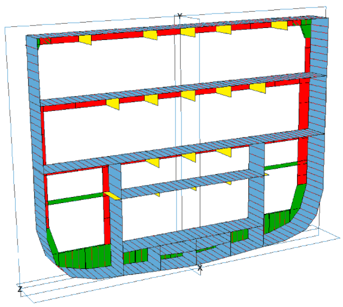
B2) Module for the **transverse strength calculation** has been examined.

Method is based on the different types of specially developed FE (macroelements: bracket beam element, stiffened Q8 elements, etc.)

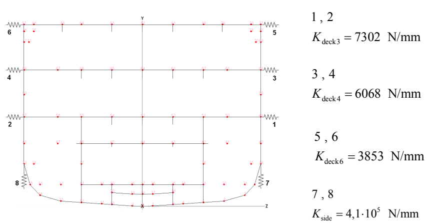
The **comparison of transverse beams normal stress between 2D OCTOPUS and 3D FE models of RoPax structure** for symmetric and asymmetric load case was carried out.

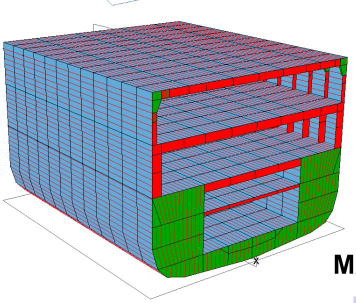
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

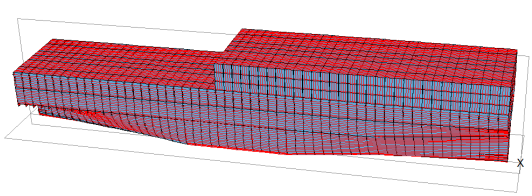
STRUCTURAL MODELS – OCTOPUS 2D MODEL& 3D FE MODEL



Octopus model – springs:





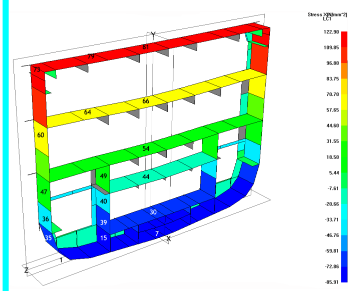


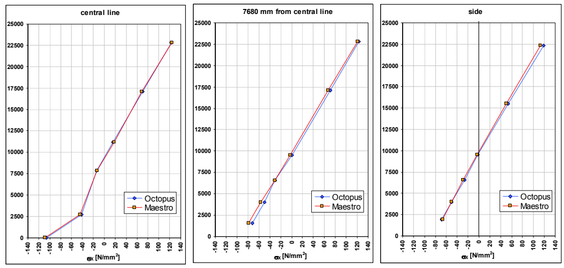
MAESTRO 3D PARTIAL MODELS

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

B1) VALIDATION – LONGITUDINAL STRESS FIELD (LC 1)

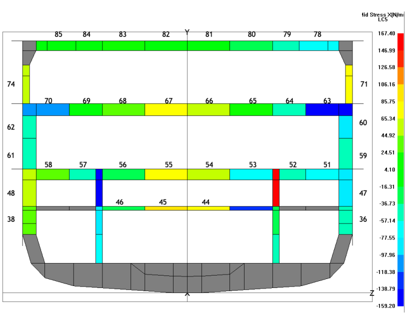
CL				z = 7680 mm from CL				side - SB			
position [mm]	strake	OCTOPUS [N/mm²]	MAESTRO [N/mm²]	position [mm]	strake	OCTOPUS [N/mm²]	MAESTRO [N/mm²]	position [mm]	strake	OCTOPUS [N/mm²]	MAESTRO [N/mm²]
0	7	-105,87	-108,80	1568	15	-72,09	-79,07	1958	1	-68,51	-66,35
2680	30	-41,34	-44,53	3980	39	-49,94	-56,34	3980	35	-49,94	-50,02
7840	44	-14,50	-13,19	6560	40	-30,17	-30,33	6560	36	-26,25	-28,73
11200	54	16,36	17,98	9520	49	0,93	-2,79	9520	47	-1,98	-3,45
17100	66	70,54	68,88	17100	64	70,54	67,09	15550	60	53,58	50,38
22800	81	122,90	123,60	22800	79	122,90	120,90	22360	73	118,45	113,00

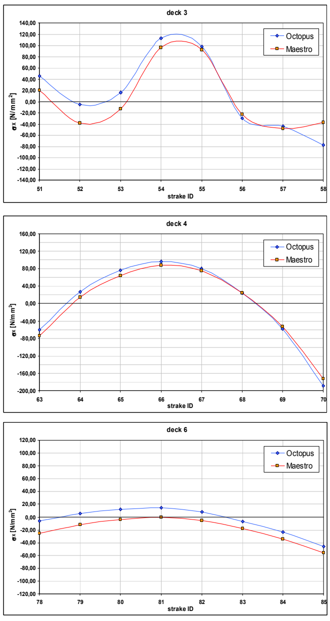




IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

B2) VALIDATION –STRESS IN TRANSVERSE BEAMS (LC 5)





deck 3				deck 4				deck 6			
strake	OCTOPUS [N/mm²]	MAESTRO [N/mm²]	Δ [%]	strake	OCTOPUS [N/mm²]	MAESTRO [N/mm²]	Δ [%]	strake	OCTOPUS [N/mm²]	MAESTRO [N/mm²]	Δ [%]
51	45,24	19,83	14,7	63	-60,31	-73,91	7,9	78	-6,03	-25,42	11,2
52	-5,56	-38,91	19,3	64	27,21	13,64	7,8	79	5,52	-12,16	10,2
53	16,03	-13,08	16,8	65	76,46	64,38	7,0	80	12,03	-3,68	9,1
54	112,30	96,06	9,4	66	96,56	87,81	5,1	81	14,38	-0,47	8,6
55	98,10	91,85	3,6	67	79,91	75,07	2,8	82	8,28	-5,00	7,7
56	-30,00	-22,82	-4,2	68	24,53	24,19	0,2	83	-6,82	-17,81	6,4
57	-44,14	-48,67	2,6	69	-58,26	-53,45	-2,8	84	-23,82	-34,27	6,0
58	-77,76	-37,33	-23,4	70	-189,20	-173,00	-9,4	85	-46,13	-56,27	5,9

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

B1-2) Validation –longitudinal and transverse stress

Accuracy regarding longitudinal stresses found to be **satisfactory** compared to 3D FEM model **for the purpose of concept design(bellow 5%)**.

Analytical formulaton of secodary stresses (due to grillage bending) were introduce and validate. The differences found in distributions of secondary longitudinal stresses are acceptable.

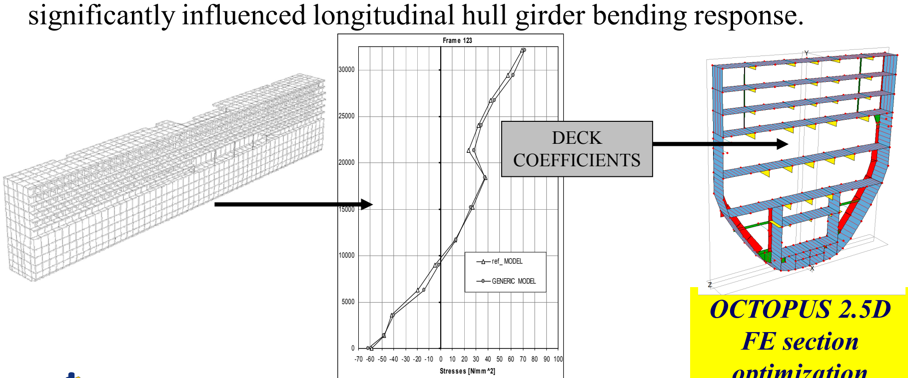
The total **normal stresses in beams flange (axial+bending) in 2D models are larger (up to 15% in racking case)** than in MAESTRO model which is acceptable for the concept design phase.

Sensitivity analysis due to **horizontal spring influences were investigated for inclined load condition**.

B3) Validation of simplified generic 3D FEM models

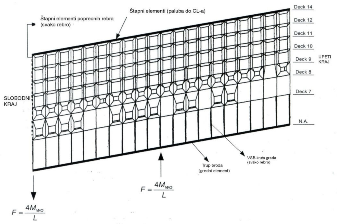
Simplified way of modelling complex primary structural response of the multi-deck ships (eg. RoPax) has been established using the generic coarse mesh 3D FE models.

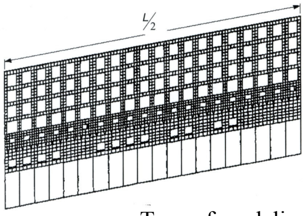
Especially considerations is given for **equivalent modelling of large side openings in large superstructure** due to fact that can significantly influenced longitudinal hull girder bending response.



GENERIC MODELS – MODELING OF SIDE OPENINGS

Comparison of accuracy of different methods – <u>LR approach</u> [2002]





Type of modeling:

	Displacement error (%)			
MODEL ($h_w/h : s_w/s$)	**A**	**B**	**C**	**D**
Model-1 (0.3 : 0.3)	/	2.1	**2.4**	8.0
Model-2 (0.5 : 0.5)	/	2.9	**3.6**	18.1
Model-3 (0.7 : 0.7)	/	5.5	**7.0**	20.1 (11.6)*
Model-4 (0.8 : 0.8)	/	6.0	6.8	**(5.6)**
Model-5 (0.9 : 0.9)	/	7.4	7.9	**(5.3)**
Model-6 (razni po visini)	/	3.6	4.1	/

Note: values in ( )* for model D – beam coarse mesh FEM model

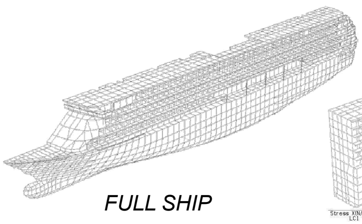
A - fine mesh FEM model,
B - orthotropic panel approach
C - equivalent plate thickness approach
D - coarse mesh FEM model,

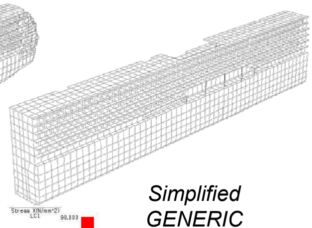
Differences in displacement of the models **<u>B, C i D (equivalent approach)</u>** with respect to model **A (fine mesh)** :

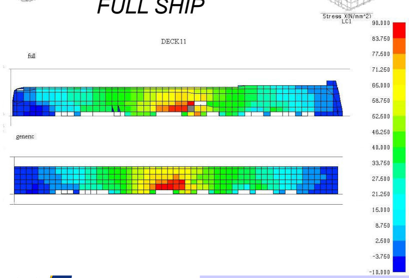
<u>Test Example: CRUISE SHIP</u>

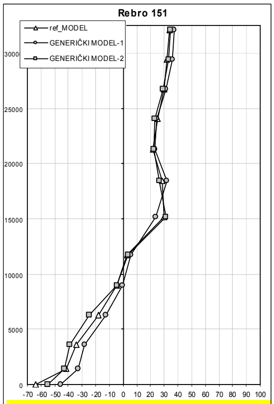
• Over **superstructure decks differences bellow 7%.**

• Over lower **hull decks structure differences bellow 15%**→ error increase with distance from the midship due to the differences in the hull form modeling.









Primary stress distribution

C) DEVELOPMENT AND IMPROVEMENTS IN THE OPTIMIZATION MODULES

Improve

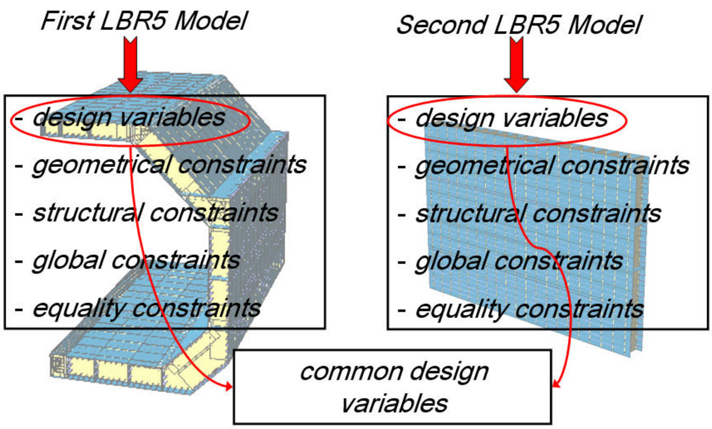
DEVELOPMENT OF A DISCRETE OPTIMIZATION MODULE IN THE LBR-5 SOFTWARE

- The LBR-5 considers only real variables to perform optimization.
- Some variables take integer values (plate thickness) or values chosen within a specified set (standard stiffeners).
- The LBR-5 solver doesn't comply with the discrete nature of such variables. This implies a post processing phase in which the designer has to round off the non-integer values, which usually reduces the benefit.
- To avoid this, **new optimization method is developed to consider the discrete nature of the design variables**. A model and a heuristic procedure have been formulated to add a discrete optimization module in LBR5.
- The algorithm has been implemented and executed with realistic ship structures. It provides very satisfying results, that are better than those obtained in the industry by manual rounding.

Improve

DEVELOPMENT OF A MULTI-STRUCTURE MODULE IN THE LBR-5 SOFTWARE

Purpose : To optimize simultaneously various sub-structures which share some common design variables, instead to optimize them separately (for example: cofferdam and tank)



Improve

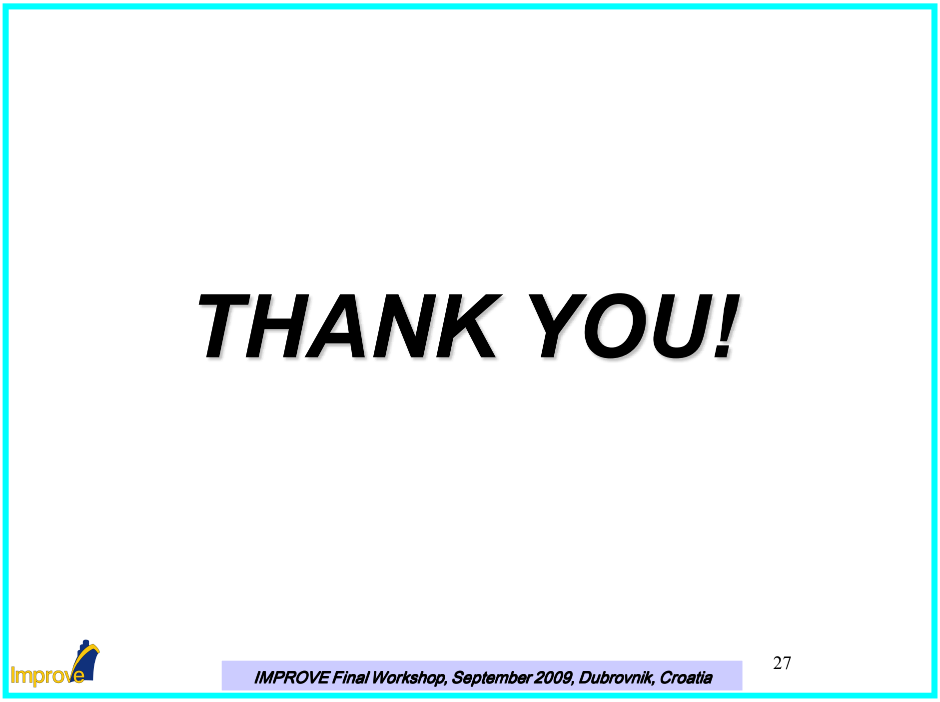
CONCLUSIONS:

Extensive theoretical models development and validation were preformed. **The results are acceptable for the concept design phase and suitable for optimization purpose.**

Finally, **newly developed modules**, integrated in existing design tools (OCTOPUS, LBR-5, CONSTRUCT) **were extensively used in application cases** to ensure rational structural design and improvement of vessels designed (LNG, ROPAX and TANKER).

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia


THANK YOU!
Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia
27

IMPROVE WP3 - T3.1.b

Local and global vibration modules

A. Constantinescu, Ph. Rigo
ANAST University of Liège, Liège, Belgium
I. Chirica, S. Giuglea
Ship Design Group, Galati, Romania

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Requirements related to vibrations

1. **Passengers, crew and drivers – comfort and human fatigue**

   - maximize human beings comfort level
   - minimize motion sickness incidences

   - vibrational parameters – measurements
   - acceptable values indicated in Standards
   - work purely experimental

Vibration avoidance for humans → specific problem of foundation and isolation

2. **Structural vibration**

   - minimize noise and vibration levels (IMO requirements)

   - global and local vibrations
   - structural damage by fatigue

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

General overview

EARLY STAGE NAVAL DESIGN

Multi-criteria optimization process

Structural calculus
Cost (construction & production)

Fatigue
Sloshing
Ultimate strength
Life cycle cost
Multi-materials
Multi-structures
Vibration

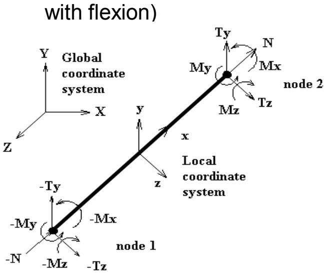
- **LBR-5 – analytical rationally based optimization software**
  - **generic stiffened structure optimization tool**
- **OCTOPUS/MAESTRO – FE analysis program**
  - **rationally-based analysis, evaluation, and structural optimization of thin-walled structures**

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Local vibrations module - Numerical modelling

- **Euler-Bernoulli beam theory (elastic homogeneous isotropic material)**
  - small perturbations
  - free vibration
  - undamped
  - free torsion (no coupling with flexion)



- **Single beam (LCS)**

$$\left[N^{L}\right]_{12x1}=\left[K^{L}\left(C_{pm},\omega\right)\right]_{12x12}\cdot\left[U^{L}\right]_{12x1}$$

C_{pm} – mechanical & physical characteristics

- **Beam structure (GCS)**

$$\left[N^{G}\right]_{nddl\,x1}=\left[K^{G}\left(C_{pm},\omega\right)\right]_{nddl\,x\,nddl}\cdot\left[U^{G}\right]_{nddl\,x1}$$

nddl – total degrees of freedom

$$\left[U^{G}\right]\rightarrow\infty$$

RESONANCE CONDITION

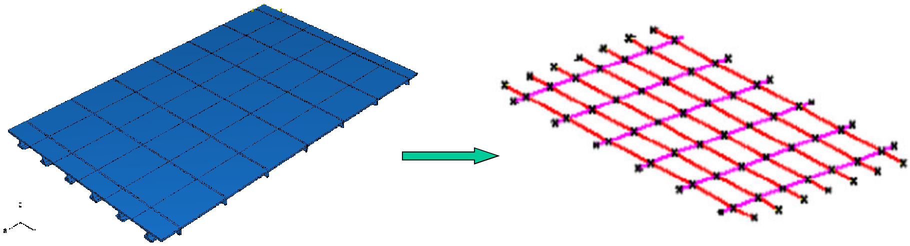
$$\det\left(\left[K^{G}\left(C_{pm},\omega\right)\right]\right)=0$$

Improve

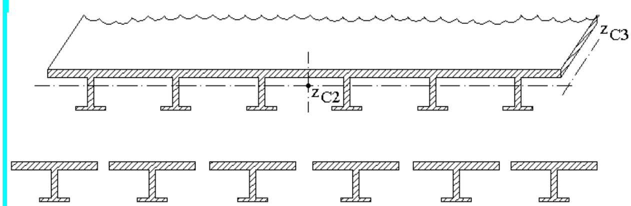
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

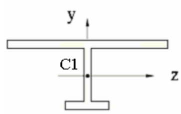
Stiffened panels model

➢ **Method → stiffened panel merged into an equivalent beam structure**



➢ **Particularities**





▪ plate mass distributed along the length of the panel

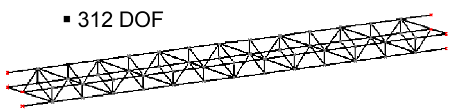
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Validation

1. 3D beam structure

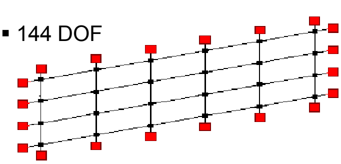
▪ 312 DOF



Frequency [Hz]	f_1	f_2	f_3
Vibration module	3.45	6.65	7.15
FE software	3.42	7.07	8.94

2. Planar beam structure

▪ 144 DOF



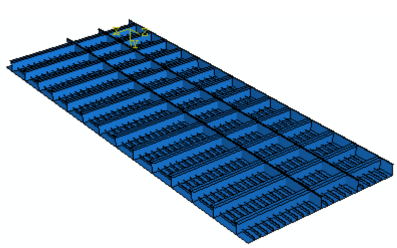
Frequency [Hz]	f_1	f_2	f_3
Vibration module	1.56	2.16	2.80
FE software	1.72	2.22	3.15

3. Complex stiffened panels

▪ real structure – half of ROPAX deck no. 1

▪ 4060 DOF

Frequency [Hz]	f_1	f_2	f_3
Vibration module	4.43	7.30	8.75
FE software (shell)	4.98	8.86	14.82
Difference	11%	17%	40%



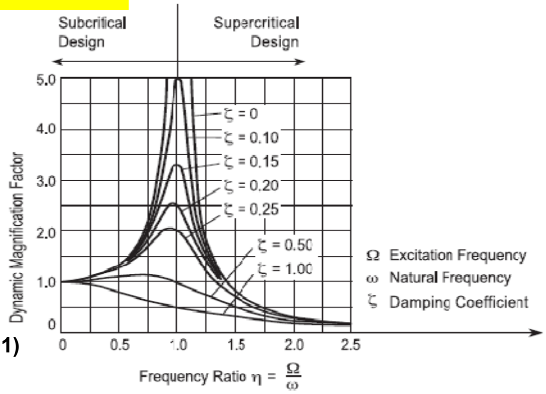
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Vibration module – structural dimensioning

Structural dimensioning and optimization in early stage design

- **Sub-critical design**
  - adapted in early stage design
  - structure more rigid
  - more heavy
- **Super-critical design**
  - more exigent
  - verifications by response calculations

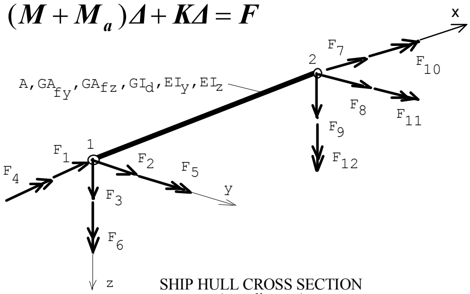


(Germanischer Lloyd, 2001)

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Global Vibrations

The equation of the ship vibrations $(\boldsymbol{M}+\boldsymbol{M}_a)\ddot{\boldsymbol{\Delta}}+\boldsymbol{K}\boldsymbol{\Delta}=\boldsymbol{F}$



$\boldsymbol{M}_a$ - added mass:

- for the horizontal vibration

$$m_H(x) = C_H \frac{\pi}{2}\rho_a d^2 J_{nH}$$

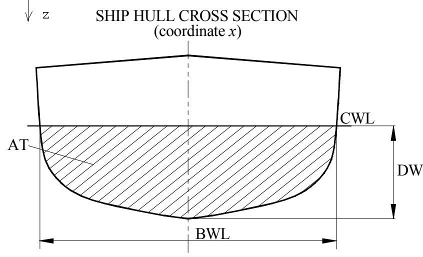
- for the vertical vibration

$$m_V(x) = C_V \frac{\pi}{8}\rho_a B^2 J_{nV}$$

- for the torsional vibration

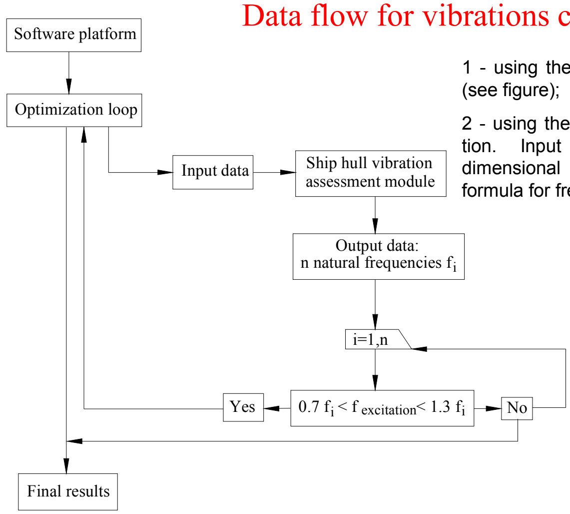
$$j_x(x) = C_{jx}\frac{\pi}{256}\rho_a B^4 \frac{(\lambda^2-4)^2}{\lambda^4} J_{nx}$$

$\lambda = 2d/B$



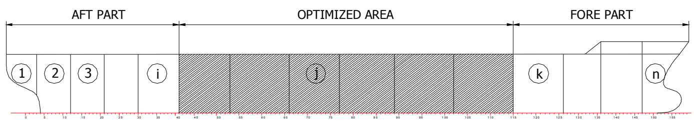
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Data flow for vibrations criteria



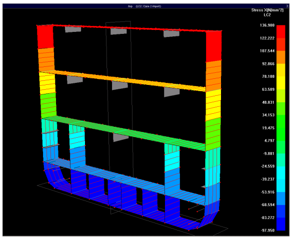
1 - using the module inside the optimization loop (see figure);

2 - using the module before to start the optimization. Input data: various combinations of dimensional parameters. Finally will be obtain a formula for frequency f(p1, p2, p3, …)



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

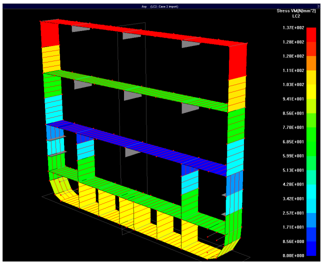
CALCULATION OF BEAM MODEL SECTIONAL PARAMETERS FEM BASED EXTENDED BEAM THEORY



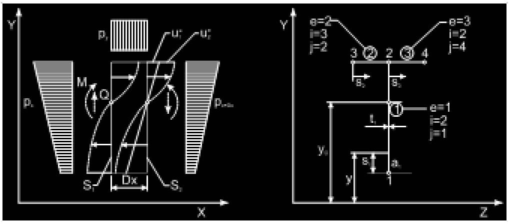
LC 2 - σ_x

- Primary strength fields
  - Warping displ.; normal/shear stresses
  - Extended beam theory (cross section warping fields via FEM in vertical / horizontal bending and warping torsion)

RoPax



LC 2 - σ_{VM}



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

CALCULATED CROSS-SECTIONAL CHARACTERISTICS
(for beam segment n)

- **Cross-section area *A***
- **Centroid *YCG, ZCG*,**
- ***Shear/torsion center* YCT, ZCT**
- **Moments of inertia w.r.t. centroid: I_Y , I_Z, I_{YZ}, I_p principal: I_1, I_2, φ_0-angle of axis-1 w.r.t. Z-axis**

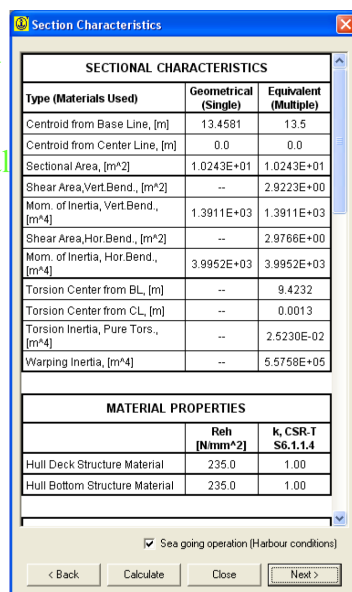
- **Bending flexural stiffness EI_Z , EI_Y**
- ***Bending shear stiffness* GA_V , GA_H**
- **Cross-section axial stiffness *EA***
- ***Torsional stiffness* GI_T**
- ***Warping stiffness* EI_W**

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

FEM PRIMARY RESPONSE ANALYSIS

- Calculation of parabolic shear stress flow from horizontal and vertical bending,
- Calculation of normal stresses and normal stress correction caused by shear stresses.
- Calculation of section characteristics required for Class minimal dimensions calculations
- Boundary conditions for 3 HOLD model
    - **Sectional characteristics for vibration analysis using 1D+2D model**



SECTIONAL CHARACTERISTICS

Type (Materials Used)	Geometrical (Single)	Equivalent (Multiple)
Centroid from Base Line, [m]	13.4581	13.5
Centroid from Center Line, [m]	0.0	0.0
Sectional Area, [m^2]	1.0243E+01	1.0243E+01
Shear Area,Vert.Bend., [m^2]	--	2.9223E+00
Mom. of Inertia, Vert.Bend., [m^4]	1.3911E+03	1.3911E+03
Shear Area,Hor.Bend., [m^2]	--	2.9766E+00
Mom. of Inertia, Hor.Bend., [m^4]	3.9952E+03	3.9952E+03
Torsion Center from BL, [m]	--	9.4232
Torsion Center from CL, [m]	--	0.0013
Torsion Inertia, Pure Tors., [m^4]	--	2.5230E-02
Warping Inertia, [m^4]	--	5.5758E+05

MATERIAL PROPERTIES

	Reh [N/mm^2]	k, CSR-T S6.1.1.4
Hull Deck Structure Material	235.0	1.00
Hull Bottom Structure Material	235.0	1.00

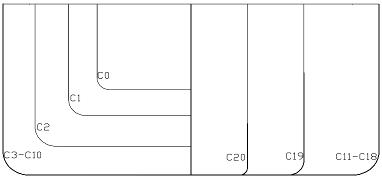
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

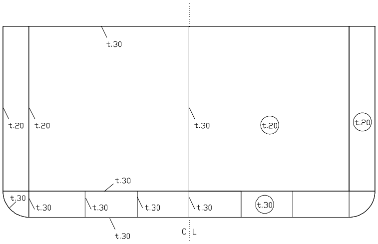
Application test for a tanker vibration calculus

The main characteristics of the ship:
Length, L = 220 m
Breadth, B = 43 m
Draught, d = 16 m

Mode No.	Vibrations in air (freq. Hz)		
	VIBHULL	COSMOS/M	Diff.(%)
1-vert.bend.	2.64	2.52	4.54
2-vert.bend.	6.49	6.11	5.85
3-vert.bend.	9.04	8.74	3.31
1-horiz.bend.	4.71	4.41	6.36
2-horiz.bend.	13.13	11.87	9.59
3-horiz.bend.	21.97	19.33	12.01
1-torsion	9.61	8.95	6.86



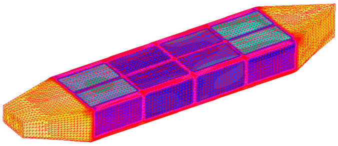
Transversal body lines



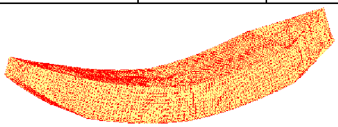
Ship cross section

Results

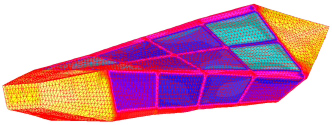
Mode No.	Vibrations in water (freq. Hz)		
	VIBHULL	COSMOS/M	Diff.(%)
1-vert.bend.	0.86	0.75	12.79
2-vert.bend.	1.94	1.68	13.40
3-vert.bend.	3.26	2.88	11.65
1-horiz.bend.	2.56	2.41	5.85
2-horiz.bend.	6.42	6.01	6.38
3-horiz.bend.	12.36	11.02	10.84
1-torsion	-	-	-



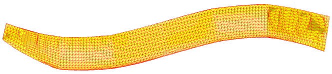
FEM 3D model (COSMOS)



First vertical modal shape (COSMOS)



First torsional modal shape (COSMOS)



Second vertical modal shape (COSMOS)

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Conclusions

1. Local vibrations module

- validated for beam structures and stiffened panels by FE results
- clamped, simply supported and free – boundary conditions on sides
- reasonable CPU time (60 s – 1100 dof, 7.30 min. – 4400 dof)
- limitation on the method (beam modeling)
- reasonable dimensions of structural elements of the stiffened panel
- compatibility structural verification system

2. Global vibration module

- vibrations in air and water (partially immerged)
- validation by FE results
- very small CPU times (< 2 s)
- limitation on the method (beam modeling)
- non-concomitant solutions

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE WP3 T3.2

Assessment of ultimate strength at the early design stage

Hendrik Naar

MEC-Insenerilahendused, Estonia

Stanislav Kitarovic, Jerolim Andric and Vedran Zanic

UZ-FMENA – University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Background

The implementation of task 3.2 should provide bases for selection of relevant tools for ultimate strength assessment in early design stage.

In early design stage, only main structural components are defined in general level. Actual topology and dimensions of those components are still subject to significant alterations.

In early design stage

•Detailed three-dimensional finite element modelling is not practical

•In the case of optimization process semi-analytical methods offer advantages over finite element analysis.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Objectives

Main requirements for method

•The method has to be time-efficient and suitable to analyse different design alternatives in early design stage.

•Despite the requirement of simplicity, for precise assessment the method could include the possibility to count for:

-influence of large shear forces

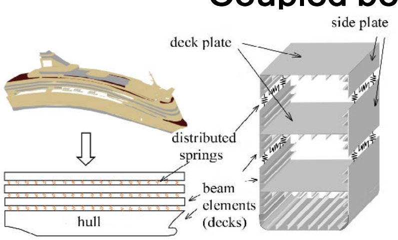
- reduction of hull girder ultimate strength due to low shear stiffness of some elements such as bulkhead or deck. (ship hull cross-section will not remain planar in bending)

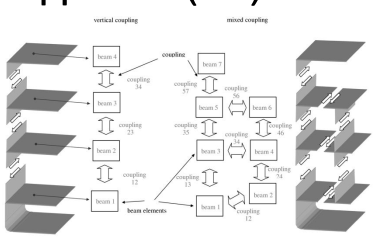
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Methods

Coupled beam approach (CB)





• Hull girder is divided into longitudinal beams that have bending and axial stiffness.

• Beams are connected by distributed springs, which transfer vertical forces and longitudinal shear forces between the beams.

• The behaviour of each beam is described with Smith type approach

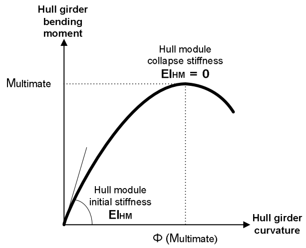
(Smith method is based on assumption that the beam cross-section remains planar in bending)

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Methods

Modified Smith approach (MS)



- Based on Smith method

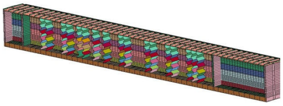
- Deck efficiency coefficients are introduced in order to consider the influence of the non-linear axial-strain distribution to ultimate strength. Estimation of efficiency coefficients is based on FE-results.

- The influence of shear stress to hull girder ultimate strength is considered by using interaction curves . The shear stress in cross-section is estimated with help of 2D finite element model describing the considered cross-section.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

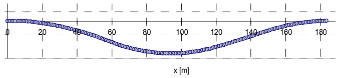
Validated structures

Tanker



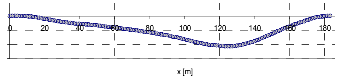
Case 1

Moment curve



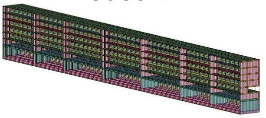
Case 2

Moment curve

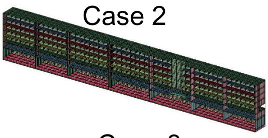


Multi-deck ship

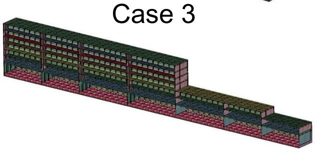
Case 1



Case 2

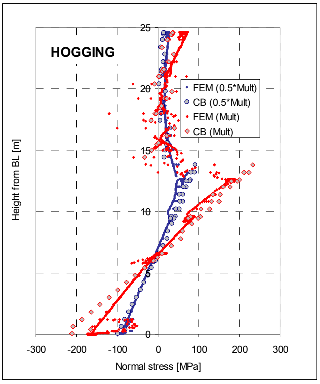


Case 3



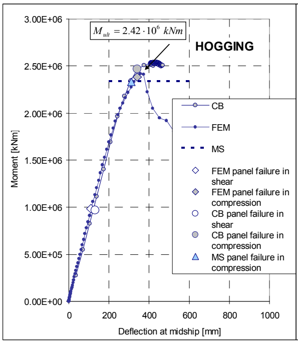
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

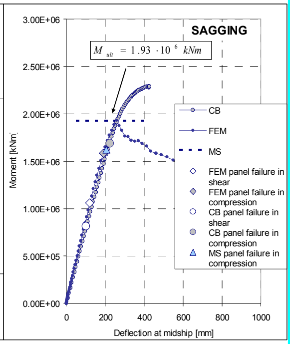
Results



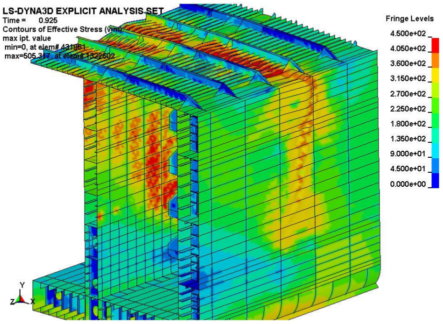
Bending stress at midship of the multi-deck ship

bending moment at failed section of chemical tanker for structural cases 1 and 2



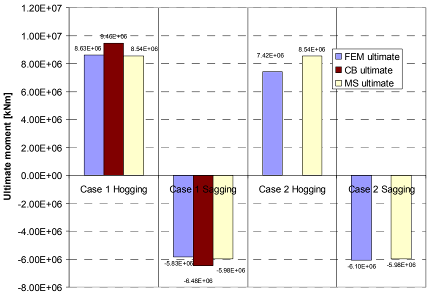


Results for tanker



Cross-section of a chemical tanker at ultimate strength in sagging loading

bending moment at failed section of chemical tanker for structural cases 1 and 2



Conclusions

The intense validation of MS and CB-approaches against FE-approach is accomplished, accuracy and limitations are given

- For MS-method a single cross-section is considered in analyses
- CB-method the structural behaviour of hull girder can be estimated well up to the ultimate load level. However, the ultimate strength will be overestimated
- For both methods the transverse strength is hard to consider
- Accuracy of MS-method
  - -for single deck ships up to 3%
  - -for multi-deck ships 1-21%
- Accuracy of CB-method
  - -for single deck ships up to 10%
  - -for multi-deck ships 2-45%

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

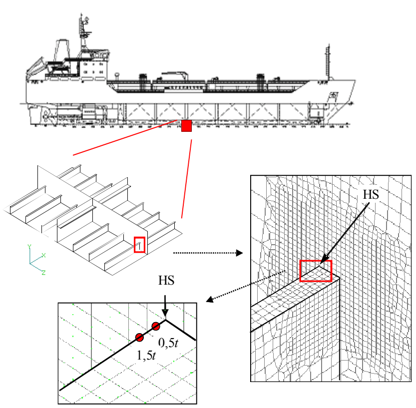
IMPROVE WP3 T3.3

Rational models to assess fatigue at the early design stage

H. Remes, M. Liigsoo
Helsinki University of Technology, Espoo, Finland
A. Amrane
ANAST University of Liège, Liège, Belgium
I. Chirica, V. Giuglea, S. Giuglea
Ship Design Group, Galati, Romania

Background and objectives

- Fatigue assessment based on detailed FE - analysis is time-consuming and is not suitable for iterative concept design
- Demand for new time-efficient approach for fatigue analysis in conceptual structural design

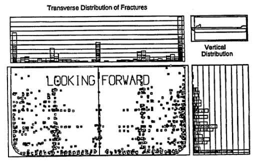


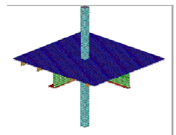
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

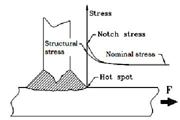
Research methods

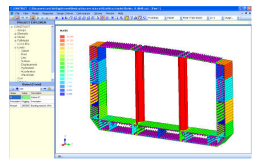
Based on a scientific and engineering approach including three steps

1. Determination of fatigue-critical connections
2. Development of fatigue approach
3. Development of implementation procedure









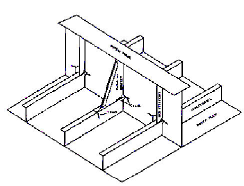
Improve

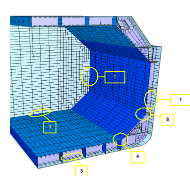
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

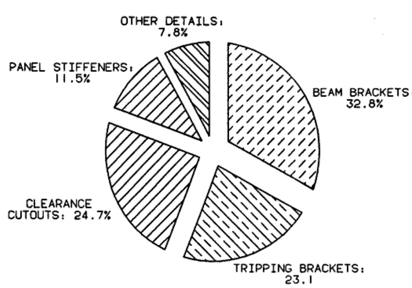
Results - Fatigue-critical details

Determination of fatigue-critical connections and details

- Base on damage statistics and pre-existing know-how
- The identification of generic and ship-type-depended features in fatigue assessment
- Focused especially on Tanker, Ropax and LNG ships







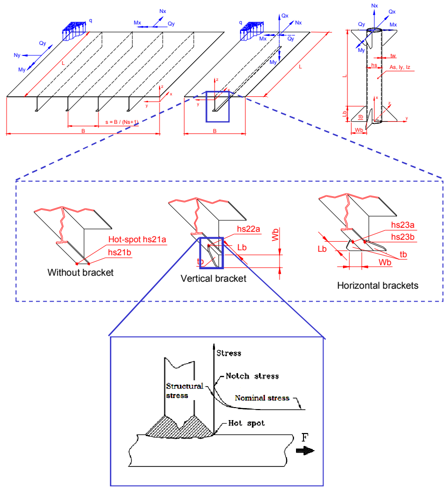
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Results – Fatigue approach

Development of fatigue approach for the early design stage

- Base on linear damage rule and notch stress method
- Generic structural elements with pre-defined hot-spot points
- Analytical formulae for notch stress analysis to obtain fast approach



$$D = \frac{N}{C} \cdot \Delta\sigma_{ln}^{\ m} \cdot log\left(10^8\right) \cdot \Gamma\left(1 + \frac{m}{h}\right)$$

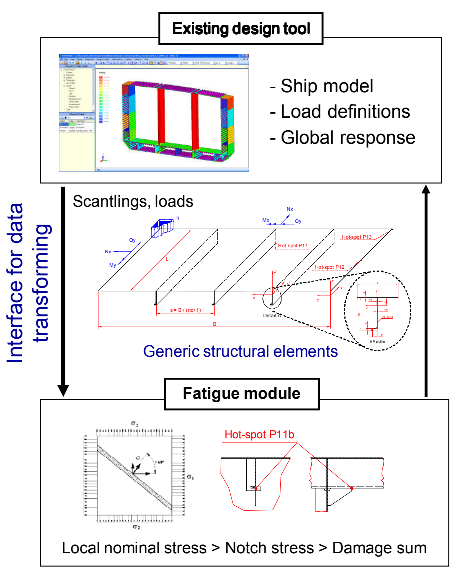
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Results – Implementation

Procedure for implementation of the approach to existing design tools

- The approach is coded to obtain stand-alone executable file (module)
- Interface between design tool and module with the help of generic structural elements
- Preliminary validation of module indicates suitable calculation speed (~1ms) and accuracy (~15%)

The details of the validation with FEM are given in WP6.



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

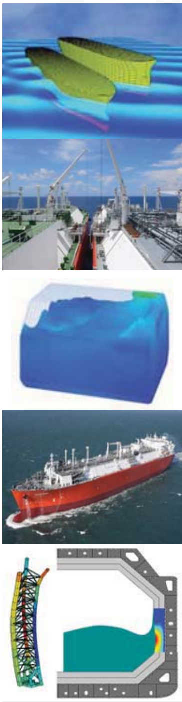
Summary

Task 3 provides:

- An approach for fatigue assessments at early design stage
  - Generic structural elements with pre-defined fatigue critical locations
  - Analytical formulas for fast analysis of notch stresses
- Procedure for implementation of the approach to product development in WP 6, 7 and 8
  - Linkage to existing design tools with the help of Generic structural elements
  - Stand-alone executable file called Fatigue module

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia



Dubrovnik, CROATIA, 17th-18th September 2009

Improve

WP3 – Task 3.4 – Sloshing Module

WP6 – Task 6.2 – STX Europe LNGC

Validation of OpenFoam for Sloshing Academic Cases

BUREAU VERITAS

Move Forward with Confidence*

*Avançons en confiance

Louis DIEBOLD
louis.diebold@bureauveritas.com

Nicolas MOIROD
nicolas.moirod@bureauveritas.com

Contents:

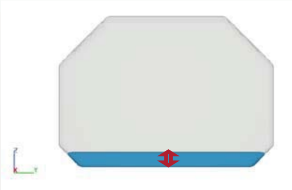
Improve

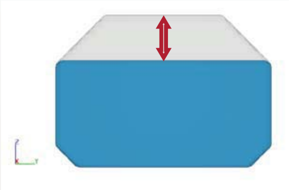
1. Objective of the WP3 – Task 3.4

WP3 – Task 3.4 – Sloshing Module

INPUT:

- **Cargo Capacities**
  - 125k ≤ Cap. ≤ 140k, 140k < Cap. ≤ 155k, 155k < Cap. ≤ 180k ⇒ some reserves are given
- **World wide service conditions**
- **Standard fillings**
  - R≤10%H
  - R≥70%H





OUTPUT:

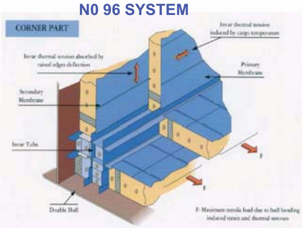
- **Representative design pressure on stiffeners and platings for structural verification according to BV Rules**

2. BV Sloshing Methodology for Membrane LNGC

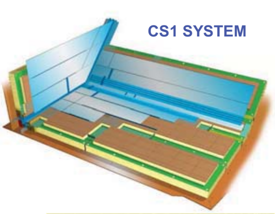
Cargo Containment System: Membrane Type

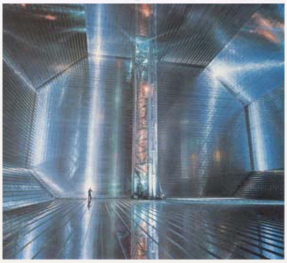
MEMBRANE LNG CONTAINMENT SYSTEMS – GTT N0 96, Mark III, CS1

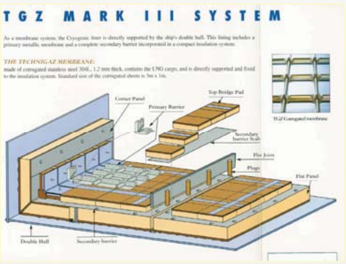
N0 96 SYSTEM



CS1 SYSTEM







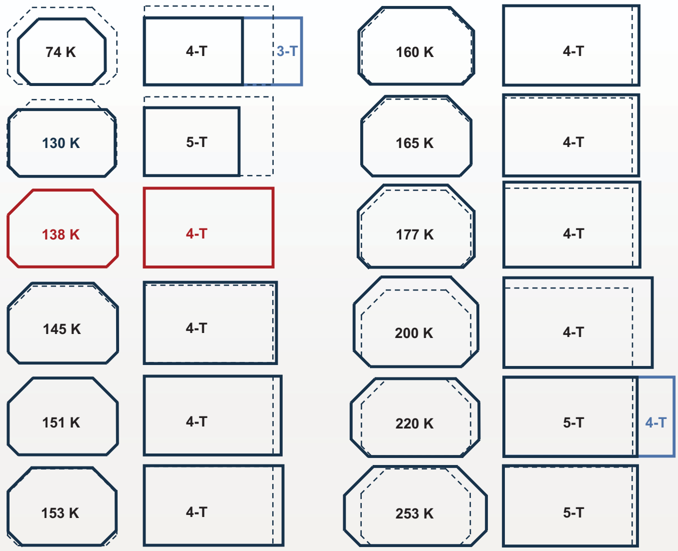
BV INVOLVEMENT DURING DEVELOPMENT AND CONCEPT APPROVAL

Sloshing Assessment – Comparative Approach

REFERENCE SHIP

COMPARATIVE APPROACH:

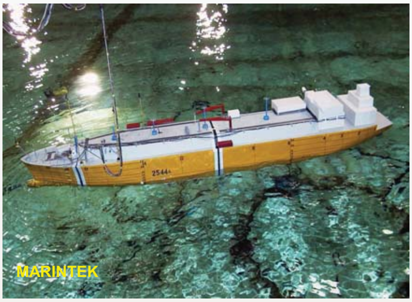
"… as good as standard 138k design…"



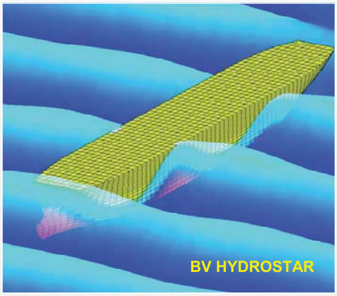
Hydrodynamic Analysis

- **WHY ?**
  - Generate response of tank liquid by wave-induced ship motion
  - Frequency & Time-domain 6 d.o.f. motion → **SLOSHING EXCITATION**
- **HOW ?**

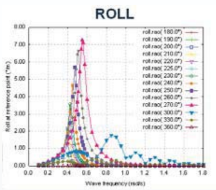
BASIN MODEL TESTS

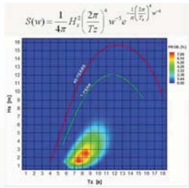


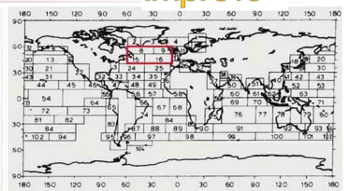
HYDRODYNAMIC COMPUTATION



Hydrodynamic Analysis (HydroSTAR)







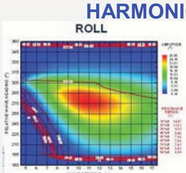
Transfer Function

Environmental Conditions

IACS North Atlantic Rec.34

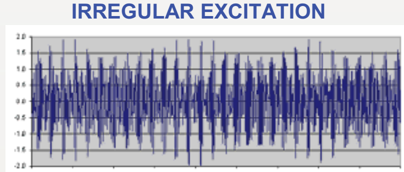
40-yr & 1-yr Retrun Period

HARMONIC EXCITATION



MOTION	Reference point: CoG		
	Ampl. (m or dg)	Period (s)	Phase (dg)
SURGE	0.409	8.95	324.1
SWAY	1.411	8.72	285.8
HEAVE	4.363	8.82	205.5
ROLL	1.396	8.99	23.4
PITCH	2.884	8.30	312.5
YAW	1.256	7.77	33.9

IRREGULAR EXCITATION

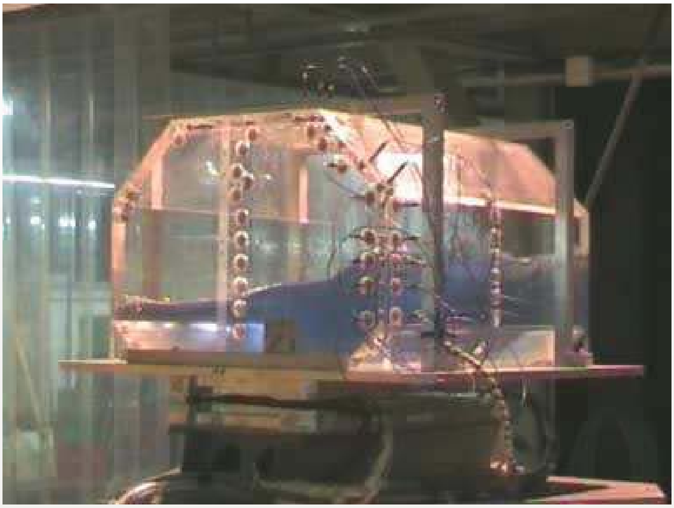


Liquid Motion Analysis: Sloshing Definition

- Sloshing, a violent behaviour of liquid contents in tanks submitted to the forced vessels' motion on the sea represents one of the major considerations in LNG vessels design over several past decades

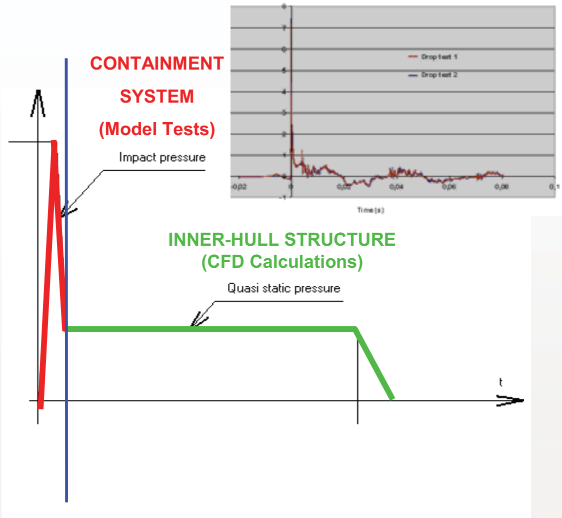
Liquid Motions Analysis

▶ **BV sloshing model tests (in cooperation with ECN)**



Liquid Motion Analysis:
CCS & Inner Hull: Impact & Quasi-static Loads

DROP TESTS OR EQUIVALENT:

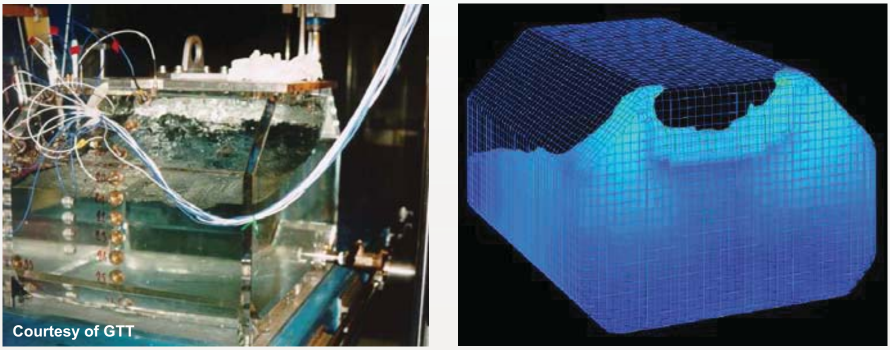


Liquid Motion Analysis:
Sloshing Model Tests & Numerical Simulation

General procedure :

State of the art of sloshing analysis relies on small-scale sloshing model tests supported by extensive developments of CFD computation techniques, commonly studying one isolated tank submitted to the forced motion without their mutual interaction

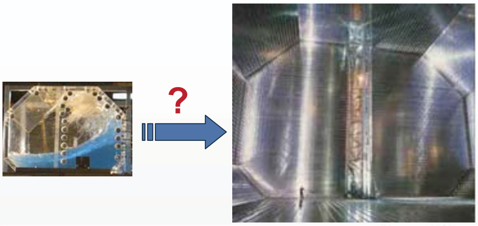
SLOSHING MODEL TESTS | **NUMERICAL SLOSHING SIMULATION**



Liquid Motion Analysis:
Sloshing Model Tests • Scaling Laws ?

FLUID FLOWS ARE CONSIDERED IDENTICAL WHEN MATCHING:

1. Same kinematics and dynamics (velocity and pressure fields)
2. Same boundary and initial conditions (geometry)
3. Same dimensionless numbers based on their physical properties



PHYSICAL PROPERTY:	MODEL:	PROTOTYPE:
Density	1000 kg/m^3	425 - 470 kg/m^3
Kinematic viscosity	1×10^6 m^2/s	3×10^7 m^2/s
Compressibility	4.8×10^{-10} m^2/N	7.25×10^{-10} m^2/N
Surface tension	74 dyne/cm	13 dyne/cm
Celerity of sound	1500 m/s	1700 m/s

INERTIA / GRAVITATION FORCE	⇨	FROUDE NUMBER	$F_n = \frac{U}{\sqrt{gD}}$
INERTIA / COMPRESSIBILITY FORCE	⇨	CAUCHY NUMBER	$C_a = \rho\gamma U^2$
INERTIA / ACOUSTIC FORCE	⇨	MACH NUMBER	$M_c = \frac{U}{C}$
INERTIA / VISCOUS FORCE	⇨	REYNOLDS NUMBER	$R_n = \frac{UD}{\nu}$
INERTIA / SURFACE TENSION	⇨	WEBER NUMBER	$W_e = \frac{\rho DU^2}{\sigma}$
INERTIA / VAPOR PRESSURE	⇨	CAVITATION NUMBER	$\varsigma = \frac{P_0 - P_v}{\frac{1}{2}\rho U^2}$
GAS / LIQUID DENSITY	⇨	DENSITY RATIO	$\frac{\rho_{gas}}{\rho_{liq}}$

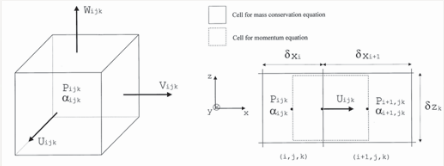
Liquid Motion Analysis: Numerical Simulation

CFD: THEORETICAL BACKGROUND

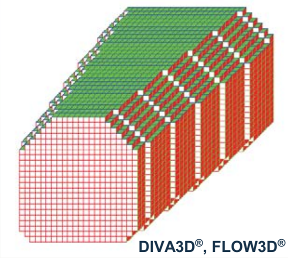
Main Features:
- 2 viscous phases: liquid + gas
- Any excitation mode (6 d.o.f.), harmonic or irregular
- Cartesian or cylindrical meshing

Mathematical formulation:
- Navier-Stokes equations: Mass & Momentum conservation
- Free surface equation

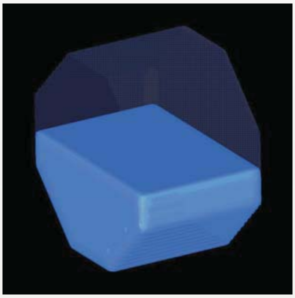
Discretisation:
- Finite volume scheme
- Volume Of Fluid method



Elementary cell with unknowns — Control volumes

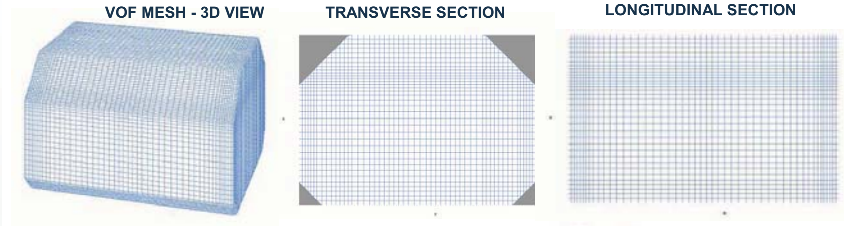


DIVA3D®, FLOW3D®

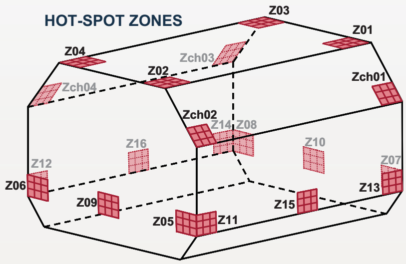


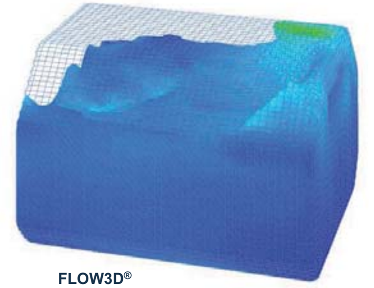
Liquid Motion Analysis: Numerical Simulation • CFD • VOF Mesh

VOF MESH - 3D VIEW — TRANSVERSE SECTION — LONGITUDINAL SECTION



HOT-SPOT ZONES





FLOW3D®

Liquid Motion Analysis:
CFD • Main Considerations ?

- **Pressure calculated in each cell of VOF mesh DOES NOT CONSIDER IMPACT PRESSURE**
  - Impact pressure is strongly related to both, liquid and gas compressibility and hydro-elasticity effects. None of these effects is taken into account in actual CFD model.
  - Impact pressure peak is also associated to the pressure wave propagation through the fluid and stress wave propagation through the containment system. Such complex phenomena may be numerically simulated using much more refined mesh and computation time-step.
- **For all these reasons, we prefer to EVALUATE KINETIC ENERGY of the liquid and "quantify" impact only by:**
  - **Quasi-static pressure**
  - Impact velocity with associated angle relative to the wall and geometry of the jet before the impact.

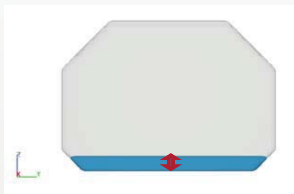
BV – Improve, Dubrovnik, 17-18 September 2009 17

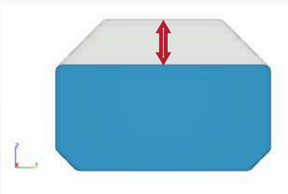
4. *WP3 – Task 3.4 – Sloshing Module*

WP3 – Task 3.4 – Sloshing Module

INPUT:

- **Cargo Capacities**
  - 125k ≤ Cap. ≤ 140k, 140k < Cap. ≤ 155k, 155k < Cap. ≤ 180k ⇒ some reserves are given
- **World wide service conditions**
- **Standard fillings**
  - R≤10%H
  - R≥70%H





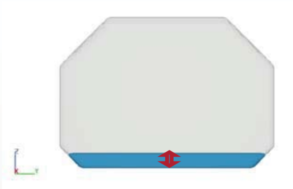
OUTPUT:

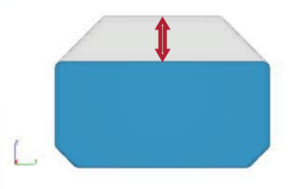
- **Representative design pressure on stiffeners and platings for structural verification according to BV Rules**

BV – Improve, Dubrovnik, 17-18 September 2009 19

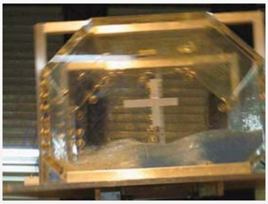
125,000 m^3 ≤ Cargo Capacity ≤ 140,000 m^3, R≤10%H & R≥70%H

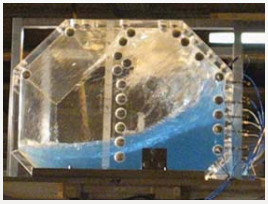
- CFD Calculations





- Model Tests





- Experience at Sea

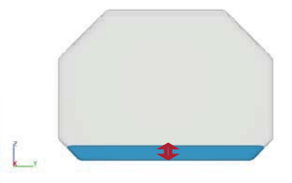
BV – Improve, Dubrovnik, 17-18 September 2009 20

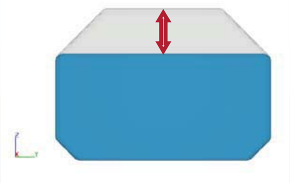
Tested Cases (CFD) for 125k ≤ Cargo Capacity ≤ 140k

- ► 4 fillings studied : 10%H, 70%H, 80%H, 95%H
- ► 40 Years Return Period, North Atlantic
- ► 5 headings tested for each filling : 180°, 202.5°, 225°, 247.5°, 270°
- ► 8 Sea-states (Hs, Tz) : 5.5s, …, 12.5s
- ► **160 cases tested for this configuration**

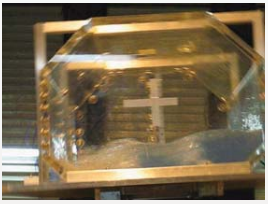
155,000 m^3 < Cargo Capacity ≤ 180,000 m^3, R≤10%H & R≥70%H

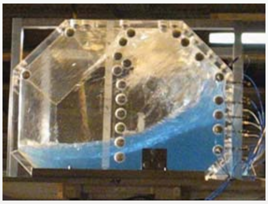
- ► CFD Calculations





- ► Model Tests

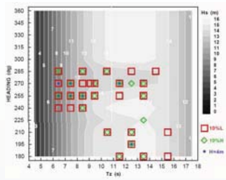


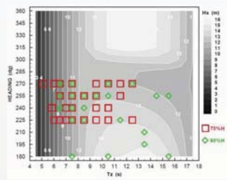


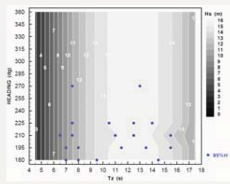
- ► Experience at Sea

Tested Cases by Numerical Calculations

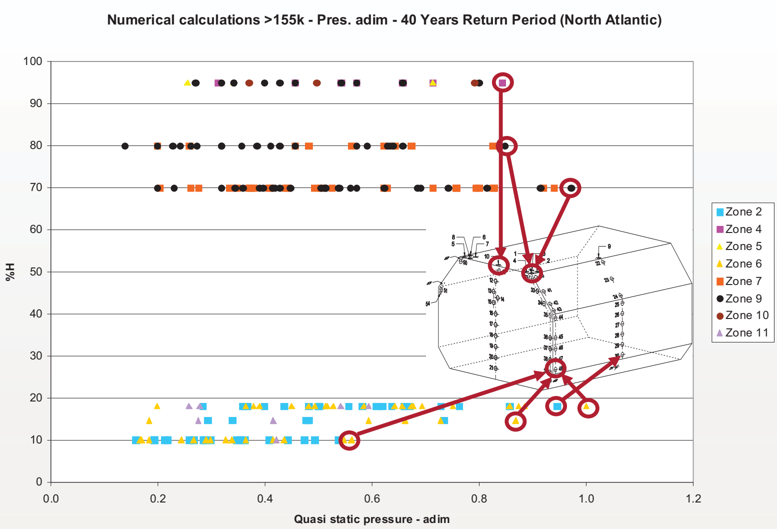
- **Low Filling ratios**
  - 10%H
  - 4.0m
  - 10%L
- **High Filling ratios**
  - 70%H
  - 80%H
- **Very high filling ratios**
  - 95%H





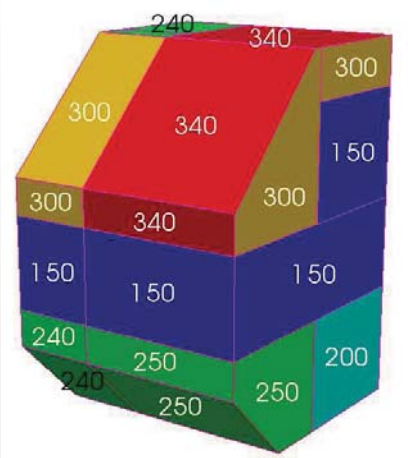


Cargo > 155k, R<10%H & R>70%H, numerical calculations



Representative Design Pressures (Example)

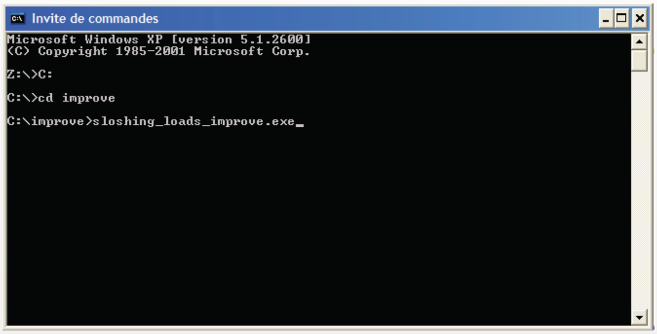
► *Quasi-static pressures loads Pw (for standard fillings) to be applied on the inner hull structure supporting the membrane cargo containment system (Example).*



Application

► **To run the sloshing module executable, type:**

- sloshing_loads_improve.exe



Input File: input_tkref.txt (file's name & format fixed)

► **The executable sloshing_loads_improve.exe reads the input file input_tkref.txt:**

input_tkref.txt - Bloc-notes

Fichier Edition Format Affichage ?

```
Ship Cargo Capcity in [m3]
135000.0
Number of Tanks
4
The tank with biggest capacity with furthest location relative to the COG is considerd as the tank of
reference
Cargo capacity of the reference tank in [m3]
33963.0
Length of the reference tank in [m]
40.000
Breadth of the reference tank in [m]
36.000
Height of the reference tank in [m]
26.000
Low chamfer of the reference tank in [m]
3.600
Upper chamfer of the reference tank in [m]
8.600
End of the file
```


Output File: sloshing_loads.txt (1)

► **Coordinates of the vertices which compose the tank panels**

sloshing_loads.txt - Bloc-notes

Fichier Edition Format Affichage ?

```
The ship's cargo capacity is equal to  135000.00 m3.
The cargo capacity belongs to this range [120000:140000]m3 of cargo capacity.

Coordinates of the vertice n°  1 (x,y,z)= (  0.0,  0.0,  0.0)
Coordinates of the vertice n°  2 (x,y,z)= (  0.0,  9.0,  0.0)
Coordinates of the vertice n°  3 (x,y,z)= (  0.0, 14.4,  0.0)
Coordinates of the vertice n°  4 (x,y,z)= (  0.0, 18.0,  3.6)
Coordinates of the vertice n°  5 (x,y,z)= (  0.0,  0.0,  7.0)
Coordinates of the vertice n°  6 (x,y,z)= (  0.0,  9.0,  7.0)
Coordinates of the vertice n°  7 (x,y,z)= (  0.0, 18.0,  7.0)
Coordinates of the vertice n°  8 (x,y,z)= (  0.0,  0.0,  6.6)
Coordinates of the vertice n°  9 (x,y,z)= (  0.0,  9.0,  6.6)
Coordinates of the vertice n° 10 (x,y,z)= (  0.0, 18.0,  6.6)
Coordinates of the vertice n° 11 (x,y,z)= (  0.0, 18.0,  8.6)
Coordinates of the vertice n° 12 (x,y,z)= (  0.0,  0.0, 22.0)
Coordinates of the vertice n° 13 (x,y,z)= (  0.0,  9.0, 22.0)
Coordinates of the vertice n° 14 (x,y,z)= (  0.0,  0.0, 26.0)
Coordinates of the vertice n° 15 (x,y,z)= (  0.0,  9.0, 26.0)
Coordinates of the vertice n° 16 (x,y,z)= (  0.0,  9.4, 26.0)

Coordinates of the vertice n° 17 (x,y,z)= ( 13.3, 14.4,  0.0)
Coordinates of the vertice n° 18 (x,y,z)= ( 13.3, 18.0,  3.6)
Coordinates of the vertice n° 19 (x,y,z)= ( 13.3, 18.0,  7.0)
Coordinates of the vertice n° 20 (x,y,z)= ( 13.3, 18.0,  6.6)
Coordinates of the vertice n° 21 (x,y,z)= ( 13.3, 18.0,  8.6)
Coordinates of the vertice n° 22 (x,y,z)= ( 13.3,  9.4, 26.0)
Coordinates of the vertice n° 23 (x,y,z)= ( 20.0, 14.4,  0.0)
Coordinates of the vertice n° 24 (x,y,z)= ( 20.0, 18.0,  3.6)
Coordinates of the vertice n° 25 (x,y,z)= ( 20.0, 18.0,  7.0)
Coordinates of the vertice n° 26 (x,y,z)= ( 20.0, 18.0,  6.6)
Coordinates of the vertice n° 27 (x,y,z)= ( 20.0, 18.0,  8.6)
Coordinates of the vertice n° 28 (x,y,z)= ( 20.0,  9.4, 26.0)

Coordinates of the vertice n° 29 (x,y,z)= ( 13.3,  6.4, 26.0)
Coordinates of the vertice n° 30 (x,y,z)= ( 13.3,  0.0, 26.0)
Coordinates of the vertice n° 31 (x,y,z)= ( 20.0,  6.4, 26.0)
Coordinates of the vertice n° 32 (x,y,z)= ( 20.0,  0.0, 26.0)
```

Output File: sloshing_loads.txt (2)

- Connectivity of panels discretizing the tanks walls
- Representative design pressure on stiffeners and platings for structural verification according to BV Rules on each panel:

sloshing_loads.txt - Bloc-notes

Fichier Edition Format Affichage ?

```
 The sloshing loads are given for one quarter of the tank for symetry reasons.
 Quasi-static pressure for the cofferdam bulkhead:
For the panel composed of the following vertices  1    2    6    5
pwi (kN/m2) =  160
For the panel composed of the following vertices  2    3    4    7    6
pwi (kN/m2) =  182
For the panel composed of the following vertices  5    7   10    8
pwi (kN/m2) =  120
For the panel composed of the following vertices  8    9   13   12
pwi (kN/m2) =  120
For the panel composed of the following vertices  9   10   11   16   15
pwi (kN/m2) =  240
For the panel composed of the following vertices 12   13   15   14
pwi (kN/m2) =  240

 Quasi-static pressure for the lower chamfer:
For the panel composed of the following vertices  3   17   18    4
pwi (kN/m2) =  182
For the panel composed of the following vertices 17   23   24   18
pwi (kN/m2) =  180

 Quasi-static pressure for the side wall:
For the panel composed of the following vertices  4   18   19    7
pwi (kN/m2) =  182
For the panel composed of the following vertices  7   19   20   10
pwi (kN/m2) =  120
For the panel composed of the following vertices 10   20   21   11
pwi (kN/m2) =  240
For the panel composed of the following vertices 18   24   25   19
pwi (kN/m2) =  180
For the panel composed of the following vertices 19   25   26   20
pwi (kN/m2) =  120
For the panel composed of the following vertices 20   26   27   21
pwi (kN/m2) =  240

 Quasi-static pressure for the upper chamfer:
For the panel composed of the following vertices 11   21   22   16
pwi (kN/m2) =  240
For the panel composed of the following vertices 21   27   28   22
pwi (kN/m2) =  240

 Quasi-static pressure for the ceiling:
For the panel composed of the following vertices 16   22   30   14
pwi (kN/m2) =  240
For the panel composed of the following vertices 22   28   31   29
pwi (kN/m2) =  210
For the panel composed of the following vertices 29   31   32   30
pwi (kN/m2) =  170
```


Structural Calculation

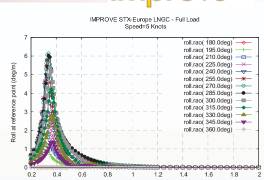
- **The assessment of inner-hull structural members is carried out using BUREAU VERITAS Rule criteria ([4]) and Guidelines for structural analysis of membrane LNG Carriers ([5]) against quasi-static pressure loads *Pw* (kN/m2) obtained from sloshing computations presented in this report.**
- **Plating**
  - A yielding assessment is to be carried out. No buckling assessment is requested.
  - The net thickness of the plating is to be assessed using the formula given in Pt B, Ch. 7, Sec1, 3.5.1 of BUREAU VERITAS Rules [4].
  - Partial safety factors *Psf* are to be taken from the Table 1 of Pt. B, Ch. 7, Sec. 1, column sloshing.
- **Stiffeners**
  - A yielding assessment is to be carried out. No buckling assessment is requested.
  - The net section of the stiffeners, including longitudinal, is to be assessed using the formula given in Pt B, Ch. 7, Sec2, 3.7.3 and 3.7.4 of BUREAU VERITAS Rules [4].
  - Partial safety factors *Psf* are to be taken from the Table 1 of Pt. B, Ch. 7, Sec. 2, column sloshing.

5. WP6.2 – STX Europe LNGC ⇒ Conventional & Partial Fillings

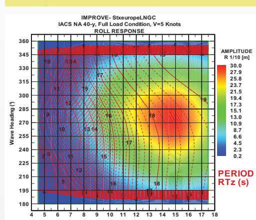
WP6 – Task 6.2 – Design Pressures for a STX Europe LNGC 220,000 m³

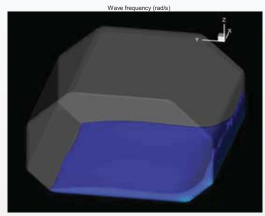
► Complete liquid motion analysis

- Hydrodynamic



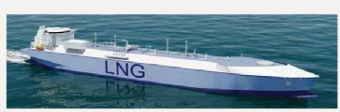
- Spectral
- Sloshing





► In order to:

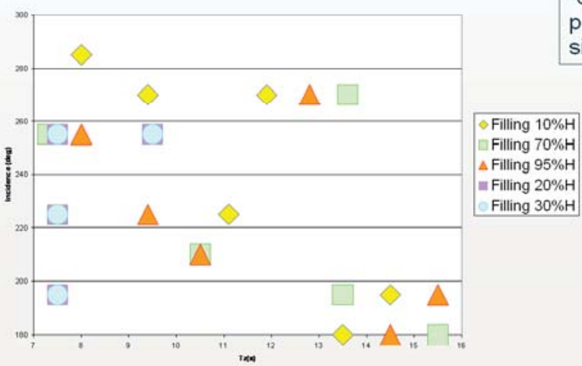
- Perform a sloshing pre-feasibility



- Give the representative design pressure to be applied on the inner hull structure

BV – Improve, Dubrovnik, 17-18 September 2009 32

Numerical Simulations • CFD • TEST – Matrix



- Total of 26 cases
- 18 cases for conventional filling (10%H, 70%H, 95%H)
- 8 additionnal cases for partial low fillings « on site » condition

Numerical Simulations • CFD • VOF Mesh

3D VOF Mesh | Transverse Section | Longitudinal Section

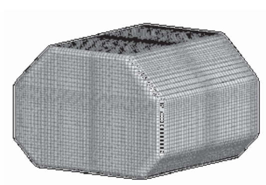
L=39.89m

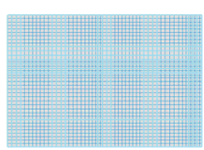
B=43.99m

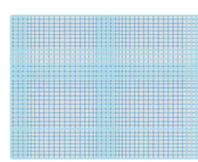
H=29.79m

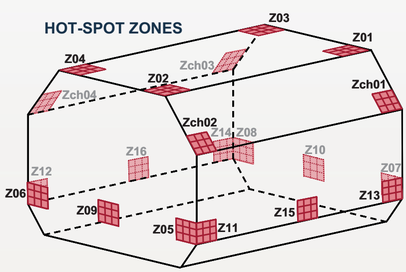
Uc=10.12m

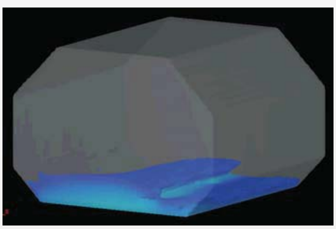
Ic=6.12m







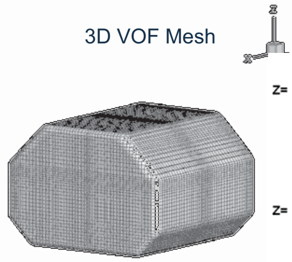




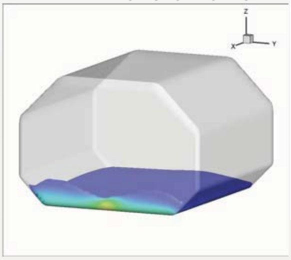
FLOW3D®

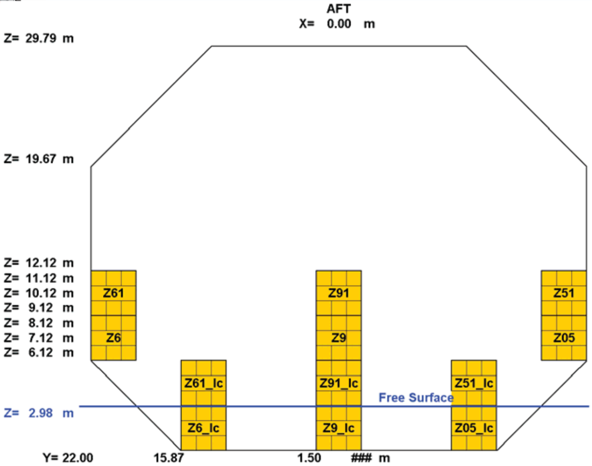
Numerical Simulations • 10%H • Detailed hot spots

3D VOF Mesh

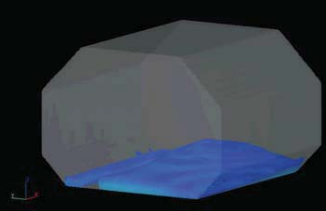


HOT-SPOT ZONES

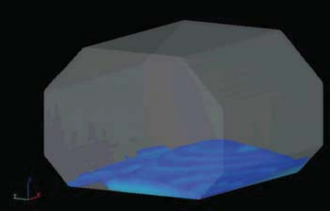




Numerical Simulations • R=10%H • W/Wo Trim

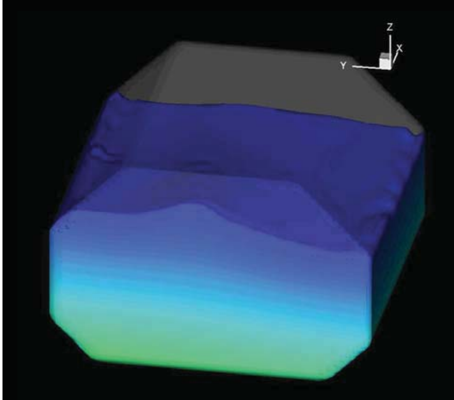


R=10%H, hdg=255°, Tz=7.5s, With Trim

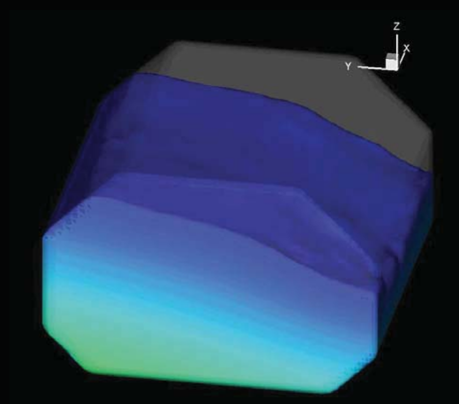


R=10%H, hdg=255°, Tz=7.5s, Without Trim

Numerical Simulations • R=70%H

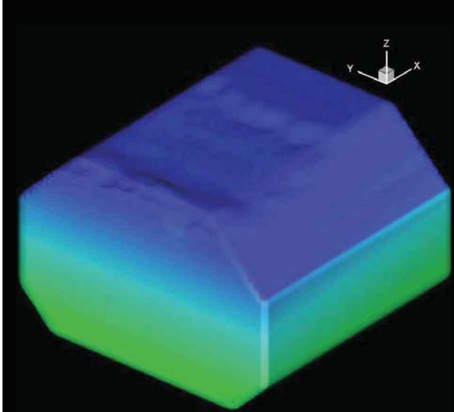


R=70%H, hdg=210°, Hs=12.2m , Tz=10.5s

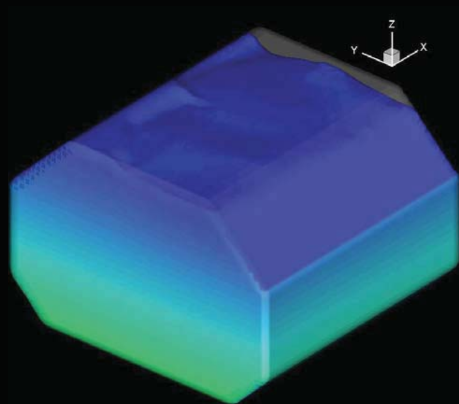


R=70%H, hdg=225°, Hs=12.7m, Tz=12.5s

Numerical Simulations • R=95%H



R=95%H, hdg=180°, Hs=14.3m, Tz=14.5



R=95%H, hdg=255°, Hs=9.4m, Tz=8.0s

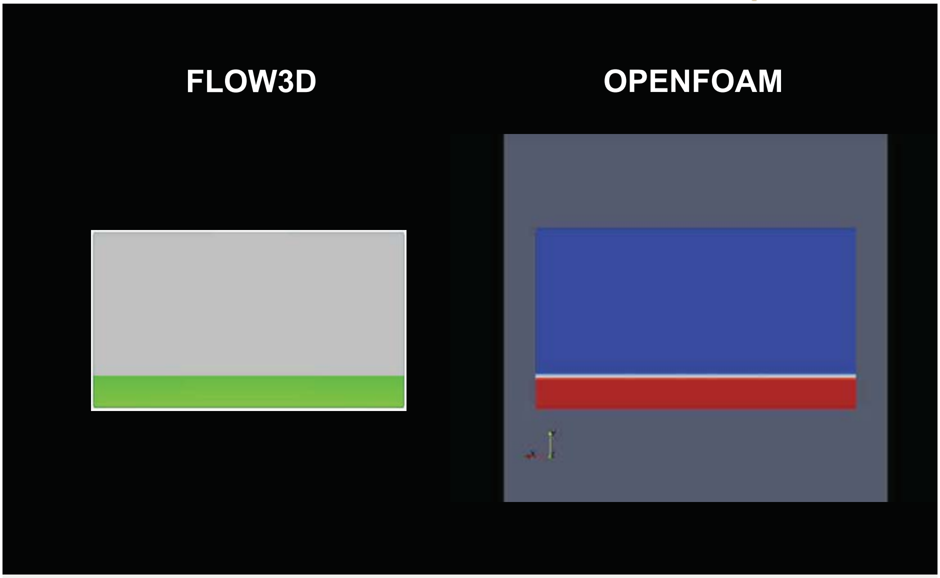
6. Validation of OpenFOAM for Sloshing Academic Cases

Sloshing Calculations using Open Source CFD code : OpenFoam

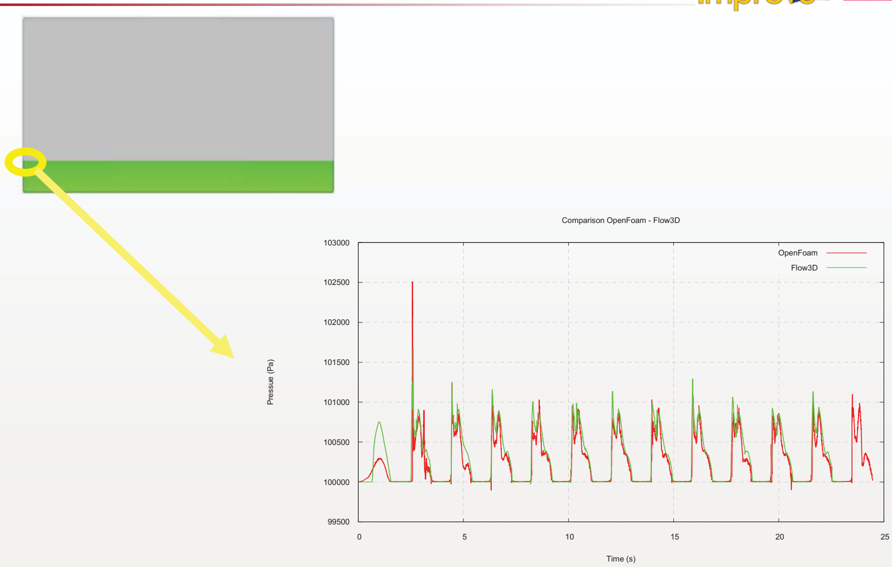
- **OpenFoam (mostly developed in Imperial College of London, 1990's) is available freely under GNU General Public License**
  - The user can freely run, copy, distribute, study, change & improve the software
  - Possibility to develop specific solvers
    - New physical models, Better post-processing tools
- **Interesting for industrials, shipyards & universities**
  - Universities: flexible tools for research
  - Shipyards: nor license fees neither constraints, tune the software for better productivity
- **For Sloshing, necessity to validate with :**
  - Academic cases like 2D experiments
  - Comparisons with commercial code like Flow3D
  - Final report for end of June 2009

BV – Improve, Dubrovnik, 17-18 September 2009 40

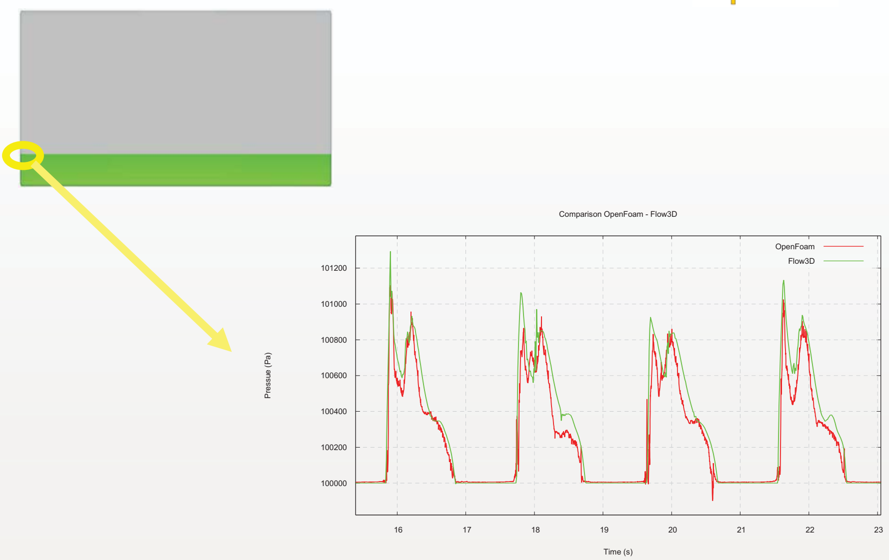
Validation : OpenFoam / Flow3D ⇨ free surface



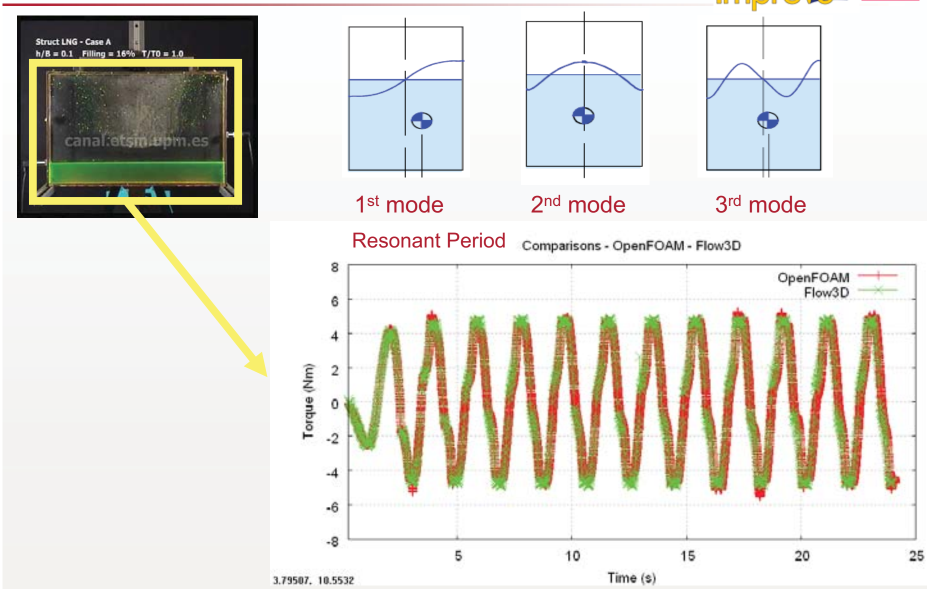
Validation : OpenFoam / Flow3D ⇨ pressure



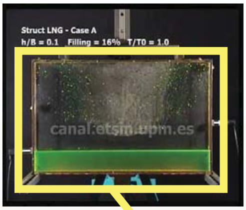
Validation : OpenFoam / Flow3D ⇨ pressure



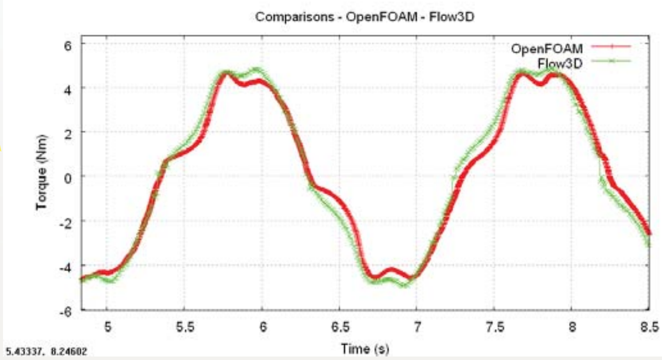
Validation : Num. Calc. / Sloshing model tests ⇨ global forces



Validation : Num. Calc. / Sloshing model tests ⇨ global forces



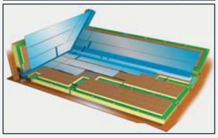
Resonant Period



8. References

Bureau Veritas & Gas Carriers

- ► 1953:
  - Classification of the 1st modern pressurised LPG carrier built in Europe: M/S «KOSAN GAS».
- ► 1995:
  - The first membrane LNG carrier built in Korea
- ► 2005:
  - The worlds first LNG RV vessels
- ► 2006:
  - The worlds first diesel electric LNG carriers
  - The worlds first CS1 containment system



LNG References • Classification

LNG CARRIERS SURVEYED AND CLASSED WITH BUREAU VERITAS

AKER France	DESCARTES	GAZOCEAN	50,000m3	MARK I	6 TANKS	1971	FRANCE
	MOURAD DIDOUCHE	SONATRACH	126,000m3	GT 85	4 TANKS	1999	ALGERIA
	RAMDANE ABANE	SONATRACH	126,000m3	GT 85	4 TANKS	1999	ALGERIA
	LNG LAGOS	BGT	123,000m3	GT 85	6 TANKS	1976	BERMUDA
	LNG PORT HARCOURT	BGT	123,000m3	GT 85	6 TANKS	1977	BERMUDA
	GAZ DE FRANCE ENERGY	GDF	75,000m3	CS 1	4 TANKS	2006	FRANCE
	PROVALYS (Hull N32)	GDF	153,500m3	CS 1	4 TANKS	2006	FRANCE
	GASELYS (Hull P32)	NYK / GDF	153,500m3	CS 1	4 TANKS	2007	FRANCE
DAEWOO	K ACACIA	KOREA LINE	138,000m3	GT 96	4 TANKS	1999	PANAMA
	K FREESIA	KOREA LINE	138,000m3	GT 96	4 TANKS	2000	PANAMA
	EXCALIBUR	EXMAR	138,000m3	GT 96	4 TANKS	2002	BELGIUM
	EXCEL (hull 2213)	EXMAR	138,000m3	GT 96	4 TANKS	2003	BELGIUM
	HISPANIA SPIRIT	TAPIAS / TK	140,500m3	GT 96	4 TANKS	2002	LIBERIA
	GALICIA SPIRIT	TAPIAS / TK	140,500m3	GT 96	4 TANKS	2004	LIBERIA
	EXCELSIOR (2208/REGAS)	EXMAR	138,000m3	GT 96	4 TANKS	2005	BELGIUM
	EXCELLENCE (2218/REGAS)	EXCELARATE	138,000m3	GT 96	4 TANKS	2006	BELGIUM
	LNG PIONEER (hull 2219)	MOL	138,000m3	GT 96	4 TANKS	2005	LIBERIA
	DISHA (hull 2210)	PETRONET	138,000m3	GT 96	4 TANKS	2004	LIBERIA
	RAHEE (hull 2211)	PETRONET	138,000m3	GT 96	4 TANKS	2004	LIBERIA
	EXCELERATE (2237/REGAS)	EXMAR	138,000m3	GT 96	4 TANKS	2006	BELGIUM
	EXPLORER (2254/REGAS)	EXMAR	151,000m3	GT 96	4 TANKS	2008	BELGIUM
	EXPRESS (2263 REGAS)	EXMAR	151,000m3	GT 96	4 TANKS	2008	BELGIUM
	Newbuilding 2261	KOREA LINE	150,000m3	GT 96	4 TANKS	2008	PANAMA
	Newbuilding 2268	TMT Taiwan	171,800m3	GT 96	4 TANKS	2009	PANAMA
	EXQUISITE (2270 REGAS)	EXMAR	151,000m3	GT 96	4 TANKS	2009	BELGIUM
	EXPEDIENT (2271 REGAS)	EXMAR	151,000m3	GT 96	4 TANKS	2009	BELGIUM
	EXAMPLAR (2272 REGAS)	EXMAR	151,000m3	GT 96	4 TANKS	2009	BELGIUM
	Newbuilding	TMT Taiwan	171,800m3	GT96	4 TANKS	2010	PANAMA

LNG References • Classification

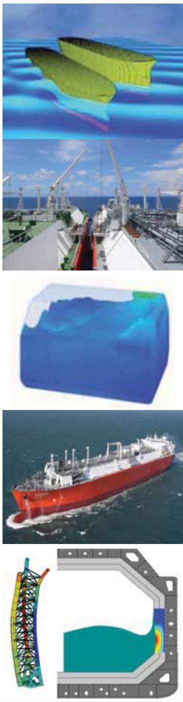
LNG CARRIERS SURVEYED AND CLASSED WITH BUREAU VERITAS (continued)

HANJIN	HANJIN MUSCAT	HANJIN SHIP.	138,000m3	GT 96	4 TANKS	1999	PANAMA
	HANJIN SUR	HANJIN SHIP.	138,000m3	GT 96	4 TANKS	2000	PANAMA
	HANJIN PYEONG TAEK	HANJIN SHIP.	130,000m3	GT 96	4 TANKS	1995	PANAMA
IZAR	IVAN TAPIAS	TAPIAS / TK	140,500m3	GT 96	4 TANKS	2004	LIBERIA
KAWASAKI	LALLA FATMA N'SOUMER	SONATRACH	145,000m3	MOSS	4 TANKS	2004	ALGERIA
HHI ULSAN	Newbuilding	MOL	177,000M3	MK III	4 TANKS	2009	TBA
HHI SAMHO	Newbuilding	MOL	177,000m3	MK III	4 TANKS	2009	TBA
MITSUBISHI	ARCTIC LADY	LEIF HOEGH	145,000m3	MOSS	4 TANKS	2006	NORWAY
	Hull n° 2222	MISC	157,000m3	GT 96	4 TANKS	2008	MALAYSIA
	Hull n° 2223	MISC	157,000m3	GT 96	4 TANKS	2008	MALAYSIA
NORMED	EDOUARD LD	DREYFUS	130,000m3	GT NO 85	5 TANKS	1977	FRANCE
	MOSTEFA BEN BOULAID	DREYFUS	130,000m3	GT 85	5 TANKS	1977	FRANCE
	BACHIR CHIHANI	SONATRACH	130,000m3	GT 85	5 TANKS	1979	ALGERIA
DUNKIRK	TENAGA DUA (dual class)	MISC	130,000m3	GT NO 88	5 TANKS	1981	MALAYSIA
	TENAGA TIGA (dual class)	MISC	130,000m3	GT NO 88	5 TANKS	1981	MALAYSIA
	TENAGA SATU (dual class)	MISC	130,000m3	GT NO 88	5 TANKS	1981	MALAYSIA
LA CIOTAT	TELLIER	GDF	40,000m3	MARK I	5 TANKS	1974	FRANCE
	BEN FRANKLIN (scrapped)	GAZOCEAN	125,000m3	MARK I	6 TANKS	1975	FRANCE
CH. SEINE	CINDERELLA	TMT	25,500m3	TYPE B	7 TANKS	1965	ST VINCENT

LNG References • Classification

LNG CARRIERS SURVEYED AND CLASSED WITH BUREAU VERITAS (continued)

LA SEYNE	LARBI BEN M'HIDI	SONATRACH	130,000m3	GT 85	5 TANKS	1977	ALGERIA
	TENAGA EMPAT (dual class)	MISC	130,000m3	GT NO 88	5 TANKS	1981	MALAYSIA
	TENAGA LIMA (dual class)	MISC	130,000m3	GT NO 88	5 TANKS	1981	MALAYSIA
	HASSI R'MEL	SONATRACH	40,000m3	GT NO 82	6 TANKS	1971	ALGERIA
SAMSUNG	SERI ALAM (hull 1502)	MISC	145,000m3	MARK III	4 TANKS	2005	MALAYSIA
	SERI AMANAH (hull 1503)	MISC	145,000m3	MARK III	4 TANKS	2005	MALAYSIA
	SERI ANNGUN (hull 1589)	MISC	145,000m3	MARK III	4 TANKS	2006	MALAYSIA
	SERI ANGKASA (hull 1590)	MISC	145,000m3	MARK III	4 TANKS	2007	MALAYSIA
	SERI AYU (hull 1591)	MISC	145,000m3	MARK III	4 TANKS	2007	MALAYSIA
	MAERSK METHANE	AP MOLLER	164,500m3	MARK III	4 TANKS	2008	DIS
	Hull n°1608	AP MOLLER	164,500m3	MARK III	4 TANKS	2008	DIS
	Hull n°1625	AP MOLLER	164,500m3	MARK III	4 TANKS	2008	DIS
	Hull n°1626	AP MOLLER	164,500m3	MARK III	4 TANKS	2009	DIS
	Hull n°1632	AP MOLLER	164,500m3	MARK III	4 TANKS	2009	DIS
	Hull n°1633	AP MOLLER	164,500m3	MARK III	4 TANKS	2009	DIS
STX	New Building	ELCANO	173,600m3	GT NO 96	4 TANKS	2010	SPAIN
UNIVERSAL	Cheikh El Mokrani	SONATRACH	75,000m3	MARK III	4 TANKS	2007	BAHAMAS
	Cheikh Bouamama	SONATRACH	75,000m3	MARK III	4 TANKS	2009	BAHAMAS
REMONTOWA	New Building	A. VEDER	7,500 m3	TYPE C	2 TANKS	2009	NETHERLANDS
GENERAL	LNG ABUJA	BGT	126,500m3	MOSS	5 TANKS	1980	BAHAMAS
DYNAMICS	LNG EDO	BGT	126,500m3	MOSS	5 TANKS	1980	BAHAMAS
NEWPORT	LNG DELTA	SHELL	125,000m3	MARK I	5 TANKS	1978	ISLE OF MAN
NEWS							



Dubrovnik, CROATIA, 17th-18th September 2009

Improve

WP3 – Task 3.4 – Sloshing Module

WP6 – Task 6.2 – STX Europe LNGC

Validation of OpenFoam for Sloshing Academic Cases

BUREAU VERITAS 1828

Move Forward with Confidence*

*Avançons en confiance

Louis DIEBOLD
louis.diebold@bureauveritas.com

Nicolas MOIROD
nicolas.moirod@bureauveritas.com

Tools for Early Design Stage - Production, Operational and Robustness Modules (WP4)

IMPROVE

Production, Operation and Robustness Module

J.D. Caprace, F. Bair
ANAST University of Liège, Liège, Belgium
M. Hübler
Center of Maritime Technologies, Hamburg, Germany
I. Lazakis, O. Turan
NAME Universities of Glasgow & Strathclyde, Glasgow, United Kingdom
K. Piric, V. Zanic, J. Andric, P. Prebeg,
University of Zagreb, Zagreb, Croatia

CONTENT

- Introduction
- Life cycle assessment
- Production simulation assessment
- Robustness assessment
- Conclusion

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

INTRODUCTION

- How to ?
  - Improve the design of ships
  - Reduce the cost of ships
  - Reduce the time to market
    - → **Life cycle engineering**

→ **70% of the total life cycle cost committed in early design**

→ **Design optimization As Early As Possible**

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

3 CHALLENGES

- Keep the high performance of the optimization loop with a very low response time cost calculation module
- Keep sufficient modeling details for a good simulation of production problems (sequencing, transport, human resources, space allocation)
- To introduce robustness into design process as practical measure that can save the designer's effort on control of the parameter variation

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

3 MODULES

- A life cycle cost/earning of production and maintenance/repair
- A detailed Discrete Event Simulation (DES) for production and scheduling
- A design robustness of the structural solution related to various fabrication and operational parameters

LIFE CYCLE MODULE

I. Lazakis, O. Turan

NAME Universities of Glasgow & Strathclyde, Glasgow, United Kingdom

LIFE CYCLE MODULE

- **Introduction**
  - **T4.1a-Maintenance/Repair database**
    - *Data collection activity for failures/repairs of hull structure (NA-ME, TPZ, EXMAR and GRIMALDI)*
  - **T4.1b-Generalised Life Cycle Maintenance Cost/Earning model**
    - *Development of a generalised life-cycle maintenance cost/earning model to be used within the integrated optimisation platform of IMPROVE project*
  - **T4.1b (updated) including a corrosion parameter**
    - *Investigate the effect of additional structural member thickness (according to ship-owners' requirements) on the repairs of the ship during its life-cycle*

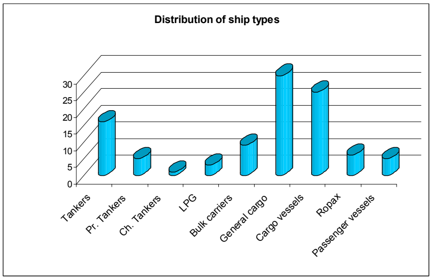
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Data collection activity (1)

Companies	Place	Dates
TPZ	Zadar, Croatia	21-26 October 2007
EXMAR	Antwerp, Belgium	3-7 February 2008
GRIMALDI	Naples, Italy	25-28 February 2008



Ship type	No of ships
Tankers	16
Pr. Tankers	5
Ch. Tankers	1
LPG	3
Bulk carriers	9
General cargo	30
Cargo vessels	25
Ropax	6
Passenger vessels	5
TOTAL	100

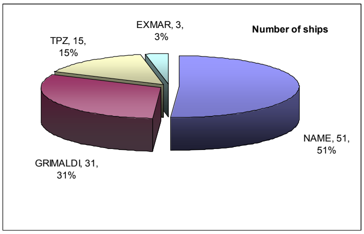
Improve

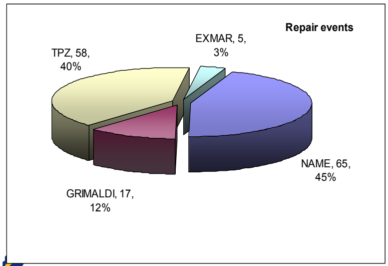
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

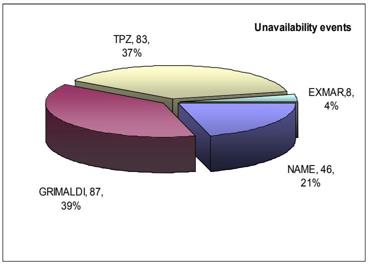
LIFE CYCLE MODULE

- Data collection activity (2)

Source	No of ships	Repair events	Unavailability events
NAME	51	65	46
GRIMALDI	31	17	87
TPZ	15	58	83
EXMAR	3	5	8
TOTAL	100	145	225







LIFE CYCLE MODULE

- Attributes of repair events

##	Ship type	Survey period	Age	LWT	Steel repair (kgs)	ARS/LWT (*10^-3)
62	LPG	1st Sp.	5	11,548	3000	0.2598
63	LPG	2nd Sp.	10	11,548	1000	0.0866
64	Cargo	Drydock	[illegible]	[illegible]	7,710	0.7226
65	Cargo	D	[illegible]	[illegible]	[illegible]	0.2688
66	Cargo	D	[illegible]	[illegible]	[illegible]	0.6351
67	Cargo	Drydock	[illegible]	[illegible]	18,725	1.2022
68	Cargo	Drydock	12	15,575	5,812	0.3732
69	Cargo	Drydock	20	15,575	33,510	1.7321
70	Cargo	Drydock	20	15,575	4,000	0.2068
71	Cargo	Drydock	12	15,575	15,974	1.0256
72	Cargo	Drydock	6	16,700	6,700	0.4012
73	Cargo	Drydock	9	18,600	44,000	2.3656
74	Cargo	Drydock	5	16,578	28,000	1.6890
75	Cargo	Drydock	2	18,600	1,500	0.0806
76	Cargo	Drydock	3	18,600	1,500	0.0806
77	Cargo	Drydock	6	12,231	2,500	0.2044
78	Cargo	Drydock	5	16,578	10,300	0.6213
79	Cargo	Drydock	3	12,231	4,000	0.3270
80	Cargo	Drydock	9	15,575	5,000	0.3210
81	Tanker	4th Int.	23	13,939	145	10.4023
82	Tanker	4th Int.	22	14,251	381	26.7350

Actual Replaced Steel /Lightweight

LIFE CYCLE MODULE

- Attributes of unavailability events

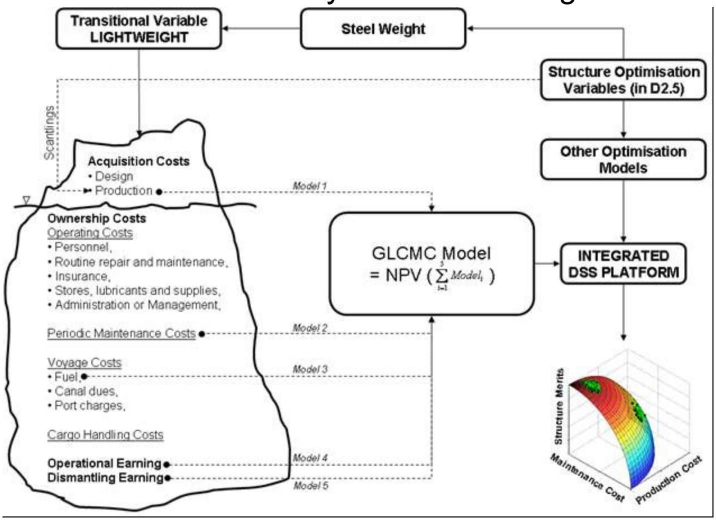
##	Ship type	Survey period	Age	Unavailability time (days)
1	Pr. Tanker	Annual	3	24
2	Pr. Tanker	Annual	4	13
3	Pr. Tanker	1st Sp.	5	42
4	Pr. Tanker	1st Int.	8	25
5	Pr. Tanker	2nd Sp.	10	37
6	Pr. Tanker	2nd Int.	13	31
7	Pr. Tanker	3rd Sp.	15	44
8	Pr. Tanker	3rd Int.	18	51
9	Pr. Tanker	4th Sp.	19	7
10	Tanker	Annual	3	18
11	Tanker	1st Sp.	6	17
12	Tanker	1st Int.	8	25
13	Tanker	2nd Sp.	10	21
14	Tanker	2nd Int.	13	30
15	Tanker	2nd Sp.	10	20
16	Tanker	Annual	2	16
17	Tanker	Annual	1	14
18	Tanker	1st Int.	3	14
19	Tanker	2nd Int.	3	23
20	Tanker	Annual	1	11
21	Tanker	Annual	3	16

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- GLCMC Model and Life-Cycle Cost/Earning elements

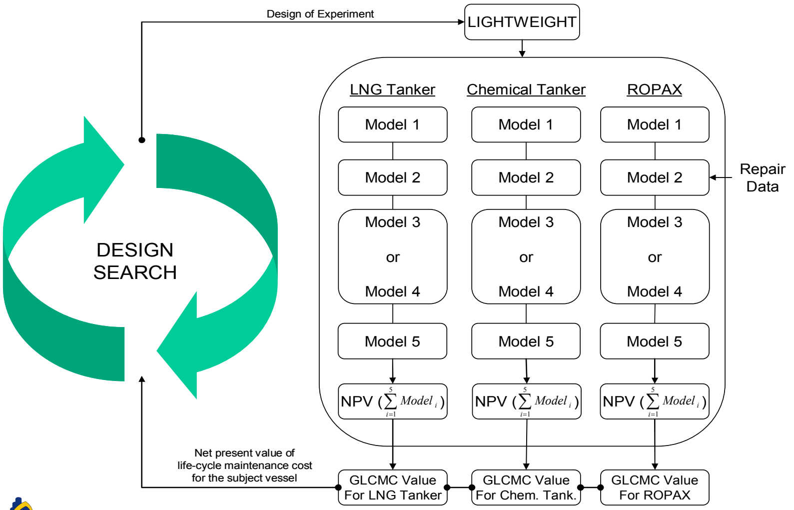


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Design search and GLCMC model



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Illustrative example (Chemical tanker)

  – Model 1: production cost
  – Model 2: maintenance cost
  – Model 3: fuel cost
  – Model 4: operational earning
  – Model 5: dismantling earning

  Two different scenarios examined:
  – Scenario 1: Deadweight constant
  – Scenario 2: Displacement constant

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Results of the illustrative example

	Lightweight (in tonnes)	% δ	Scenario 1 M2 + M3 – M5 (DWT is constant)	% δ	Scenario 2 M2 – M4 – M5 (Δ is constant)	% δ
1	8,500	-10.53%	79,522,514	-0.41%	-378,717,768	3.11%
2	9,000	-5.26%	79,685,660	-0.20%	-372,997,550	1.56%
3	9,250	-2.63%	79,766,962	-0.10%	-370,137,442	0.78%
4	9,500 (base design)	0.00%	79,848,086	0.00%	-367,277,333	0.00%
5	9,750	2.63%	79,929,033	0.10%	-364,417,225	-0.78%
6	10,000	5.26%	80,009,804	0.20%	-361,557,116	-1.56%
7	10,500	10.53%	80,170,825	0.40%	-355,836,899	-3.11%

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Conclusions
  - The developed life-cycle maintenance/repair cost model is robust enough to be used within the IMPROVE's integrated search platform. That is to find maintenance/repair related cost/earning values for the three IMPROVE vessels with respect to design of experiments throughout the optimisation
  - The developed method can efficiently help designers, ship owners and production engineers to make rationale decisions during early design phases
  - Although the model is able to calculate generalized life-cycle maintenance cost, it can also be used for what if scenario analyses with respect to other parameters of the model, such as unit price of steel replacement per kg, price of fuel oil, and so on
  - This model can further be improved with the inclusion of other life-cycle cost elements

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Future research
  - To employ advanced inference and/or reasoning systems that are to perform reasoning under vagueness environments; where maintenance/repair data is difficult to obtain and expert knowledge expressed in verbal settings is present
  - To make use of neural networks for better predictions of annually replaced steel and unavailability times
  - To create ship specific regression models and databases with the availability of additional maintenance/repair data
  - To extend the existing model to take account of the maintenance/repair requirements of ship owners/operators

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- T4.1b (updated) including a corrosion parameter

Investigate the effect of additional structural member thickness (according to ship-owners' requirements) on the repairs of the ship during its life-cycle

  - Follow the CSR *"Net thickness approach"* which differentiates between the local and the global corrosion effect.
  - General corrosion pattern is applied in this case study.
  - Mean annual corrosion rates used are from the Gratsos & Zachariadis (2005) research work.
  - The scenarios for the Chemical tanker examined are the ones for the original LWT case (9,500 tons-Turan et al 2009).
  - Additional LWT in terms of thicker structural members (bottom plates in this case): 5% of the original LWT.
  - Productivity of repair yard: 7 tons of steel/day

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Research questions
  - Question 1

    What is the additional plate thickness for the Chemical tanker in order to have a 25 year repair-free life?

  - Question 2

    What are the financial results in terms of Models 2-5 examined before?

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

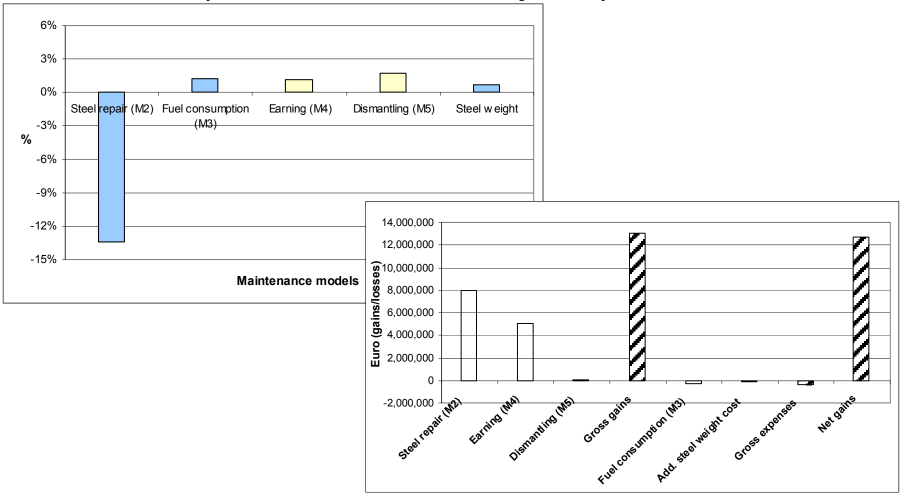
- Methodology
  - Three different cases are described:
    - "case 1-0.12mm/year" : mean annual corrosion rate of 0.12mm
    - "case 2-0.20mm/year" : mean annual corrosion rate of 0.20mm
    - "case 3-0.40mm/year" : mean annual corrosion rate of 0.40mm
  - Results
    - Case 1: 1.0 mm additional plate thickness
    - Case 2: 2.5 mm additional plate thickness
    - Case 3: 6.5 mm additional plate thickness

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Results (case 1-0.12mm/year)

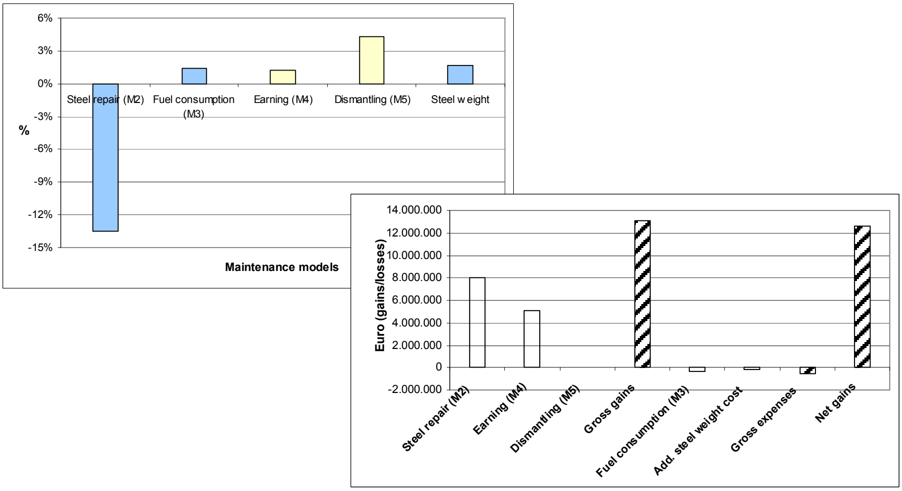


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Results (case 2-0.20mm/year)

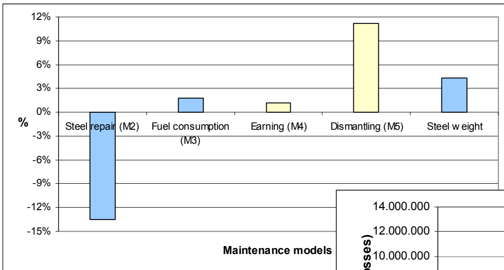


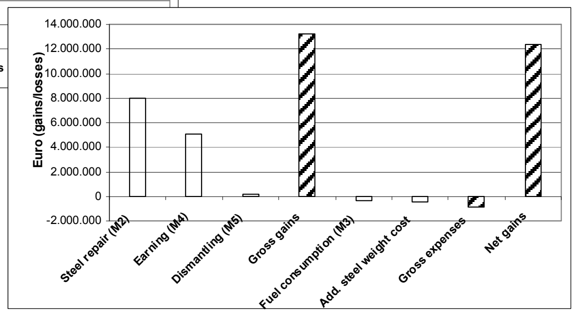
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Results (case 3-0.40mm/year)



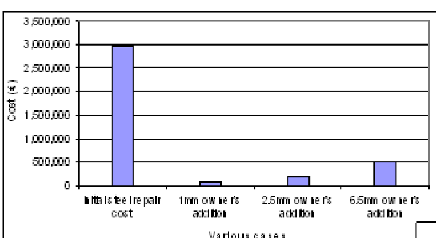


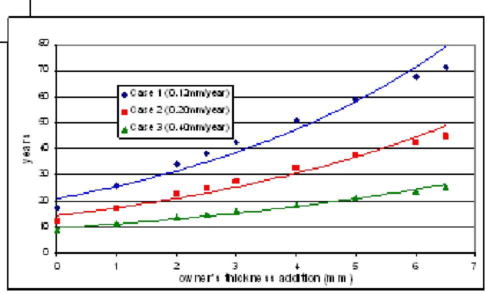
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LIFE CYCLE MODULE

- Further results





Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

J.D. Caprace, F. Bair
ANAST University of Liège, Liège, Belgium

M. Hübler
Center of Maritime Technologies, Hamburg, Germany

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

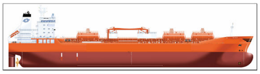
- **Objectives**
  - **Assessment and study the effect of**
    - **Scantling modification**
    - **Block/Section splitting**

LNG

Simulation of
block and ship assembly

ROPAX

Simulation of
section and block assembly



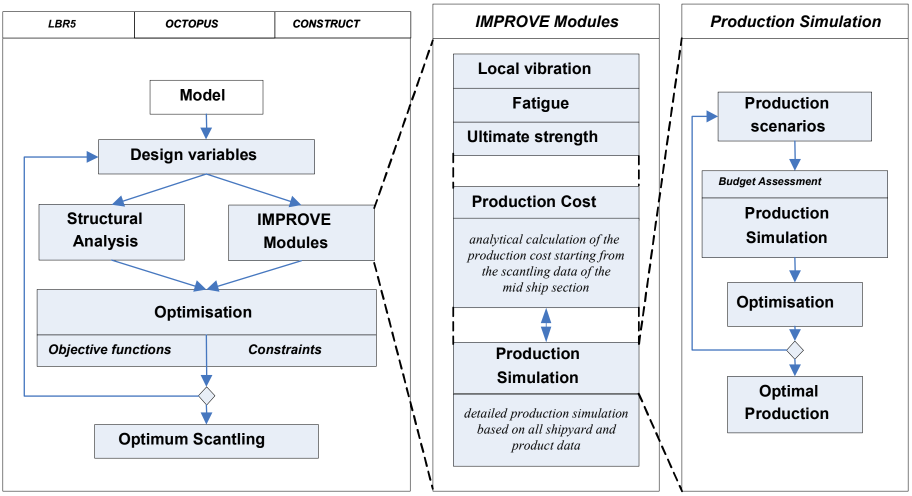
Chemical Tanker

No simulation

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Cost modules comparison

Production cost DLL

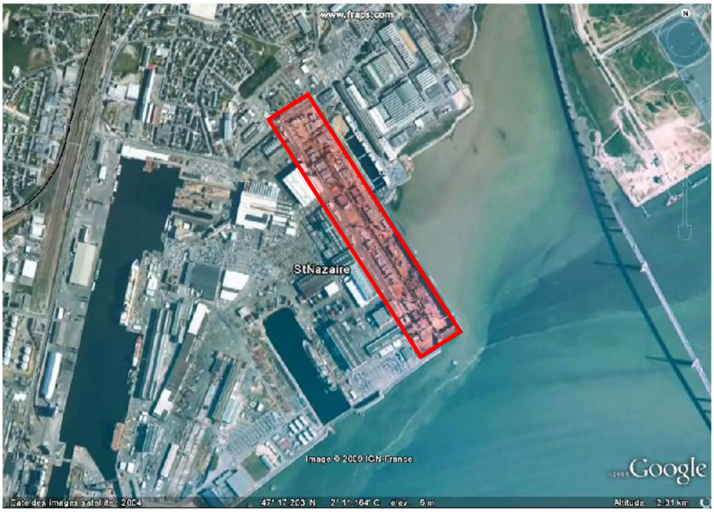
- Inside Optimization loop
- Low CPU time
- Basic link between scantling and production cost
- Reliable sensitivities but not accurate cost values

Production simulation

- Outside Optimization loop
- High CPU time
- Scheduling and sequences
- Surface allocation constraint
- Transport resources constraint
- Human resources constraint
- Block splitting consideration

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

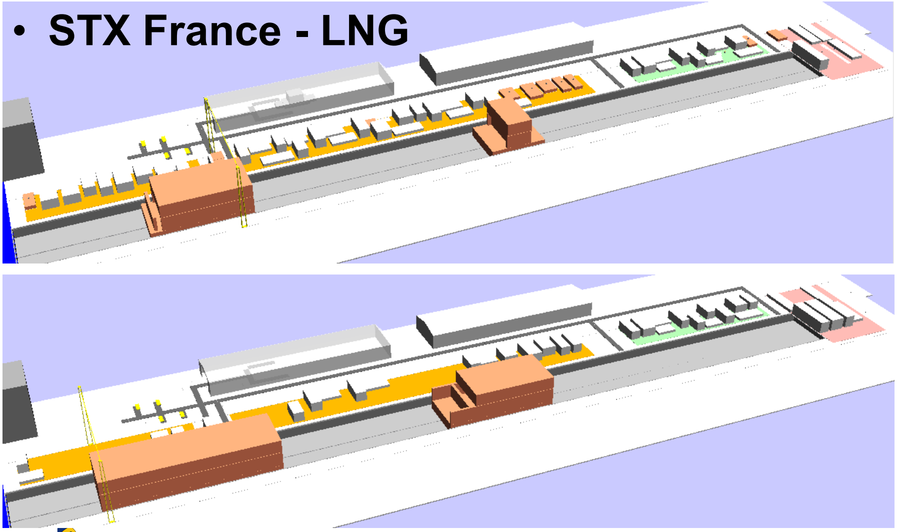
PRODUCTION SIMULATION



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

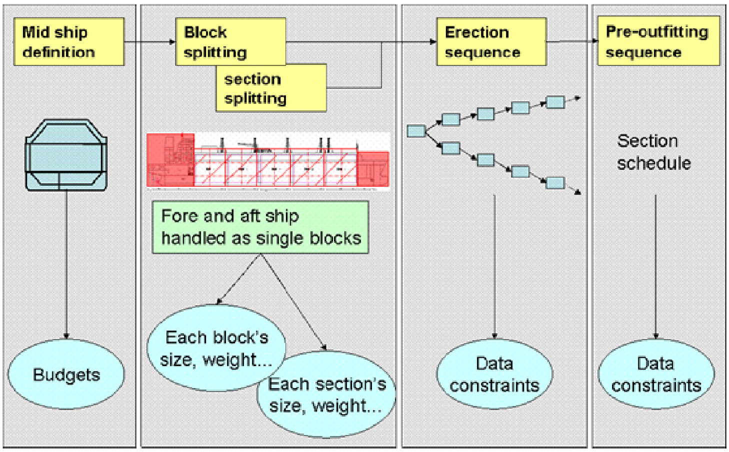
- STX France - LNG



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

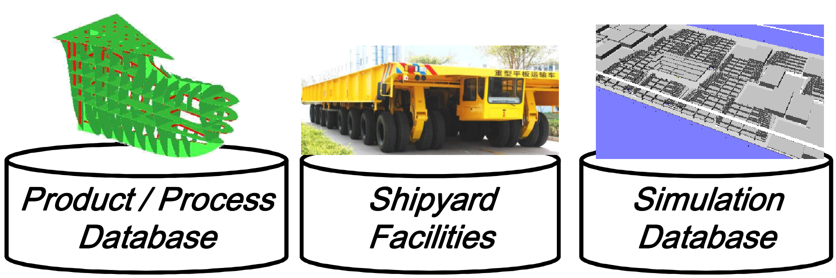
- LNG Simulation Workflow



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- DATABASE structure



- *Ship structure*
- *Production activities*
- *Welds and Seams*
- *Budgets*

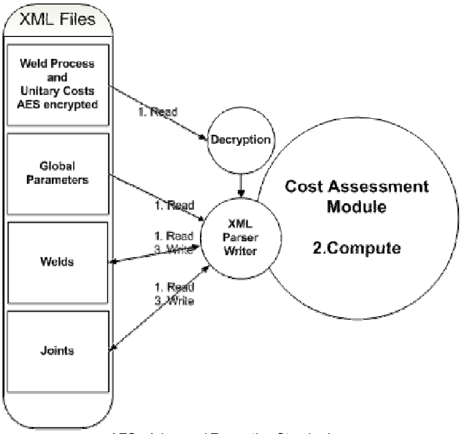
- *Workshops dimensions*
- *Transport ressources*
- *Human ressources*
- *Working calendar*

- *Constraints (global and local)*
- *Assembly strategy*
- *User parameters*
- *Results*

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- COST and BUDGET assessment module



AES - Advanced Encryption Standard

First loop for all welds labour cost

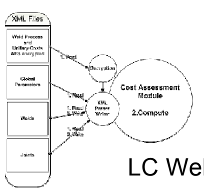
- Preparation: Prepare steel elements for welding
- Welding: Weld elements together with variable parameters
- Rework: Clean and straightening

INPUT DATA

- *Welding position*
- *Welding type (fillet or butt)*
- *Plate thickness*
- *Welding throat*
- *Welding process*
- *Dimension of the profile welded*

PRODUCTION SIMULATION

- COST and BUDGET assessment module



$$LC = U \times L \times Q \times A \times E$$

LC Welding labour cost

U Unitary cost related to one or more design variables like plate thickness, weld throat, weld type (butt or fillet), weld position, etc.

L Welding length

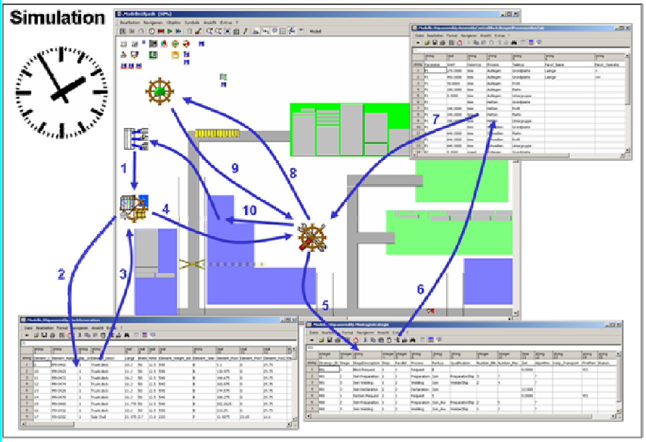
Q Welding quantity

A Accessibility coefficient – Cost increases due to the bad accessibility of the items to weld

E Shipyard efficiency

PRODUCTION SIMULATION

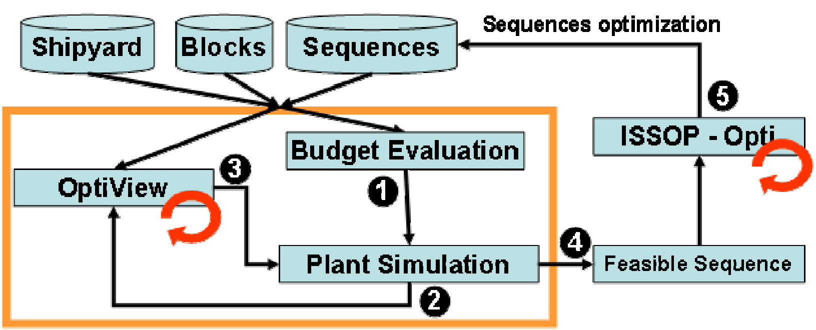
- Model methodology



1. Order generation
2. Material requisition
3. Preparation and Transport of Material
4. Activation of assembly
5. Definition of next assembly step
6. Determination of process data
7. Activation of assembly process
8. Requisition of worker
9. Allocation of worker

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

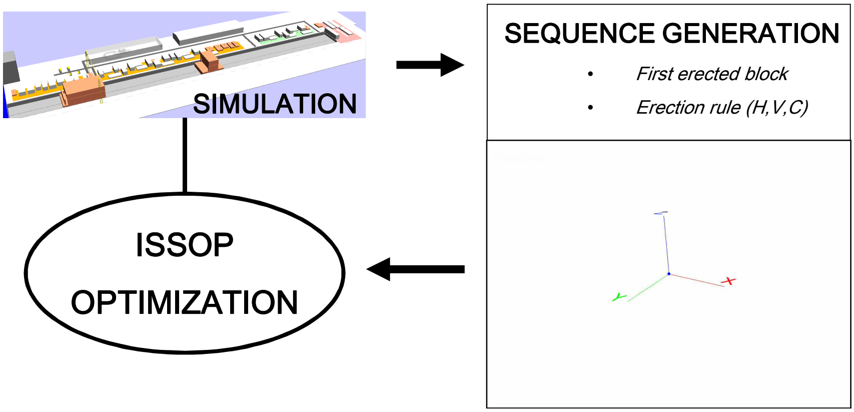


1. Budget evaluation by cost assessment module
2. First production with Plant Simulation to find input data for OptiView (Rough allocation)
3. Run OptiView to perform a optimisation of the space allocation
4. Second run of the Simulation with given assembly positions
5. Optimizing sequence of parts like blocks with ISSOP

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Optimization of erection sequence

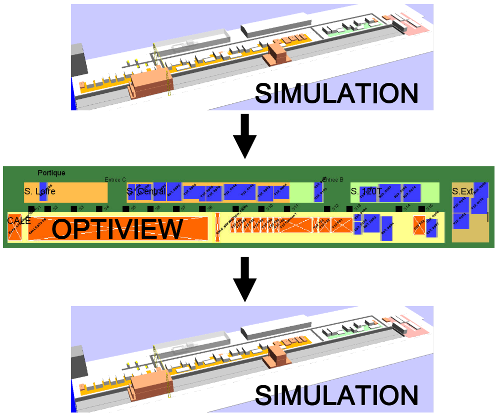


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Surface allocation optimization



First production simulation to find input data for OptiView (Rough allocation)

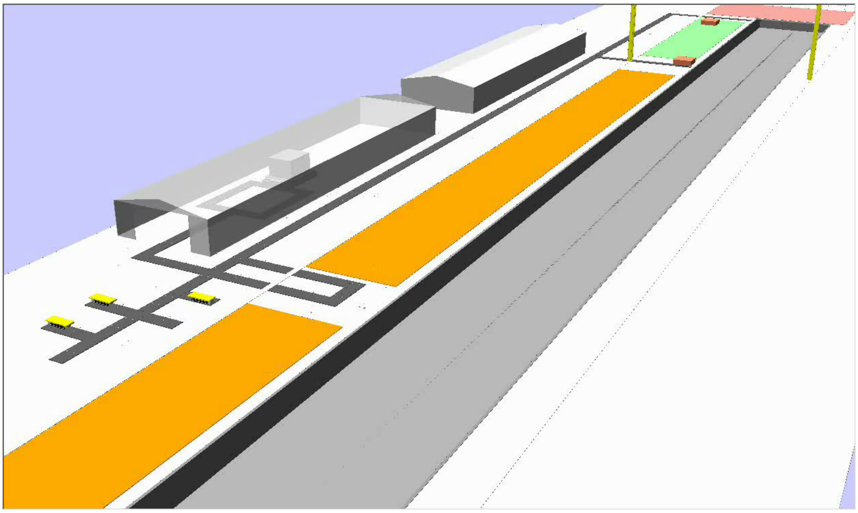
OptiView space allocation optimization

Second run of the simulation With given block position

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

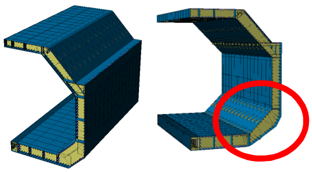


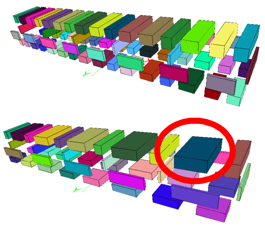
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Simulation scenarios
  - Two designs
    - Standard design
    - Free ballast improved design
  - Two Block/Section splitting
    - 800 tons
    - 1200 tons
  - Two scantlings
    - First scantling
    - Optimized scantling (LBR5)





Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

SIMULATION INPUT

Description	Stage	Units	Ships Alternatives			
Ship Name			**M9**	**M10**	**M11**	**M12**
Sister Ships			**M9A, M9B**	**M10A, M10B**	**M11A, M11B**	**M12A, M12B**
Design type			*Standard*	*Free ballast*	*Free ballast*	*Free ballast*
Block Splitting strategy			*800t*	*800t*	*1200t*	*1200t*
Scantling optimization			*No*	*No*	*No*	*Yes*
Time frame between ships		Days	*60*	*60*	*60*	*60*
Keelaying date of the first ship			*1/04/2008*	*1/04/2008*	*1/04/2008*	*1/04/2008*
Number of blocks			*70*	*70*	*43*	*43*
Number of section			*174*	*174*	*172*	*172*
Number of joins			*297*	*297*	*291*	*291*
Number of welds			*1960*	*2097*	*1967*	*1967*
Volume of blocks		m³	*268 856*	*269 567*	*269 567*	*269 567*
Volume of sections		m³	*183 151*	*183 592*	*183 592*	*183 592*
Real weight of ship	(mid section)		32 064			
Weight (estimated)		tons	*28 360*	*27 000*	*26 387*	*24 276*
Welding length	Block Erection	meters	*13 797*	*12 054*	*10 001*	*9 975*
Welding length	Block Assembling	meters	*6 605*	*6 994*	*7 832*	*7 832*
Total length		**meters**	***20 402***	***19 048***	***17 833***	***17 807***
Welding_Budget	Block Erection	hours	*34 340*	*35 988*	*24 328*	*24 151*
Preparation_Budget	Block Erection	hours	*16 480*	*14 526*	*11 437*	*11 371*
Welding_Budget	Block Assembling	hours	*15 984*	*15 572*	*25 995*	*24 384*
Preparation_Budget	Block Assembling	hours	*6 351*	*6 675*	*8 550*	*8 536*
Total_Budget		**hours**	***73 155***	***72 761***	***70 310***	***68 443***

Results from budget calculation module and shipyard design

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Results
  - Lead time
  - Production cost
    - Transport cost
    - Labour cost
    - Surface utilization cost
  - Space allocation ratio
  - Workload

- Key Findings
  - → Significant reduction of Lead time and cost after scantling optimization
    - → Main factor = plate thickness reduction
  - → More can be saved after the improvement of the organization (block splitting, surface allocation optimization, etc.)
    - → Especially when outfitting is considered
  - → Surface utilization influence the lead time
  - → Workload smoothing → very difficult in the simulation

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Table scenario and results

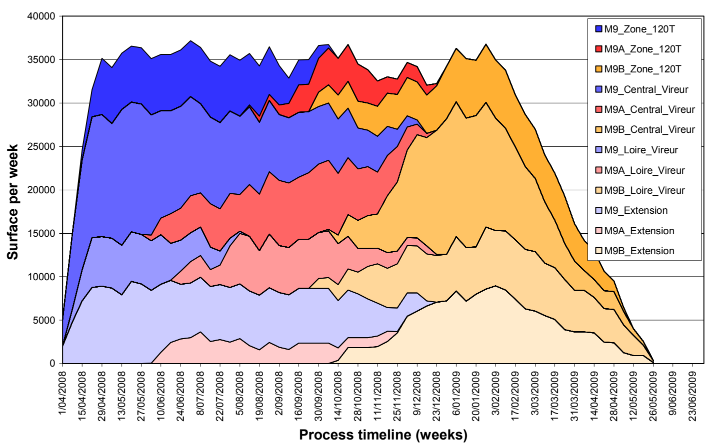
Description	Ships Alternatives						
Experiment	**STX5**		**STX6**		**STX7**		**STX8**
Ship Name	**M9**		**M10**		**M11**		**M12**
Sister Ships	**M9A, M9B**		**M10A, M10B**		**M11A, M11B**		**M12A, M12B**
Design type	*Standard*		*Free ballast*		*Free ballast*		*Free ballast*
Block Splitting strategy	*800t*		*800t*		*1200t*		*1200t*
Scantling optimization	*No*		*No*		*No*		*Yes*
Surface optimization	*No*		*No*		*No*		*No*
Budget		***-1%***		***-3%***		***-3%***	
Lead Time		**23%**		**-10%**		**-29%**	
Labour cost		**-5%**		**29%**		**-7%**	
Transport cost		**0%**		**24%**		**-65%**	
Surface utilization cost		**-3%**		**-3%**		**-2%**	
Total cost		**28%**		**-5%**		**-31%**	

- **Outfitting is not considered in the simulation**
- **STX budget assessment between M9 and M10 = -3.6%**
- **LBR5 labour cost assessment between M11 and M12 = -3.06%**

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

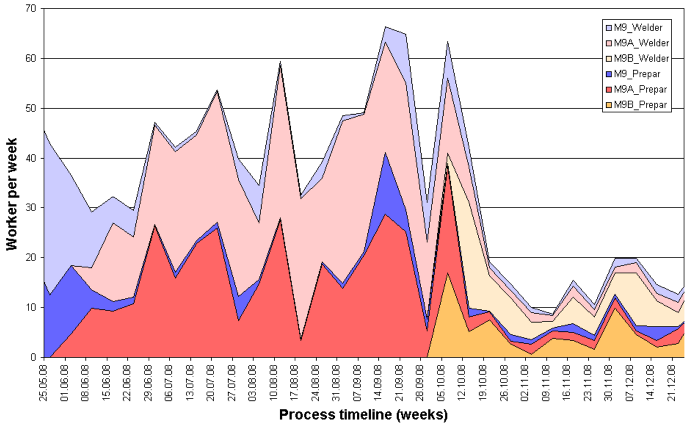
- Space allocation (qualitative example)



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

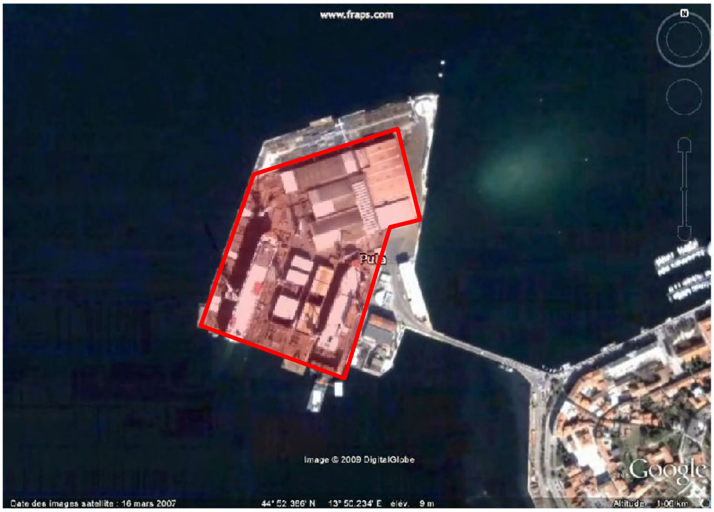
PRODUCTION SIMULATION

- Work load (qualitative example)



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

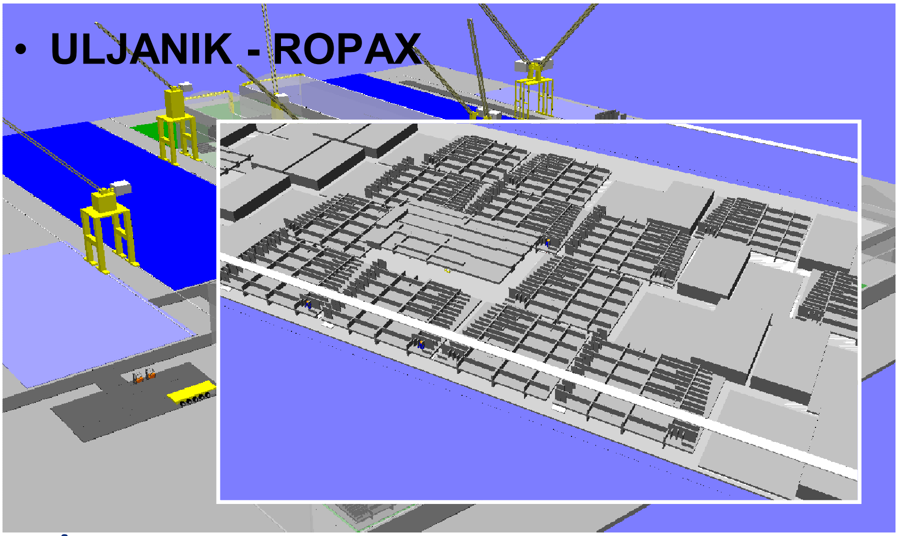
PRODUCTION SIMULATION



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- **ULJANIK - ROPAX**



PRODUCTION SIMULATION

- Differences with STX model
  - No budget/cost assessment → Shipyard input data
    - No welds/seams data
  - No sequence optimization
    - Only one section/block splitting strategy
  - No surface allocation optimization
  - Only 3 scenarios have been considered
    - 2 ships design and 1 optimized scantling

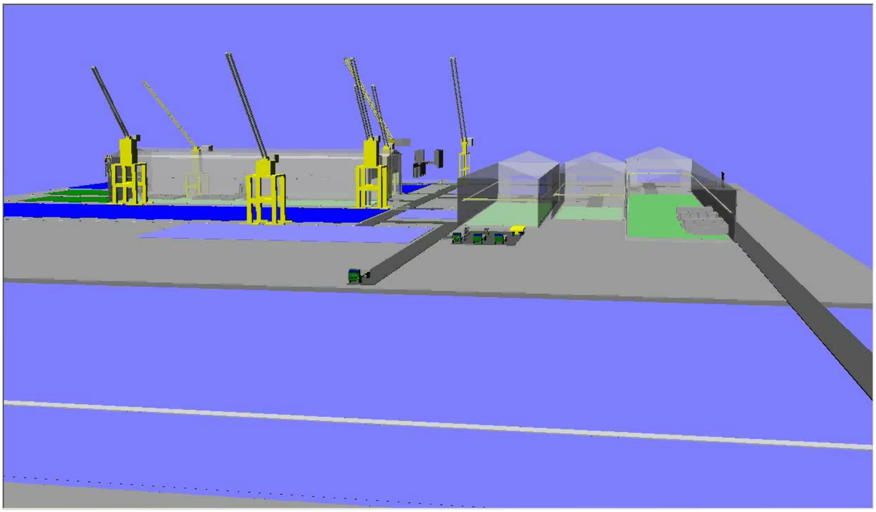
SIMULATION INPUT

	Stage	Units	ULJ_1	ULJ_2	ULJ_3
Ship Name			R10	R11	R12
Design			Standard	Improved	Improved
Scantling optimization			No	No	Yes
Number of SuperSection			118	140	140
Number of Section			278	280	280
Number of SubSection			116	20	20
Number of Assembly			180	0	0
Number of SubAssembly			4478	4020	3990
Volume of SuperSection		m^3	62639	39325	38242
Volume of Section		m^3	65055	52770	51802
Volume of SubSection		m^3	14469	9488	9488
Volume of Assembly		m^3	2486	0	0
Volume of SubAssembly		m^3	19136	20358	21047
Weight estimated		Tons	21196	20190	20834
Number of Activities			1384	880	880
Preparation_Budget	Assembly	Hours	2296	0	0
Welding_Budget	Assembly	Hours	4186	0	0
Preparation_Budget	SubSection	Hours	15274	6700	6900
Welding_Budget	SubSection	Hours	13610	12260	12620
Preparation_Budget	Section	Hours	30156	34560	34640
Welding_Budget	Section	Hours	32020	40600	40740
Preparation_Budget	SuperSectio	Hours	17250	16144	16064
Welding_Budget	SuperSectio	Hours	14868	14344	14264
Total_Budget		Hours	129660	124608	125228

Results from budget calculation module and shipyard design

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Table scenario and results

Description	Ships Alternatives				
Experiment	**ULJ1**		**ULJ2**		**ULJ3**
Ship Name	**R10**		**R11**		**R12**
Sister Ships	**R10_1, R10_2**		**R11_1, R11_2**		**R12_1, R12_2**
Design type	*Standard*		*New*		*New*
Scantling optimization	*No*		*No*		*Yes*
Budget		**-4%**		**0.5%**	
Lead Time		**11%**		**0.0%**	
Overall labour time		**-65%**		**0%**	
Transport cost		**-99%**		**-0.2%**	
Surface utilization cost		**-100%**		**5%**	

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Conclusions
  - The developed production cost method consists of three parts
    - Simulation database supporting data for the cost and budget calculation as well as for the simulation process
    - Cost and budget assessment module for very fast analytical calculation based on algorithm
    - Simulation models (AKER YARDS, ULJANIK) based on event oriented simulation for production using the Simulation Toolkit for Shipbuilder working with high degree of details and accuracy

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Conclusions
  - Two steps
    - The **analytical assessment module** is implemented in the integration platform and **performs the IMPROVE optimisation**. This will keep the high performance of the optimisation because the response time of the cost and budget assessment module is very low.
    - To **improve the analytical module** and their algorithms the **simulation models** will be used because it can consider more details, like sequencing, transport, human resources etc., and it will deliver more accurate results for the cost calculation.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

PRODUCTION SIMULATION

- Conclusions

CST – Cost

LT – Lead time

  - STX
    - Savings by scantling (CST **-31%**, LT **-10%**)
    - Savings by block splitting (CST **-5%**, LT **-29%**)
  - ULJ
    - Savings by scantling (CST <1**%**, LT <1**%**)

- Savings are hardly influenced by the constraints and the system borders
- Outfitting and pre-outfitting is not considered in the simulation

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

ROBUSTNESS MODULE

K. Piric, V. Zanic, J. Andric, P. Prebeg
University of Zagreb, Zagreb, Croatia

SVEUČILIŠTE U ZAGREBU

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Robustness – theory

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Introduction

Robust means that the product or process performs consistently on target and is relatively insensitive to factors that are difficult to control.

Robust design has been developed with the expectation that an insensitive design can be obtained.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Genechi Taguchi's Method

Taguchi imposes a general quadratic loss function of the form:

$$L(y) = k \cdot (y - T)^2$$

He also suggests analyzing variation using an appropriately chosen signal-to-noise ratio.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Nam Pyo Suh's Method

He uses *information* (*I*) and his *Information Axiom* provides a quantitative measure of the merit.

The Information Axiom states that the design with the highest probability of success is the best design.

Experimental Design

Usual time and financial limitations preclude the use of a full factorial experiment.

Statisticians have developed efficient test plans, which are referred to as fractional factorial experiments (FFEs). FFEs use only a portion of the total possible combinations to estimate the main factor effects and some, not all, of the interactions.

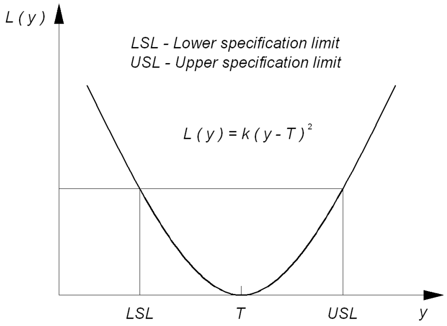
Taguchi has developed a family of FFE matrices (orthogonal arrays) which can be utilized in various situations.

Signal to noise ratio (*SNR*)

SNR developed by Taguchi is performance measure to choose control levels that best cope with noise. Three of them are considered standard and are generally applicable in the following situation:

- Smallest is best quality characteristic (contamination, weight, energy consumption and turn around time)
- Nominal is best quality characteristic (dimension, control system such as steering and motor control)
- Biggest is best quality characteristic (strength, yield, speed and cargo capacity)

Nominal is best quality characteristic



$$SNR = 10 \cdot \log\left(\frac{\mu^2}{\sigma^2}\right)$$

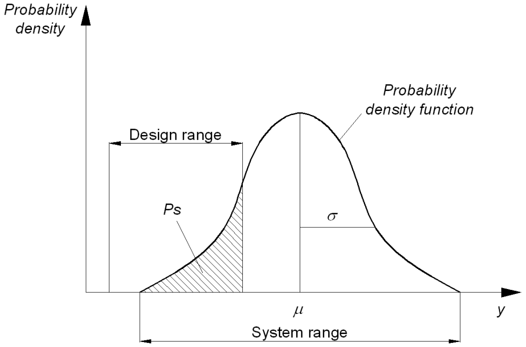
$\mu = \frac{1}{n} \cdot \sum_{i=1}^{n} y_i$ - mean of the variables

$\sigma^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{n} (y_i - \mu)^2$ - variance of the variables

y_i - comparison variables in experiment i for a certain combination of control factor levels

n - number of experiments performed for that combination

System range, design range and probability of success



μ , σ - mean and standard deviation that describe probability density function

Ps - probability of success (= shaded area)

Information (I)

Information may be expressed as:

$$I = \ln \frac{1}{Ps} = -\ln Ps$$

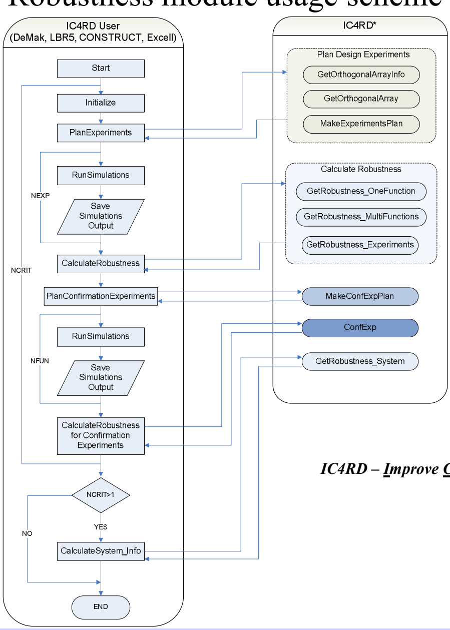
The logarithmic function is chosen so that the information will be additive when there are many criteria that must be satisfied simultaneously.

Robustness – module

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Robustness module usage scheme



IC4RD – Improve Component for (4) Robust Design

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Robustness – example

Robust design regarding structural safety

Example shows bottom panel robustness calculation for Ropax ship using experimental design with inner array (where user assigns controllable factors) and outer array (where user assigns uncontrollable-noise factors).

For that purpose, four different controllable and noise factors are selected, as follows:

❑ Controllable factors

- t_p – Thickness of plate, in [*mm*]
- s – Spacing of ordinary stiffeners, in [*mm*]
- h_w – Web height of ordinary stiffener, in [*mm*]
- t_w – Web thickness of ordinary stiffener, in [*mm*]

❑ Noise factors

- σ_x – Normal stress in x-direction, in [N/mm^2]
- σ_y – Normal stress in y-direction, in [N/mm^2]
- τ – Shear stress, in [N/mm^2]
- p – Pressure, in [kN/m^2]

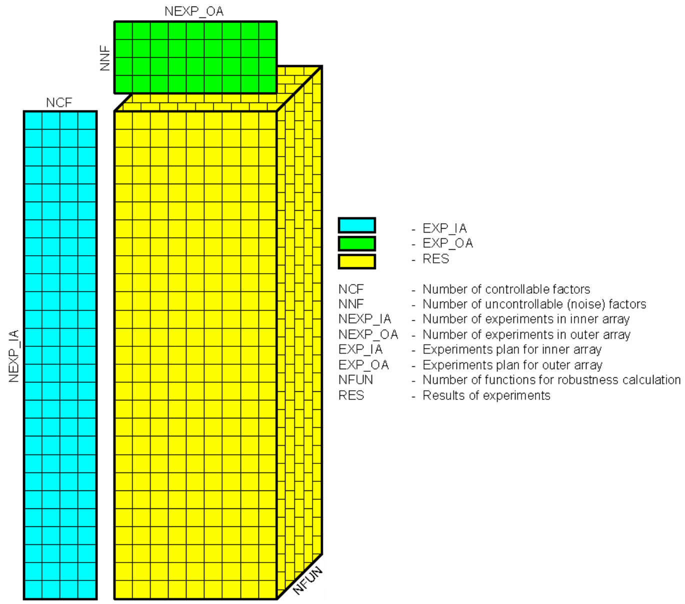
All controllable and noise factors will be contemplate on three levels as is shown in tables:

	CONTROLLABLE FACTOR LEVELS			
t_p	14	15	16	[mm]
s	500	550	611	[mm]
h_w	240	270	300	[mm]
t_w	9	10	11	[mm]

	NOISE FACTOR LEVELS			
σ_x	-85	-105	-146	[N/mm^2]
σ_y	-90	-98	-126	[N/mm^2]
τ	6	8	8.6	[N/mm^2]
p	120	130	140	[kN/m^2]

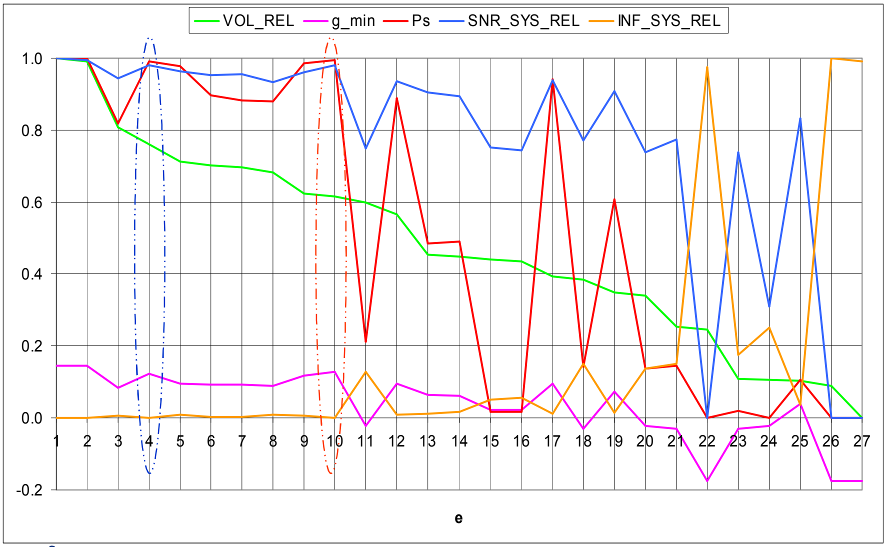
Considering panel dimension the following feasibility criteria functions should be satisfied:

- SYCP – Stiffener Yield Compression Plate
- SYCF – Stiffener Yield Compression Flange
- PP_CB – Plane Panel Compression and Bending
- PP_BACS – Plane Panel Bi-axial Compression and Shear
- OS_VBM – Ordinary Stiffener Various Buckling Modes
  - Column buckling
  - Torsional buckling
  - Web buckling
- OS_US – Ordinary Stiffener Ultimate Strength



Improve IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Result analysis



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

WP4 CONCLUSION

- The simultaneous consideration of:
  - Life cycle cost/earning of production and maintenance/repair
  - Discrete Event Simulation for Production issues
  - Design robustness of the structural solution related

→ **Lead to the improvement of the scantling optimization solution**

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Thank You for Your Attention!

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Improve

Sixth Framework Programme

UNIVERSITY OF STRATHCLYDE

IMPROVE

T4.1a-Maintenance/Repair database
T4.1b-Generalised Life Cycle Maintenance Cost /Earning model
T4.1b (updated) including a corrosion parameter

By NAME, Universities of Glasgow and Strathclyde

Dubrovnik, 17-19 September 2009

Improve

IMPROVE | **NAME, University of Strathclyde**

UNIVERSITY OF STRATHCLYDE

Introduction

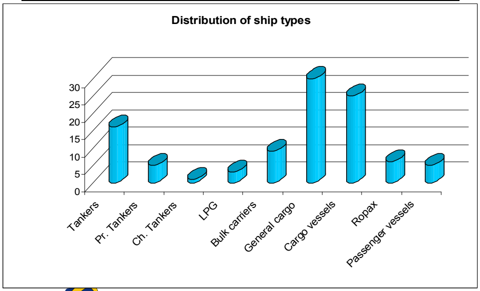
- T4.1a-Maintenance/Repair database
  Data collection activity for failures/repairs of hull structure (NA-ME, TPZ, EXMAR and GRIMALDI)
- T4.1b-Generalised Life Cycle Maintenance Cost /Earning model
  Development of a generalised life-cycle maintenance cost/earning model to be used within the integrated optimisation platform of IMPROVE project
- T4.1b (updated) including a corrosion parameter
  Investigate the effect of additional structural member thickness (according to ship-owners' requirements) on the repairs of the ship during its life-cycle

Improve

IMPROVE | **NAME, University of Strathclyde**

Data collection activity (1)

Companies	Place	Dates
TPZ	Zadar, Croatia	21-26 October 2007
EXMAR	Antwerp, Belgium	3-7 February 2008
GRIMALDI	Naples, Italy	25-28 February 2008



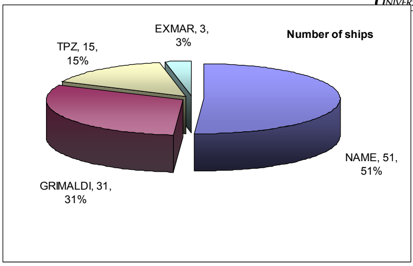
Ship type	No of ships
Tankers	16
Pr. Tankers	5
Ch. Tankers	1
LPG	3
Bulk carriers	9
General cargo	30
Cargo vessels	25
Ropax	6
Passenger vessels	5
TOTAL	100

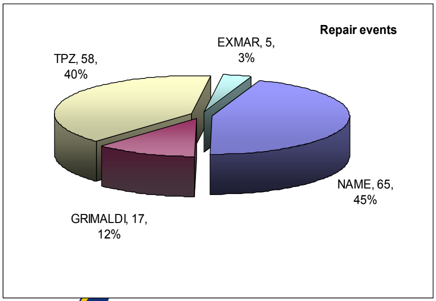
IMPROVE

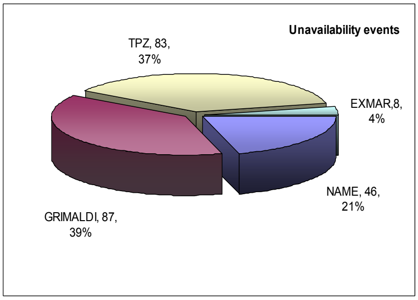
NAME, University of Strathclyde

Data collection activity (2)

Source	No of ships	Repair events	Unavailability events
NAME	51	65	46
GRIMALDI	31	17	87
TPZ	15	58	83
EXMAR	3	5	8
TOTAL	100	145	225







IMPROVE

NAME, University of Strathclyde

Attributes of repair events

##	Ship type	Survey period	Age	LWT	Steel repair (kgs)	ARS/LWT (*10^-3)
62	LPG	1st Sp.	5	11,548	3000	0.2598
63	LPG	2nd Sp.	10	11,548	1000	0.0866
64	Cargo	Drydock	[illegible]	[illegible]	7,710	0.7226
65	Cargo	[illegible]	[illegible]	[illegible]	[illegible]	0.2688
66	Cargo	[illegible]	[illegible]	[illegible]	[illegible]	0.6351
67	Cargo	Drydock	[illegible]	[illegible]	18,725	1.2022
68	Cargo	Drydock	12	15,575	5,812	0.3732
69	Cargo	Drydock	20	15,575	33,510	1.7321
70	Cargo	Drydock	20	15,575	4,000	0.2068
71	Cargo	Drydock	12	15,575	15,974	1.0256
72	Cargo	Drydock	6	16,700	6,700	0.4012
73	Cargo	Drydock	9	18,600	44,000	2.3656
74	Cargo	Drydock	5	16,578	28,000	1.6890
75	Cargo	Drydock	2	18,600	1,500	0.0806
76	Cargo	Drydock	3	18,600	1,500	0.0806
77	Cargo	Drydock	6	12,231	2,500	0.2044
78	Cargo	Drydock	5	16,578	10,300	0.6213
79	Cargo	Drydock	3	12,231	4,000	0.3270
80	Cargo	Drydock	9	15,575	5,000	0.3210
81	Tanker	4th Int.	23	13,939	145	10.4023
82	Tanker	4th Int.	22	14,251	381	26.7350

Actual Replaced Steel /Lightweight

IMPROVE

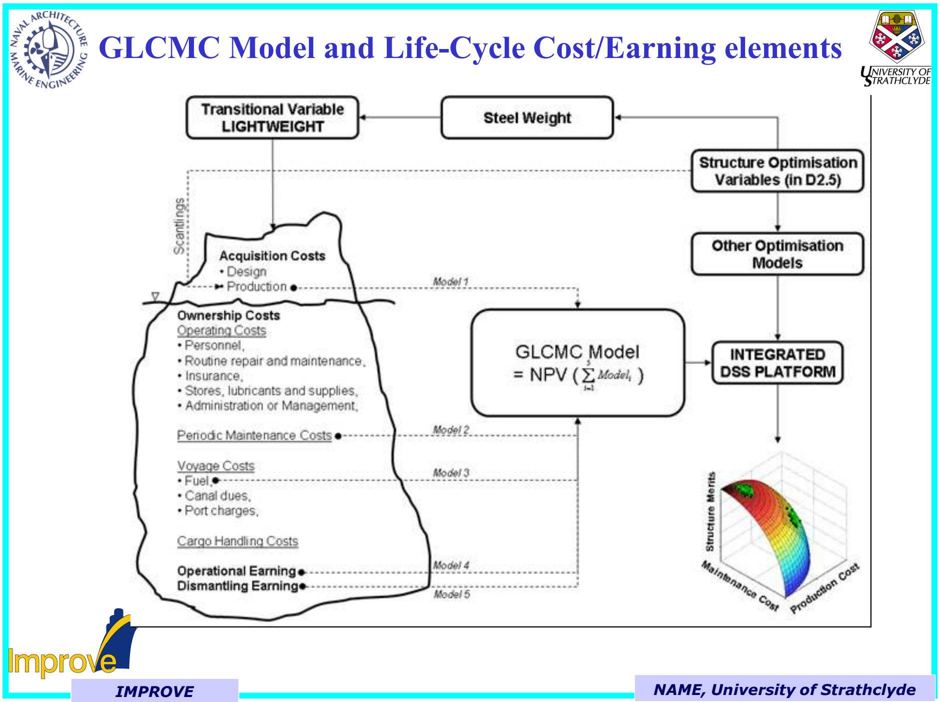
NAME, University of Strathclyde

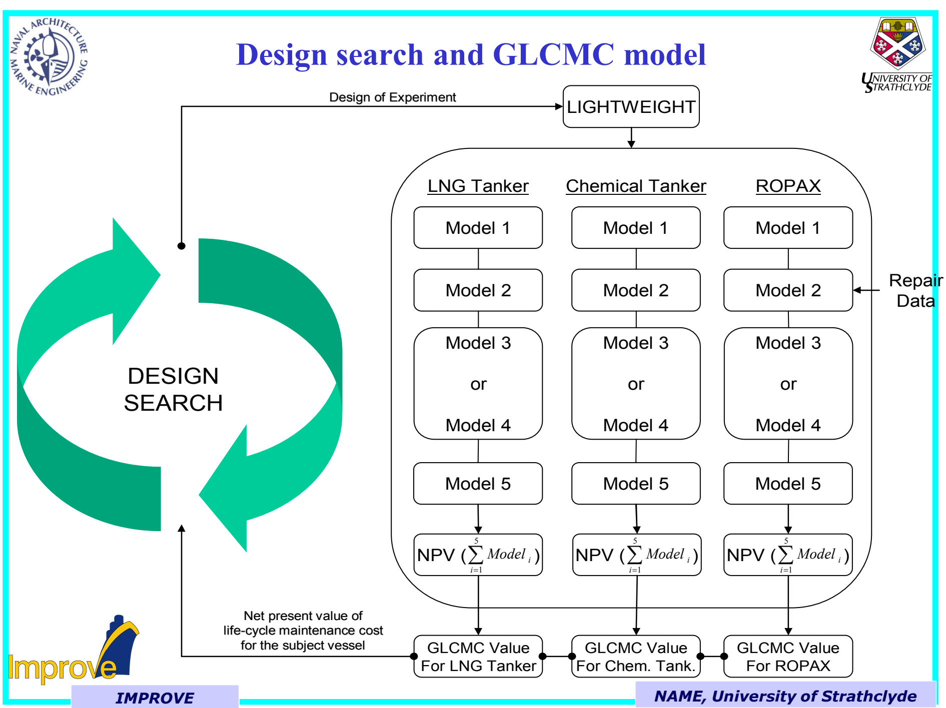
Attributes of unavailability events

##	Ship type	Survey period	Age	Unavailability time (days)
1	Pr. Tanker	Annual	3	24
2	Pr. Tanker	Annual	4	13
3	Pr. Tanker	1st Sp.	5	42
4	Pr. Tanker	1st Int.	8	25
5	Pr. Tanker	2nd Sp.	10	37
6	Pr. Tanker	2nd Int.	13	31
7	Pr. Tanker	3rd Sp.	15	44
8	Pr. Tanker	3rd Int.	18	51
9	Pr. Tanker	4th Sp.	19	7
10	Tanker	Annual	3	18
11	Tanker	1st Sp.	6	17
12	Tanker	1st Int.	8	25
13	Tanker	2nd Sp.	10	21
14	Tanker	2nd Int.	13	30
15	Tanker	2nd Sp.	10	20
16	Tanker	Annual	2	16
17	Tanker	Annual	1	14
18	Tanker	1st Int.	3	14
19	Tanker	2nd Int.	3	23
20	Tanker	Annual	1	11
21	Tanker	Annual	3	16

IMPROVE

NAME, University of Strathclyde


GLCMC Model and Life-Cycle Cost/Earning elements
NAVAL ARCHITECTURE MARINE ENGINEERING
UNIVERSITY OF STRATHCLYDE
Transitional Variable
LIGHTWEIGHT
Steel Weight
Structure Optimisation Variables (in D2.5)
Other Optimisation Models
Scantlings
Acquisition Costs
• Design
• Production
Model 1
Ownership Costs
Operating Costs
• Personnel,
• Routine repair and maintenance,
• Insurance,
• Stores, lubricants and supplies,
• Administration or Management,
Periodic Maintenance Costs
Model 2
Voyage Costs
• Fuel,
• Canal dues,
• Port charges,
Model 3
Cargo Handling Costs
Operational Earning
Dismantling Earning
Model 4
Model 5
GLCMC Model
= NPV ($\sum_{i=1}^{5} Model_i$)
INTEGRATED DSS PLATFORM
Structure Merits
Maintenance Cost
Production Cost
Improve
IMPROVE
NAME, University of Strathclyde


Design search and GLCMC model
NAVAL ARCHITECTURE MARINE ENGINEERING
UNIVERSITY OF STRATHCLYDE
Design of Experiment
LIGHTWEIGHT
DESIGN SEARCH
LNG Tanker
Chemical Tanker
ROPAX
Model 1
Model 2
Model 3 or Model 4
Model 5
NPV ($\sum_{i=1}^{5} Model_i$)
Repair Data
Net present value of life-cycle maintenance cost for the subject vessel
GLCMC Value For LNG Tanker
GLCMC Value For Chem. Tank.
GLCMC Value For ROPAX
Improve
IMPROVE
NAME, University of Strathclyde

Illustrative example (Chemical tanker)

- Model 1: production cost
- Model 2: maintenance cost
- Model 3: fuel cost
- Model 4: operational earning
- Model 5: dismantling earning

Two different scenarios examined:

- Scenario 1: Deadweight constant
- Scenario 2: Displacement constant

IMPROVE

NAME, University of Strathclyde

Results of the illustrative example

	Lightweight (in tonnes)	% δ	Scenario 1 M2 + M3 – M5 (DWT is constant)	% δ	Scenario 2 M2 – M4 – M5 (Δ is constant)	% δ
1	8,500	-10.53%	79,522,514	-0.41%	-378,717,768	3.11%
2	9,000	-5.26%	79,685,660	-0.20%	-372,997,550	1.56%
3	9,250	-2.63%	79,766,962	-0.10%	-370,137,442	0.78%
4	9,500 (base design)	0.00%	79,848,086	0.00%	-367,277,333	0.00%
5	9,750	2.63%	79,929,033	0.10%	-364,417,225	-0.78%
6	10,000	5.26%	80,009,804	0.20%	-361,557,116	-1.56%
7	10,500	10.53%	80,170,825	0.40%	-355,836,899	-3.11%

IMPROVE

NAME, University of Strathclyde

Conclusions

- The developed life-cycle maintenance/repair cost model is robust enough to be used within the IMPROVE's integrated search platform. That is to find maintenance/repair related cost/earning values for the three IMPROVE vessels with respect to design of experiments throughout the optimisation
- The developed method can efficiently help designers, ship owners and production engineers to make rationale decisions during early design phases
- Although the model is able to calculate generalized life-cycle maintenance cost, it can also be used for what if scenario analyses with respect to other parameters of the model, such as unit price of steel replacement per kg, price of fuel oil, and so on
- This model can further be improved with the inclusion of other life-cycle cost elements

Improve

IMPROVE

NAME, University of Strathclyde

Future research

- To employ advanced inference and/or reasoning systems that are to perform reasoning under vagueness environments; where maintenance/repair data is difficult to obtain and expert knowledge expressed in verbal settings is present
- To make use of neural networks for better predictions of annually replaced steel and unavailability times
- To create ship specific regression models and databases with the availability of additional maintenance/repair data
- To extend the existing model to take account of the maintenance/repair requirements of ship owners/operators

Improve

IMPROVE

NAME, University of Strathclyde

T4.1b (updated) including a corrosion parameter

Investigate the effect of additional structural member thickness (according to ship-owners' requirements) on the repairs of the ship during its life-cycle.

- Follow the CSR *"Net thickness approach"* which differentiates between the local and the global corrosion effect.
- General corrosion pattern is applied in this case study.
- Mean annual corrosion rates used are from the Gratsos & Zachariadis (2005) research work.
- The scenarios for the Chemical tanker examined are the ones for the original LWT case (9,500 tons-Turan et al 2009).
- Additional LWT in terms of thicker structural members (bottom plates in this case): 5% of the original LWT.
- Productivity of repair yard: 7 tons of steel/day

Research questions

Question 1

What is the additional plate thickness for the Chemical tanker in order to have a 25 year repair-free life?

Question 2

What are the financial results in terms of Models 2-5 examined before?

Methodology

Three different cases are described:

- *"case 1-0.12mm/year"* : mean annual corrosion rate of 0.12mm
- *"case 2-0.20mm/year"* : mean annual corrosion rate of 0.20mm
- *"case 3-0.40mm/year"* : mean annual corrosion rate of 0.40mm

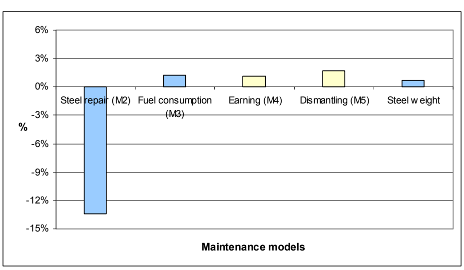
Results

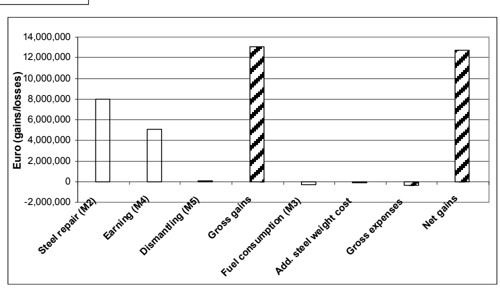
- Case 1: 1.0 mm additional plate thickness
- Case 2: 2.5 mm additional plate thickness
- Case 3: 6.5 mm additional plate thickness

IMPROVE

NAME, University of Strathclyde

Results (case 1-0.12mm/year)

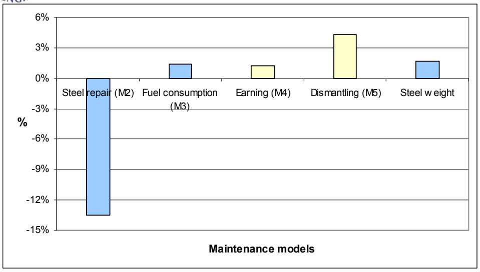


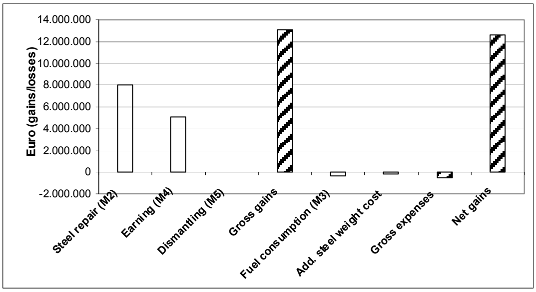


IMPROVE

NAME, University of Strathclyde

Results (case 2-0.20mm/year)

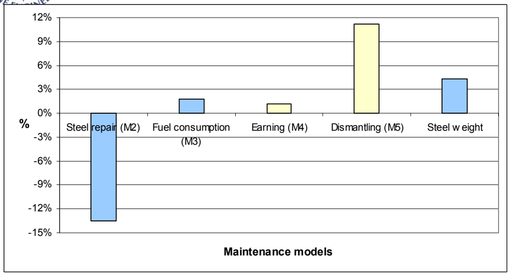


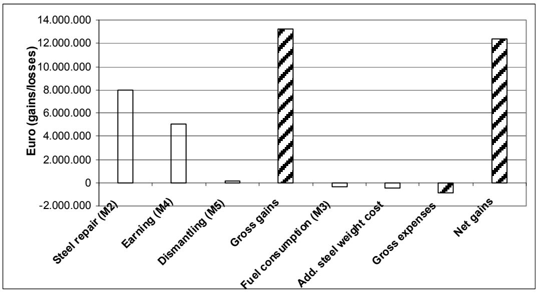


IMPROVE

NAME, University of Strathclyde

Results (case 3-0.40mm/year)

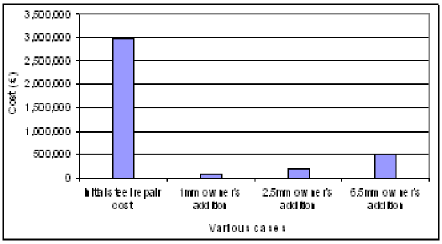


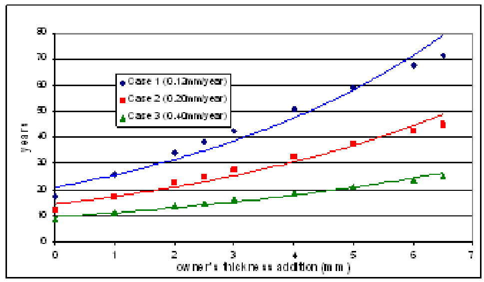


IMPROVE

NAME, University of Strathclyde

Further results





IMPROVE

NAME, University of Strathclyde

QUESTIONS

THANK YOU

IMPROVE

NAME, University of Strathclyde

Tools for Early Design Stage - Integration and Tools

IMPROVE

Software Integration in the Context of the IMPROVE Project

Stephan Wurst, Markus Lehne

BALance, Bremen, Germany

Bernard Cupic, Milan Milanovic

USCS, Pula, Croatia

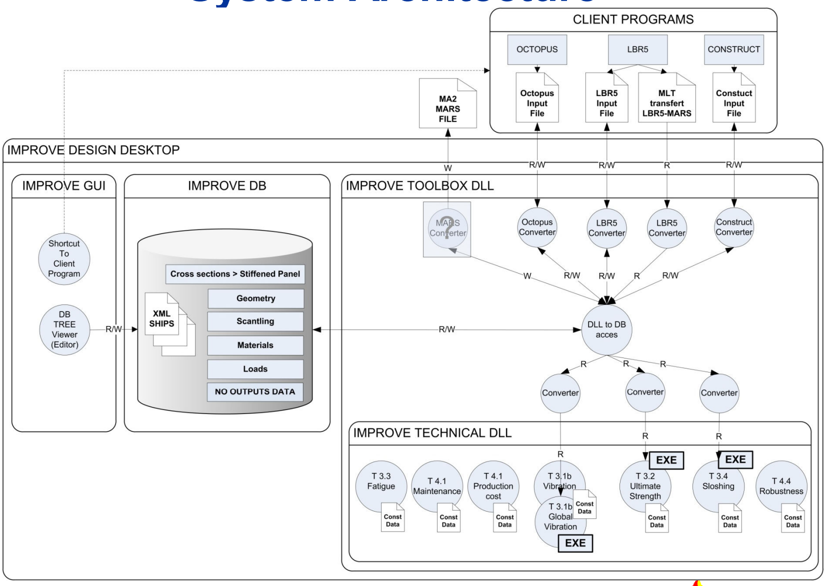
Content

- General Idea
- System Architecture
- IMPROVE Data Model and Database
- Integration on API level
- Integration on User Level
- Demo
- Conclusion

General Idea

- Integration of
  - IMPROVE algorithms
  - IMPROVE database
  - Background applications
- Integration levels
  - Database
  - API
  - User interface
- Pre-conditions
  - IMPROVE is not a software development project
  - Integration solutions have to be pragmatic
  - Integration platforms are heterogeneous
    - Java
    - C++
  - A network wide integration should be possible without large development effort

System Architecture



IMPROVE Data Model and Database

- Data Model
- Implementation
  - Database API automatically generated from the XML model
  - Can be used directly
  - For use in the IMPROVE context simplified API as a separate DLL
    - Only implements functions relevant for IMPROVE related objects

Integration on API level

- Direct access to functions via a DLL
  - Integration of the algorithms under a unified API
  - Consideration of different compilers and languages (Fortran and C++)
  - Running algorithms
  - Running converters
  - Opening the database (actual access to the objects via a separate library)

Integration on API level

- Java API
  - "Translation" of all algorithm calls into Java
  - JNI (Java Native Interface) is used to connect the underlying DLLs
  - Recommended interface for new developments (easy adaptation to networked environments)
- Data conversion
  - Calling of converters for IMPROVE to MARS/OCTOPUS and vice versa

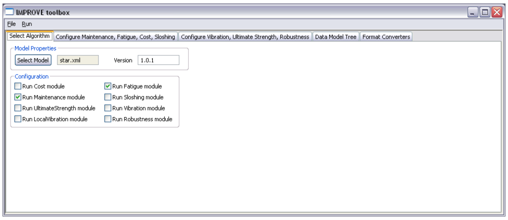
IMPROVE

Slide 7 --------1----2----3----4----5----6----7----8----9----10----------

BALance Technology Consulting

Integration on User Level

- A Java user interface exists for
  - Manually starting data import and export
  - Conversion of files
  - Viewing and editing database content
  - Configuration of algorithm parameters
  - Running the algorithms for testing

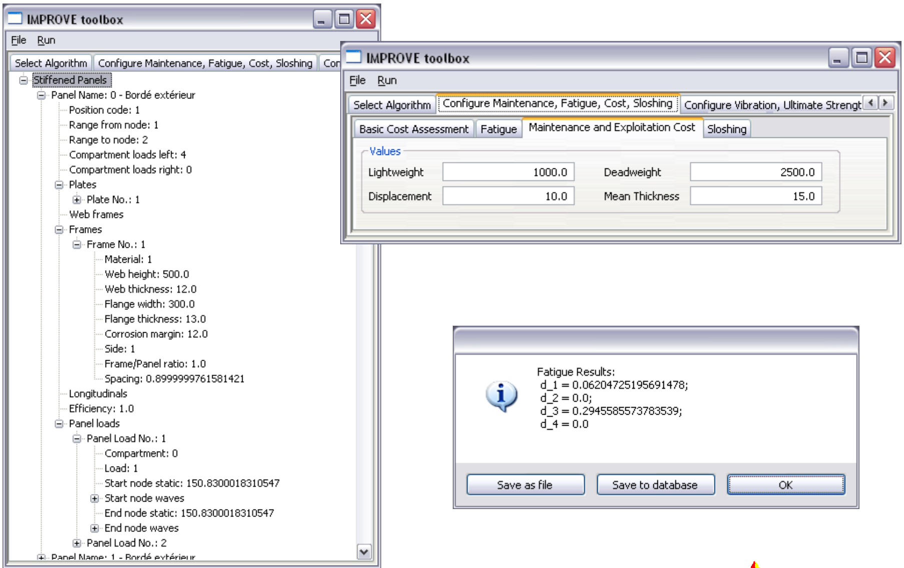


IMPROVE

Slide 8 --------1----2----3----4----5----6----7----8----9----10----------

BALance Technology Consulting

Integration on User Level



IMPROVE

BALance Technology Consulting

Slide 9 --------1----2----3----4----5----6----7----8----9----10----------

Integration on Network Level

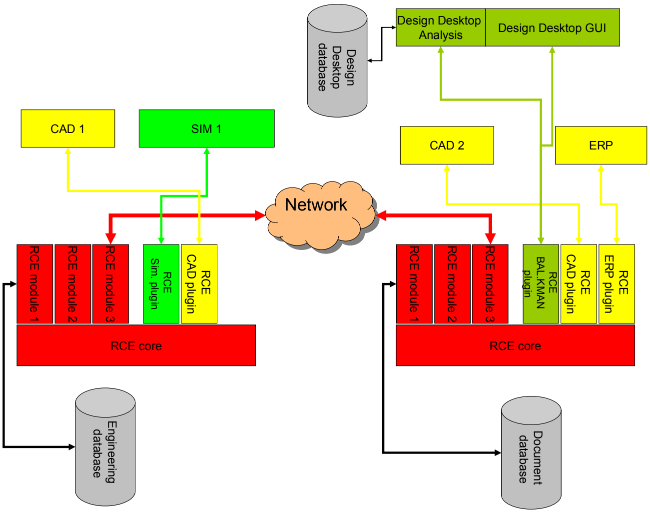
- Idea: Distributed environment with different engineering tools
- Comparison of two different technologies
- User level oriented
  - VIP
- Developer oriented
  - RCE
- Both solutions worked but where too complex for use in the IMPROVE context

IMPROVE

BALance Technology Consulting

Slide 10 --------1----2----3----4----5----6----7----8----9----10--------

Integration on Network Level

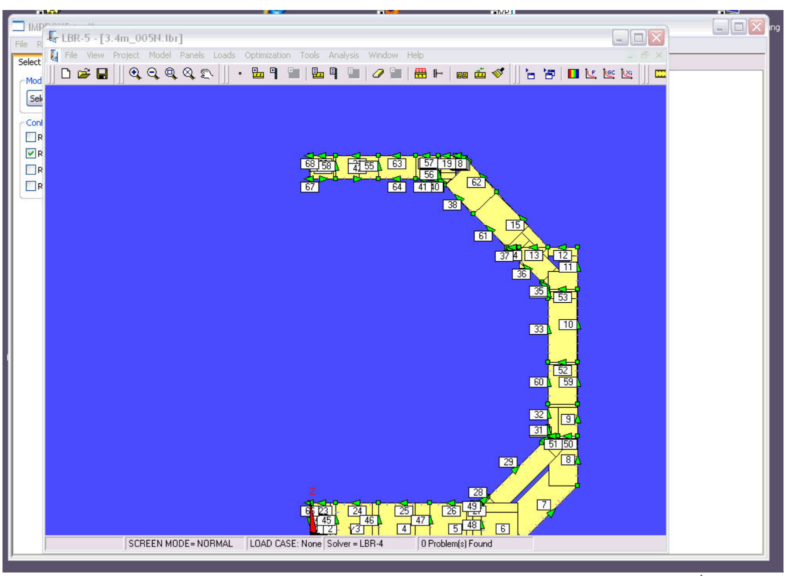


IMPROVE

BALance Technology Consulting

Slide 11 --------1----2----3----4----5----6----7----8----9----10--------

Demo



IMPROVE

BALance Technology Consulting

Slide 12 --------1----2----3----4----5----6----7----8----9----10--------

Conclusion

- BALance and USCS have created a pragmatic integration environment for use within the IMPROVE context.
- The developed components are flexible enough for easy integration into existing software environments.
- Use is possible for in-house integration as well as for service providers

IMPROVE

Slide 13 --------1----2----3----4----5----6----7----8----9----10--------

BALance Technology Consulting

Future developments

- IMPROVE will set up a post project interest group
- Target partners
  - Universities
  - Technology providers
- Interested partners can join and contribute
  - Algorithm/Module developers
  - Tool developers
  - End users

IMPROVE

Slide 14 --------1----2----3----4----5----6----7----8----9----10--------

BALance Technology Consulting

Future developments

- Major ideas
  - Validate IMPROVE modules against different boundary conditions
  - Set up standard procedures for module testing and validation
  - Further development of modules
  - Co-operation with new partners

IMPROVE

Slide 15 --------1----2----3----4----5----6----7----8----9----10--------

BALance Technology Consulting

Future developments

- Expected outcome
  - Mature and reliable algorithms
  - Generic integration platform
  - Extendability by new algorithms

IMPROVE

Slide 16 --------1----2----3----4----5----6----7----8----9----10--------

BALance Technology Consulting

IMPROVE

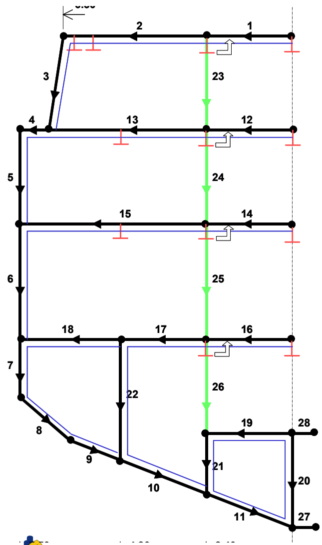
Tools Presentation: LBR-5

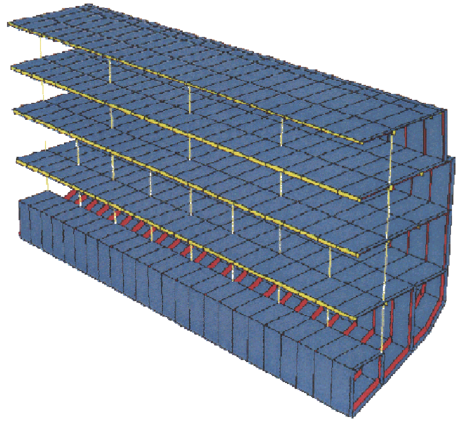
F. Bair, A. Amrane, A.Constantinescu, J.D. Caprace, Ph. Rigo
ANAST University of Liège, Liège, Belgium
E.Pircalabu, A.Hage
DN&T, Liège, Belgium

CORSAIRE 10000 : A FAST FERRY

ALSTOM

MIDSHIP SECTION DEFINED by LBR5
(→ Corsaire Fast Ferry)

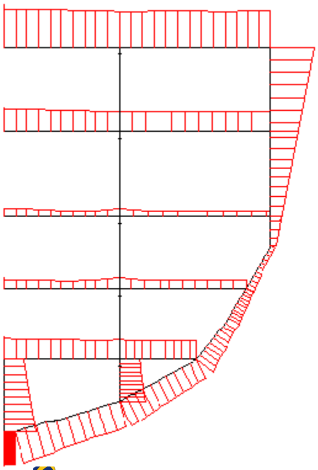




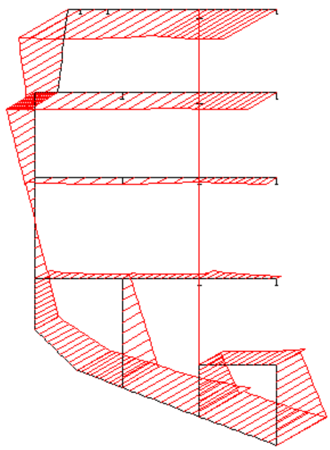
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Stress induced by the maximum hull girder bending moment
(Hogging and sagging)

von-Mises Stresses

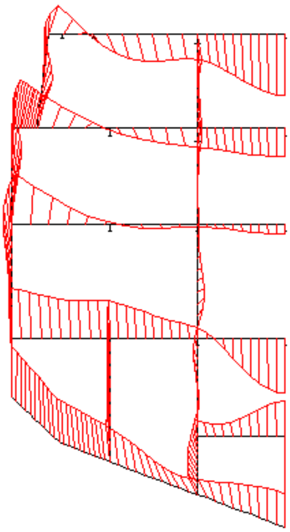


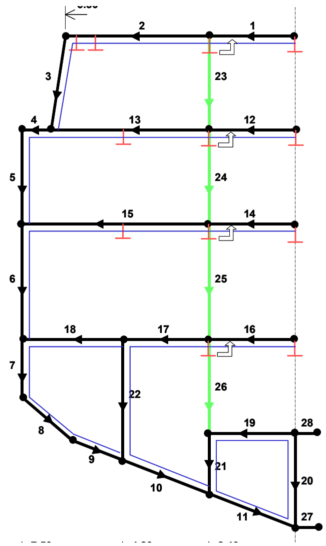
Longitudinal Stresses



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Hull deflection under Hogging bending moment





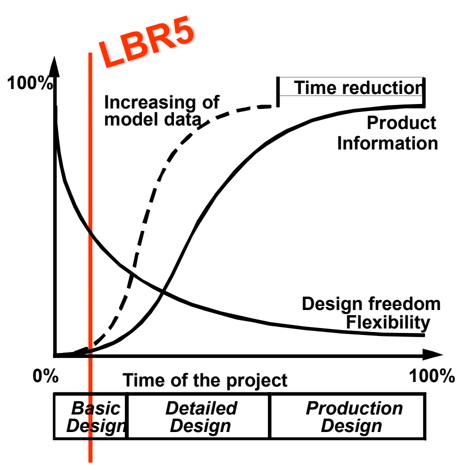
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

Context of application

- Concurrent Engineering
- To make the best decision earlier
- **Multicriterion Scantling Optimization of the Midship Section in the early design stage**
  - **Decrease global cost**
  - **Increase global performance**

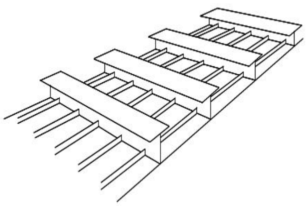


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

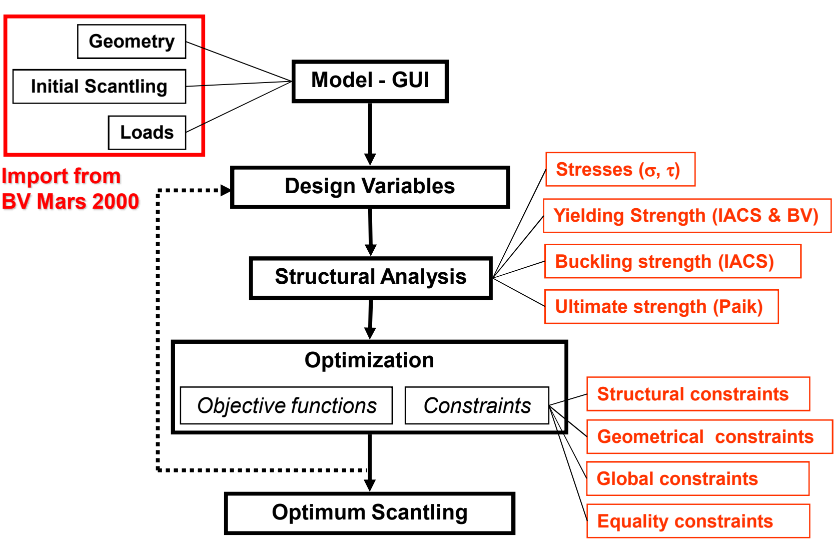
- **What is the LBR-5 tool ?**
  - **Scantling optimization tool for naval and hydraulics structures**
  - **Dedicated to early design stage**
  - **3D structural analysis based on a extruded 2D mesh**
  - **Scantling optimization of the structural elements**
    - 9 variables per strake
      - Spacing (frames & stiffeners)
      - Thicknesses & dimensions
  - **Different objectives are implemented**
    - *Minimize the manufacturing* ***cost***
    - *Minimize the structural steel* ***weight***
    - *Maximize the flexional* ***inertia***



LBR5 strake element

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

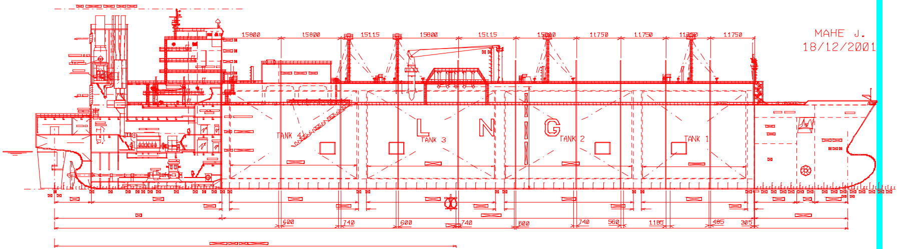


IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Medium Size LNG Carrier

60 000 Elements
150 Panels
40 Blocs

Indicative values



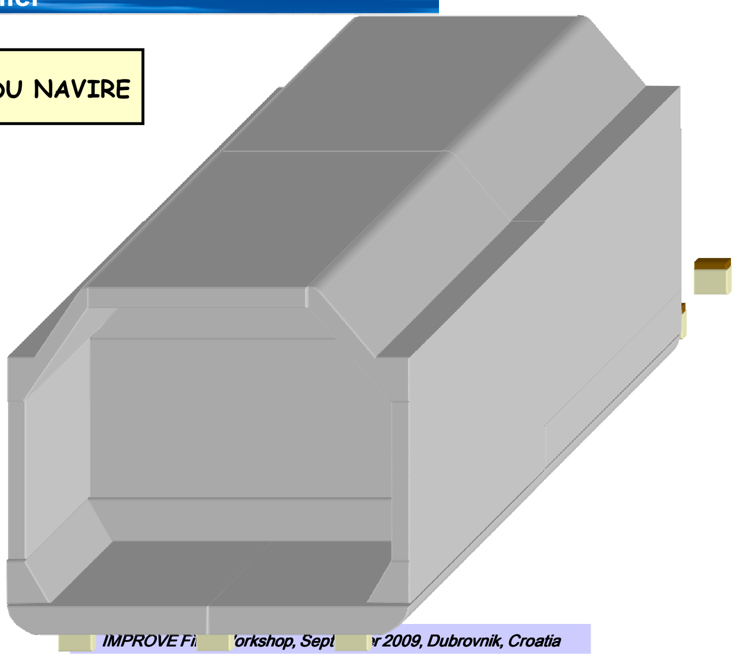
220 m

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Méthanier

MONTAGE DU NAVIRE



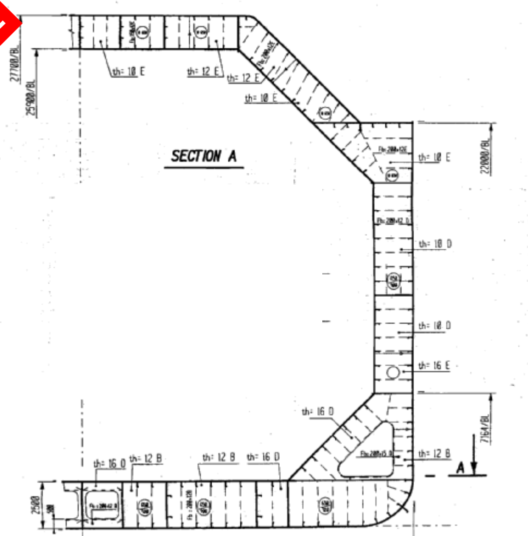
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Medium Size LNG Carrier

VERSION INITIALE

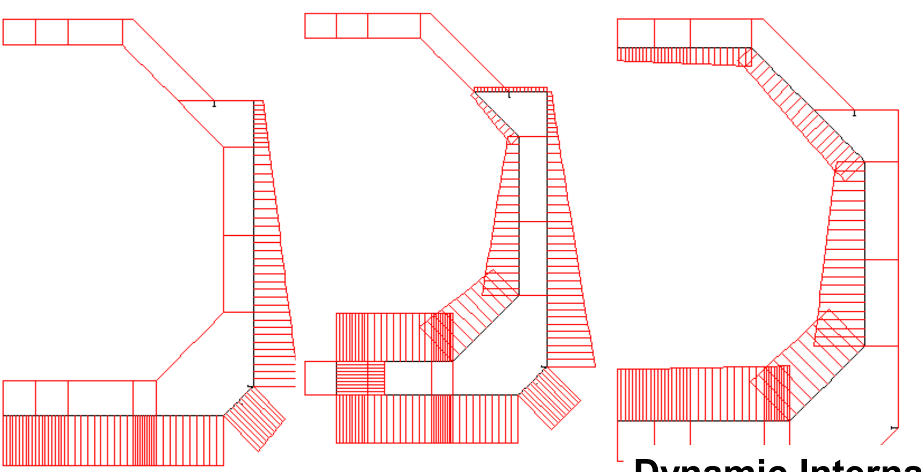
MID-SHIP SE



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

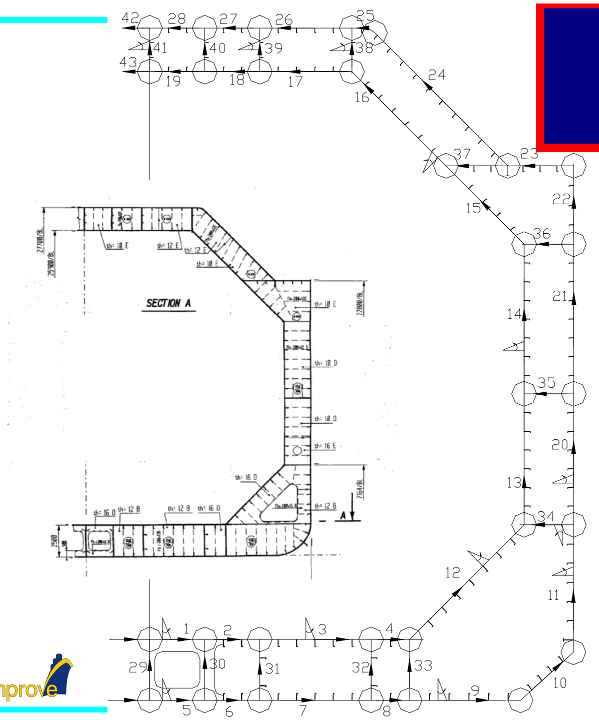
Medium Size LNG Carrier



Sea Loads (BV's rules)

Internal pressure in BALLAST (BV's rules)

Dynamic Internal Pressure in GAS Tank (BV's rules)



Medium Size LNG Carrier

LBR5 Mesh Model

Medium Size LNG Carrier

The mesh model of the gas carrier includes:

- ✓**41 stiffened panels with 9 design variables each,**
- ✓**4 additional panels to simulate the sym. axis,**
- ✓**278 design variables (5 to 9 variables per panel);**
- ✓**106 equality constraints between design variables, e.g., to impose uniform frame spacing for the deck, bottom and the side ballast tanks.**
- ✓**203 geometrical constraints (about 5 to 6 x 41 panels).**

For instance longitudinal web heights are limited by such constraints to control the web slenderness.

Medium Size LNG Carrier

<u>1900 structural constraints</u> (380 per load case):

- **σ_c frame & σ_c stiffener (web/plate junction – web/flange junction and flange),**
- **σ_c plate ,** to check if $\sigma_c \leq s_1 . \sigma_o$ (with s_1 a partial safety factor and σ_o the yield stress);
- **Local plate buckling: $\delta_{MIN} \leq \delta$ (with δ_{MIN} the minimum plate thickness to avoid buckling and local yielding);**
- **Ultimate strength of stiffened panel: $\sigma / \sigma_{ULT} \leq s_2$**

  with s_2 a partial safety factor.

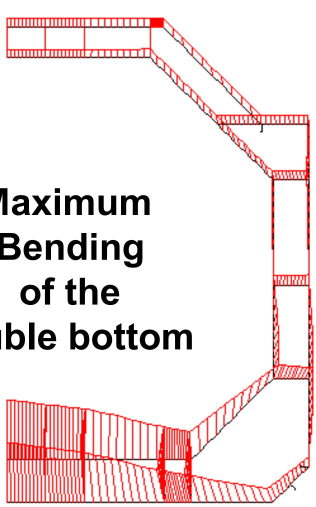
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

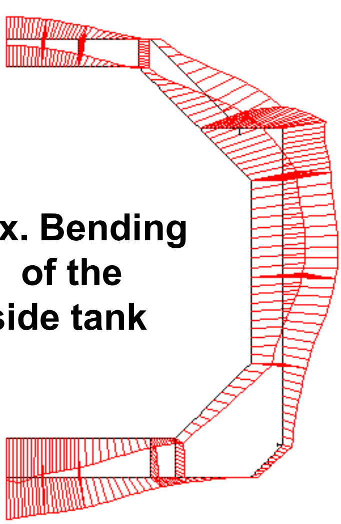
Medium Size LNG Carrier

Deflections (Frame bending)

Maximum Bending of the double bottom

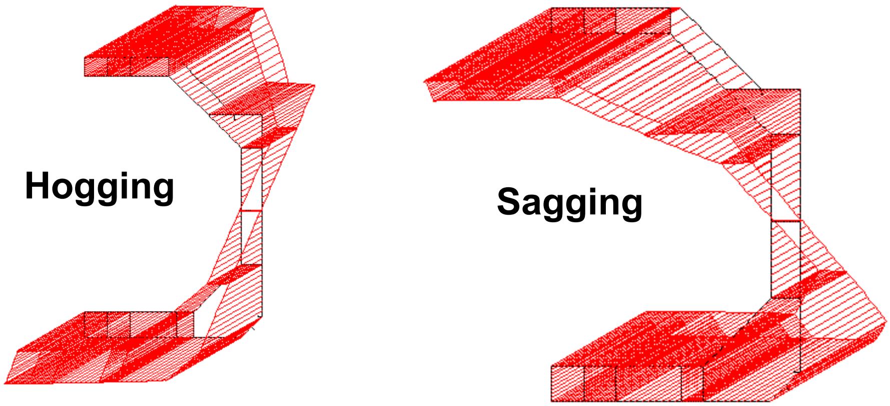


Max. Bending of the side tank



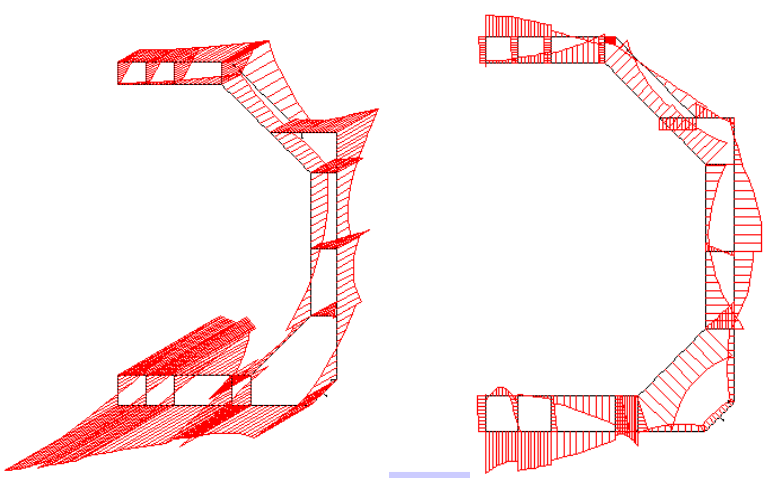
Medium Size LNG Carrier

Longitudinal bending moments

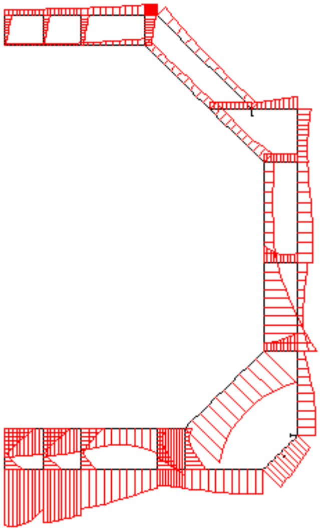


Medium Size LNG Carrier

Longitudinal Stresses   Transverse Stresses



Medium Size LNG Carrier



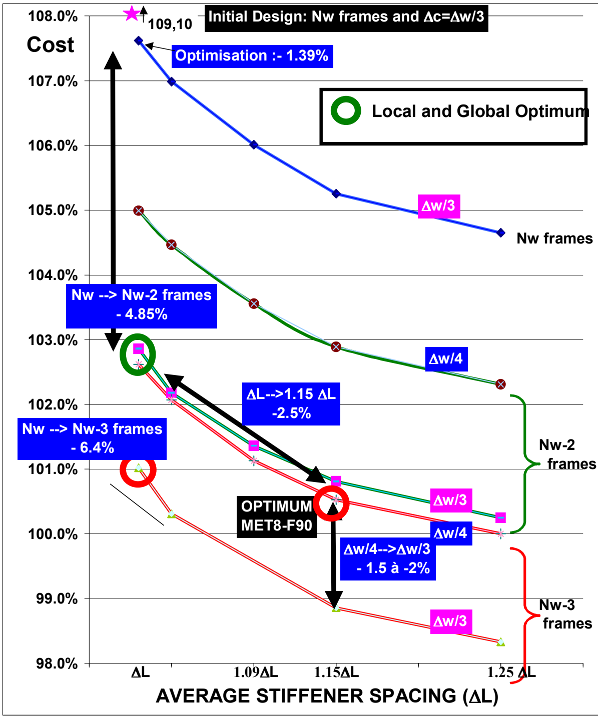
Von-Mises Stresses

Medium Size LNG Carrier

	SEARCH FOR THE LEAST COST DESIGN (with continuous design variables)			
		SPACINGS		
	Optimum Type	Number of Web-frames	Secondary Frames (Δ_C)	Stiffeners (Δ_L)
1- ALSTOM	MARS BV	N_W	Δw/3	Δ_L (Alstom)
2- MET8 E00	Least Cost (*)	N_W	Δw/3	Δ_L (Alstom)
3- MET8 E90	Least Cost	N_W	Δw/3	1.15 Δ_L (*)
4- MET8 B90	Least Cost	N_W -3 (*)	Δw/3	1.15 Δ_L (*)
5- MET8 F90	Least Cost	NW -3	Δw/4 (*)	1.15 Δ_L (*)
6- MET8 F	Least Cost	N_W -3	Δw/4	1.28 Δ_L (*)

(*) Shows the modified parameter (or variable) betv

Steps of the Optimisation Process



Medium Size LNG Carrier

LEAST COST

Initial design

- N_W & Δ_W (frames)
- $\Delta_C = \Delta_W/3$ (second. Frames)
- Δ_L (Stiffeners)

ubrovnik, Croatia

Medium Size LNG Carrier

Steps of the Optimisation Process

SEARCH FOR THE LEAST COST DESIGN (with continuous design variables)

CONFIGU-RATIONS	Optimum Type	SPACINGS: Number of Web-frames	SPACINGS: Second. Frame (Δc)	SPACINGS: Stiffeners (ΔL)	Duct keel bulkhead Plate Thickness	LEAST COST – COST SAVING (%) (see 1): Between 2 successive steps	LEAST COST – COST SAVING (%) (see 1): Cumulated saving	WEIGHT (%)	
	Shown change(s) between 2 successive steps								
1- ALSTOM	MARS BV	Nw	Δw/3	ΔL (Alstom)	100%	0.00%	0.00%	100% (ref)	Initial Design (use as reference)
2- MET8 E00	Least Cost	Nw	Δw/3	ΔL (Alstom)	105%	-1.39%	-1.39%	98.34%	
3- MET8 E90	Least Cost	Nw	Δw/3	1.15 ΔL	105%	-2.46%	-3.85%	101.61%	
4- MET8 B90	Least Cost	Nw -3	Δw/3	1.15 ΔL	130%	-6.40%	-10.25%	104.73%	plate thickness too large
5- MET8 F90	Least Cost	NW -3	Δw/4	1.15 ΔL	100%	1.67%	-8.58%	103.42%	OPTIMUM SOLUTION
6- MET8 F	Least Cost	Nw -3	Δw/4	1.28 ΔL	100%	-0.53%	-9.11%	105.29%	(*) Poor efficiency

(*) Stiffener spacing too large ==> cost savings of 0.5% but increased straightening work ==> not efficient !!

(1 Variation induced by the changes occured between two configurations.

Medium Size LNG Carrier

Optimum solution with a weight constraint

SEARCH FOR THE LEAST COST DESIGN (with constraint on the weight)

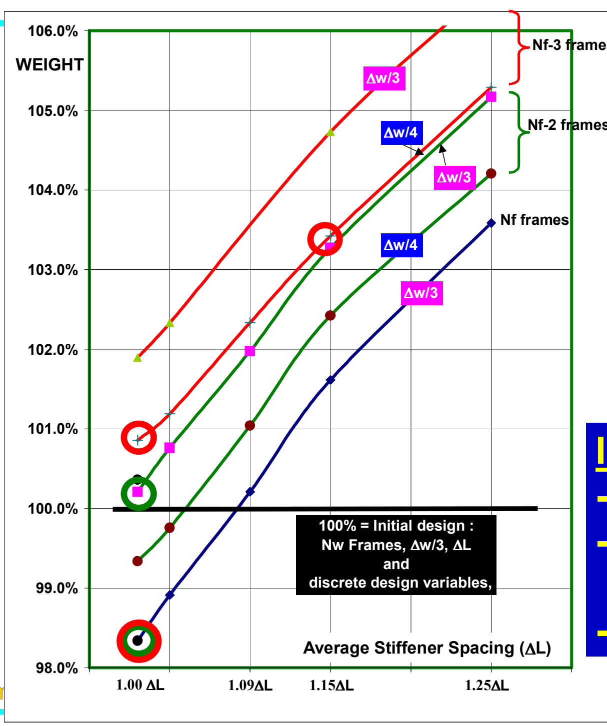
CONFIGU-RATIONS	Optimum Type	SPACINGS: Number of Web-frames	SPACINGS: Second. Frame (Δ_C)	SPACINGS: Stiffeners (Δ_L)	Duct keel bulkhead. Plate Thickness (mm)	LEAST COST: COST SAVING (%) (see 1) Between 2 successive steps	LEAST COST: COST SAVING (%) (see 1) Cumulated saving	WEIGHT (%)	
	Shown change(s) between 2 successive steps								
ALSTOM	MARS BV	N_W	Δw/3	Δ_L (Alstom)	100%	0.00%	0.00%	100.00%	Initial Design (used as reference)
MET8 E-78	Least Cost	N_W	Δw/3	Δ_L (Alstom)	105%	-1.39%	-1.39%	98.34%	
MET8 C-78	Least Cost	N_W -2	Δw/3	Δ_L (Alstom)	122%	-4.85%	-6.24%	100.21%	Duct-keel plate thickness too large
MET 12 (*) Continuous	Least Cost	N_W -2	Δw/3 (*)	Δ_L (Alstom)	88% (*)	-0.68%	-6.92%	99.68%	OPTIMUM SOLUTION (with discrete design variables)
MET 12.b (*) Discrete	Least Cost	N_W -2	Δw/3 (*)	Δ_L (Alstom)	88% (*)	0.45%	-6.47%	100.88%	OPTIMUM SOLUTION (with continuous design variables)

(*) Layout is modified

(1) Variation induced by the changes occured between two configurations.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia



Medium Size LNG Carrier

LEAST WEIGHT

<u>Initial design</u>
- N_W & Δ_W (frames)
- $\Delta_C = \Delta_W/3$ (second. Frames)
- Δ_L (Stiffeners)

Medium Size LNG Carrier

Tracks to Minimize the Construction Costs

To increase the web-frame spacing:
(N_w – 2) web-frames instead of N_w web-frames
→ Cost saving: 4.85 %
(N_w – 3) web-frames instead of N_w web-frames
→ Cost saving: 6.40 %

- **To increase the stiffener spacing (Δ_L):**
  - **1.09 Δ_L instead of Δ_L → Cost saving: 1.61 %**
  - **1.15 Δ_L instead of Δ_L → Cost saving: 2.40 %**
  - **1.28 Δ_L instead of Δ_L → Cost saving: 2.97 %**

(if *straightening cost is not considered)*

Improve
1-Oct-09

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

ANAST ULg

Tools presentation: LBR-5

- Improvements done in the IMPROVE framework:
  - Integration of a Sloshing module
  - Integration of a Fatigue module
  - Integration of a Vibration module
  - Integration of a Life Cycle Cost module
  - Integration of a Multi-materials module
  - Integration of a Multi-structures module

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

- <u>The Sloshing module</u>

<u>Inputs</u>: Sloshing pressure for each LBR-5 panel

Given by Bureau Veritas

<u>Outputs</u>: Three new constraints for each LBR-5 panel

- Constraint on the net minimum thickness (**plate**)

- Constraint on the net minimum section modulus (**stiffeners**)

- Constraint on the net minimum shear sectional area (**stiffeners**)

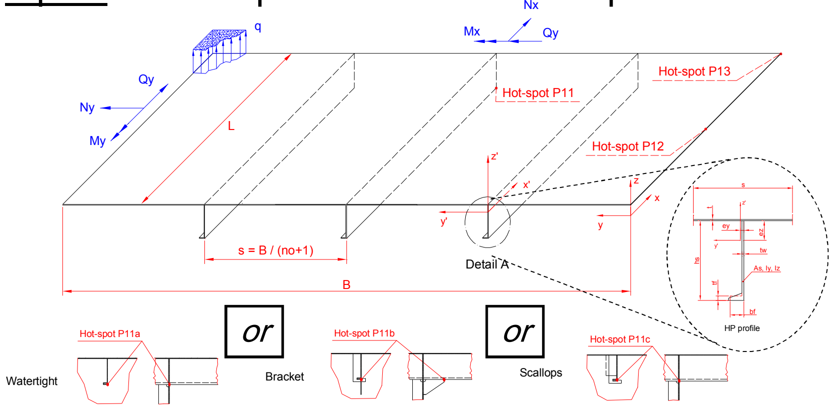
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

- <u>The Fatigue module</u>

<u>Inputs</u>: For the plate: choice of Hot-spot and brackets



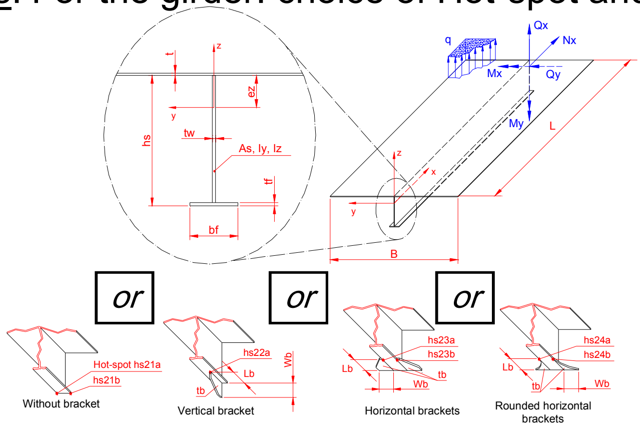
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools Presentation: LBR-5

- The Fatigue module

Inputs: For the girder: choice of Hot-spot and brackets



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

- The Fatigue module

Outputs:

- Damage for each selected hotspot

→ A new constraint is obtained for each LBR-5 panel

= the maximum damage in the panel

→ Fatigue is taken into account at the preliminary design stage!

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

- The Vibration module

- Gives frequency for each panel selected

- Uses only as a check at the end of the process because:

  - One panel takes about 1 minute to be evaluated (to much !!)

  - One LBR-5 model can have 300 design variables (9 by panel) → finite difference can take 10 minutes for 1 iteration and 1 panel → more than 16 hours for one optimization with 10 vibration panels !!!

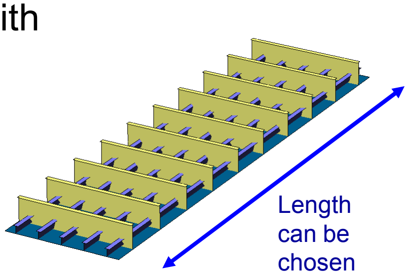
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

- The Vibration module

"Vibration" panel could be:

- A simple LBR-5 panel with
  - Primary stiffeners
  - Secondary stiffeners
  - Primary frames
  - Secondary frames
  - Girders



For each extremity: boundary condition must be chosen!

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

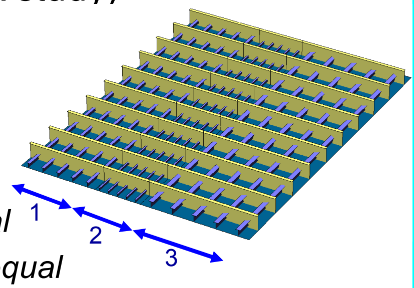
- <u>The Vibration module</u>

"Vibration" panel could be:

- A set of LBR-5 panels (deck study)

Rem.:

- *Frames must be identical*
- *Panels must be aligned*
- *Material must be the same*
- *Vibration length must be equal*
- *Panels thicknesses must be equal*
- *Same boundaries condition for each panel*



→ **19 tests done into LBR-5**

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

- <u>The Life Cycle Cost module</u>

= New objective function

<u>Inputs</u>: Lightweight – Deadweight – Scenario – indCorrosion

Scenario → *Displacement constant* | *Deadweight constant*

<u>Outputs</u>: four different cost/revenue

- Cost of periodic maintenance (2)
- Cost of oil consumption (3)
- Operational revenues (4)
- Dismantling revenues (5)

indCorrosion:
0 → "Classic" LCC module
1 → With corrosion scenario

Life Cycle Cost = (2) + (3) – (4) – (5)

(possibility to add production cost)

Improve

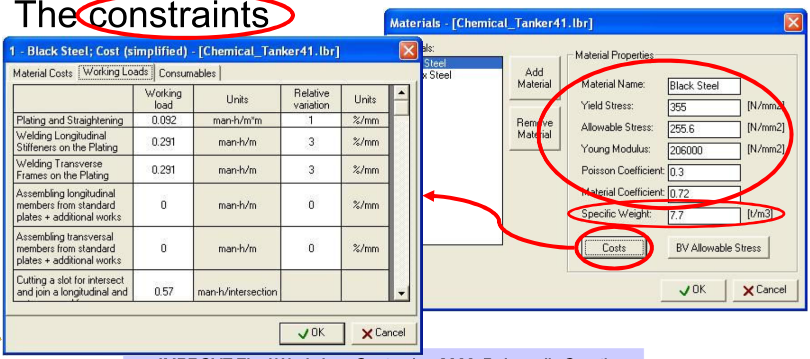
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

- The Multi-materials module

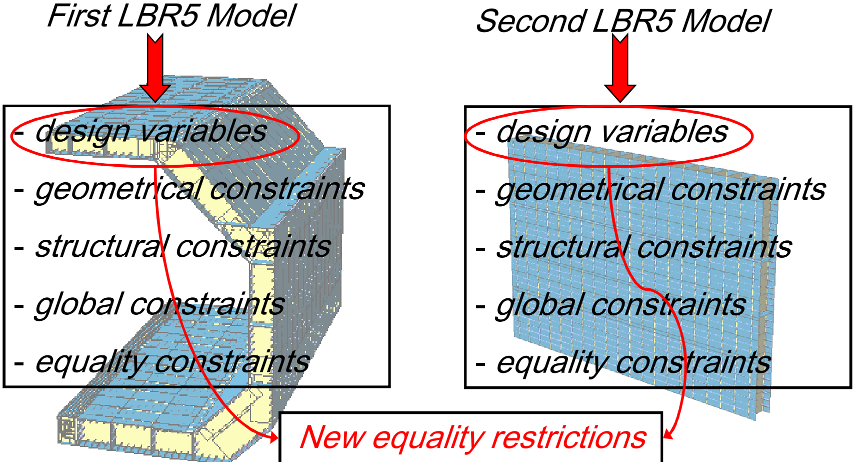
Each material has an impact on:

- The objective function (weight or cost)
- The constraints



Tools presentation: LBR-5

- The Multi-structures module



Tools presentation: LBR-5

- Applications of the new modules in the framework of IMPROVE:

- LNG: Sloshing, Fatigue, Multi-structures
- Chemical Tanker: Life Cycle Cost, Multi-materials
- Ropax: Vibration

→ Study of each module on the optimised scantling

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Tools presentation: LBR-5

- Conclusions
  - Six new modules have been implemented divided into 3 categories:
    - Improvements of constraints (Sloshing, Fatigue, Vibration)
    - New objective function (Life Cycle Cost)
    - Improvements of flexibility (Multi-materials, Multi-structures)
  - Applications done on different ships (LNG, Chemical Tanker and Ropax)

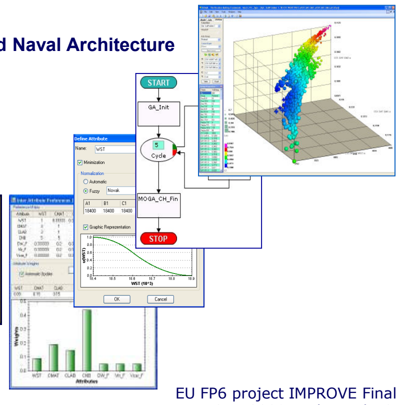
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OCTOPUS and MAESTRO Software tools

UZ-FMENA
University of Zagreb
Faculty of Mechanical Engineering and Naval Architecture

Presenting:
Vedran Zanic
Stanislav Kitarovic
Pero Prebeg



EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Contents

- Introduction;
- Design procedure formulation;
- Analysis and synthesis toolboxes (MAESTRO and OCTOPUS Designer/Analyzer);
- Integrated IMPROVE modules;

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Introduction

Objectives are:

- Present the decision support problem (DSP) rationale for the concept and preliminary design phases where the most far-reaching decisions are made regarding safety and cost;
- Present the design environment, capable of imbedding multiple quality criteria (including cost, weight, reliability and nonlinear ultimate strength calculations);

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Introduction

Concept design phase:

Small amount of data available → Low fidelity tools → Capital decisions (~70% of the total costs are fixed) → Experienced designer → Large number of design variants.

Preliminary design phase:

All major questions answered → Design sufficiently constrained → High fidelity tools → Large optimization problems

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Introduction

Optimization based design process includes:

- Design problem identification;
- Formulation of the Decision Support Problem (DSP) methodology;
- Problem solution (including sensitivity assessment).

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Introduction

Design problem identification implies:

- Selection of design variables and design criteria (constraints and attributes);
- Determination of design objectives and corresponding measures of robustness;

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Introduction

Formulation of the DSP methodolgy involves:

- DSP manipulation into equivalent but mathematically more convenient form;
- Selection of solution strategy (e.g. optimization technique) for the manipulated problem;
- Development of the final selection method for the generated design variants;
- Sensitivity/uncertainty analysis.

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Introduction

DSP solution requires practical implementation of selected methodology trough two basic mathematical models:

- **Design analysis model** for technical and economical evaluations. For many engineering problems mathematical model can be decomposed into six meta-systems: two basic ones (Φ, ε) and four behavioral systems (ρ, α, π, Ω);
- **Design synthesys model** includs interactive decision making shell with desigh utilities: design definition modules , optimization and sensitivity solvers , databases, visualization and selection modules.

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Introduction

Software applied:

- MAESTRO is an integrated ship structural modeling, analysis, and optimization system for the preliminary design phase. It is also applied in concept design phase for generic 3D models;
- OCTOPUS is integrated ship structural modeling, analysis, and optimization system for initial design space exploration;
- 2.5D structural model is produced interactively using MAESTRO Modeler.

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

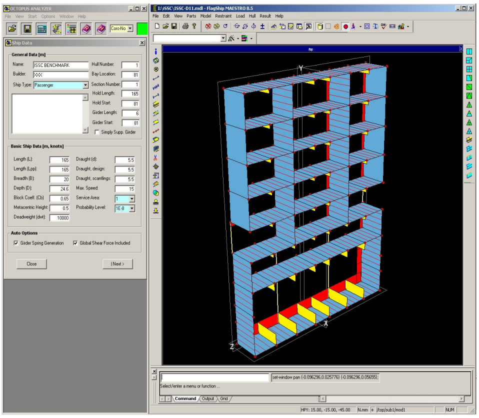
METASYSTEM (MODULES)	OCTOPUS/CREST ANALYZER MODULES (IMPLEMENTED MAPPINGS)	DESCRIPTION OF THE ANALYSIS MATHEMATICAL MODELS / MAPPINGS
Physical (Φ)	FEM STRUCTURAL MODELER	MAESTRO MODELER used to define 2,5D FEM model with different cross-sections (web-frame, bulkhead).
Environment (ε-1, 2)	Load module: CRSLOAD/CSRLOAD	MAESTRO loads, Classification society loads (e.g. IACS-CSR) are generated automatically. Designer given loads from seakeeping analysis.
Response (ρ-1) (ρ-123)	LTOR – Primary strength fields (warping displacements; normal/shear stresses) MAESTRO solver	Extended beam theory (cross section warping fields via FEM in vertical/horizontal bending and warping torsion).Full 3D FEM models.
Response (ρ-2, 3)	**TOKV/TBHD – Secondary strength fields (transverse and lateral displacements, stresses)**	FEM analysis of web-frame and bulkhead (beam element with rigid ends; stiffened shell 8-node macro-element).
Adequacy/ Feasibility (α-1, 2)	MAESTRO ELAN / ULSAP, **OCTOPUS EPAN – Library of stiffened panel and girder ultimate strength & serviceability criteria.** FATCS – Rules fatigue calculation – Level 1	Calculation of macroelement feasibility based on super-position of response fields and using the library of analytical safety criteria.
Adequacy (α-3, 4, 5, 6)	ALPS _HULL, **LUSA – Longitudinal ultimate strength module** MIND – Generator of minimal dimensions **IMPROVE FATIGUE MODULE** **IMPROVE LOCAL VIBRATIONS MODULE**	Incremental ultimate strength analysis of cross-section using J. Paik's formulae, IACS and Hughes/Adamchak procedures. Minimal dimensions definition from classification society rules.
Reliability (π-1)	US-3 – Reliability calculation of element and system failure probability (Level 1-3, mechanism) SENCOR – Sensitivity to correstion of input variables	FORM approach to panel reliability. β-unzipping method used to determine system probability of failure. Sensitivity calculation based on Nataf model.
Quality (Ω-1, …, 9)	WST/INC - Cost/weight modules in MAESTRO and OCTOPUS DCLV - Ultimate vertical bending moment DCLT - Ultimate racking load FLIFE - Fatigue life SSR/SCR - Reliability measures ICM/TSN - Robustness measures **PRODUCTION COST MODULE** **LIFE CYCLE COST MODULE**	Min. struct. weight = max. DWT increase; Min. initial cost. Calculations using LUSA and SORM. Deterministic calculation using US-3. IACS fatigue life calculation for longitudinals. Upp. Ditlevsen bound of panel failure/racking failure probability. Information context measure / Taguchi S/N ratio via FFE.

Improve

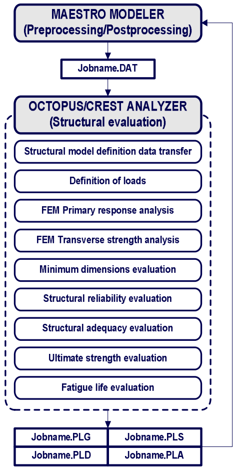
EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

MAESTRO – OCTOPUS/CREST

Working environment and flowchart



OCTOPUS/CREST MAESTRO MODELER



Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

BASIC MODELING BLOCKS

Macro-elements
(e.g. finite elements incorporating discrete stiffeners on the plate field);

Gross-elements
(Set of macro-elements unified with ‘natural boundaries’ e.g. deck at side);

Super-elements
(Statically condensed parts of the structure);

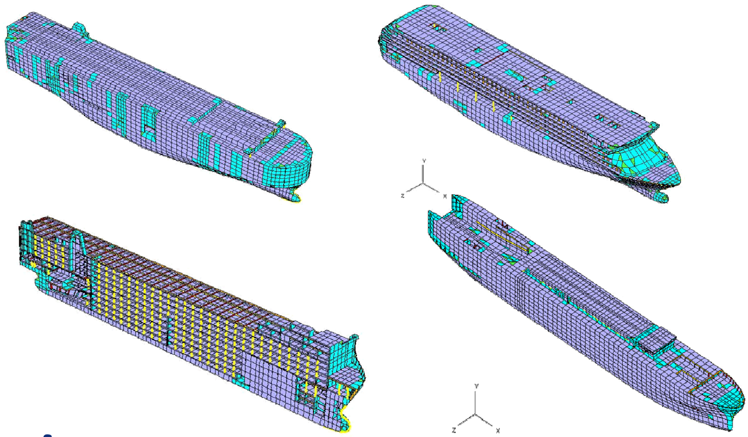
Surrogates
(equivalent-elements or compounds) are sets of finite elements with equivalent characteristics (e.g. for modeling of large side openings, doors, windows, etc.).

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

GENERIC SHIP MODELS

Characteristic structural models (Data base)

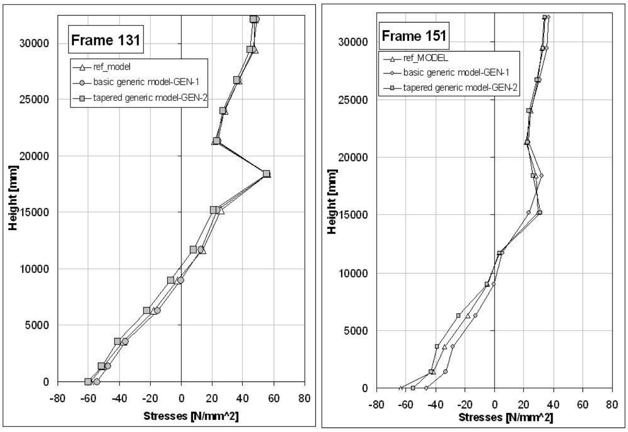


EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

GENERIC SHIP MODELS

LONGITUDINAL STRESS COMAPARISON:

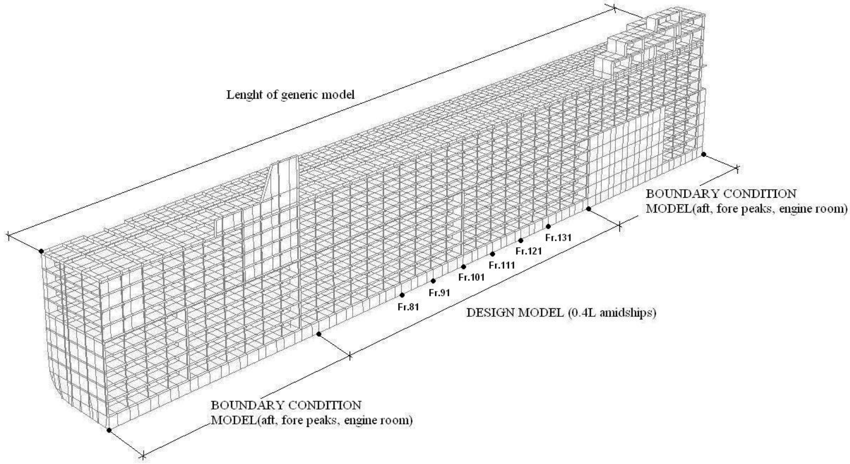
Full ship (REF_MODEL) vs. Basic generic (GEN-1) vs. Tapered generic (GEN-2)



EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

GENERIC SHIP MODELS

Concept design model - Subdivision

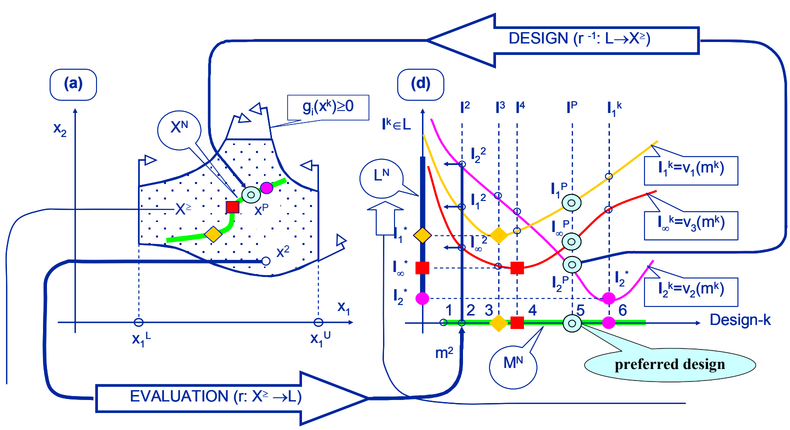


Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

SYNTHESIS

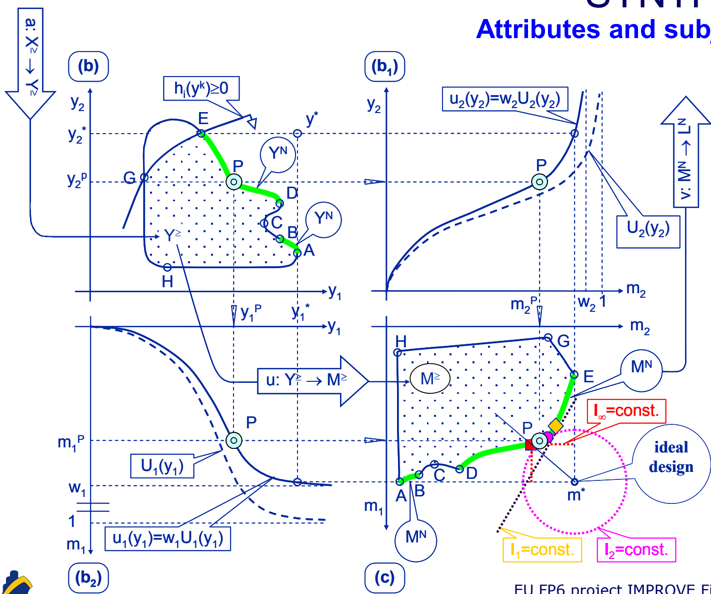
Design and evaluation



Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

SYNTHESIS
Attributes and subjectivity



EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

SYNTHESIS MODULES *(DeMak)*
Toolbox

SYNTHESIS MODELS	OCTOPUS DESIGNER MODULES
Problem definition (Δ)	**C# shell:** SYNCHRO **– decision support problem definition, selection of analysis and synthesis methods.** Auxiliary modules: CAPLAN – control of Pareto surface generation LINC – definition of feasible subspace based on subset of linear/linearized constraints
Problem solution (Σ)	**DeMak optimization solvers:** MONTE – multilevel multi criteria evolution strategy FFE – Fractional Factorial Experiments CALMOP - SLP cross section optimizer MOGA - Multi objective GA DOMINO – Pareto frontier filter MINIS – subspace size controller HYBRID – combination solver-sequencer
Problem graphics and interactivity (Γ)	**MAESTRO Graphic Environment + De View C# Environment** Design selection modules in metric space: GOAL- interactive goal input SAATY - inter-attribute preferences FUZZY - intra-attribute preferences COREL - statistical analysis of results

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

MAESTRO Software

Method for Analysis Evaluation and STRuctural Optimization

Description:

The first and most widely spread integrated software for 'first principles' analysis of ship structures and preliminary design phase optimization.

User base:

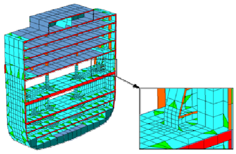
Navies, Shipyards, Classification societies, Design offices, Universities, …

Distribution and support:

DRS-C3 Advanced Technology Center, Stevensville, Maryland, USA.

Web: http://www.orca3d.com/maestro/

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

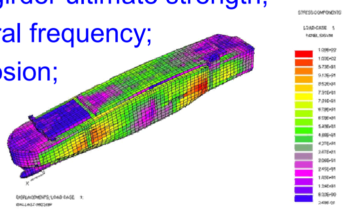


MAESTRO Software

Key features:

Global design analysis:

- Rapid modeling/modification;
- Ship based loading;
- Finite element analysis;
- Structural failure evaluation;
- Hull girder ultimate strength;
- Natural frequency;
- Corrosion;



Local design analysis:

- Top-down analysis;
- Embedded analysis;
- 3rd party import;
- Automated global BCs;

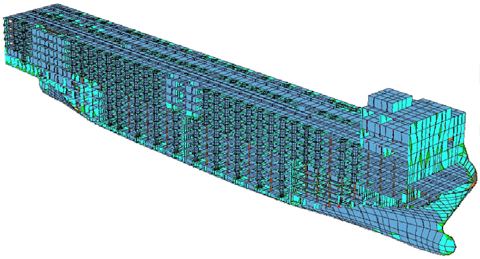
3rd Party data exchange:

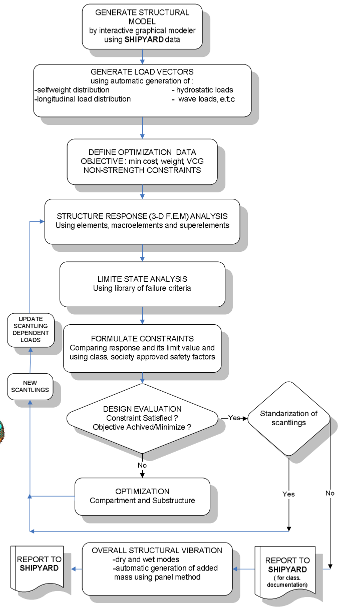
- Hydrodynamic code interface;
- Import/export Nastran data;
- Geometry import;

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

MAESTRO Software

General design procedure



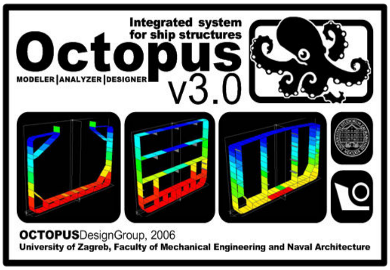


Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

OCTOPUS/CREST Analyzer

One-bay structural evaluation software developed by UZ-FMENA.
Employs MAESTRO MODELER for preprocessing/postprocessing.



Software version for structural evaluation for arbitrary type of ship structure.

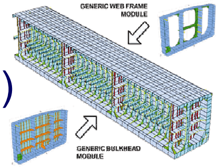
Software version with implemented IACS CSR for Double-hull Oil Tankers / Bulk Carriers.

Improve

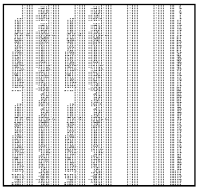
EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

FEM STRUCTURAL MODELER (Φ)

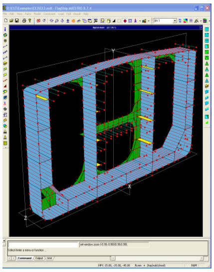
Scheme of the dataflow



- **Topology, geometry and scantlings input from jobname.DAT file.**
- **Grouping of the input data and calculation of related parameters.**
- **Data transfer to Analyzer (OCTOPUS/CREST).**

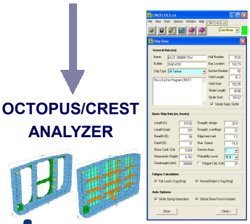


Jobname.DAT



MAESTRO MODELER used to generate 2.5D one-bay generic model (web frame, bulkhead).

OCTOPUS/CREST ANALYZER

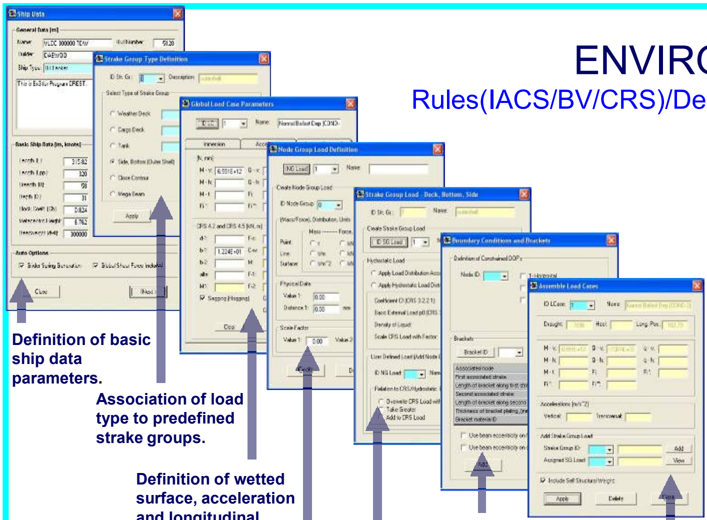


Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ENVIRONMENT (ε)

Rules(IACS/BV/CRS)/Designer given loads



Definition of basic ship data parameters.

Association of load type to predefined strake groups.

Definition of wetted surface, acceleration and longitudinal strength parameters.

Definition of strake group loads for predifined strake groups.

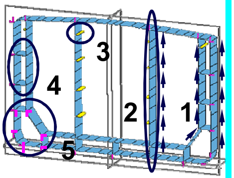
Definition of nodal (concentrated) load for predifined node groups.

Definition of boundary conditions and brackets.

Superposition of load components into loadcases.

AUTOMATIC B.C. CREATION:

1. **Automatic balancing of non-balanced loads.**
2. **Strong global girders** (long. bulkhead, double side plating).
3. **Longitudinal girders** (automatic spring generation).
4. **Strong longitudinal girders** (automatic spring generation).
5. **"Megabeams"** (automatic spring generation).

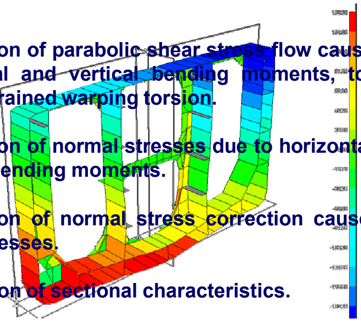


Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

RESPONSE (ρ-1)

FEM Primary response analysis

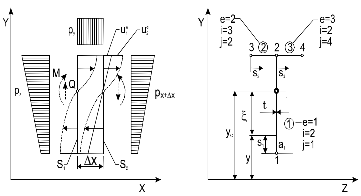


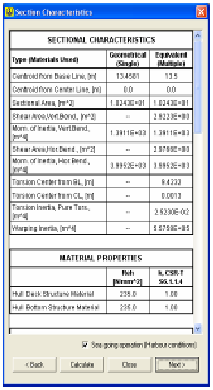
Calculation of parabolic shear stress flow caused by horizontal and vertical bending moments, torsion and restrained warping torsion.

Calculation of normal stresses due to horizontal and vertical bending moments.

Calculation of normal stress correction caused by shear stresses.

Calculation of sectional characteristics.

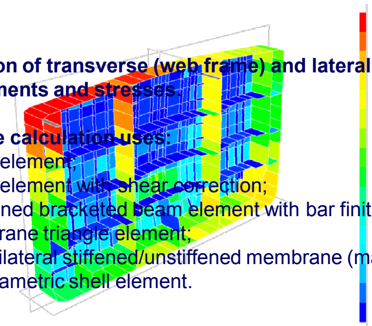




EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

RESPONSE (ρ-2/3)

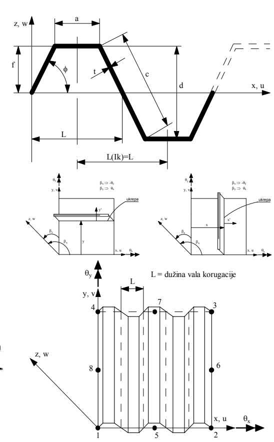
FEM Transverse strength analysis

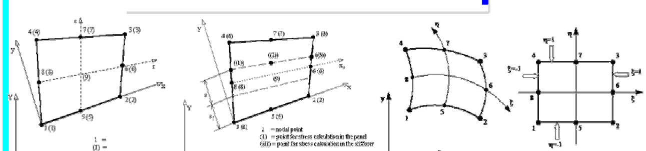


Calculation of transverse (web frame) and lateral (bulkhead) displacements and stresses.

Response calculation uses:

1. Beam element;
2. Beam element with shear correction;
3. Combined bracketed beam element with bar finite element;
4. Membrane triangle element;
5. Quadrilateral stiffened/unstiffened membrane (macro)element;
6. Isoparametric shell element.





Quadrilateral genaral mambrane element.

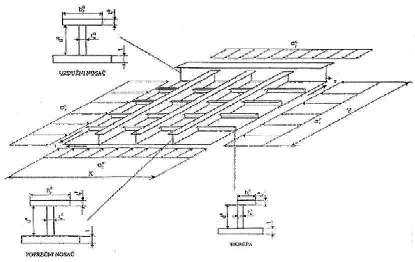
Quadrilateral stiffened mambrane macroelement.

8-node isoparametric shell element.

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-1)

Library of structural adequacy criteria



ADEQUACY PARAMETER:

$$g = \frac{C - \gamma \cdot D}{C + \gamma \cdot D}$$

Where: **C - Capability;**
D - Demand;
γ - Safety Factor.

Definition range:

$$-1 \le g \le 1$$

Boundary cases:

g = 1 for D = 0
g = -1 for C = 0

IMPLEMENTED CRITERIA:

- **IACS CSR for Double-hull Oil Tankers;**
- **IACS CSR for Bulk Carriers;**
- **Bureau Veritas;**
- **Croatian Register of Shipping;**
- **Prof. Owen F. Hughes;**
- **Prof. Douglas Faulkner;**
- **Prof. Alaa Mansour;**

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-1)

Library of structural adequacy criteria

Bureau Veritas criteria

PLATE BETWEEN STIFFENERS

OCTAN criteria	DESCRIPTION & REFERENCE	MAESTRO name
BV_PP_BACS	BUCKLING (BIAXIAL COMPRESSION & EDGE SHEAR) OF PLATES (BV Rules, Part B, Chapter 7, Section 1, Subsection 5.3.3, pp 78.)	PCSF
BV_PP_CB	BUCKLING (COMPRESSION & BENDING) OF PLATES (BV Rules, Part B, Chapter 7, Section 1, Subsection 5.3.1, pp 77.)	PCCB
BV_PP_S	BUCKLING (EDGE SHEAR) OF PLANE PLATES (BV Rules, Part B, Chapter 7, Section 1, Subsection 5.3.2, pp 77.)	PCMY

CORRUGATED BULKHAEDS,

OCTAN criteria	DESCRIPTION & REFERENCE	MAESTRO name
BV_CB_CF	BUCKLING (IN-PLANE COMPRESSION) OF CORRUGATION WEBS (BV Rules, Part B, Chapter 7, Section 1, Subsection 5.3.5, pp 78.)	PCSB

FRAMES

OCTAN criteria	DESCRIPTION & REFERENCE	MAESTRO name
BV_F_NS	NORMAL STRESS CRITERIA FOR FRAME (BV Rules Part B, Chapter 7, Section 3, Subsection 3.6.1)	G[F]YCF
BV_F_SS	SHEAR STRESS CRITERIA FOR FRAME (BV Rules Part B, Chapter 7, Section 3, Subsection 3.6.1)	G[F]YCP

STIFFENERS

OCTAN criteria	DESCRIPTION & REFERENCE	MAESTRO name
BV_OS_NS	NORMAL STRESS CRITERIA FOR ORDIANARY STIFFENERS (BV Rules Part B, Chapter 7, Section 2, Subsection 3.6.1)	PYTF
BV_OS_SS	SHEAR STRESS CRITERIA FOR ORDIANARY STIFFENERS (BV Rules Part B, Chapter 7, Section 2, Subsection 3.6.1)	PYTP
BV_OS_D	DIMENSIONS CRITERIA FOR STIFFENERS (BV Rules, Part B, Chapter 7, Section 2, Subsections 1.4.1, 1.4.2, 1.4.3)	PYCF
BV_OS_US	ULTIMATE STRENGTH IN BUCKLING OF ORDINARY STIFFENERS (BV Rules, Part B, Chapter 7, Section 2, Subsection 5.5.1, pp 91.)	PYCP
BV_OS_VBM	BUCKLING (VARIOUS MODES) OF ORDINARY STIFFENERS (BV Rules, Part B, Chapter 7, Section 2, Subsections 4.4.1 & 4.4.2, pp 90..)	PSPBT

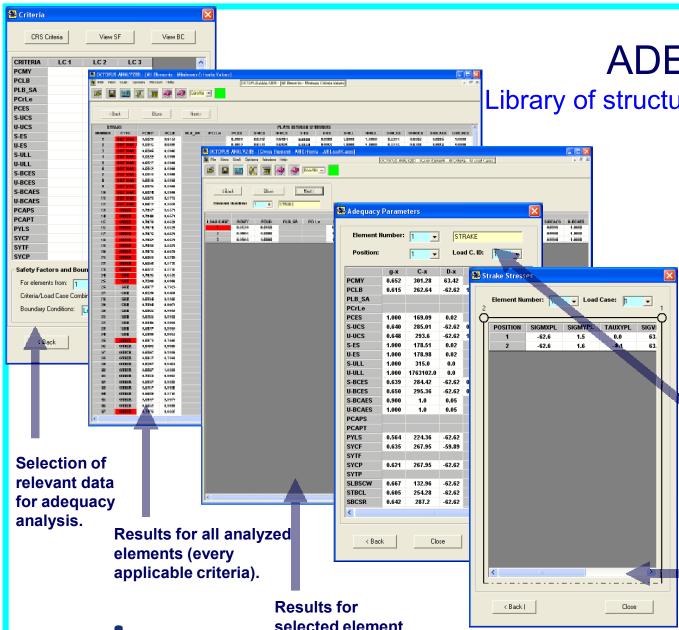
Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-1)

Library of structural adequacy criteria

GUI forms / Results



Selection of relevant data for adequacy analysis.

Results for all analyzed elements (every applicable criteria).

Results for selected element (all applicable criteria).

Detailed display of adequacy parameter defining data (every applicable criteria for selected element).

Detailed stress display for selected element.

Improve

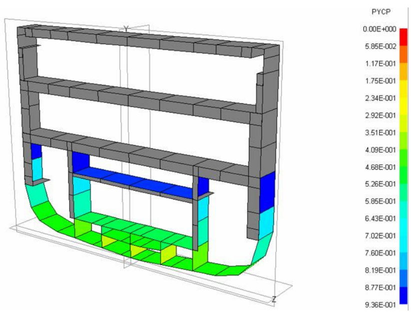
EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-1)

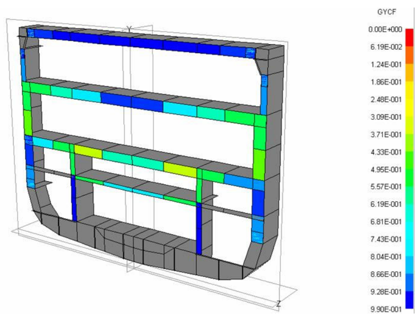
Library of structural adequacy criteria

Visualization of results

(ROPAX Web frame module)



BV_OS_US
Adequacy parameter distribution for Bureau Veritas ultimate strength criteria for ordinary stiffeners.



BV_F_NS
Adequacy parameter distribution for Bureau Veritas normal stress criteria for frames.

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-2)

Fatigue life evaluation (Nominal stress approach)

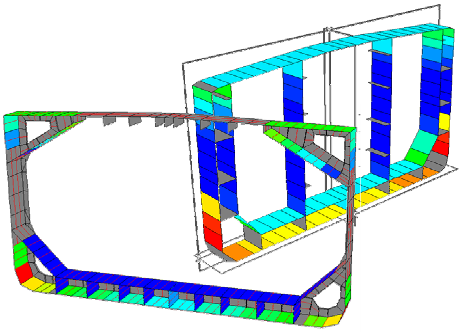
Visualization of results

(VLCC & BC Web frame module)

FATIGUE ADEQUACY PARAMETER:

$$g = \frac{FL - DL}{FL + DL}$$

Where: **FL – Calculated Fatigue Life**
DL – Design Life



PCSF Criteria
Panel Collapse Stiffener Fatigue

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-3)

Longitudinal Ultimate Strength Analysis

Modified Hughes/Adamchak method

LUSA uses method which is a further development of method described in:

Owen F. Hughes:
"Ship Structural Design",
The Society of Naval Architects and Maritime Engineers, 1988.

NOTE:
Implemented modifications of original method are mainly due to very extensive linear FEM analysis application which discarded the need for any structural member collapse related predictions based on approximations, and thus improved accuracy of the basic method.

Longitudinal Ultimate Strength Analysis – LUSA

START

STOP

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-3)

Longitudinal Ultimate Strength Analysis

IACS CSR One-step method

(Advanced buckling analysis)

START

Loop on deck structural elements

Calculated ultimate sagging capacity should not give stresses exceeding the yield stress of the bottom shell plating material.

This method is not valid if the structural configuration is souch that the ultimate sagging capacity is not determined by the failure of the stiffened deck panels.

STOP

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-3)

Longitudinal Ultimate Strength Analysis

IACS CSR Incremental-iterative method

(Smith method)

START

Adjustment of the N.A. position

Loop on all structural elements

Next cycle curvature increment

STOP

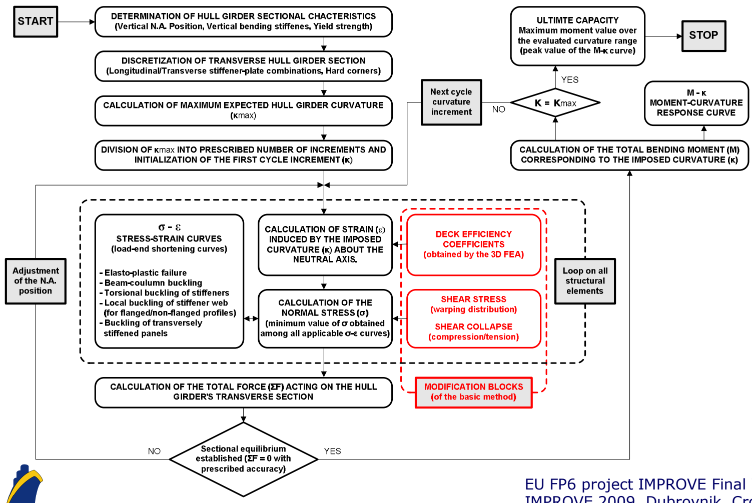
Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-3)

Longitudinal Ultimate Strength Analysis

Modified IACS CSR Incremental-iterative method

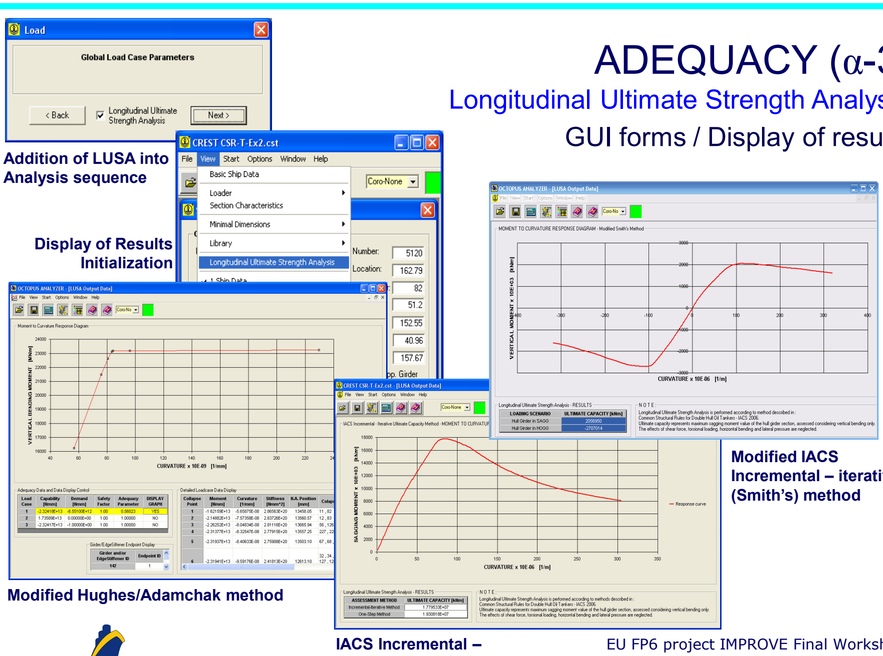


EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

ADEQUACY (α-3)

Longitudinal Ultimate Strength Analysis

GUI forms / Display of results



Addition of LUSA into Analysis sequence

Display of Results Initialization

Modified Hughes/Adamchak method

Modified IACS Incremental – iterative (Smith's) method

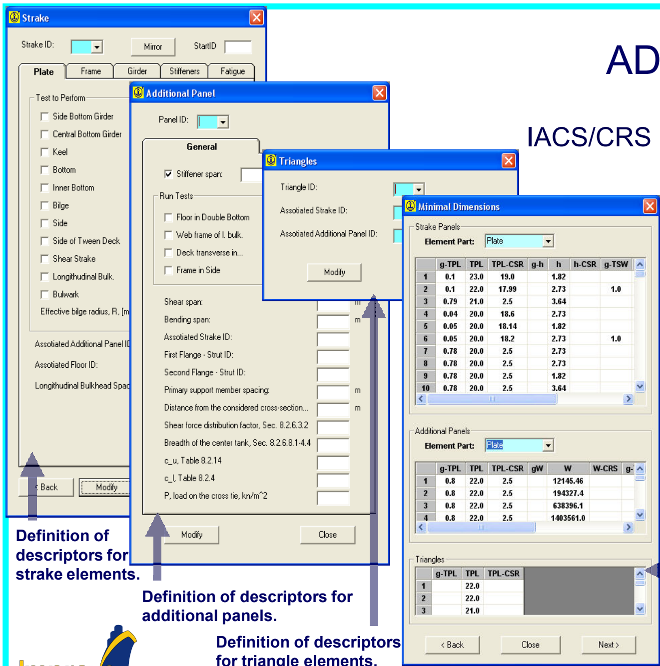
IACS Incremental – iterative (Smith's) method

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

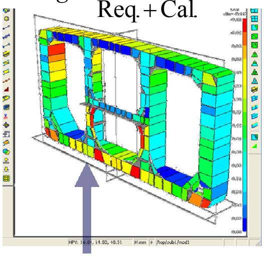
ADEQUACY (α-4)

Minimum dimensions

IACS/CRS Rule based evaluation



$$g = \frac{\text{Req.} - \text{Cal.}}{\text{Req.} + \text{Cal.}}$$



Definition of descriptors for strake elements.

Definition of descriptors for additional panels.

Definition of descriptors for triangle elements.

Visualization of obtained results.

Evaluation results displaying feasibility margin, project variables and rule requirement.

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

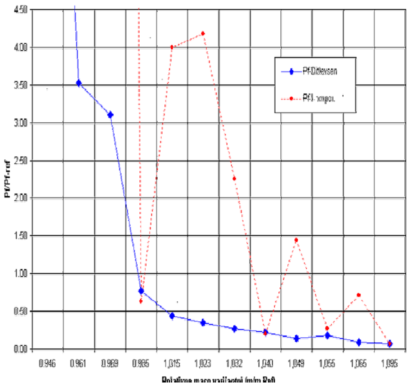
RELIABILITY (π-1)

System failure probability based on β – unzipping method

Probabilistically dominant collapse scenarios are selected from the (large) set of potential collapse scenarios at the first, second, third and mechanism level.

The system reliability measure at third level (RM-3) was found sufficient for the optimization (design) purpose.

RM-3 is modeled as a series system of identified, probabilistically. dominant collapse scenarios.

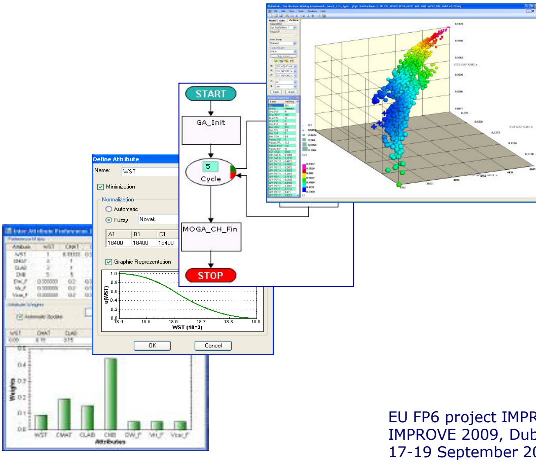


Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

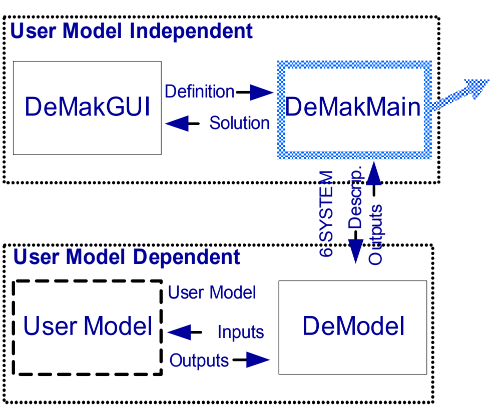
OCTOPUS Designer (DeMak)

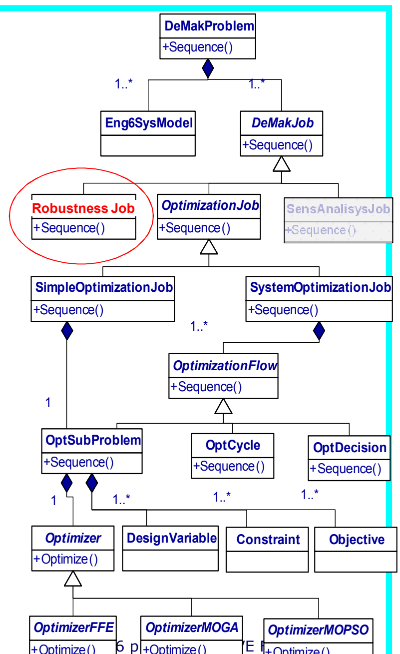
Decision Making Framework



EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

OCTOPUS DESIGNER components





IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

DeMak class diagram

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

Optimization / strategies / solvers

- OCTOPUS DESIGNER solver modules Σ includes:
  - Σ-1 Sequential Linear Programming (SLP)
  - Σ-2 Sequential Adaptive Monte Carlo (SAMC)
  - Σ-3 Sequential Adaptive Fractional Factorial Experiments (SAFFE)
  - Σ-4 Multi Objective Genetic Algorithms (MOGA)
  - Σ-5 Multi Objective Particle Swarm Optimization (*MOPSO*)
  - Σ-X Hybrid solver

Improve

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

DeMak - Optimization Job Main Input Panel

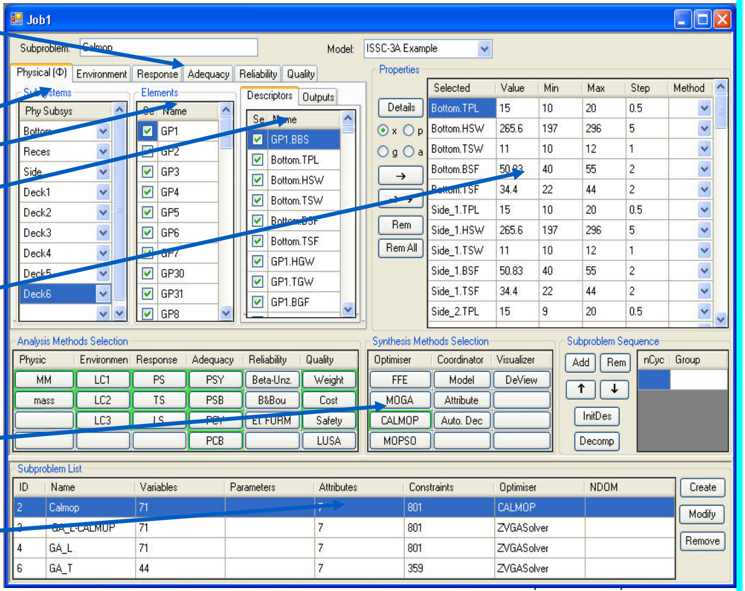
The Six Engineering Systems

Subsystems, Elements, Descriptors in The Physical System

Selected Subproblem Variables

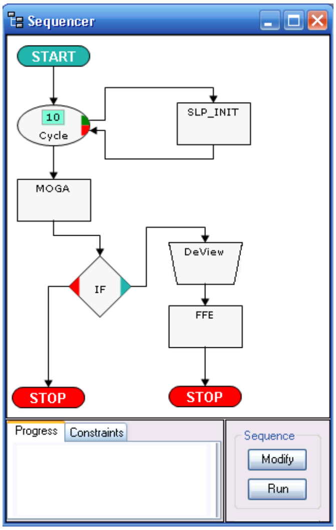
Model and Synthesys methods Control

Optimization Subproblems List and Controls



DeMak – System Optimization Job Sequence Control

- ❑ Enables Optimization of Complex Systems
- ❑ Gives better understanding of overall process
- ❑ Enables various combinations of optimization algorithms (HYBRID Optimizers)
- ❑ Enables optimization of decomposed structure (longitudinal – transversal)

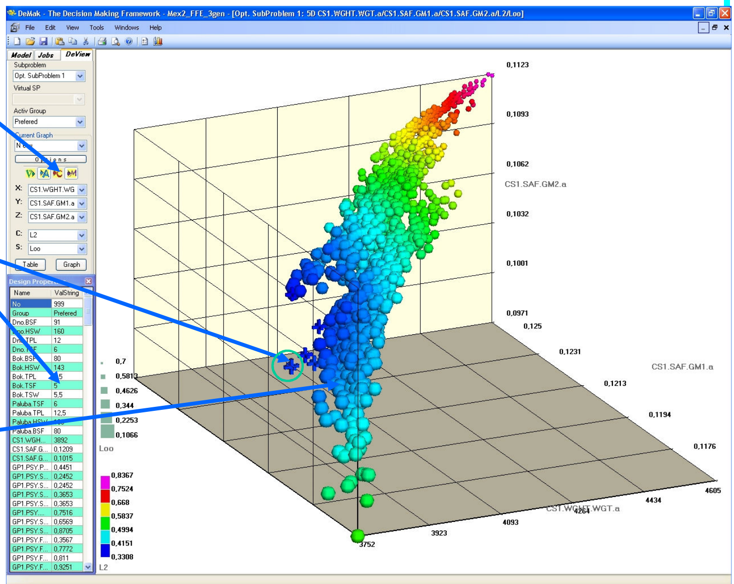


DeView – Visualization of Pareto Designs in 5D Space

Visualization control for Graphs and Tables

Properties of the Currently Selected Design

Graphical Representation of Pareto surface



Improve

17-19 September 2009.

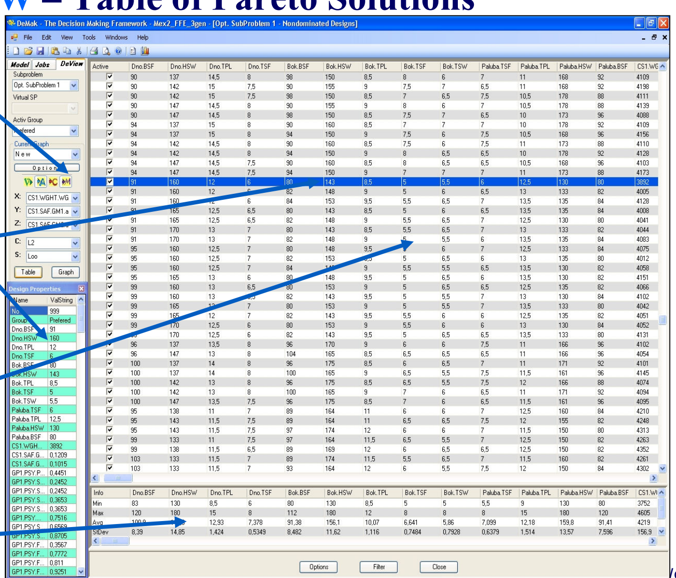
DeVIEW – Table of Pareto Solutions

Visualization control for Graphs and Tables

Properties of the Currently Selected Design

Table View of the set of Nondominated Designs

Summary Information on Nondominated Designs



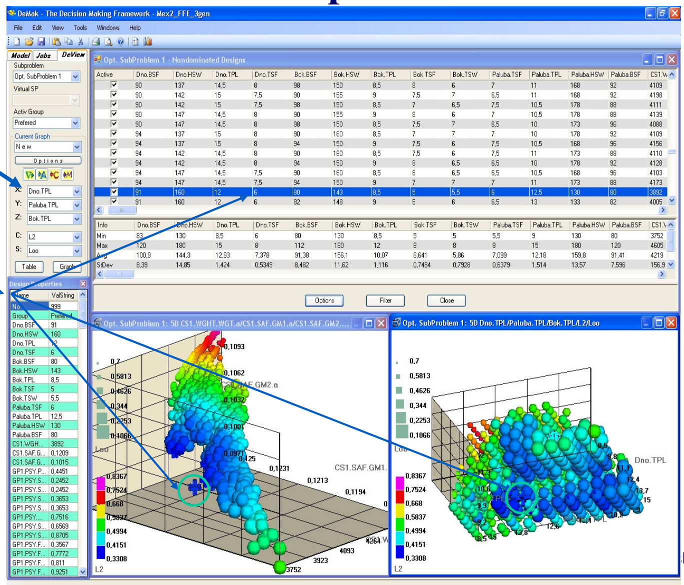
Improve

...orkshop IMPROVE 2009, Dubrovnik, Croatia 17-19 September 2009.

Multiple Views of X+Y Spaces

Visualization control for Graphs and Tables

Properties of the Currently Selected Design (marked cross)



hop

17-19 September 2009.

DeMak – Definition of Inter / Intra Attribute Preferences

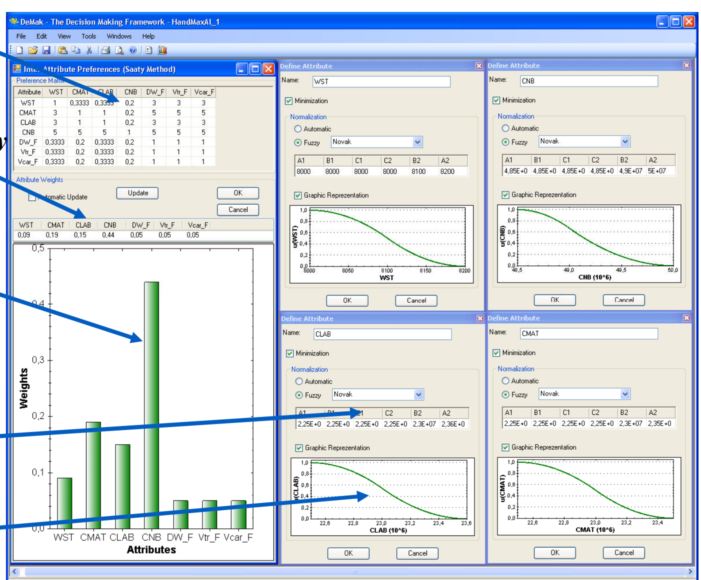
Inter Attribute Preference Matrix

Weights Calculated by Saaty AHP Method

Weights Graphical Visualization

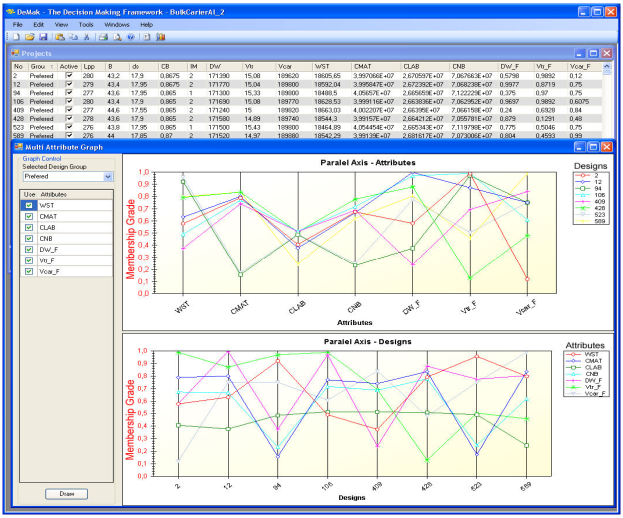
Fuzzy Functions Definition

Graphical Visualization of Fuzzy Functions

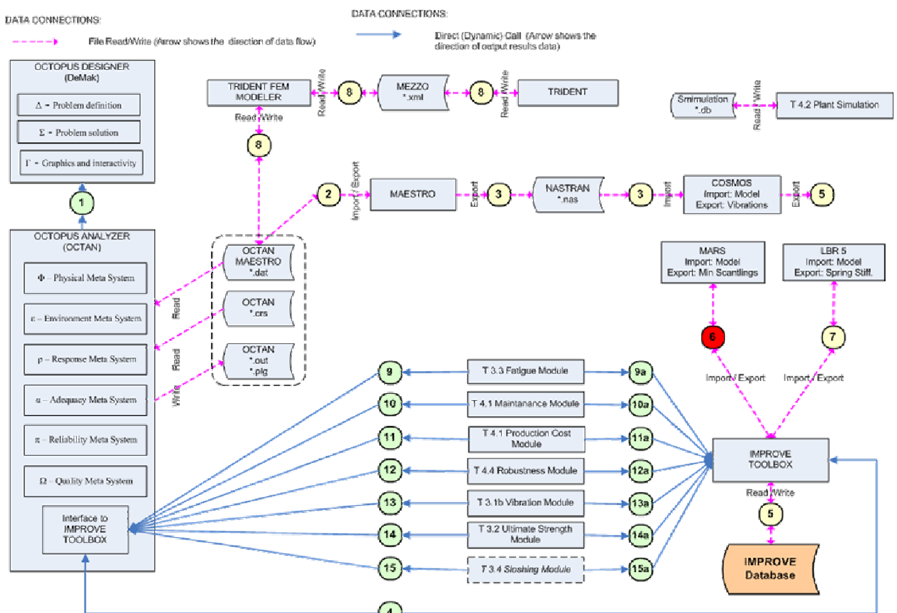


17-19 September 2009.

Paralel Axis Visualization of The Selected Prefered Designs



EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.



EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

OCTOPUS Team members that participated in OCTOPUS developments (* denotes DeMak developers):

www.fsb.hr/octopus

Vedran Žanić*,
Tomislav Jančijev*,
Jerolim Andrić*,
Marko Stipčević*,
Pero Prebeg*,
Stanislav Kitarović,
Karlo Pirić*,
Bozo Vazic*,

Svemir Bralić,
Darko Frank*,
Josip Hozmec.

EU FP6 project IMPROVE Final Workshop
IMPROVE 2009, Dubrovnik, Croatia
17-19 September 2009.

IMPROVE

ConStruct

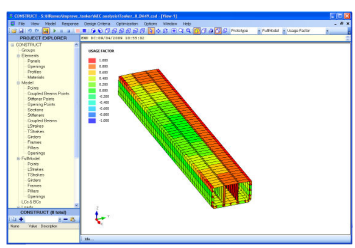
Platform for Conceptual Structural Design

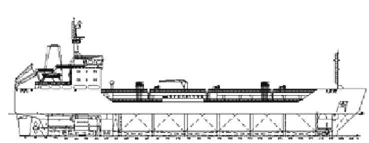
H. Remes, A. Klanac, P. Varsta, S. Ehlers
Helsinki University of Technology, Espoo, Finland

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Table of contents

- Introduction
  - Background
  - Aims of ConStruct
- ConStruct platform
  - Main principles
  - Methods for analysis
  - Software architecture
- Utilisation in EU/IMPROVE
  - Objectives
  - Improve analysis modules
  - Case analysis
- Conclusions

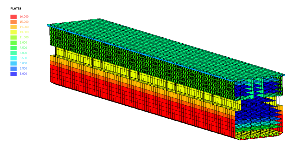


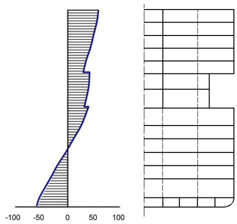


IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Background

- Challenges to structural design of novel ships
  - Reference database do not exits or it is limited
  - Large complex structures require advanced analysis methods
  - FEM is commonly used, but it is time-consuming and thus inefficient at concept design stage





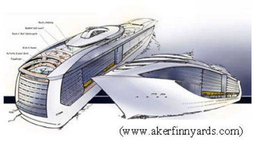
Stress distribution

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

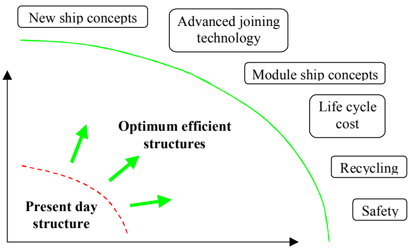
3

Aims of ConStruct platform

- ConStruct platform was developed in the national research project by TKK with co-operation of Finnish maritime industry
- ConStruct platform targets
  - efficient conceptual structural design
  - implementation of new research results for practice

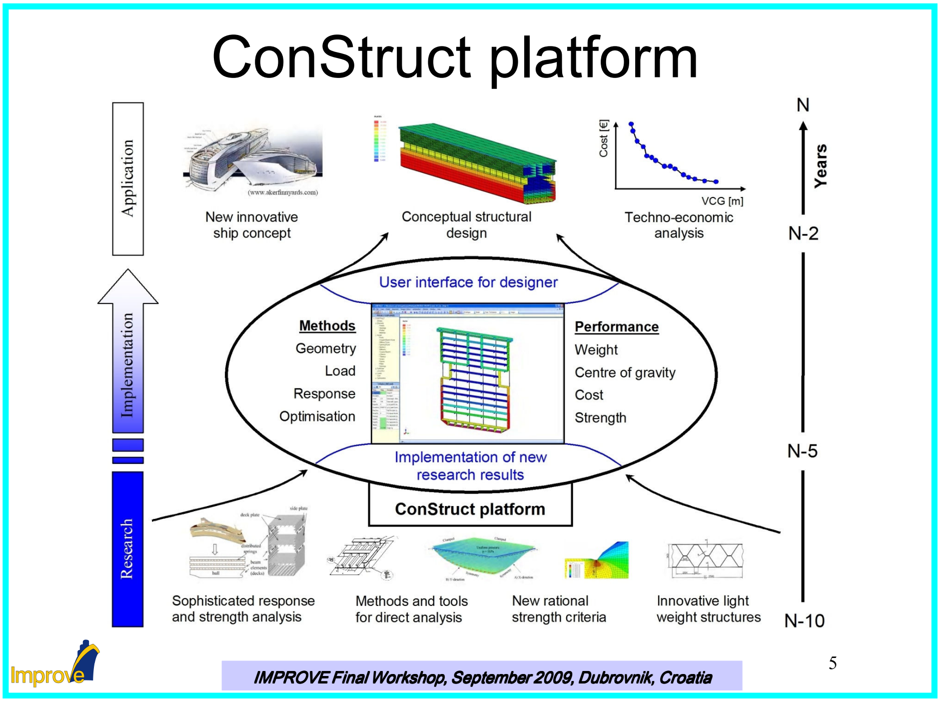


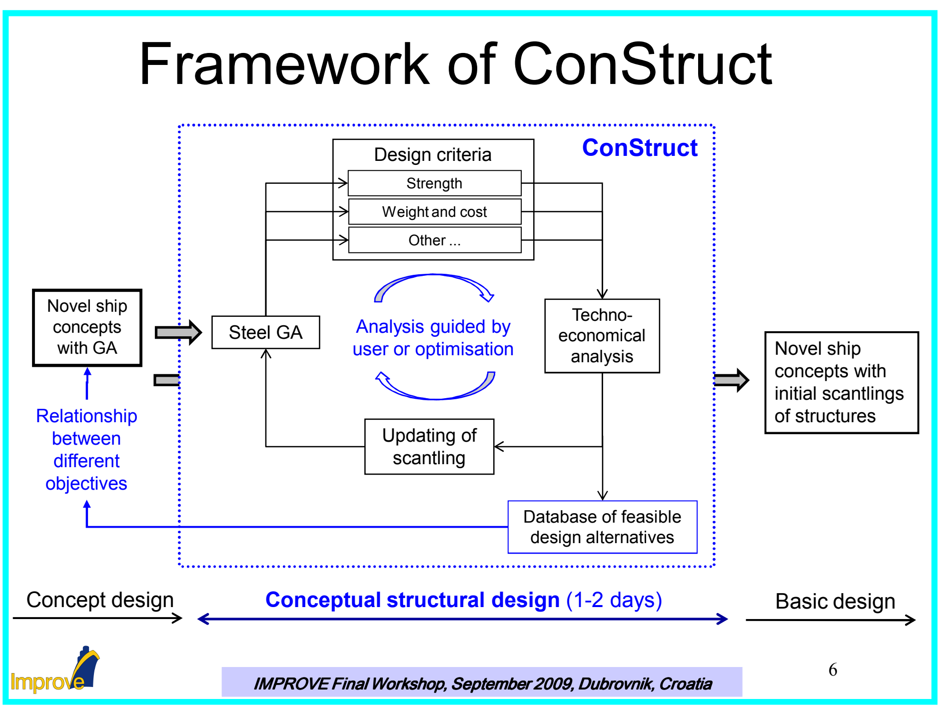
Techno-economical ship concept



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

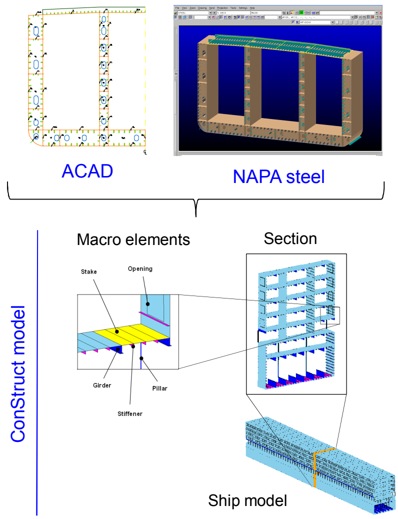
4


ConStruct platform
Application
Implementation
Research
New innovative ship concept
(www.akerfinnyards.com)
Conceptual structural design
Cost [€]
VCG [m]
Techno-economic analysis
N
Years
N-2
N-5
N-10
User interface for designer
Methods
Geometry
Load
Response
Optimisation
Performance
Weight
Centre of gravity
Cost
Strength
Implementation of new research results
ConStruct platform
Sophisticated response and strength analysis
Methods and tools for direct analysis
New rational strength criteria
Innovative light weight structures
Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia
5


Framework of ConStruct
ConStruct
Design criteria
Strength
Weight and cost
Other ...
Novel ship concepts with GA
Steel GA
Analysis guided by user or optimisation
Techno-economical analysis
Novel ship concepts with initial scantlings of structures
Relationship between different objectives
Updating of scantling
Database of feasible design alternatives
Concept design
Conceptual structural design (1-2 days)
Basic design
Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia
6

ConStruct tool

- Structural modelling
  - Utilisation of digital information such as GA and hull shape
  - Efficient modelling functions for iterative conceptual design
- Structural analysis
  - Advanced methods for fast response analysis, and for efficient post-processing
- Software architecture
  - User-friendly interface
  - Flexible architecture for new research results



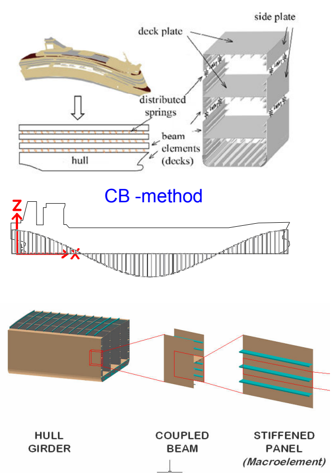
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

7

ConStruct tool

- Structural modelling
  - Utilisation of digital information such as GA and hull shape
  - Efficient modelling functions for iterative conceptual design
- Structural analysis
  - Advanced methods for fast response analysis, and for efficient post-processing
- Software architecture
  - User-friendly interface
  - Flexible architecture for new research results



Strength evaluations of macro- element

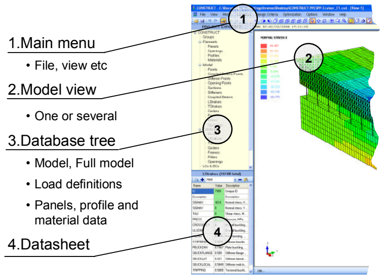
Improve

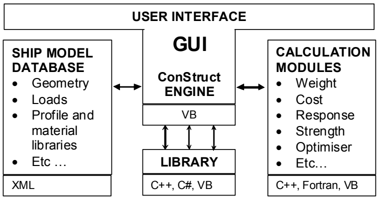
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

8

ConStruct tool

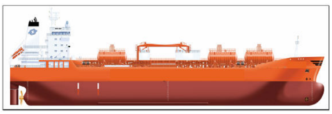
- Structural modelling
  - Utilisation of digital information such as GA and hull shape
  - Efficient modelling functions for iterative conceptual design
- Structural analysis
  - Advanced methods for fast response analysis, and for efficient post-processing
- Software architecture
  - User-friendly interface
  - Flexible architecture for new research results



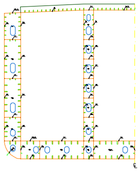


Utilisation in EU-Improve

- Concept development of new chemical tanker
  - Utilising ConStruct design platform
  - Applying new research results of Improve
    - Fatigue assessment
    - Cost calculations
    - Ultimate strength analysis



L_{pp} = 175.25 m
B = 32.2 m
T = 10.8 m
T_{sc} = 11.5 m
C_b = 0.8
Z = 27 m^3



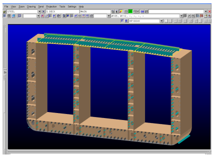
Design objectives:
- Cost
- Fatigue life
- Weight

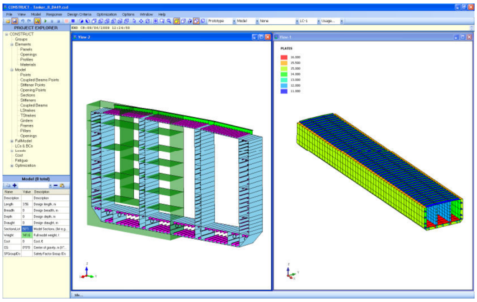
Production constraints:
- Thickness ranges
- Profile ranges

Tanker optimisation in ConStruct

- Modelling
  - NAPA Steel
  - ConStruct model
- Problem definition
  - Load definitions
  - Design variables
  - Objectives
- Optimisation with genetic algorithm
  - Initial population
  - Structural evaluation
  - Pareto frontier

Ship basic info
- GA from the previous design step
- Definitions of steel GA with help of NAPA steel



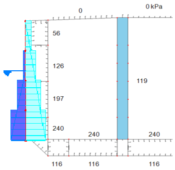


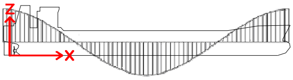
ConStruct modelling

Tanker optimisation in ConStruct

- Modelling
  - NAPA Steel
  - ConStruct model
- Problem definition
  - Load definitions
  - Design variables
  - Objectives
- Optimisation with genetic algorithm
  - Initial population
  - Structural evaluation
  - Pareto frontier

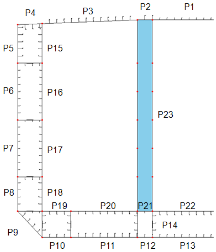
Load definitions
- Vertical bending moment
- Internal and external pressure load





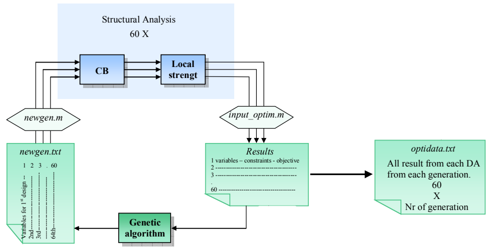
Variables
- Material (AH, Duplex)
- Thickness t = 5...36
- Spacing s= 450...800
- Profile height 75...400

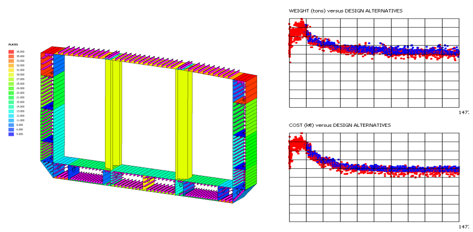
Objectives
- Min Weight (ton/m)
- Min Cost (ton/m)
- Min Fatigue Damage



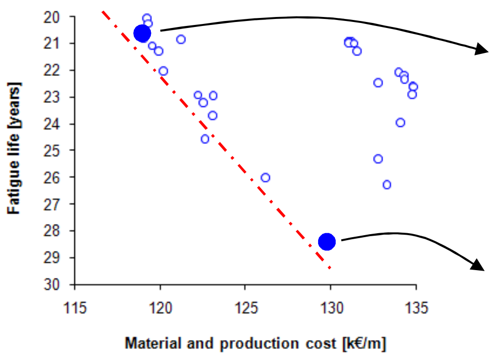
Tanker optimisation in ConStruct

- Modelling
  - NAPA Steel
  - ConStruct model
- Problem definition
  - Load definitions
  - Design variables
  - Objectives
- Optimisation with genetic algorithm
  - Initial population
  - Structural evaluation
  - Pareto frontier

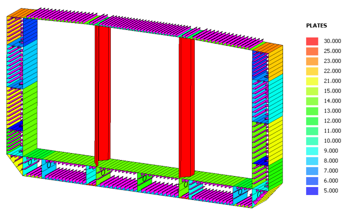




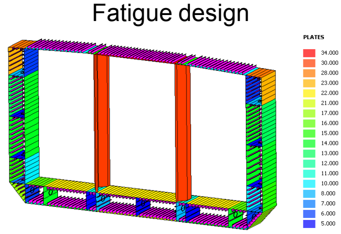
Example of results for tanker



Minimum cost design



Fatigue design



Note!

The final selections of design alternative is based on all design objectives and on target of ship-owner and shipyard.

Conclusion

- ConStruct platform is a new design platform established in national research project in Finland
  - Efficient conceptual structural design
  - Easy utilisation of research results e.g. fatigue module
- Efficient platform for techno-economical analysis of novel ship concepts
  - Understanding of relations between different design objectives
  - Structures scantlings already at early design stage

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Thank you for

your kind attention!

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

APPLICATION CASES

Product Presentation: LNG Carrier (WP6)

IMPROVE

LNG Carrier – Ship Owner requirements, markets & technical trends

F. Van Nuffel, M. Bouckaert
EXMAR, Antwerp, Belgium

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

EXMAR

Ship-Owner Requirements – Why?

- LNG vessels are generally designed for a 40 years fatigue life
- Vessels built in the 70ties are still sailing today
- Time charters for 25 years are frequently signed

→ Ship Owner has to operate the vessel in a good condition during a long time

→ LNG vessels have an excellent track record, it has to be kept this way.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

EXMAR

Ship-Owner Requirements – Why?

- Correct choices made in the early stage of design can save a lot of costs in maintenance during the vessel's lifetime
  - Equipment arrangement
  - Deck & Engine room layout
  - Equipment selection
  - Material selection
  - Ballast tank & underwater hull coating

LNG vessel maintenance

- Cargo containment system
  - No corrosion related problems
  - Fatigue is an important topic
  - In some particular cases, serious problems related to design or construction methodology occur
- Propulsion system
  - Before 2005: almost exclusive steam propulsion
  - Steam turbines have an excellent track record
  - Steam boiler maintenance also minimal due to gas burning

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG vessel maintenance

- Hull Structure & Ballast tanks
  - Many and large ballast tanks in an LNG vessel
  - Maintenance is not strongly influenced by hull structural optimisation
  - Coating is very important, if not done properly corrosion can be real problem
  - On the long term, fatigue problems can pop up in way of the hot spots if structural details are not carefully designed
  - Indents due to hard contact with tugboats or jetties
- Electric / Automation system
  - Cargo operations fully automated on the recent vessels
  - Cable trays on open deck are critical
- Cargo and Auxiliary machinery
  - Planned maintenance needs to be done

Speed & Performance

- Cargo is transported at -163°C and atmospheric pressure under "boiling" condition
- Daily boil-off gas is generally used for the propulsion
- Vessels design speed is generally 19.5 kn
- Increasing efficiency or reducing consumption is positive, taking into account that the propulsion plant should use the full boil-off gas
- Fuel is usually paid by the charterer

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

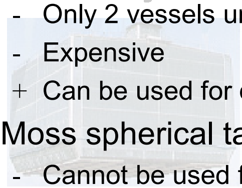
EXMAR

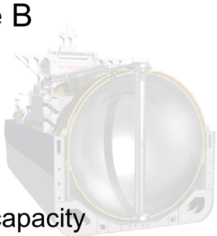
Requirements related to steel structure

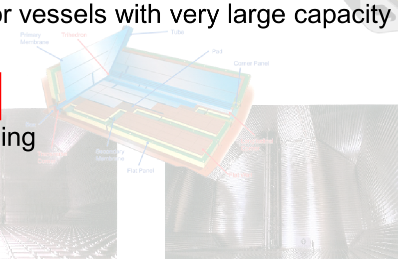
- Minimizing the amount of ballast (ballastless vessel)
  - Less coating problems
  - Environmental friendly – no need for ballast treatment
- Minimizing the structure in the ballast tanks
- Maximise the usage of profiles with rounded edges in ballast tanks
  - → Bulb profiles and flat bars better as T- or L-profiles in view of corrosion and fatigue
- Design for a fatigue life of more than 40 years in North-Atlantic conditions
- Minimizing the lightship weight

Cargo Containment system

- SPB: self supporting prismatic tank type B
  - \- Only 2 vessels until now
  - \- Expensive
  - \+ Can be used for different types of cargo
- Moss spherical tanks
  - \- Cannot be used for vessels with very large capacity
  - \+ Good track record
- Membrane tanks
  - \- Sensitive for sloshing
  - \+ Good track record
  - \+ Easy scalable
  - \+ Cost effective

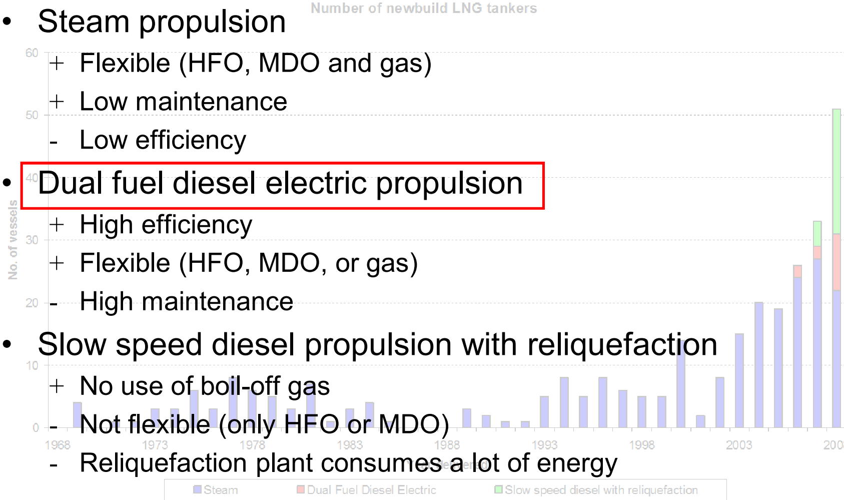






Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia
EXMAR

Propulsion system



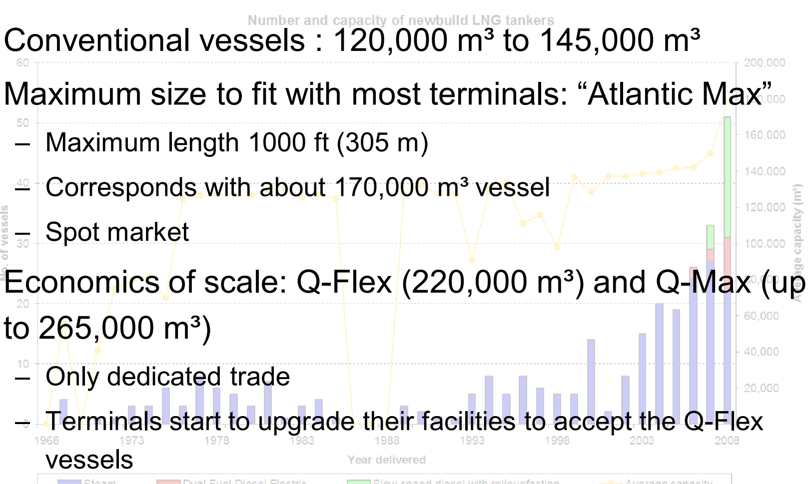
- Steam propulsion
  - \+ Flexible (HFO, MDO and gas)
  - \+ Low maintenance
  - \- Low efficiency
- Dual fuel diesel electric propulsion
  - \+ High efficiency
  - \+ Flexible (HFO, MDO, or gas)
  - \- High maintenance
- Slow speed diesel propulsion with reliquefaction
  - \+ No use of boil-off gas
  - \- Not flexible (only HFO or MDO)
  - \- Reliquefaction plant consumes a lot of energy

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

EXMAR

Cargo capacity



- Conventional vessels : 120,000 m³ to 145,000 m³
- Maximum size to fit with most terminals: "Atlantic Max"
  - – Maximum length 1000 ft (305 m)
  - – Corresponds with about 170,000 m³ vessel
  - – Spot market
- Economics of scale: Q-Flex (220,000 m³) and Q-Max (up to 265,000 m³)
  - – Only dedicated trade
  - – Terminals start to upgrade their facilities to accept the Q-Flex vessels

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

EXMAR

Thank you for your attention

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE

LNG Carrier – General Ship Design

J-L Guillaume Combecave, M. Venot
STX Europe, Saint-Nazaire, France

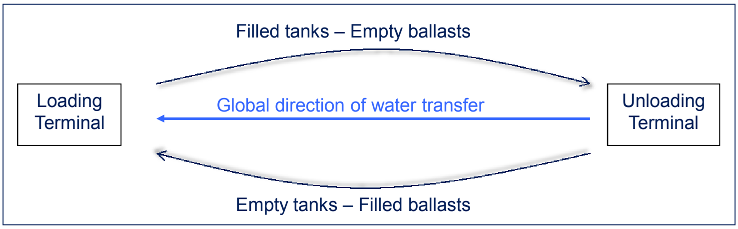
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Presentation's Plan

I. Problem analysis
II. Solution's presentation
III. Solution's comparison

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Ballasts during trips



Transport of ballast water → Energy Wasting = Money wasting + Pollution

→ Transfer of invasive marine species

→ Transfer of sediments

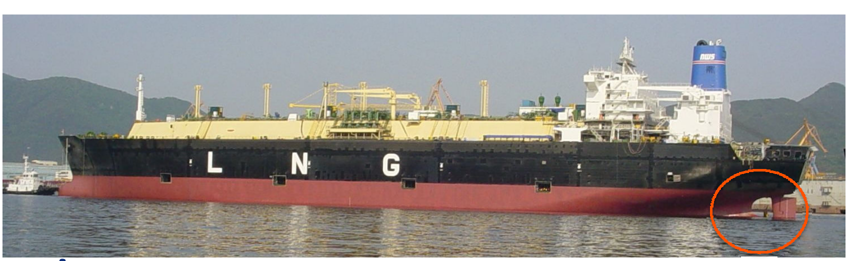
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Aim of the study

TARGET : TO REDUCE THE NEED FOR BALLAST → Immersion of the propeller(s)

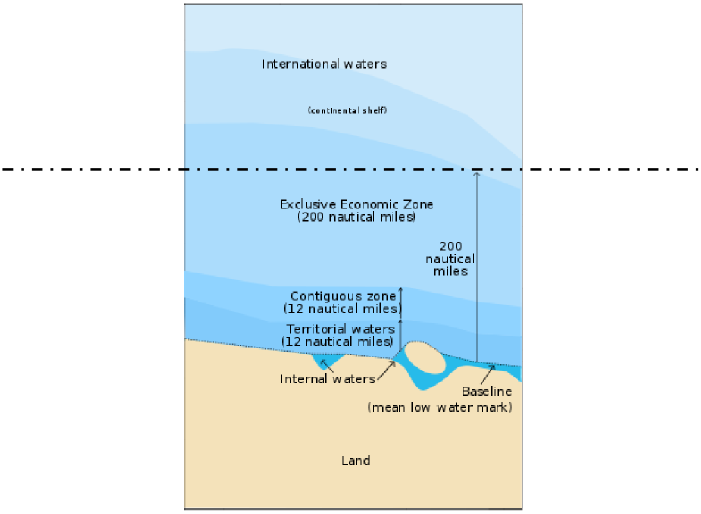
→ Hull modifications - ↗ unloaded draft

→ Propulsion modifications - ↘ diameter of the propeller(s)



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Ballast unloading possibilities



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

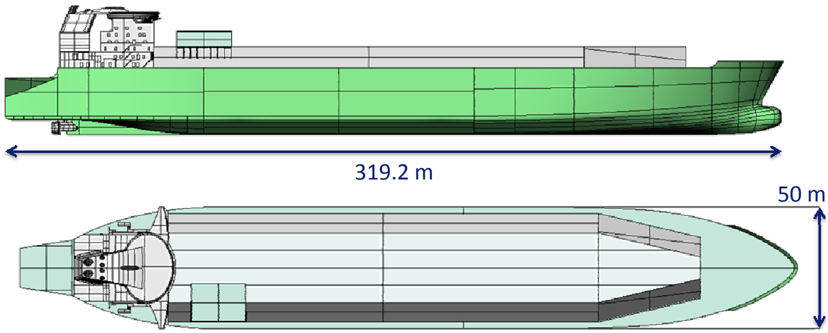
Presentation's Plan

I. Problem analysis
II. Solution's presentation
III. Solution's comparison

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Main dimensions



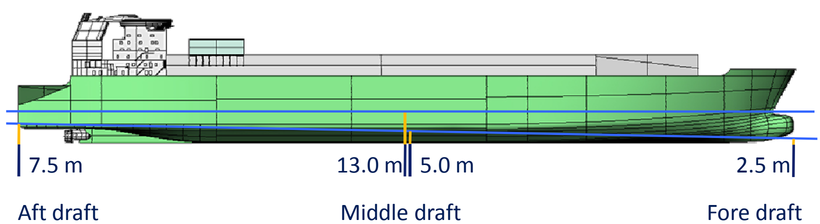
LNG volume capacity : 220 000 m^3

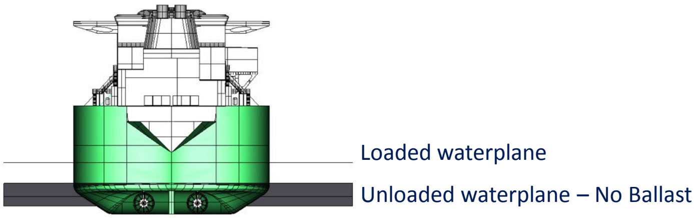
No need for ballasts

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Two-drafts design

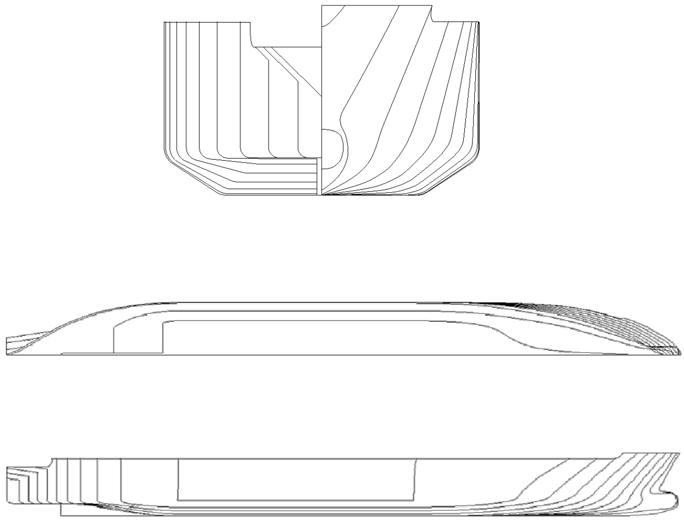




Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

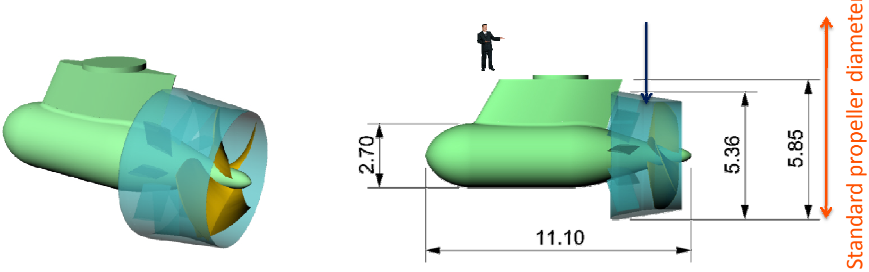
Hull lines



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Propulsion – Inovelis Pod



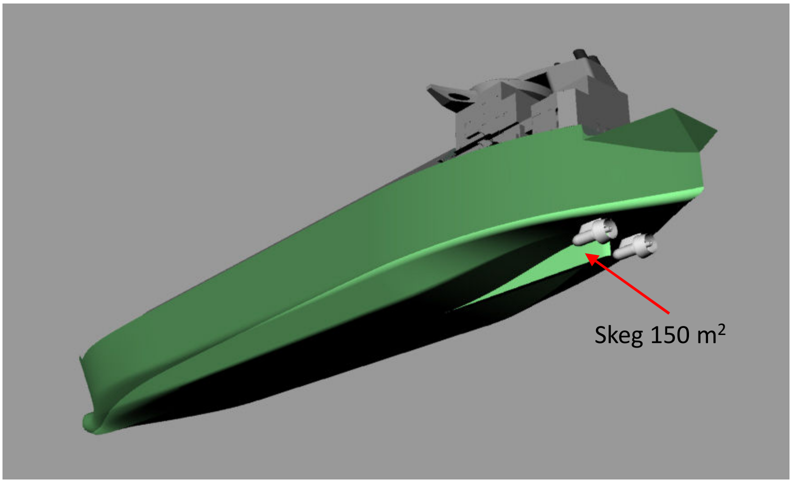
- Smaller diameter than standard propellers
- Better efficiency than standard Pods

→ Required unloaded draft ↘

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Route stability

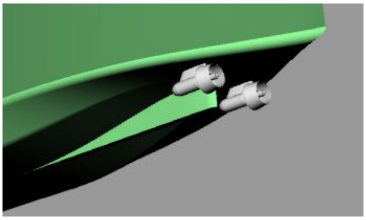


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Manoeuvrability

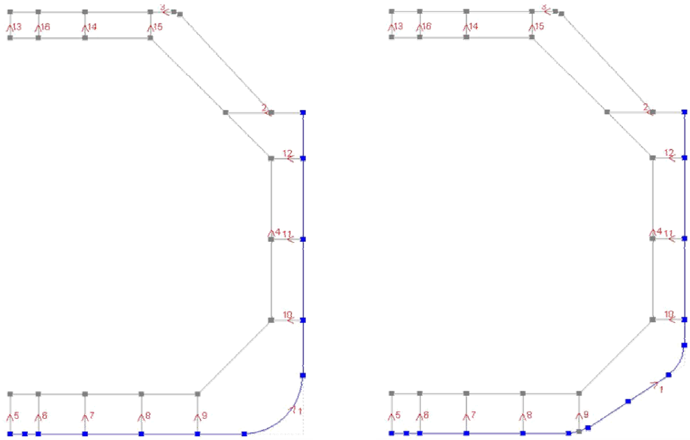
- Skeg ⟶ ↘ Manoeuvrability
- Inovelis Pod ⟶ ↗ Manoeuvrability



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

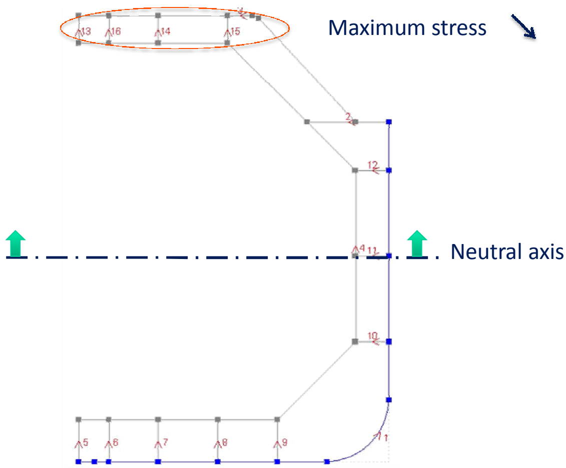
Structure - Midshipsection



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structure - Midshipsection



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

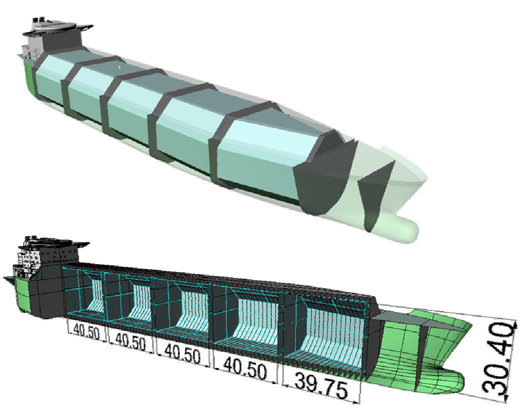
Structure – Design for production

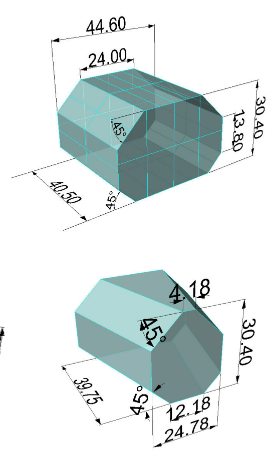
More than 80% of
developable surface

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structure - Tanks





Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Stability - Definitions

Criteria : SOLAS + IGC

Loading conditions :

Design deadweight	5 for 1 tank full
Loaded departure	10 for 2 tanks full
Loaded arrival	10 for 3 tanks full
Ballasted departure	10 for 4 tanks full
Ballasted arrival	
Unloaded	

Damage definitions :
18 side damages conditions
26 bottom damages conditions

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

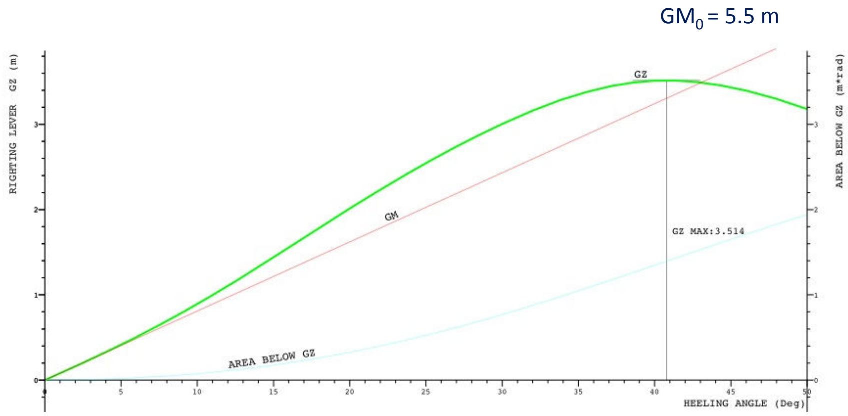
Stability - Results

All the criterions are verified for all the intact and damage situations, for every loading conditions

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

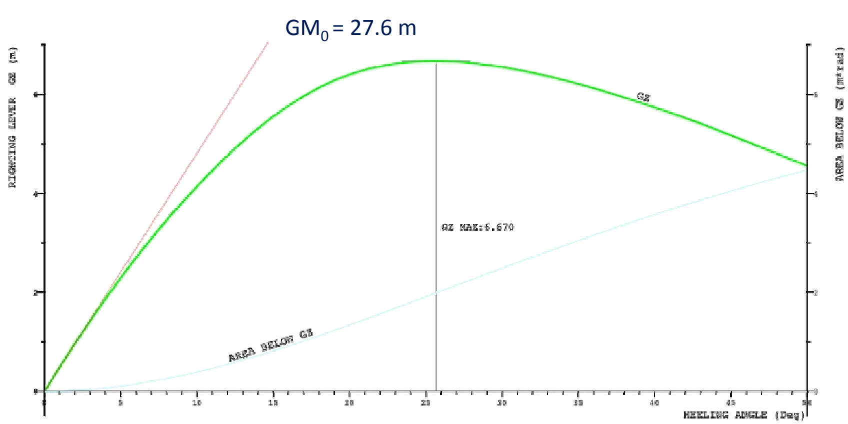
Stability – Loaded case



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Stability – Unloaded case

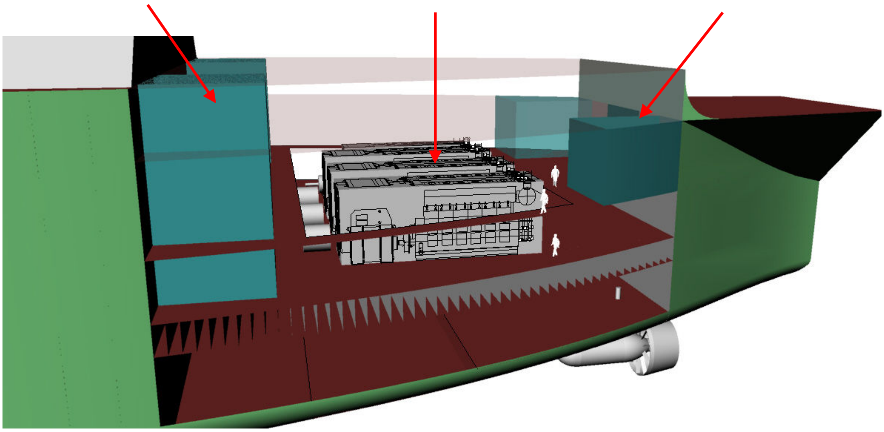


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Machine compartment

Fuel capacities · Engines & generators · Electrical switchboards



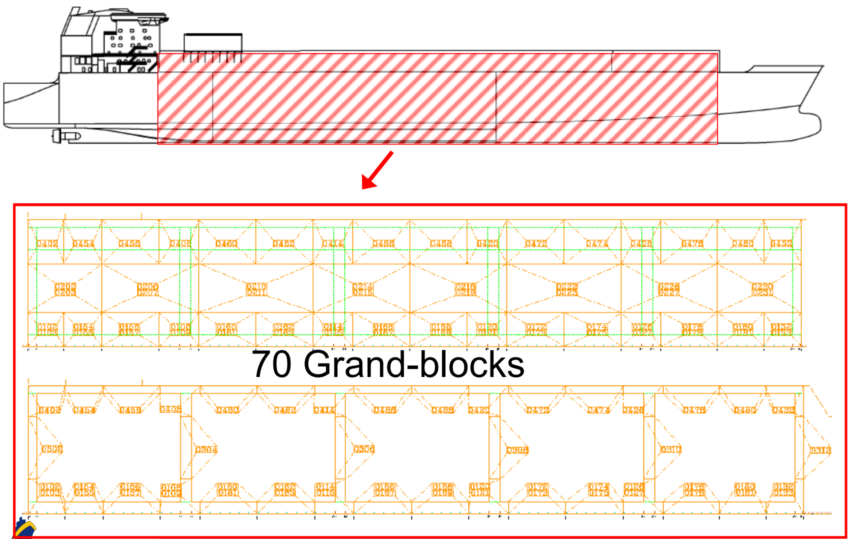
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Presentation's Plan

I. Problem analysis
II. Solution's presentation
III. Solution's comparison

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Grand-blocks distribution in tank zone



Improve

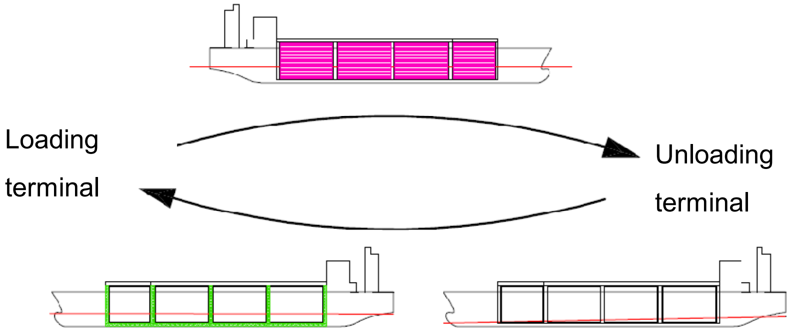
Indicative time

Indicative time	Conventional LNG	Syolgas
Manufacture part	65629	63228
Forming	2766	2665
Preprefabrication	44509	42881
Prefabrication	222618	214472
Assembly	105162	101314
Total	440685	424560

-3.7%

Improve

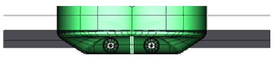
LNG savings

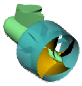


LNG savings : 8.6 tonnes/day = 9%

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Summary





V-shape → Unloaded draft ↗
Unloaded trim → Unloaded aft draft ↗
Smaller propellers → Required unloaded draft ↘

→ Immersion of the propellers without ballasts

→ No invasion of non-indigenous marine species
→ No sediment transfer
→ LNG savings = 9%

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Conclusion

No need for ballasts during unloaded trips

→ Ecological & Economical impacts

Design adaptable to other types of ships

No disadvantage except loaded draft (terminal restrictions)

→ Better adapted to smaller ships

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Thank you for your attention

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Sixth Framework Programme

IMPROVE

LNG carrier Structural design aspects

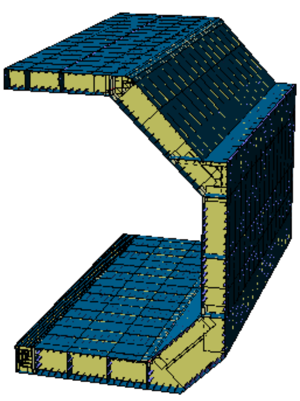
P. Rigo, A.Amrane, A. Constantinescu, F. Bair
ANAST University of Liège, Liège, Belgium

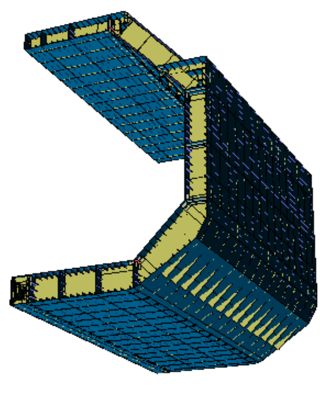
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMIZATION OF LNG

Two different Geometries

- **Standard Design**
- **Free ballast Design**





IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Optimization procedure

Optimization carried out on two principal steps:

- without New IMPROVE modules;
- with New IMPROVE modules, i.e. the *sloshing*, the *fatigue* and the *multi-structure* modules.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG SLOSHING ASSESSMENT

INPUT :

- Cargo capacity

- Nr. of tanks

- Reference tank geometry

→ **SLOSHING MODULE (Bureau VERITAS)** →

OUTPUT :

sloshing pressure inner tank

↓

LBR-5 implementation by 3 constraints :

- Plating – **the net (minimum) thickness**

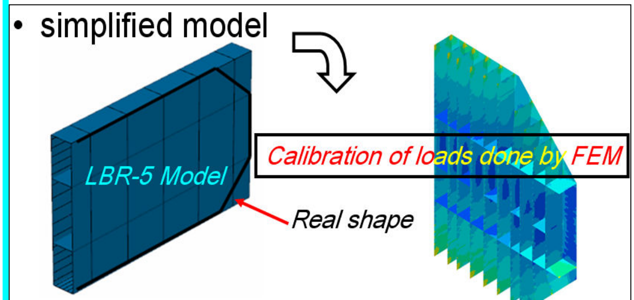
B) Stiffeners – the net (minimum) section modulus

C) Stiffeners – the net (minimum) shear sectional area

Improve

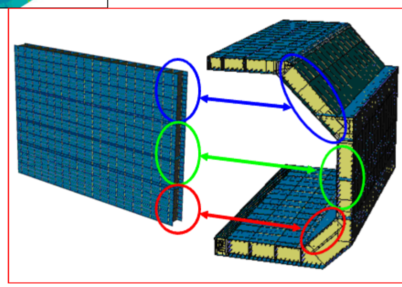
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG multi-structures module



➢**simultaneous optimization** of several sub-structures (tank and cofferdams)

➢New **equality constraints** on stiffeners spacing



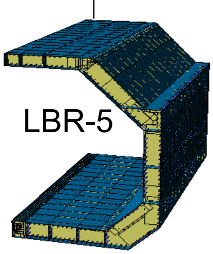
LNG FATIGUE ASSESSMENT

Panel's Scantling & internal forces → Fatigue module → Fatigue Damage → Fatigue constraint → LBR-5 → Panel's Scantling & internal forces

Fatigue constraint :

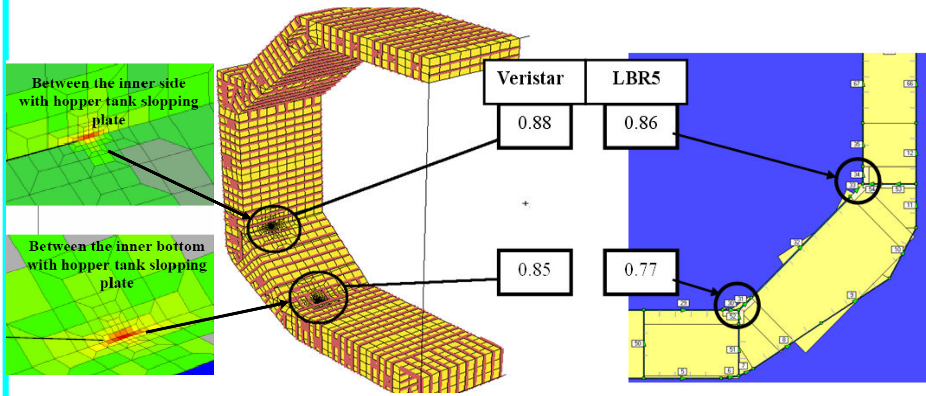
$$D \leq \frac{1}{\gamma_R}$$

γ_R : safety factor



LNG FATIGUE ASSESSMENT

Calibration of LBR5 fatigue module / VeriSTAR



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

CONSTRAINTS

A. Structural constraints:

➤**Von Mises stress** in plates, longitudinal stiffeners and web-frames ≤ 175 MPa

➤**ultimate strength** of the beam column

➤**minimum plate thickness** to avoid yielding / buckling .

B. Geometrical constraints:

➤$\delta \leq 2 \times Tw$; $0{,}625 \times D_F \leq D_W$;

➤$D_W \leq 2{,}5 \times D_F$; $D_W \leq 36 \times T_W$;

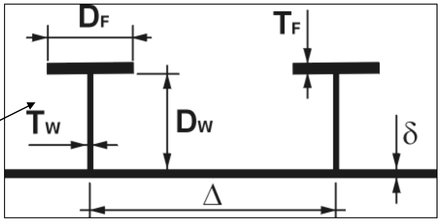
➤$T_W \leq 2 \times \delta$.

C. Equality constraints:

➤All web-frame spacing is equal;

➤Stiffeners on deck and bottom have equal spacing and dimensions;

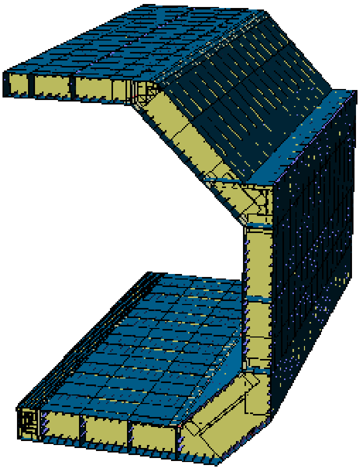
➤Thickness on deck and bottom (inner and outer hull) plates is constant;

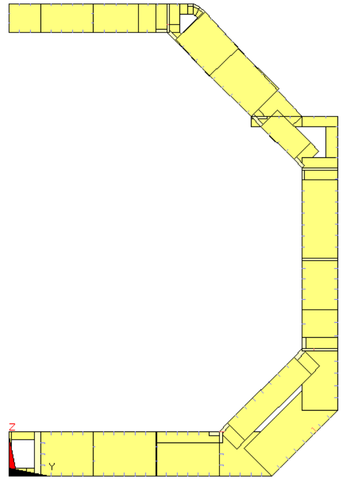


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMIZATION OF STANDARD DESIGN





Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMIZATION OF STANDARD DESIGN

➢ **5 LOAD CASES**

N°	Description	Draught (m)	Still Water Bending Moment (kN.m)	Ship upright			Inclined ship	
				A1	A2	B	C	D
LC1	Homogeneous loading conditions	13.2	1700000 (sagging)		X	X		X
LC2	Ballast conditions	11.62	3500000 (hogging)	X			X	

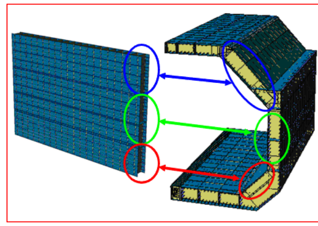
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMIZATION OF STANDARD DESIGN

LBR-5 – LNG optimization taking into account multi-structure constraint – *academic approach*

➢Gain in cost of **18.9 % for the cofferdam**. **Not realistic** results and reveals that the cofferdam is **not strongly constrained**.
➢Results remains "academic" due to simplifications (shape of the cofferdam and no stresses transfer)
➢For the main tank, the gain in **cost remains the same (9.7 % ≅9.67%).**



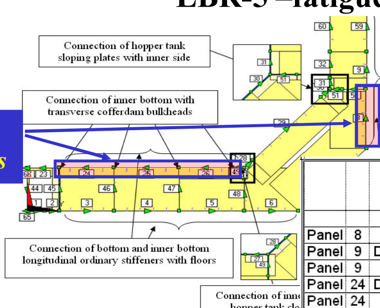
Scantling	Mass [tons]	Gain in mass	Cost [M€]	Gain in cost
Initial	1 840.44		3.168	
Optimized	1 682.81	**10.34 %**	2.861	**9.71 %**
Optimized with cofferdam	1 648.47	**10.43 %**	2.862	**9.67 %**

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMIZATION OF STANDARD DESIGN

LBR-5 –fatigue verification

Fatigue problems



				Before optimization	after optimization (sloshing module)	after optimization (sloshing module) after correction
				DAMAGE	DAMAGE	DAMAGE
Panel	8	Arrival	Node	0.579	7.596	0.758
Panel	9	Departure	Node	0.727	0.671	0.66
Panel	9	Arrival	Node	0.367	0.339	0.335
Panel	24	Departure	Node	0.432	13.462	0.646
Panel	24	Arrival	Node	0.49	14.061	0.733
Panel	25	Departure	Node	0.349	12.379	0.509
Panel	25	Arrival	Node	0.421	13.292	0.631
Panel	26	Departure	Node	0.33	11.612	0.459
Panel	26	Arrival	Node	0.346	12.428	0.513
Panel	59	Departure	Node	0.385	0.347	0.342
Panel	59	Arrival	Node	0.096	0.079	0.079
Panel	23	Departure	Node	0	0	0
Panel	23	Arrival	Node	0	0	0
Panel	24	Departure	Node	0.429	1.739	0.732
Panel	24	Arrival	Node	0.47	1.826	0.796
Panel	25	Departure	Node	0.452	1.806	0.772
Panel	25	Arrival	Node	0.478	1.851	0.805
Panel	26	Departure	Node	0.201	1.921	0.832
Panel	26	Arrival	Node	0.212	1.917	0.84

IMPROVE Final Wor

OPTIMIZATION OF STANDARD DESIGN

LBR-5 – LNG optimization results

Scantling	Mass [tons]	Gain in mass	Cost [M€]	Gain in cost
Initial	1840.44		3.16	
Optimized	1682.81	**8.56%**	2.86	**9.62%**
Optimized with sloshing	1 694.98	**7.90%**	3	**5.25%**
Optimized with sloshing & Corrected fatigue	1714.13	**6.86%**	3.02	**4.58%**

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

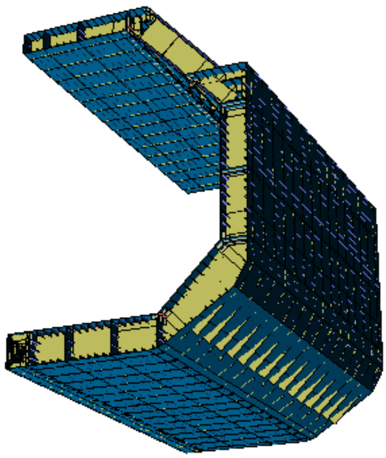
OPTIMIZATION OF STANDARD DESIGN

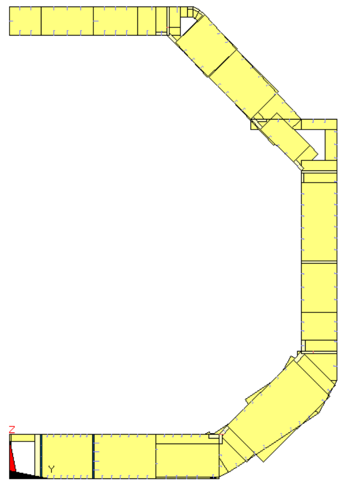
- ➢Plate thickness ⇘ (in general)
- ➢Stiffener web height ⇘ (except upper outer deck)
- ➢Stiffener web thickness ⇘ (except inner hull and outer bottom)
- ➢Stiffener spacing ⇗ (less stiffeners on the optimized scantling)
- ➢Web-frame thickness generally ⇘
- ➢Web-frame spacing ⇘ (more web-frames on the optimized scantling).

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMIZATION OF FREE BALLAST DESIGN





Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMIZATION OF FREE BALLAST DESIGN

07 LOAD CASES

N°	Description	Draught (m)	Still Water Bending Moment (kN.m)	Ship upright			Inclined ship	
				A1	A2	B	C	D
LC1	Homogeneous loading conditions	14.1	3700000 (sagging)		X	X		X
LC2	Ballast conditions	9.52	4500000 (hogging)	X			X	
LC3	Unloaded conditions	5.03	4500000 (hogging)	X			X	

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

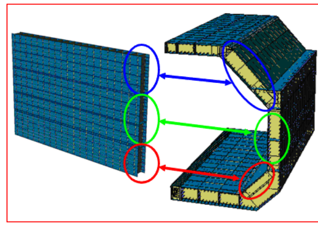
OPTIMIZATION OF FREE BALLAST DESIGN

LBR-5 – LNG optimization taking into account multi-structure constraint – *academic approach*

➢For the main tank, gain in cost remains the same (5.81 % ≅ 5.75%).

➢Results remains "academic" due to simplifications (shape of the cofferdam and no stresses transfer)

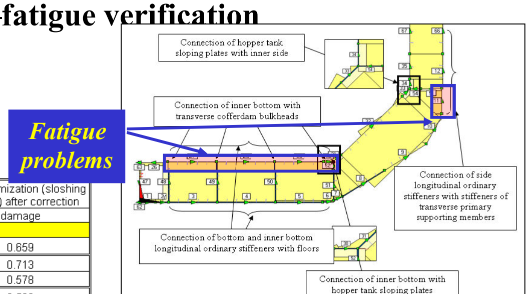
➢Multi-structure module cannot be used to define the final scantling.



Scantling	Mass [tons]	Gain in mass	Cost [M€]	Gain in cost
Initial	1 845.70		3.13	
Optimized	1 642.29	**11.02 %**	2.95	**5.81 %**
Optimized with multi-structure	1 641.64	**11.05 %**	2.96	**5.751 %**

OPTIMIZATION OF FREE BALLAST DESIGN

LBR-5 –fatigue verification



				Before optimization	after optimization (sloshing module)	after optimization (sloshing module) after correction
Panel				damage	damage	damage
Panel	11	Arrival	Node	0.63	4.894	0.659
Panel	27	Departure	Node	0.52	7.382	0.713
Panel	27	Arrival	Node	0.433	6.637	0.578
Panel	28	Departure	Node	0.422	6.512	0.562
Panel	28	Arrival	Node	0.311	5.285	0.384
Panel	29	Departure	Node	0.301	5.154	0.373
Panel	29	Arrival	Node	0.31	4.286	0.312
Panel	66	Departure	Node	0.368	0.37	0.357
Panel	26	Arrival	Node	0.003	0.021	0.024
Panel	27	Departure	Node	0.948	2.43	0.586
Panel	27	Arrival	Node	0.695	1.994	0.342
Panel	28	Departure	Node	1.066	2.724	0.653
Panel	28	Arrival	Node	0.81	2.242	0.422
Panel	29	Departure	Node	0.542	2.903	0.666
Panel	29	Arrival	Node	0.462	2.757	0.547
Panel	30	Departure	Node	0.154	1.03	0.231
Panel	30	Arrival	Node	0.172	1.206	0.264

OPTIMIZATION OF FREE BALLAST DESIGN

LBR-5 – LNG optimization taking into account fatigue corrections

Scantling	Mass [tons]	Gain in mass	Cost [M€ (M$)]	Gain in cost
Initial	1 845.70		3.13	
Optimized	1 674.83	**9.25%**	2.95	**5.81%**
Optimized with sloshing	1 714.55	**7.10%**	3.04	**3.06%**
Optimized with sloshing & Corrected fatigue	1744.37	**5.49%**	3.05	**2.71%**

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

OPTIMIZATION OF FREE BALLAST DESIGN

Non-optimized vs. Optimized

- Plate thickness ⇗ (except outer hull)
- Stiffener web height ⇘
- Stiffener web thickness ⇗ (except inner bottom and outer slopes)
- Stiffener spacing ≃
- Web frame thickness ⇘
- Web frame spacing ⇘ (not significantly : 2662 mm instead 2700 mm).

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

STANDARD Design versus FREE BALLAST Design

➢WITHOUT ANY NEW MODULE

	Initial Cost [M€]	Final Cost [M€]	Difference %
Standard Design	3.16	2.86	9.70 %
Free ballast Design	3.13	2.95	5.81 %

➢ SLOSHING MODULE

	Initial Cost [M€]	Final Cost [M€]	Difference %
Standard Design	3.16	3.00	5.25 %
Free ballast Design	3.13	3.04	3.06 %

➢SLOSHING & FATIGUE MODULES

	Initial Cost [M€]	Final Cost [M€]	Difference %
Initial Design	3.16	3.02	4.58
New Design	3 .13	3.05	2.71

➢Normalized scantling (sloshing and fatigue)

	Initial Cost [M€]	Final Cost [M€]	Difference %
Initial Design	3.16	3.06	3.14%
New Design	3.13	3.07	2.09%

- LNG standard Design Gain > LNG free ballast Design Gain
  - ➢ **more severe loading conditions for New Design**
- Sloshing & fatigue Modules → important impact
  - ➢Initial scantling (**50% panels don't respect sloshing**)
  - ➢**Increase of certain panel's scantling** to avoid fatigue cracks

	standard	free ballast
Design still water moment (kN.m)	1700000 (sagging)	3700000 (sagging)
	3500000 (hogging)	4500000 (hogging)

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

STANDARD Design versus FREE BALLAST Design

Design	Standard		Free ballast	
	Initial scantling			
Mass [tons]	1840.44		1845.70	
	Optimized scantling (only sloshing constraints)			
Mass [tons] / Gain	1694.98	7.90%	1714.55	7.10%
	Optimized scantling (sloshing & fatigue constraints)			
Mass [tons] / Gain	1714.13	6.86%	1744.37	5.49%
	Normalized scantling (sloshing and fatigue constraints)			
Mass [tons] / Gain	1709.76	7.10%	1724.73	6.55%

standard Design weight < free ballast Design weight before and after optimization

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

➢STANDARD Design versus FREE BALLAST Design

- LNG Initial Design VS. LNG New Design – on optimized structure
  - plate thickness : S.D. < F.B.D.
  - stiffeners web height : S.D. < F.B.D.
  - stiffeners web thickness : S.D. > F.B.D.
  - stiffeners spacing : S.D. ≈ F.B.D.
  - frames web thickness : S.D. > F.B.D.
  - frames spacing : S.D. ≈ F.B.D.

➢ LBR-5 cost gain source – standardized scantling

- Standard Design : cost/weight → from 1.72 €/kg to 1.79 €/kg
- Free ballast design : cost/weight → from 1.70 €/kg to 1.78 €/kg
- the cost gain influenced by the decrease of the global weight

LBR-5 least weight optimization
least weight objective function

Design	Standard		Free ballast	
	Initial scantling			
Mass [tons]	1840.44		1845.70	
Cost [M€]	3.16		3.13	
	least cost optimization			
Mass [tons] / Gain	1694.98	**7.90%**	1714.55	**7.10%**
Cost [M€] / Gain	3.00	**5.25%**	3.04	**3.06%**
	least weight optimization			
Mass [tons] / Gain		**15.84%**		**14.41 %**
Cost [M€] / Gain	**3.94**	**-24.68% (increase)**	**3.13**	**-18.21% (increase)**

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LBR-5 least weight optimization results

➤Differences can be explained by the strong variation of the scantling.

➤"Least cost" and "least weight" optimizations of the "Standard" design drive to different scantlings

	Least cost	Least weight
Plate thickness	10 ÷ 25 mm	10 ÷ 24 mm
Stiffeners spacing	870 mm	400 ÷ 600 mm
Web-frame spacing	2600 mm	1950 mm

WP6 LNG CARRIER

STRUCTURAL OPTIMIZATION

V. Zanic, J. Andric, N. Hadzic

(UZ),University of Zagreb, Zagreb, Croatia

OBJECTIVE

- **STRUCTURAL MULTICRITERIAL OPTIMIZATION**
- **DESIGN PROCEDURE:**

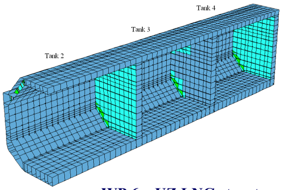
  - FORMULATION OF DESIGN SUPPORT PROBLEM

  - ANALYSIS OF PROTOTYPE STRUCTURE

  - STRUCTURAL OPTIMIZATION

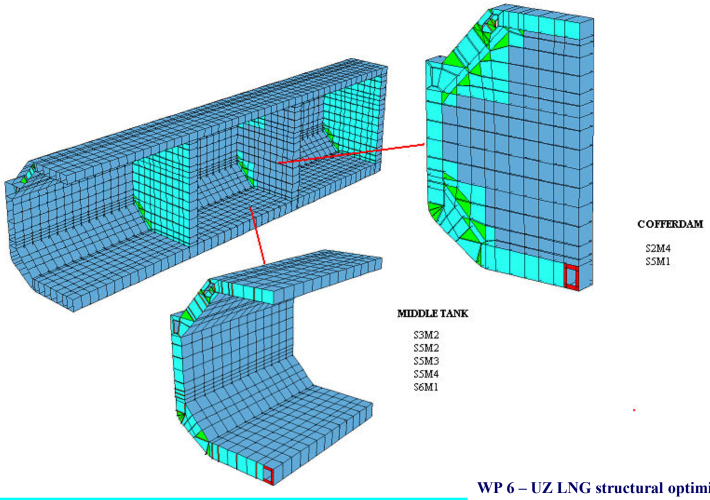
  - COMPARISON OF RESULTS

- **DESIGN VARIABLES: structural scantlings, BBS and web frame spacing**
- Tank 3 was chosen to be optimized



Structural FE model:

3-hold structural FE MAESTRO model and two basic sub models (tank and cofferdam structures) that will be jointly optimized



LOADING CONDITIONS: 5 loading conditions, 17 load cases

Loading condition	LC	Description	Draft, m	M_{VTOTAL}, kNm	M_{HTOTAL}, kNm	Q_{HTOTAL}, Kn
FULL LOAD	1	SAGG, a2	14.1	-8720500	0	0
	2	SAGG, b	14.1	-8720500	0	0
	3	SAGG, d	14.1	-5708200	2080283	0
BALLAST	4	HOGG, a1	9.525	8929816	0	0
	5	HOGG, c	9.525	6271926	-2080283	0
UNLOAD	6	HOGG, a1	5.03	8929816	0	0
	7	HOGG, c	5.03	6271926	-2080283	0
ALTERNATE CONDITION - EMPTY MIDDLE TANK	8	HOGG, a1	12.69	8479816	0	0
	9	HOGG, a1	12.69	6885082	0	39951
	10	SAGG, b	12.69	-970500	0	0
	11	HOGG, b	12.69	836880	0	-23797
	12	HOGG, c	12.69	5821926	-2080283	0
ALTERNATE CONDITION - FULL MIDDLE TANK	13	SAGG, a2	10.575	-8350500	0	0
	14	SAGG, a2	10.575	-6543120	0	-38626
	15	SAGG, b	10.575	-8350500	0	0
	16	SAGG, b	10.575	-6543120	0	-38626
	17	SAGG, d	10.575	-5338200	2080283	0

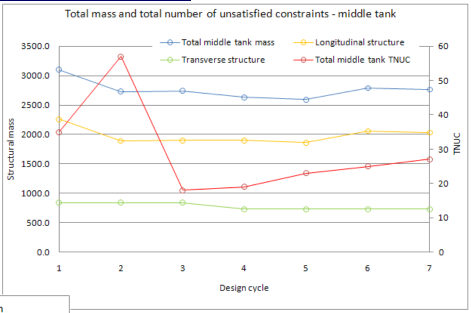
SLOSHING LOADS : According to BV Rules

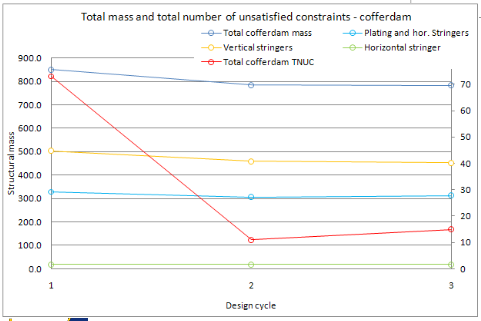
Used for calculation of allowable minimum plate and stiffener characteristics

Initial exploration of design space

Design variables:

TECHNOLOGICAL LIMITS	VARIABLE	MIN	MAX
	TPL	6	25
	TGW	6	35
	TFW	5	20
	S_W	1000	3500
	HSW	80	460
	TSW	5	20
	BSF	10	100
	BBS	400	900





-Structural mass was decreased successfully for 474 t, or 12% with respect to the initial mass.

-Strong coupling between longitudinal and transverse elements has been identified

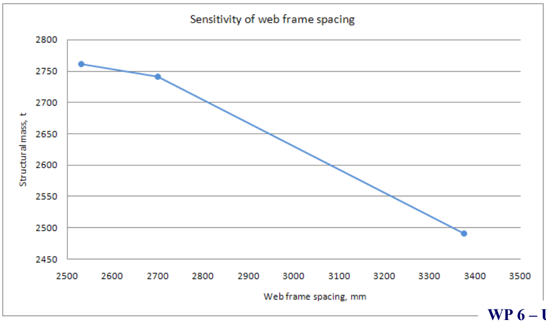
WP 6 – UZ LNG structural optimization

Sensitivity studies

Three sensitivity studies related to tank structure were done regarding breadth between stiffeners, material selection and web frame spacing

Achieved results:

- providing additional stiffeners offers weight savings
- providing higher tension steel offers weight savings
- enlarging web frame spacing offers weight savings

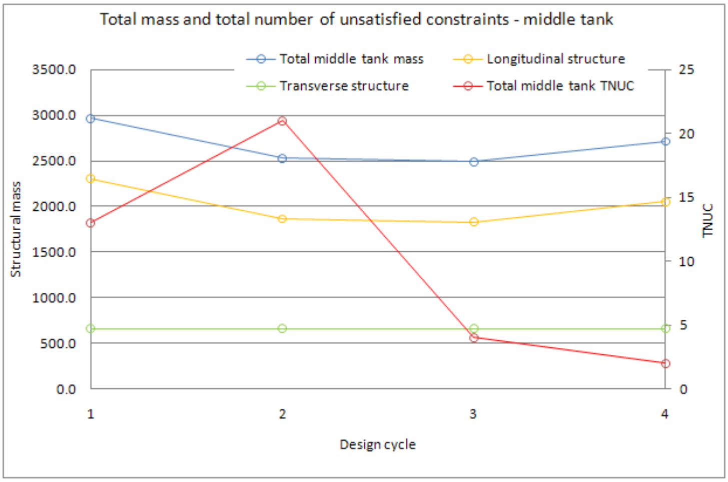


WP 6 – UZ LNG structural optimization

Preliminary optimization

- Increased web frame spacing (3375 mm)

- Breadth between stiffeners: bbs ≈ 600 mm



Improve

WP 6 – UZ LNG structural optimization

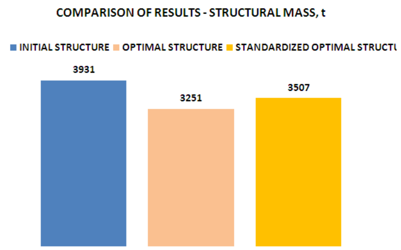
Final results and comparison

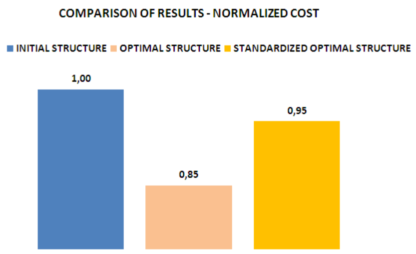
	Design solution	Structural mass (middle tank	Mass savings, %	Safety (TNUC)	VCG, mm	Normalized cost
Concept desing	Initial, P^0	3931	/	110	16155	1.00
	Optimal, $O^{3Concept}$	3457	12.0	42	15957	0.87
Preliminary design	Optimal, $O^{3Preliminary}$	3251	17.3	3	15931	0.85
	Standardized, D^4	3507	10.8	0	15951	0.95

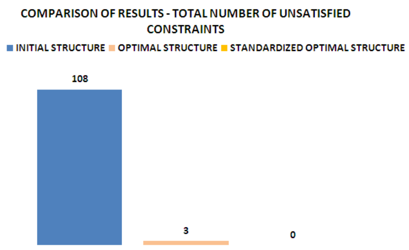
Improve

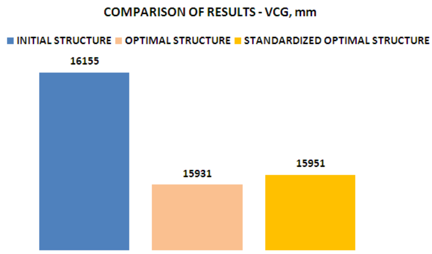
WP 6 – UZ LNG structural optimization

Comparison of results:

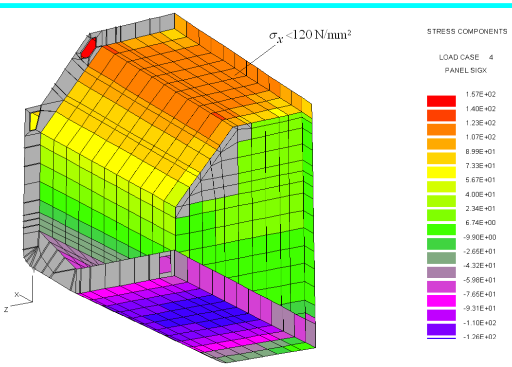




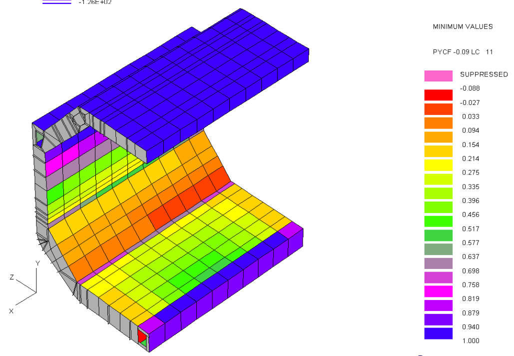




Final analysis:



All constraints satisfied !




THANK YOU!
Improve
WP 8-UZ TBHD optimization

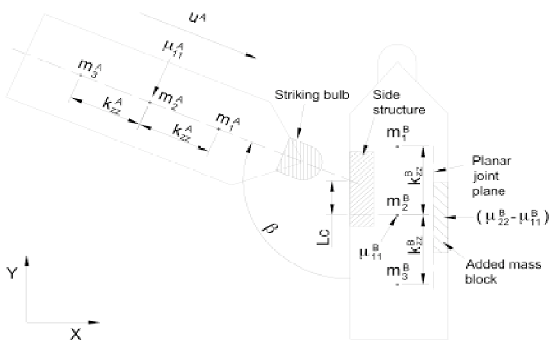
IMPROVE

LNG – Tug collision

S. Ehlers
Helsinki University of Technology, Finland

LNG – Tug Collision

- Coupled inner mechanics and outer dynamics are solved in LS-DYNA to evaluate planar motions under external forces
- The colliding ships experience fluid forces due to the surrounding water, gravity loading F_G and contact force F_C
  - Only the fluid force due to the hydrodynamic added mass is considered
  - The collision model consists of the striking and the struck ship



Collision scenario

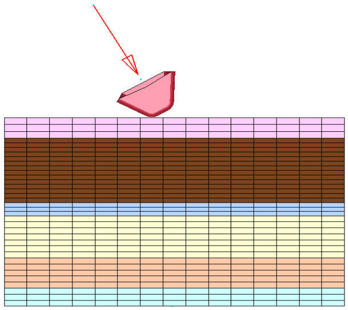
- contact point is at amidships
  - collision at amidships presents the most critical scenario as the largest amount of the initial kinetic energy of the striking ship is transmitted into the structural deformation energy
- assumption:
  - All the deformations are limited to the struck ship and the striking ship is treated as rigid

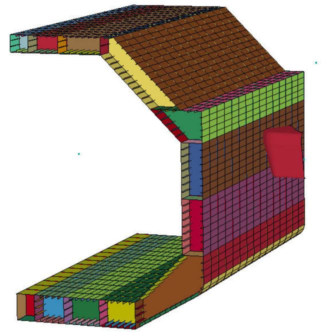
Collision scenario

Collision velocity	v= 13 kn or 5 kn
Collision angle	b=60 deg
Mass of the striking ship	
Structural mass	m^A=930 [ton]
Hydrodynamic added mass in surge	m_1^A=46.5 [ton] (5% of m^A)
Mass of the struck ship	
Structural mass	m^B=179 211 [ton]
Hydrodynamic added mass in surge	m_1^B=8960 [ton] (5% of m^B)
Hydrodynamic added mass in sway	m_2^B=35842 [ton] (20% of m^B)

Improve
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Collision scenario





IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Collision scenario

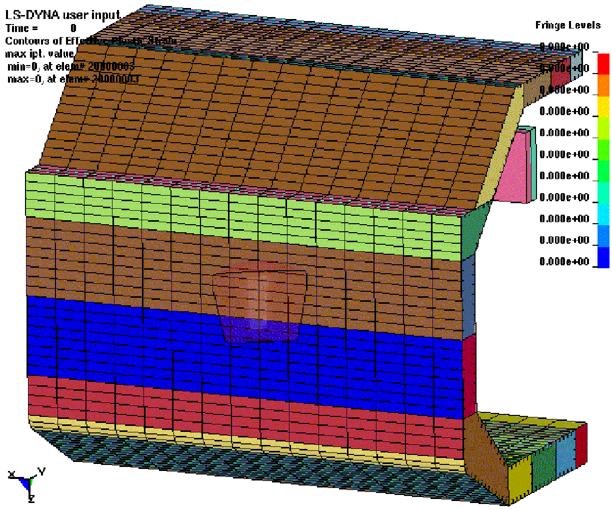
- In first three simulations:
  - tug collides with the struck ship at its maximum speed of 13 kn
  - three different plating thicknesses at the contact region are used
    - 17 mm, 25 mm and 35 mm
- In the fourth simulated scenario
  - speed of the striking ship is reduced to 5 kn
  - plating thickness of the struck ship is 17 mm

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Results

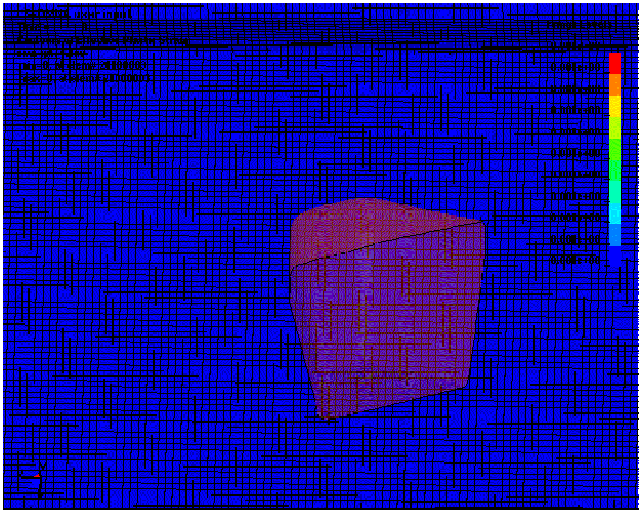
- **Scenario 1. – Assumed to be the most critical scenario from a structural point of view for the given vessels.**
- V=13 kn, t=17 mm
- outer hull is heavily penetrated
- tearing initiates at about t=0.1 s
- the inner hull remains intact

Results



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

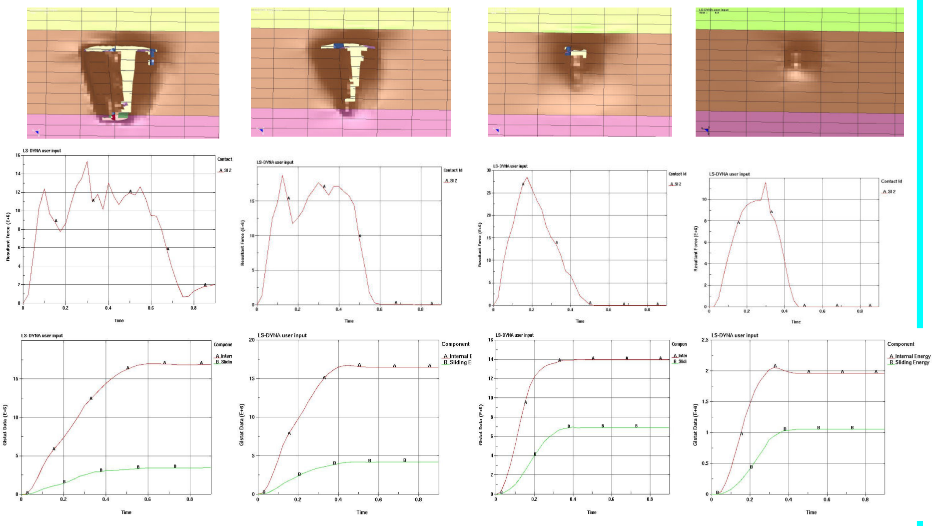
Results



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

v=13kn, t=17mm	v=13kn, t=25mm	v=13kn, t=35mm	V=5kn, t=17mm



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Conclusions

- At maximum speed, the outer hull will be penetrated (t=35mm)
- The size of the damage opening increases significantly as the thickness becomes lower
- Altering the structural configuration could improve the crashworthiness of the side structure
- In the current design, the longitudinal stringer just above the collision point presents a hard point in the structure and prevents deformation to spread more evenly
- Reduction of the speed of the striking ship reduces the amount of energy available for structural deformations and the outer plating of the struck ship remains intact even in the case of 15 mm plating.
- The inner plating remains intact for all scenarios.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE

LNG carrier – new innovative product

- achievements through project, conclusions -

A. Constantinescu, Ph. Rigo
ANAST University of Liège, Belgium
J.-L. G. Combecave
STX-Europe, St. Nazaire, France
G. Smyrnakis
WEGEMT, Newcastle, United Kingdom

General overview

IMPROVE Project Objectives – improve generic ship design

New generation of design

- 220 000 m^3 capacity LNG
- pronounced V-shape section

Structural design optimization at the early stage design

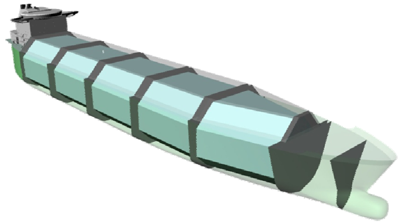
- multi-stakeholders requirements
- using existing design platforms and tools
- create and/or improve rational models
- design characteristics optimization

Principal objectives

- reduction of the manufacturing costs and production lead-time
- reduction of the maintenance costs for ship-owners

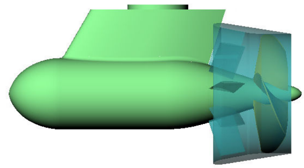
IMPROVE – LNG carrier methodology

1. First phase – definition of the problem

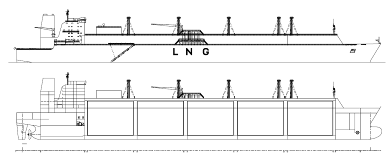


- multi-stakeholders requirements
- KPI – key performance indicators

- first design of the ship - geometry
- propulsion proposal – Innovelis pod
- machinery and general arrangements



- CFD simulations – outer pressure
- sea-keeping
- maneuverability, stability

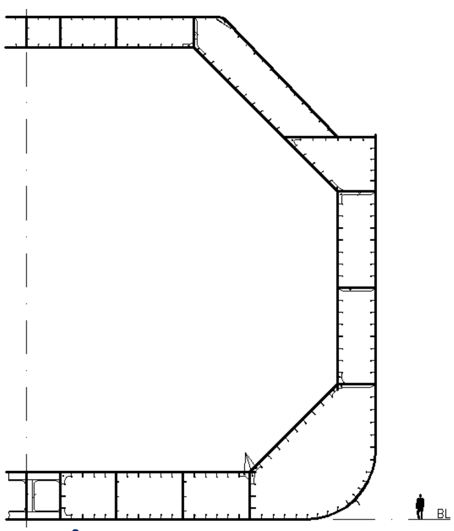


- **furnish initial scantling**

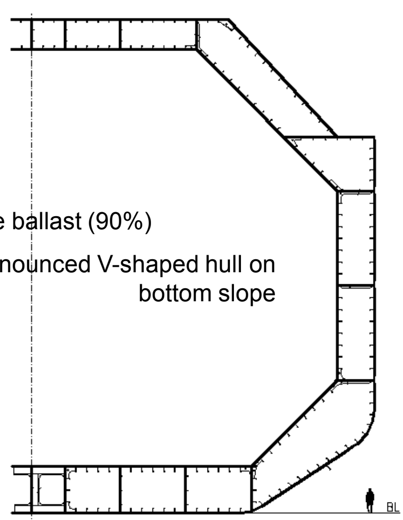
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG designs

"Standard" design



"Free ballast" design



- free ballast (90%)
- pronounced V-shaped hull on bottom slope

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG designs

Free ballast design – advantages

- eliminate the need for ballast water within a wide range of sea states
- the quantity of water transport – 80% lower than a conventional LNG

- up to 10% of fuel saving
- up to 9.5 of gas per day

- lower wetted surface – unloaded
- higher neutral axis → lower critical stress at the top

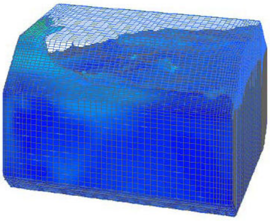
- slightly lower propeller efficiency

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE – LNG carrier methodology

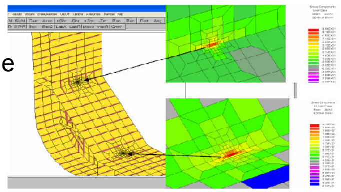
2. Second phase – development and integration of new IMPROVE modules



Sloshing module (BV)

- quasi-static pressure – on the inner hull
- CFD, sloshing test campaign (ECN, GTT)

Fatigue module (TKK)



- fatigue damage on critical connections
- based on "nominal stress" and Miner's rule
- ANAST – validation by FEA

Cost module (ANAST)

- Production cost – provide reliable assessment of production cost
- Life cycle cost (NAME), dll (ANAST)
- Multi-materials cost (Chemical tanker)

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG design tools development

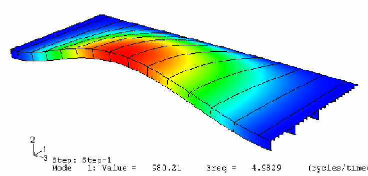
2. Second phase – development and integration of new IMPROVE modules

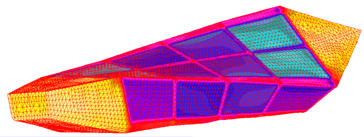
Multi-structure module (ANAST)

- simultaneous optimization of structures
- main application – cofferdam and tank
- specific for LBR-5

Vibration modules (ANAST, SDG)

- local vibrations – stiffened panels
- global vibrations – hull beam
- beam modeling
- ROPAX product





Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG design tools development

3. Third phase – application of new modules to LNG developments

- Least cost optimization

- materials cost
- labor and consumables cost

- Least weight optimization

- indirect cost optimization

- Fatigue assessment

- fatigue damage on critical connections of ship structure

- Crashworthiness analysis

- impact tests

- Sloshing direct calculations

- to provide quasi-static pressure to be applied on the inner hull structure

- Production simulation

- modeling and simulation of production systems and processes

Improve

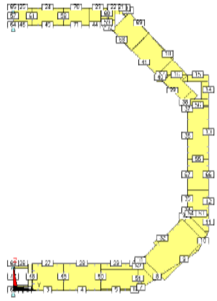
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

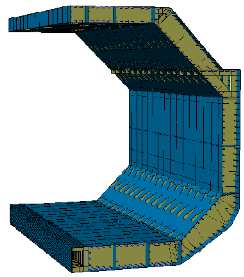
LNG designs – optimization process

LBR-5 modeling

- analytical modeling
- elastic cylindrical stiffened shell theory

- 1 tank (half) – 40.5 m of length
- 5 load cases for "Standard" design
- 7 load cases for "Free ballast" design
- sloshing constraints
- fatigue post-analysis
- include the unitary construction costs and the production sequences in the optimisation process





Improve

LNG designs – optimization

LBR-5 least cost optimization results

Design	Standard		Free ballast	
	Initial scantling			
Mass [tons]	1840.44		1845.70	
Cost [M€]	3.16		3.13	
	Optimized scantling (only sloshing constraints)			
Mass [tons] / Gain	1694.98	7.90%	1714.55	7.10%
Cost [M€] / Gain	3.00	5.25%	3.04	3.06%
	Normalized scantling (sloshing and fatigue constraints)			
Mass [tons] / Gain	1709.76	7.10%	1724.73	6.55%
Cost [M€] / Gain	3.06	3.14%	3.07	2.09%

- indirect weight gain
- the values correspond to a half of tank
- more severe loading conditions imposed to "Free ballast" design

Improve

LNG carrier – least cost optimization

LBR-5 least weight optimization results

- Standard Design - 15.84% gain in weight, but the cost increase 24.68%
  - from 3.16 M€ to 3.94 M€

	Least cost	Least weight
Plate thickness	10 ÷ 25 mm	10 ÷ 24 mm
Stiffeners spacing	870 mm	400 ÷ 600 mm
Web-frame spacing	2600 mm	1950 mm

LBR-5 cost gain source – standardized scantling

- Standard Design : cost/weight → from 1.72 €/kg to 1.79 €/kg
- Free ballast design : cost/weight → from 1.70 €/kg to 1.78 €/kg
- the cost gain influenced by the decrease of the global weight

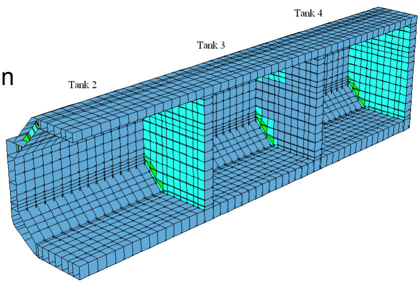
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG carrier – optimization

OCTOPUS/Maestro modeling

- FE modeling – “Free ballast” design
- 3 tanks
- 17 load cases
- sloshing pressure



1) Prototype structure analysis
   - to assess the adequacy of the initial model of LNG
   - library of failure criteria (inbuilt MAESTRO software)
   - allow to establish the starting point of the design problem
2) Preliminary design phase
   - optimization of the remodeled LNG ship structure

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG carrier – optimization

OCTOPUS/Maestro results

	Design solutions	Structural mass (middle tank + cofferdam)	Mass saving	Safety (TNUC)	Normalized cost
Concept design	Initial	3931 tons	-	110	1.00
	Optimal, concept	3457 tons	**12.0 %**	42	0.87
Preliminary design	Optimal, preliminary	3251 tons	**17.3 %**	3	0.85
	Standardized	3507 tons	**10.8 %**	0	0.95 / **5 %**

- 4 ÷ 7 % saving in weight for preliminary design with respect to the good concept design
- 12 % saving for concept design with respect to the initial design
- objective function – minimization of total mass and cost

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

LNG carrier – optimization

Gravity center variation

	Design	Initial	Standardized	Difference
LBR-5	“Standard”	15269 mm	15135 mm	↘ **13 cm**
	“Free ballast”	15380 mm	15895 mm	↗ **50 cm**
OCTOPUS/MAESTRO	“Free ballast”	16155 mm	15951 mm	↘ **20 cm**

Free ballast design net weight (tank + cofferdam)– LBR-5 versus OCTOPUS

	Initial	Standardized	Gain
LBR-5*	4312 tons	3909 tons	**9.39 %**
OCTOPUS/MAESTRO**	3931 tons	3507 tons	**10.8 %**

* LBR-5 cofferdam rectangular

** OCTOPUS – some missing structural elements

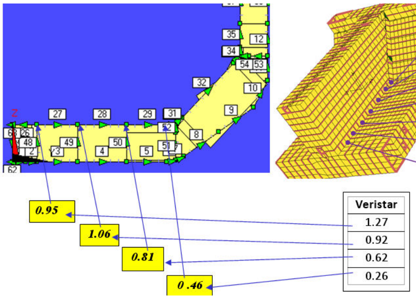
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

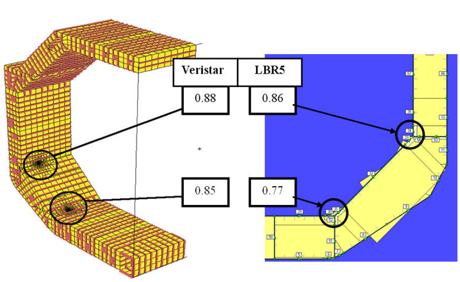
LNG carrier – fatigue assessment

VeriSTAR validations

- in LBR-5 – fatigue module used as post-analysis
- good agreement with VeriSTAR FE software results
- more fatigue problems on “Free ballast” design (LBR-5)



Cofferdam – inner bottom intersection

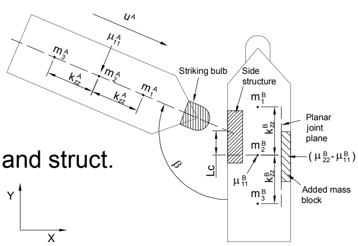


Knuckles

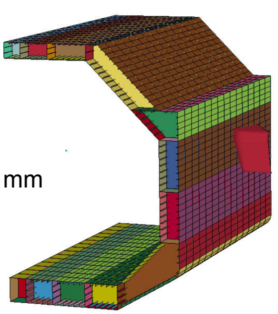
LNG carrier – crashworthiness analyses

LNG carrier and TUG collision

- side impact – most dangerous
- non-linear explicit solver LS-Dyna
- ship masses, inertias, added masses and struct. resistance



- 4 scenarios
- collision angle 60°
- collision velocity 5 kn and 13 kn

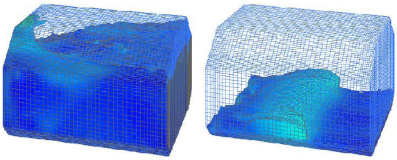


- outer hull is penetrated at 13 kn even thick. 35 mm
- inner hull remains intact
- longitudinal stringer – hard zone

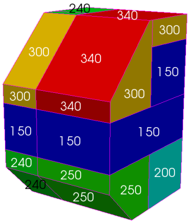
LNG carrier – sloshing direct calculations

Objective : sloshing pre-feasibility analysis – to provide quasi-static pressure to be applied on the inner hull structure

- standard filling ratios (< 10%H and > 70%H) – worldwide ship service
- partial filling ratios (> 10%H and < 70 %H)



- Hydrodynamic analysis
  - hydrodynamic computation - HydroSTAR
  - spectral analysis
- Liquid motion analysis
  - small-scale sloshing model tests
  - numerical CFD simulations – FLOW3D code



- 18 + 8 cases - various types of fluid flows and sloshing impacts
- structural criteria - plating and stiffeners

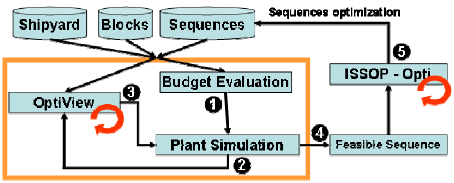
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

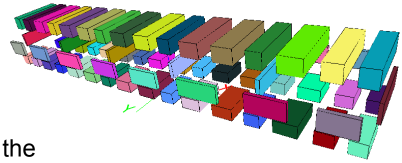
LNG carrier – production simulation

Objective : modeling and simulation of production systems and processes at the early stage design – operations at peak efficiency

- analytical calculation of the production cost from the scantling data of the midship section
- detailed production simulation



Results :



- lead time
- production cost
- space allocation ratio
- work load

→ KPI of the production simulation

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Conclusions

- **Reduced fuel consumption**
  - Vessel is more attractive for charterer
  - Reduced emissions: vessel is environmental friendly
- **Ballast free design – no ballast water treatment**
  - Newbuild vessels have to comply with the IMO regulations regarding ballast water treatment
  - LNG vessels have a large amount of ballast water, typical ballasting/deballasting flows: 3,000 m^3/h
  - Existing ballast treatment systems only feasible up to 1,000 m^3/h
  - Ballasting/deballasting times will have to be increased
  - Operational cost for treatment systems can be saved:
    - Power consumption
    - Use of chemicals

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Conclusions

- **Ineluctable advatages of the "Free ballast" design**
- **Slightly lower propeller eficiency**
- **13 m design draught – bigger for some terminals**

- **LNG reduction cost – strongly influenced by the descrease of the weight (LBR-5 simulations)**
- **The weight gains very close – LBR-5 and OCTOPUS/MAESTRO**
- **Less cost gain with LBR-5 comared to OCTOPUS/MAESTRO**

- **A least cost structural design with an optimization tool corresponds at the end to a multi-objective optimization, as the production cost and the weight are merged in the objective function**

IMPROVE project delivered an integration support system for a methodological assessment of LNG ship design

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Product Presentation: ROPAX Ship (WP7)

IMPROVE

ROPAX

Ship Owner requirements, markets and future trends

Dario Bocchetti
Stefano Melisi
Luca Ferrari

Grimaldi Group

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

RoPax Vessels are built to combine basically, and of course to take profit on it, 2 genre of transport: the roll on roll of services (as trailer, semi trailers, cars and special cargo) and the passenger transfer.

To make the difference in a competitive market the essential aspects are mainly two.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The first aspect is the creation of a solid network to guarantee to each client the most flexible and wide range of possibilities. With this vision since the beginning of Improve Project three years ago, Grimaldi Group has extended the initial RoPax fleet of only 5 Vessels into an exponential growth with a huge new building program. Furthermore two major RoPax operators have joined the GROUP: Minoan for Greek links and Finnlines for Scandinavian routes.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The second utmost is to have a young, competitive, environmentally friendly and most efficient fleet. Considering the daily operative cost a RoPax (and nowadays still more with economic crisis) only an extremely high efficiency can allow to remain on the market.

For above reasons. the global goal of the Improve project for a RoPax project have been:

•Reduced production cost;
•Reduced fuel oil consumptions;
•Reduced maintenance cost;
•Increased lane metres as possible;

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Key Performance Indicators

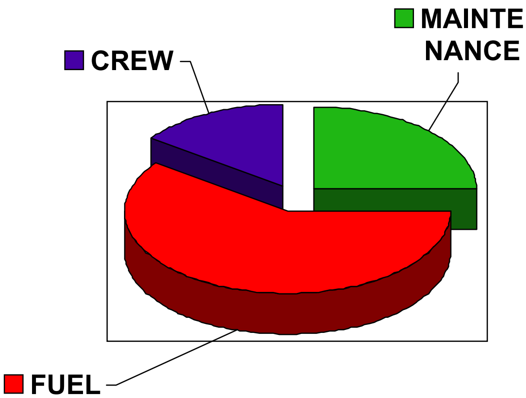
- *Capacities (3000LM300cars and flexibility)*
- *Structures*
- *Stability*
- *Sea keeping*
- *Manouvrability*
- *Resistance and Powering*
- *Confort*
- *Machinery and Systems*
- *Economic Function (LCC)*
- *Safety*

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Operative aspects and load cases

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Operative cost



Propulsion configuration and power plant

Energy Efficiency Design Index

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Life Cycle Cost

- *Maintenance*
- *Maintenability*
- *Maker list*

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Thank You !

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Sixth Framework Programme

IMPROVE

An Innovative ROPAX vessel

18th September 2009
Final Workshop, Dubrovnik, Croatia

Improve **IMPROVE** **ULJANIK Shipyard**

An Innovative Concept of ROPAX Vessel

RO - RO - PAX

- **Djani Dundara, (ULJANIK), Pula/CROATIA** djani.dundara@uljanik.hr
- **Obrad Kuzmanovic, (ULJANIK), Pula/CROATIA,** obrad.kuzmanovic@uljanik.hr
- **Vedran Zanic, University of Zagreb, Zagreb/CROATIA,** vedran.zanic@fsb.hr
- **Dario Bocchetti, (Grimaldi),Napoli/ ITALY,** bocchetti.dario@grimaldi.napoli.it

Improve **IMPROVE** **ULJANIK Shipyard**

IMPROVE design methodology – 3 main phases:

1. Identification of stakeholder's requirements and the definition of key performance indicators (KPI) – Selection of STANDARD SHIP which was used as prototype.
2. Development of new modules (fatigue assessment, vibration level investigation, ultimate strength, load assessment, production and maintenance cost) which were integrated in the optimization tool (LBR5, OCTOPUS) – NEW SHIP was designed (improvement in terms of main particulars, general arrangement, hydrodynamic and propulsion performance) using existing tools.
3. Application of the new (improved) optimization tool for the final ship design (IMPROVE SHIP). It is integrated decision support system for a methodological assessment of alternative ship designs. This system provided a rational basis for decision making regarding the design, production and operation of a innovative ROPAX ship.Based on this system all the aspects related to general arrangement, propulsion, hull shape and design of the structure were investigated.

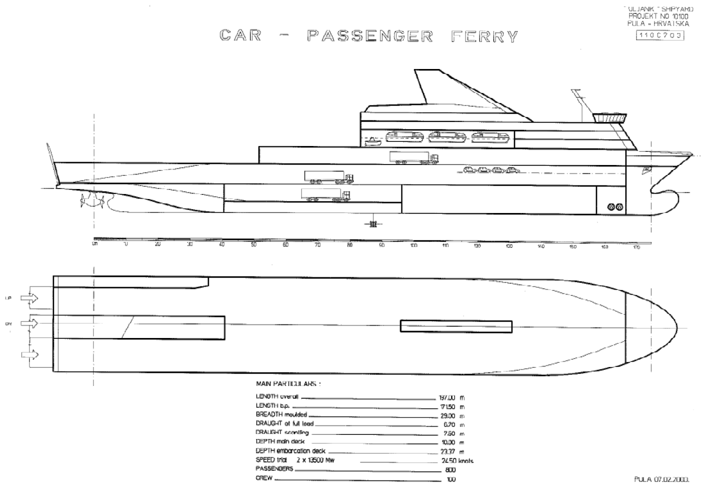
IMPROVE ULJANIK Shipyard

Main Global Goals

- Reduced production cost 10 %
- Reduced fuel oil consumptions 12 %
- Reduced maintenance cost 10 %
- Increased lane metres on tank top 8 %

IMPROVE ULJANIK Shipyard

Standard ship



Improve

IMPROVE **ULJANIK Shipyard**

Shipowner requirements

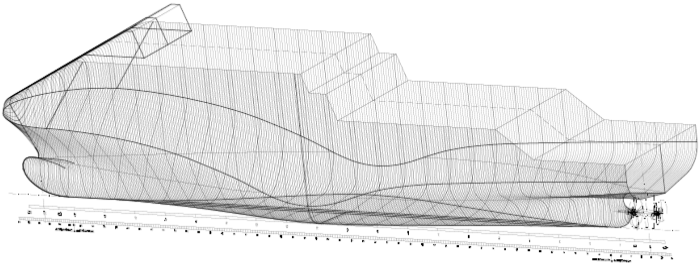
T	7.5 m
Trial speed	24.5 knots
Deadweight	8200 t
Passengers	1400 passengers in 350 cabins + 200 passengers in aircraft seats
Crew	200 persons
Cargo capacities	Trailers - 3000 lane meters Clear height = 4.7 m Cars - 300 pcs Clear height = 2 m
Capacities	HFO=860 m3, DO=440 t, FW=1000 m3, SW=600 m3
Increase carrying capacity (lane meters) on tank top	
Achieve load carrying flexibility (no pillars in cargo space)	
Improve the vessel’s operational performance and efficiency	
Maximize the robustness of the required freight rate (large variations in season trade – summer 3000 pax, winter 100 pax)	
Design for redundancy and simplicity of systems	
Maximize comfort – minimize vibrations	
Increase ship’s manoeuvrability	
Optimize the seakeeping performance for the Mediterranean Sea	

Improve

IMPROVE **ULJANIK Shipyard**

Body Lines

Main dimensions of ROPAX are optimized using TRIDENT/SEAKING software – best combination of main dimensions in order to improve hydrodinamic and propulsion performance.



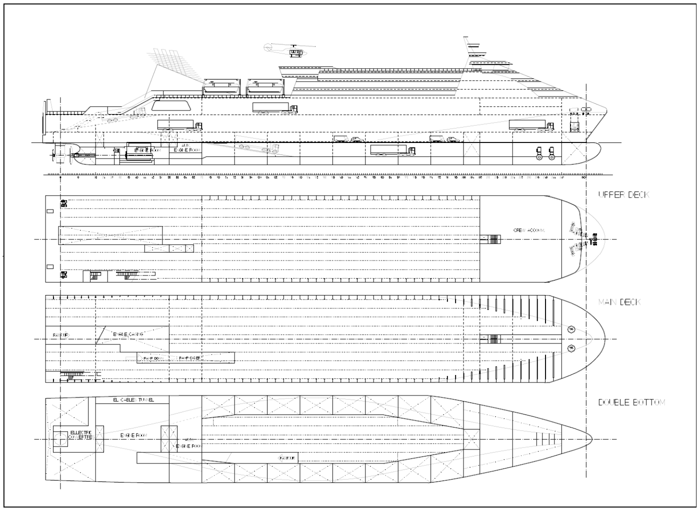
IMPROVE ULJANIK Shipyard

Main Characteristics

• Length overall	abt 193 m
• Length between perpendicular	180 m
• Breadth	29.8 m
• Design draft	7.5 m
• Block coeff.	0.53
• Trial speed	24.5 kn
• Main engine power (MCR)	14940 kW
• Active rudder output	5000 kW

IMPROVE ULJANIK Shipyard

General Arrangement



IMPROVE   *ULJANIK Shipyard*

Propulsion variants

- Two selected propulsion variants are analyzed:

  1st variant - one slow speed main engine directly coupled to fix pitch propeller.
  (Level2bI) - one active rudder/pod

  2nd variant - two medium speed main engine coupled via gearbox to CP-propeller .
  (Level2bII) - two retractable side thrusters.

- The main idea of propulsion concept is to avoid as much as possible the running of electrically driven thrusters in seagoing condition i.e. to use it only :

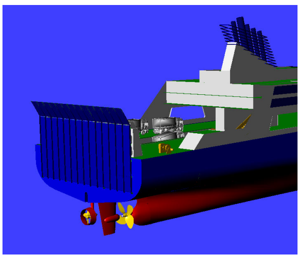
  - During manoeuvring in harbour (no tugs).
  - In order to obtain 100% redundancy notation.

IMPROVE   *ULJANIK Shipyard*

Propulsion variants

1st variant (Level2bI)

ENGINE:MAN-B&W-ULJANIK 9S50MC-CMk8 P = 14940 kW
+ ACTIVE RUDDER/POD 5000 kW
TRIAL SPEED V = 23.86 KNOTS (24.58 KNOTS)*
(*) CORRECTED AS PER SISTER VESSEL SEA TRIALS RESULTS



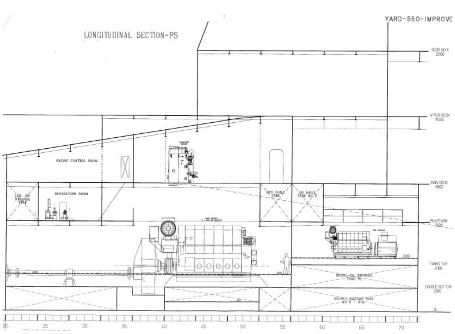
2nd variant (Level 2bII)

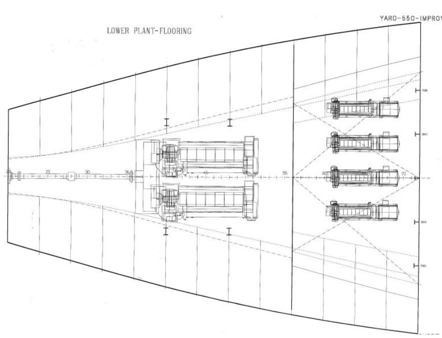
ENGINE:MAN-B&W-ADRIADIESEL 2x6L58/64 P = 2x8400 kW
+ THRUSTERS 2x2000 kW
TRIAL SPEED V = 24.27 KNOTS (24.60 KNOTS)*
(*) CORRECTED AS PER SISTER VESSEL SEA TRIALS RESULTS

The owner requirement (ship must never stop) request selection of two main engines coupled via gearbox to one CP-propeller.
This arrangement give the possibility to operate vessel with one main engine running and carry out maintenance on the other main engine.
2nd propulsion variant shows smaller efficiency 9 %.

IMPROVE ULJANIK Shipyard

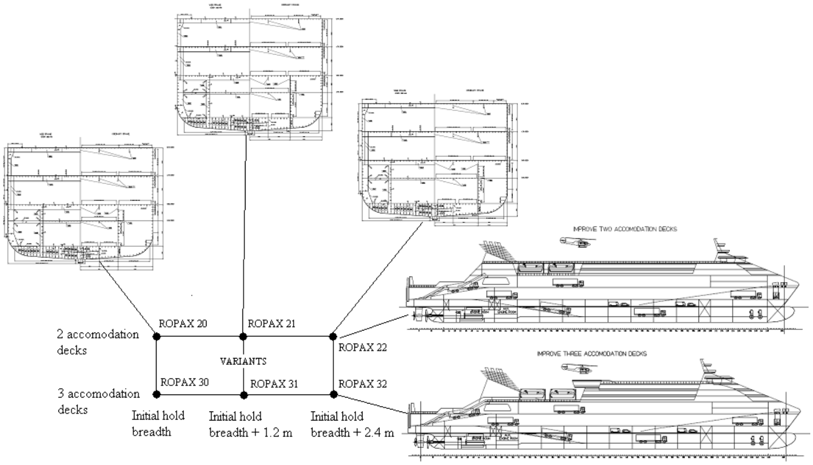
Engine Room Layout





IMPROVE ULJANIK Shipyard

Basic Concept Design Scheme



IMPROVE

ULJANIK Shipyard

Initial and proposed Model for each Variant

ROPAX 30		
	INITIAL MODEL	PROPOSED MODEL
MASS, t	3282.9	2990.6
COST, $	4.01E+06	3.65E+06
VCG, mm	13595	13376
TOTAL NUMBER OF SUTISFIED CONSTRAINTS	5272	5471
TOTAL NUMBER OF UNSUTISFIED CONSTRAINTS	201	2
RAI - S1M1	0.922	0.9599
RAI - S1M2	0.9543	0.9549
RAI - S1M2	0.9482	0.9679
Height, mm	31800	32250
	RANGE	PROPOSED MODEL
PARKING AREA, m^2	10100 10500	10150
PRODUCTION CRITERIA	3200 - 3000	2991
STABILITY CRITERIA	12000 - 13700	13376
AIR DRAUGHT, m	29200-32600	32250
PASSENGER COMFORT, HxMG*1/2	31800-36800	30765
SAFETY	0.91-0.97	0.9599

ROPAX 31		
	INITIAL MODEL	PROPOSED MODEL
MASS, t	3296.7	3038
COST, $	4.02E+06	3.71E+06
VCG, mm	13759	13405
TOTAL NUMBER OF SUTISFIED CONSTRAINTS	5154	5356
TOTAL NUMBER OF UNSUTISFIED CONSTRAINTS	215	13
RAI - S1M1	0.914	0.9497
RAI - S1M2	0.9509	0.957
RAI - S1M2	0.9438	0.9643
Height, mm	31950	32400
	RANGE	PROPOSED MODEL
PARKING AREA, m^2	10100 10500	10360
PRODUCTION CRITERIA	3200 - 3000	3038
STABILITY CRITERIA	12000 - 13700	13405
AIR DRAUGHT, m	29200-32600	32400
PASSENGER COMFORT, HxMG*1/2	31800-36800	35964
SAFETY	0.91-0.97	0.9497

ROPAX 32		
	INITIAL MODEL	PROPOSED MODEL
MASS, t	3239	3057.6
COST, $	3.95E+06	3.73E+06
VCG, mm	13522	13450
TOTAL NUMBER OF SUTISFIED CONSTRAINTS	5149	5341
TOTAL NUMBER OF UNSUTISFIED CONSTRAINTS	209	17
RAI - S1M1	0.9184	0.9519
RAI - S1M2	0.9504	0.9609
RAI - S1M2	0.9489	0.9655
Height, mm	32100	32550
	RANGE	PROPOSED MODEL
PARKING AREA, m^2	10100 10500	10570
PRODUCTION CRITERIA	3200 - 3000	3058
STABILITY CRITERIA	12000 - 13700	13450
AIR DRAUGHT, m	29200-32600	32550
PASSENGER COMFORT, HxMG*1/2	31800-36800	35479
SAFETY	0.91-0.97	[illegible]

ROPAX 20		
	INITIAL MODEL	PROPOSED MODEL
MASS, t	3265	2930
COST, $	3.98E+06	3.57E+06
VCG, mm	13231	12797
TOTAL NUMBER OF SUTISFIED CONSTRAINTS	5110	5239
TOTAL NUMBER OF UNSUTISFIED CONSTRAINTS	141	12
RAI - S1M1	0.9357	0.9469
RAI - S1M2	0.9579	0.9542
RAI - S1M2	0.9553	0.9555
Height, mm	28800	29250
	RANGE	PROPOSED MODEL
PARKING AREA, m^2	10100 10500	10150
PRODUCTION CRITERIA	3200 - 3000	2930
STABILITY CRITERIA	12000 - 13700	12797
AIR DRAUGHT, m	29200-32600	29250
PASSENGER COMFORT, HxMG*1/2	31800-36800	33345
SAFETY	0.91-0.97	0.9469

ROPAX 21		
	INITIAL MODEL	PROPOSED MODEL
MASS, t	3263	[illegible]
COST, $	3.98E+06	[illegible]
VCG, mm	13288	[illegible]
TOTAL NUMBER OF SUTISFIED CONSTRAINTS	5015	[illegible]
TOTAL NUMBER OF UNSUTISFIED CONSTRAINTS	175	[illegible]
RAI - S1M1	0.9251	[illegible]
RAI - S1M2	0.9481	[illegible]
RAI - S1M2	0.9504	[illegible]
Height, mm	28950	[illegible]
	RANGE	PROPOSED MODEL
PARKING AREA, m^2	10100 10500	[illegible]
PRODUCTION CRITERIA	3200 - 3000	[illegible]
STABILITY CRITERIA	12000 - 13700	[illegible]
AIR DRAUGHT, m	29200-32600	29400
PASSENGER COMFORT, HxMG*1/2	31800-36800	32034
SAFETY	0.91-0.97	0.9415

ROPAX 22		
	INITIAL MODEL	PROPOSED MODEL
MASS, t	3313	3000
COST, $	4.04E+06	3.66E+06
VCG, mm	13378	12906
TOTAL NUMBER OF SUTISFIED CONSTRAINTS	5028	5147
TOTAL NUMBER OF UNSUTISFIED CONSTRAINTS	150	41
RAI - S1M1	0.9314	0.9451
RAI - S1M2	0.9542	0.951
RAI - S1M2	0.9525	0.9427
Height, mm	29100	29550
	RANGE	PROPOSED MODEL
PARKING AREA, m^2	10100 10500	10570
PRODUCTION CRITERIA	3200 - 3000	3000
STABILITY CRITERIA	12000 - 13700	12906
AIR DRAUGHT, m	29200-32600	29550
PASSENGER COMFORT, HxMG*1/2	31800-36800	32209
SAFETY	0.91-0.97	0.9451

IMPROVE

ULJANIK Shipyard

Optimum Variant Selection

Parking Area Deck No. 2: + 201.6 m² x 3000 €/m² = 604 800 €

Parking Area Deck No. 1: + 201.6 m² x 5000 €/m² = 1 008 000 €

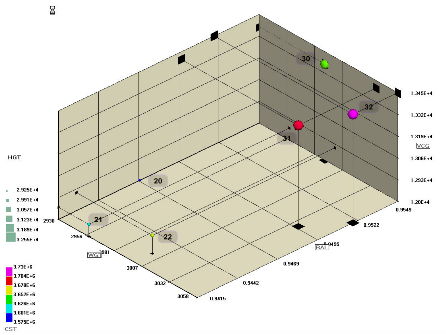
Total Parking Area: + 403.2 m² = 1 612 800 €

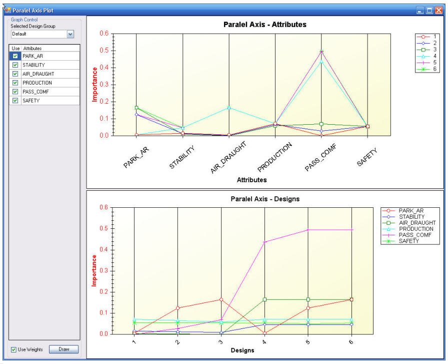
- No additional ballasting – the vessel will sail at smaller draught in arrival condition

-The air draught is 2.5 m smaller in respect to variant 32 (three acc. decks and same position of long. bulkhead)

-Reduced weight of wing tank blocks

-Smaller distance to WL = smaller accelerations = better passenger comfort

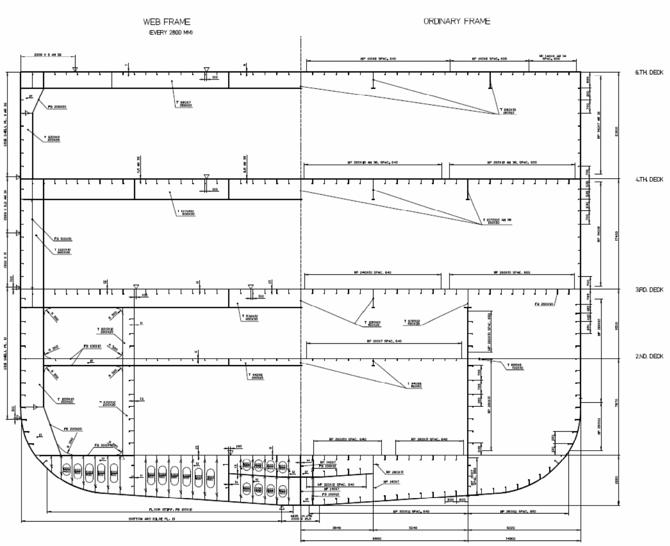




IMPROVE

ULJANIK Shipyard

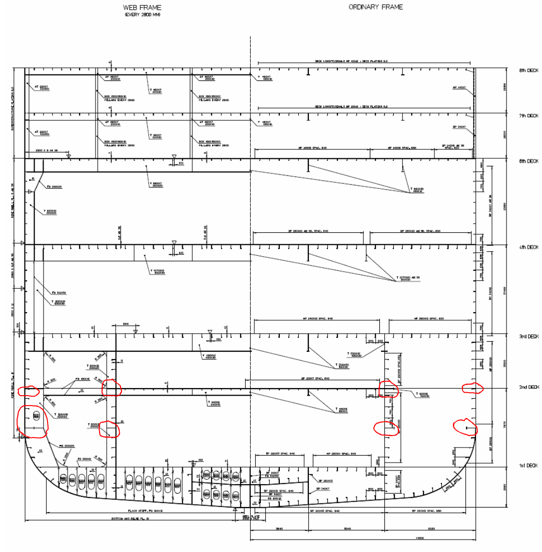
Midship Section – selected variant



IMPROVE

ULJANIK Shipyard

Midship Section – maintenance optimization



Addional stringers – scaffoldings for ballast tanks inspection

Maker's list

- **Maker A – price 100**
- **Maker B – price 120**
- **Communication with the shipowner**
- **Common decision based on :**

  - detailed maker's technical specification (type of model, characteristics etc.)

  - shipowner database

Conclusions on optimum Design Selection

- A total number of six RoPax ship model variants were investigated in order to determine the best variant with respect to multiple objectives (lowering of ship height, minimization of total mass, cost and position of vertical centre of gravity, safety criteria).
- Comparison between all six models (initial and proposed) with the following conclusions:

  - It can be seen that total mass of every model is successfully decreased for approximately 200 to 300 t (depending on a model).

  - Also, cost and VCG are successfully decreased.

  - Regarding safety, it is increased due to smaller number of unsatisfied constraints and greater relative adequacy index.

  - Height of chosen model is increased for 300 mm due to damage stability criteria (freeboard height mainly depends on cargo space breadth).

Improve

IMPROVE — *ULJANIK Shipyard*

ROPAX KPI overview

	Key Performance Indicators (KPI)	YARD PROTOTYPE SHIP LEVEL 1	PROTOTYPE CONCEPT + OWNER'S REQUIREMENTS LEVEL 2a	IMPROVE PROJECT SHIP-OWNER AND YARD EXPECTATIONS			GAIN (%) LEVEL 3 vs. LEVEL 2bII
				INITIAL DESIGN GAINS LEVEL 2bI	INITIAL DESIGN GAINS LEVEL 2bII	TOTAL EXPECTED GAINS LEVEL 3	
1.0	SHIP FUNCTIONS						
1.1							
	Lightship mass [t]	12200	12700	12700	12700	12200	4%
	Total lane metres	3000	3000	3000	3000	3000	0%
	Trailer lane meters on tank top [m]	180	200 (GAIN 11 %)	400 (GAIN 122 %)	400 (GAIN 122 %)	420 (GAIN 133 %)	5%
	Load flexibility	15 t/axle, 168 cab, 4500 mm	15 t/axle, 350 cab, 4700 mm	15 t/axle, 350 cab, 4700 mm	15 t/axle, 350 cab, 4700 mm	15 t/axle, 350 cab, 4700 mm	
	Volume of ballast tanks [m^3]	3700	3700	2800	2800	2800	
	Number of ballast tanks [#]	12	12	10	10	10	
1.2							
	Steel mass [t]	8100	8500	8500	8500	8100	-5%
	Fatigue life [years]						
	Use of MS (% of total mass)	70%	minimum 70 %	75%	75%	minimum 75%	
	Painted surface [m^2]	110000		130000	130000	128000	GAIN 2 %
	Longitudinal spacing [mm]	640		640/600	640/600		
1.3	STABILITY						
	Speed loss in waves [kn]						
	Number of deck wetness [#]						
	Number of propeller racings [#]	2 POD	2 POD	1 FPP + 1 POD	1 CPP + 2 RT	1 CPP + 2 RT	
	Turning ability index	As per IMO Req	As per IMO Req	As per IMO Req	As per IMO Req	As per IMO Req	

Improve

IMPROVE — *ULJANIK Shipyard*

ROPAX KPI overview

	Key Performance Indicators (KPI)	YARD PROTOTYPE SHIP LEVEL 1	PROTOTYPE CONCEPT + OWNER'S REQUIREMENTS LEVEL 2a	IMPROVE PROJECT SHIP-OWNER AND YARD EXPECTATIONS: INITIAL DESIGN GAINS LEVEL 2bI	INITIAL DESIGN GAINS LEVEL 2bII	TOTAL EXPECTED GAINS LEVEL 3	GAIN (%) LEVEL 3 vs. LEVEL 2bII
1.4							
	Power requirements [MW]	26900	24000 (GAIN 11 %)	19000 GAIN 29 %	20500 GAIN 24 %	19560 (GAIN 27 %)	GAIN -5%
	Trial speed [kn]	24.50 kn	24.50 kn	24.50 kn	24.50 kn	24.50 kn	
1.5							
	Machinery mass	1300 t		860 t (GAIN -34 %)	860 t (GAIN -34 %)	830 t (GAIN -36 %)	GAIN -4%
	Diesel engines cost	7,8 ME		6,7 ME (GAIN - 14 %)	6,7 ME (GAIN - 14 %)	6,5 ME (GAIN -17 %)	GAIN -3%
	Machinery reliability	64 cyl	48 cyl	(9+24) cyl	(12+24) cyl	(12+24) cyl	
1.6							
	Passenger's comfort level	Accom. Area 5700 m2	Accom. area 10200 m2	Accom. area 10200 m2	Accom. area 10200 m2	Accomodations area 10200 m2	
	Motion sickness incidences (MSI) [%]	MG=2,7 m	MG=2,1 m	MG=1,1 m		MG=1,1 m	
	Vibration levels	IMO req	Minimize	IMO req		Price difference for 10 % reduction	
	Noise levels	IMO req	Minimize	IMO req		Price difference for 10 % reduction	

IMPROVE ULJANIK Shipyard

	Key Performance Indicators (KPI)	YARD PROTOTYPE SHIP LEVEL 1	PROTOTYPE CONCEPT + OWNER'S REQUIREMENTS LEVEL 2a	IMPROVE PROJECT SHIP-OWNER AND YARD EXPECTATIONS: INITIAL DESIGN GAINS LEVEL 2bI	INITIAL DESIGN GAINS LEVEL 2bII	TOTAL EXPECTED GAINS LEVEL 3	GAIN (%) LEVEL 3 vs. LEVEL 2bII
2.0							
2.1							
	Lifecycle costs						
2.2							
	Acquisition costs						
2.3							
	FO consumption [FO cost per cargo unit] and [specific fuel consumption]	118+ 12 =130 t/24h	105+12=117 t/24h (GAIN 10 %)	82+12=94 t/24h (GAIN 27 %)	90+12=102 t/24h (GAIN 22 %)	85+12=97 t/24h (GAIN 25 %)	GAIN -5 %
	Crew costs [€]						
	Turnaround time in port [hours						
	Port charges						
	Cost of maintenance [€]					5 - 10 %	
	Time out of service [hours]						
	Operation efficiency [€]					10% - 15%	
2.4							
	RFR [€/cargo unit]						
3.0							
	Subdivision index	0.72	Maximize	0.75	0.75	Price difference for A=0,76	
	Redundancy index	100%		100%	100%	100%	
	Structural safety index (system and component)			As per BV Rules	As per BV Rules	As per BV Rules	
	Evacuation ability index						
4.0							
	RFR robustness						
	Structural robustness						

IMPROVE ULJANIK Shipyard

IMPROVE

ULJANIK Shipyard

EURO - RO - PAX 3000

Thank You for Your Attention !

IMPROVE

ULJANIK Shipyard

University of Zagreb

Sixth Framework Programme

IMPROVE

RoPaX- Structural design aspects

V. Zanic, J. Andric, P. Prebeg, M. Stipcevic,
M. Grgic, S. Kitarović, N. Hadzic, K. Piric
UZ, University of Zagreb, FAMENA, Zagreb, Croatia

I. Chirica, S. Giuglea & V. Giuglea
Ship Design Group, Galati, Romania

O. Turan, & H. Khalid
NAME, Universities of Glasgow and Strathclyde, Glasgow, Scotland, United Kingdom

P. Rigo
ANAST, University of Liege, Liege, Belgium

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

MULTISTEP DESIGN PROCEDURE

Decision support problem - main steps:

- **(1) topology / geometry optimization (D7.1)**
- **(2) scantling / material optimization of the preferred variant (D7.2)**
- **(3) final scantling preliminary design phase optimization and evaluation based on full ship 3D FEM model.**

Improve

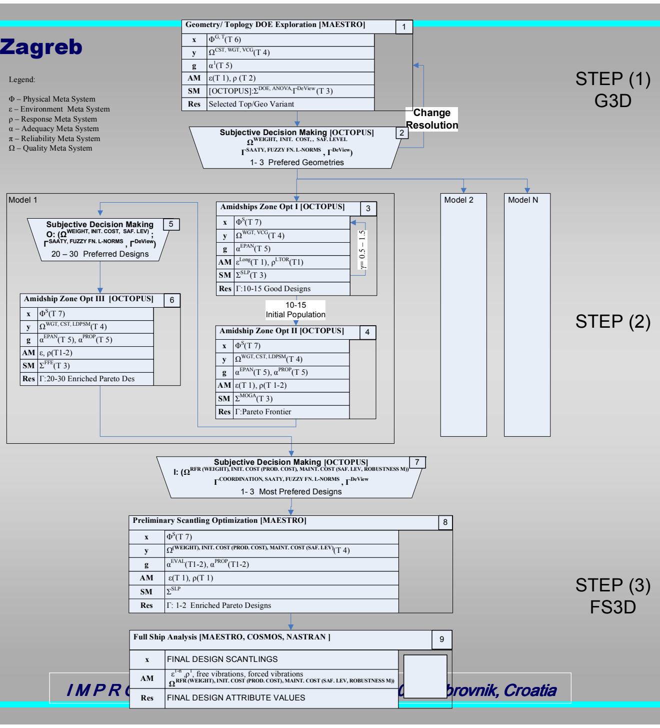
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Generic problem synthesis block	
variables (x)	Φ: x^G x^T d^S d^M [3D generic / 2.5D strip]
objectives (y)	Ω: min Ω1, Ω2, max Ω3- Ω9
constraints (g)	Layout/General arrangement (GA); α: [EPAN, LUSA/ EVAL]
AnMod	ε: [LS, racking]; ρ: [OCTOPUS/ MAESTRO]
SyMod	Σ: [SLP, ES (MCS, FFE (OA, ANOVA, ort. poly.), MOGA, MOPSO, ENUM)]
Result	Γ: [Pareto designs, preferred designs (fuzzy fn., L_p)]

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

STEP (1) Topology/geometry Optimization - Blocks 1- 2

Block 1: Geometry/Topology exploration. It is based upon the extruded generic 3D FEM MAESTRO models based on geometric/topological variables determined using DOE.

(**Block 2:** Subjective Selection of Designs with Preferred Geometry / Topology. It is based on designers preferences)

University of Zagreb

Variables (x^T, x^G)

Item	Subsystem	DESIGN VARIABLES PROPERTIES					
		Type	Name	Min	Max	Step	Comment
1	CS	G	Width_D1 to D3				One more car lane
2	CS	G	Height_D3				Damage stability calc.
4	Deck 4	G	Height of Deck 4 transverse beam				Influences height of deck 4
5	CS	T	Superstructure decks	e.g. 2	e.g. 3		Same operating area

Constr. ($g(x) > 0$) using Adeqacy Set (α)

Item	Limit state	Application	Description
1	BV_CB_CF	Corrugated plating	Buckling due to in-plane compression.
2	BV_PP_CB	Plane plating	Buckling due to compression and bending.
3	BV_PP_S		Buckling due to edge shear.
4	BV_PP_BACS		Buckling: bi-axial compression and shear.
5	BV_CP_C	Curved plating	Buckling due to compression.
6	BV_CP_S		Buckling due to edge shear.
7	BV_CP_CBS		Buckling: compression, bending and shear.
8	BV_OS_VBM	Ordinary stiffeners	Various buckling modes due to axial loading.
9	BV_OS_US		Ultimate strength
10	BV_PSM_VBM	Primary supp. members	Various buckling modes due to axial loading.

Improve
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

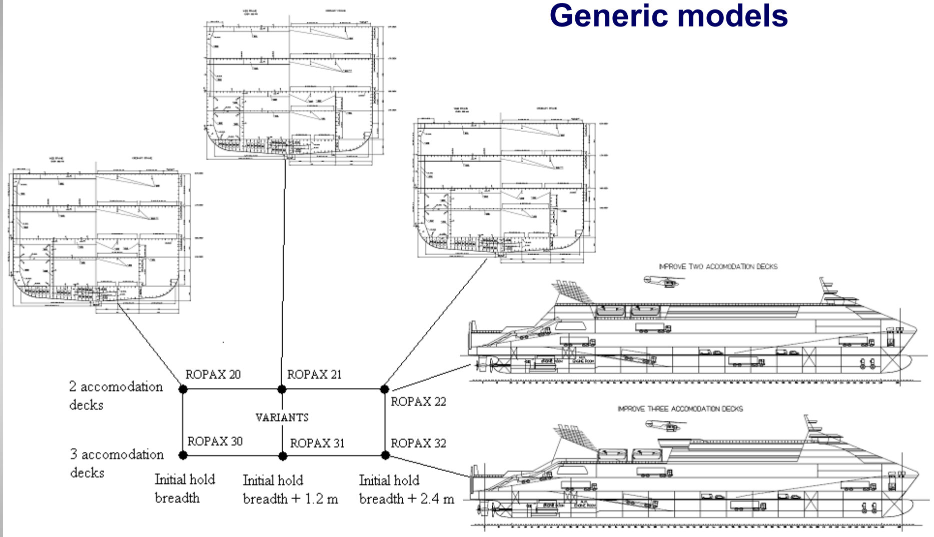
Objectives y_i (x) using quality atributes set (Ω)

Item	NAME	ACRONYM	ANALYSIS TOOL	APPLICABLE TO	Type
1	Production cost – simple calculation	CST-O	OCTOPUS	Ship zone	Min.
2	Structure weight	WGT-O	OCTOPUS	Ship zone	Min.
3	Local deterministic panel safety measure	LDPSM	OCTOPUS	One bay	Max.
4	Max. ult. bending moment in hogging	MUH-O	OCTOPUS		Max
5	Vertical position of center of gravity	VCG-O	OCTOPUS		Min
6	Production cost – simple calculation	CST-M	MAESTRO	Ship zone	Min.
7	Structure weight	WGT-M	MAESTRO	Ship zone	Min.
8	Vertical position of center of gravity	VCG-M	MAESTRO		Min
9	Fatigue life of structural details	FATLIFE	IMPROVE	Cross Section	Max
10	Preventive maintenance cost	PMC	IMPROVE	Cross Section	Max
11	Corrective maintenance cost	CMC	IMPROVE		Min
12	Production cost - advanced	ACST	IMPROVE		Min
13	Production cost - simulation	SIMCST	Plant Sim.		Min
14	Robustness of structural maintenance cost	RMC	IMPROVE		Min
15	Robustness of production cost of structure	RPC	IMPROVE		Min
16	Required Freight Rate	RFR	Head Designer		Max
17…	User defined utility functions of items 1-16	$U_1 \ldots U_n$	Head Designer		

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

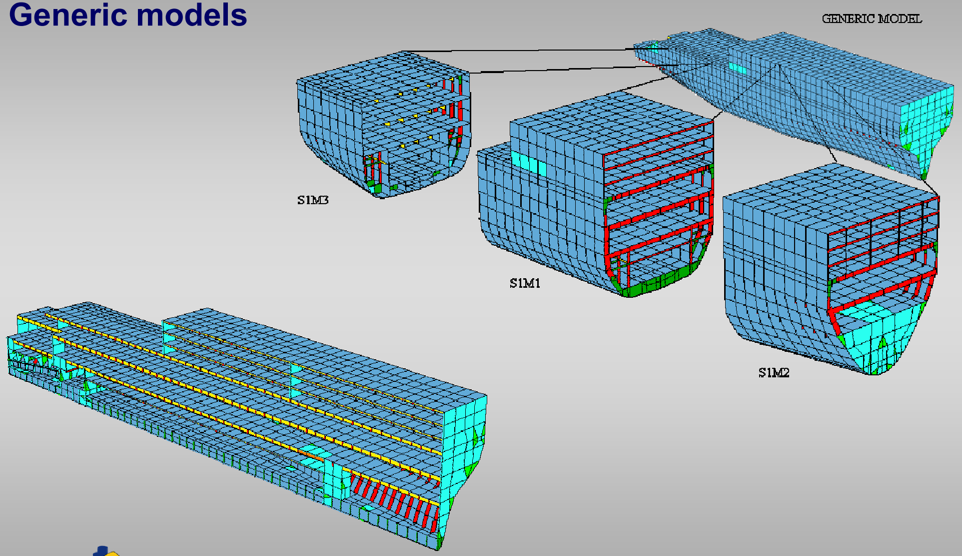
Generic models



I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Generic models



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Design variables for longitudinal structural elements for S1M1

Structure	Strakes		Plate thickness			BBS (NS)			Stiffeners HP			Longitudinal girder										
												HGW			TGW			BGF			TGF	
			P0	Min	Max	P0	Min	Max	P0	Min	Max	P0	Min	Max	P0	Min	Max	P0	Min	Max	P0	Min
"Keel"	8	119	15.5	14.0	18.0	640	600	900	HP300x11	240x10	300x14											
"Bottom Inner"	9-11	120-122	13.0	10.5	15.0		600	900	HP300x11	240x10	300x14											
"Bottom Outer + Bilge"	13,14,37	124,125,135	13.0	11.0	15.0	650	600	900	HP280x11	220x10	280x13											
"Inner Bottom Girder Down"	22	128	14.0	10.0	18.0	500	600	900	FB 150 X 10	100 X 6	200 X 15											
"Inner Bottom Girder Upp"	21	127	14.0	8.5	18.0	493	400	700	HP280x11	220x10	280x13											
"Inner Bottom LBHD"	16	126	11.0	10.0	15.0	670	600	900	HP140x7	220x10	300x14											
"HFO tank top"	25, 26	129,130	13.0	11.0	18.0	640	600	900	HP320x12	240x10	320x14											
"Deck 1 Inner"	31, 32	131,132	11.0	9.5	18.0	640	600	900	HP260x10	240x11	260x13											
"Deck 1 Outer"	33, 34	133,134	13.0	11.0	18.0		600	900	HP280x11	260x12	280x13											
"Side 1"	38, 48	136,141	12.0	10.0	16.0	Multi spac.	600	900	HP260x10	200x9	260x13											
"LBHD D1-D2"	41, 42	137,138	13.0	11.5	17.0	Multi spac.	600	900	HP280x11	200x9	280x13											
"LBHD D2-D3"	50	142	11.0	9.0	15.0	650	600	900	HP260x10	160x7	260x13											
"Deck 2"	45, 46	139,140	6.0	4.5	10.0	640	600	900	HP100x7	100x6	100x8	380	100	400	6	5	10	150	50	250	10	5
"Deck 3 Inner + Outer"	55,56,57,58	143,144,145, 146	13 (11.0)	10.0	15.0	640	600	900	HP240x10	220x12	240x12	970	600	1200	10	5	15	150	50	600	30	5
"Side 2 + Side 3"	61,62	147,148	11.0	7.5	17.0	Multi spac.	400	700	HP140x8	120x6	160x8											
"Side 4"	74	153	9 AH	7.0	12.0	700	400	700	HP140x7 AH	80x5	140x9											
"Shear Strake"	75, 76	154,155	9 AH	FIX		Multi spac.	400	700	HP140x7 AH	FIX												
"Deck 4 Inner + Outer"	67,68,69,70	149,150,151, 152	9.5 AH	8.5	12.0	Multi spac.	400	700	HP260x10	240x12	260x13	1070	300	1100	10	5	12	150	25	200	30	5
"Deck 6 Inner + Outer"	82,83, 117,118	156,157,175, 176	7.0	5.0	12.0	Multi spac.	400	700	HP140x8	120X7	140x9	880	500	1200	10	5	12	180	25	250	12	5
"Superstructure"	93,94,99, 100,105-108,113-116	163-174	6.0	5.0	12.0	Multi spac.	600	900	HP120x6	60x5	140x9	460.0	200.0	400.0	7.0	5.0	10.0	100.0	25.0	150.0	10.0	5.0

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

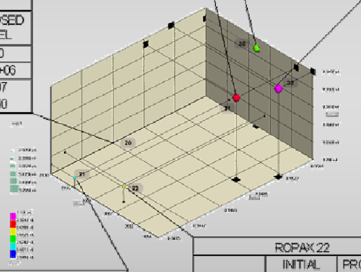
Assessment of the optimal design variants presented in DeView

ROPAX 31	INITIAL MODEL	PROPOSED MODEL
MASS, t	3296.7	3038
COST, $	4.02E+06	3.71E+06
VCG, mm	13759	13405
H, mm		32400

ROPAX 30	INITIAL MODEL	PROPOSED MODEL
MASS, t	3282.9	2990.6
COST, $	4.01E+06	3.65E+06
VCG, mm	13695	13376
H, mm		32250

ROPAX 20	INITIAL MODEL	PROPOSED MODEL
MASS, t	3265	2930
COST, $	3.98E+06	3.57E+06
VCG, mm	13231	12797
H,mm		29250

ROPAX 32	INITIAL MODEL	PROPOSED MODEL
MASS, t	3239	3057.6
COST, $	3.95E+06	3.73E+06
VCG, mm	13622	13450
H, mm		32550



ROPAX 22	INITIAL MODEL	PROPOSED MODEL
MASS, t	3313	3000
COST, $	4.04E+06	3.66E+06
VCG, mm	13378	12906
H,mm		29550

ROPAX 21	INITIAL MODEL	PROPOSED MODEL
MASS, t	3263	2958
COST, $	3.98E+06	3.61E+06
VCG, mm	13268	12870
H, mm		29400

Improve

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Inter-attribute preferences (ULJ)

Inter Attribute Preferences (Saaty Method)

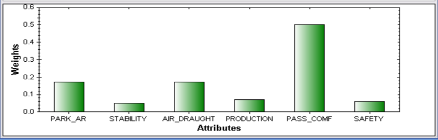
Preference Matrix

Attribute	PARK_AR	STABILITY	AIR_DRAUGHT	PRODUCTIO	PASS_COM	SAFETY
PARK_AR	1	3	1	3	0.33333334	3
STABILITY	0.333333343	1	0.333333343	0.333333343	0.11111111	1
AIR_DRAUGHT	1	3	1	3	0.33333334	3
PRODUCTION	0.333333343	3	0.333333343	1	0.11111111	1
PASS_COMF	3	9	3	9	1	9
SAFETY	0.333333343	1	0.333333343	1	0.11111111	1

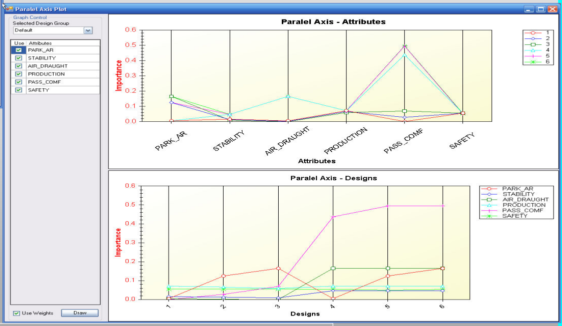
Attribute Weights

Automatic Update | Update | OK | Cancel

PARK_AR	STABILITY	AIR_DRAUGHT	PRODUCTION	PASS_COMF	SAFETY
0.17	0.05	0.17	0.07	0.5	0.06

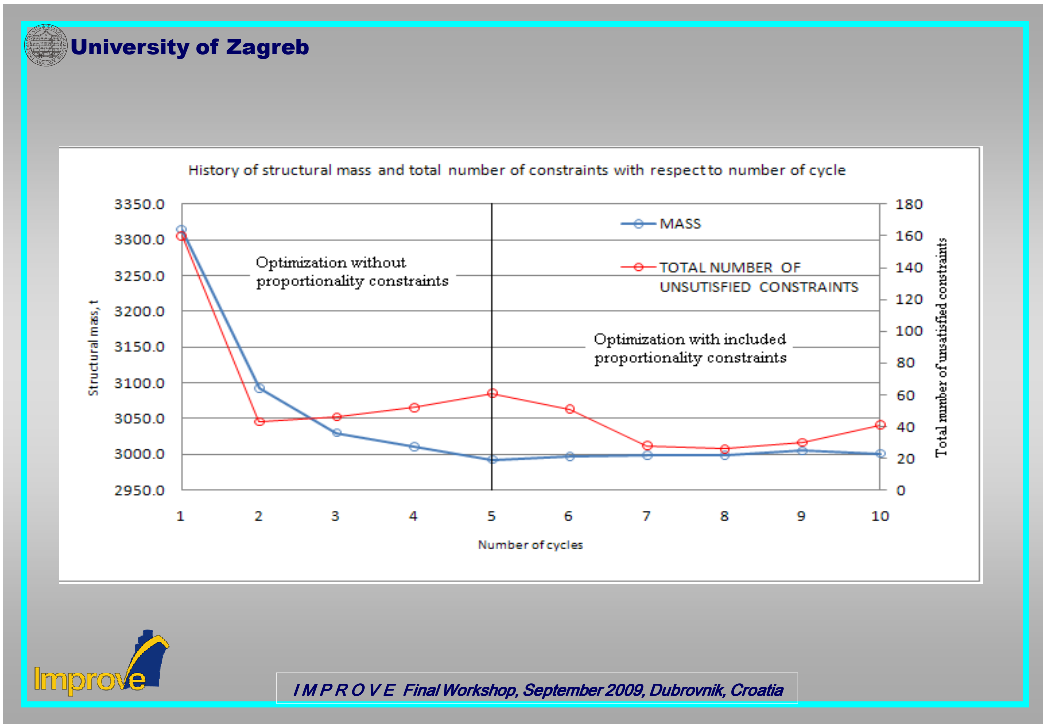


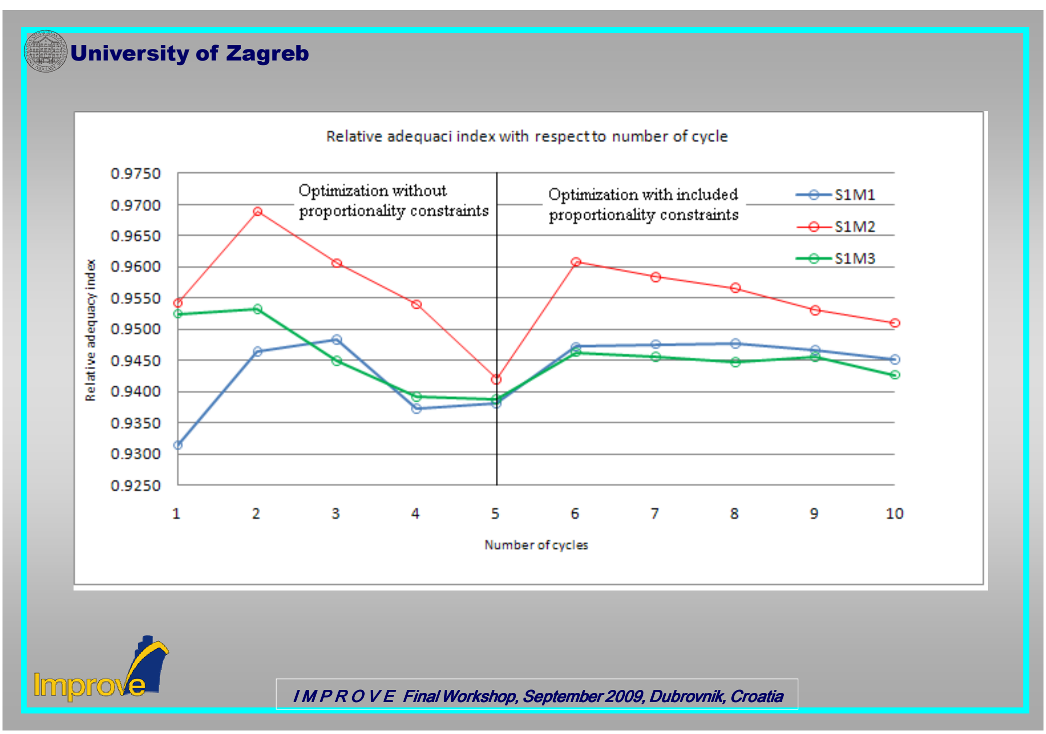
Parallel axis diagram for DM

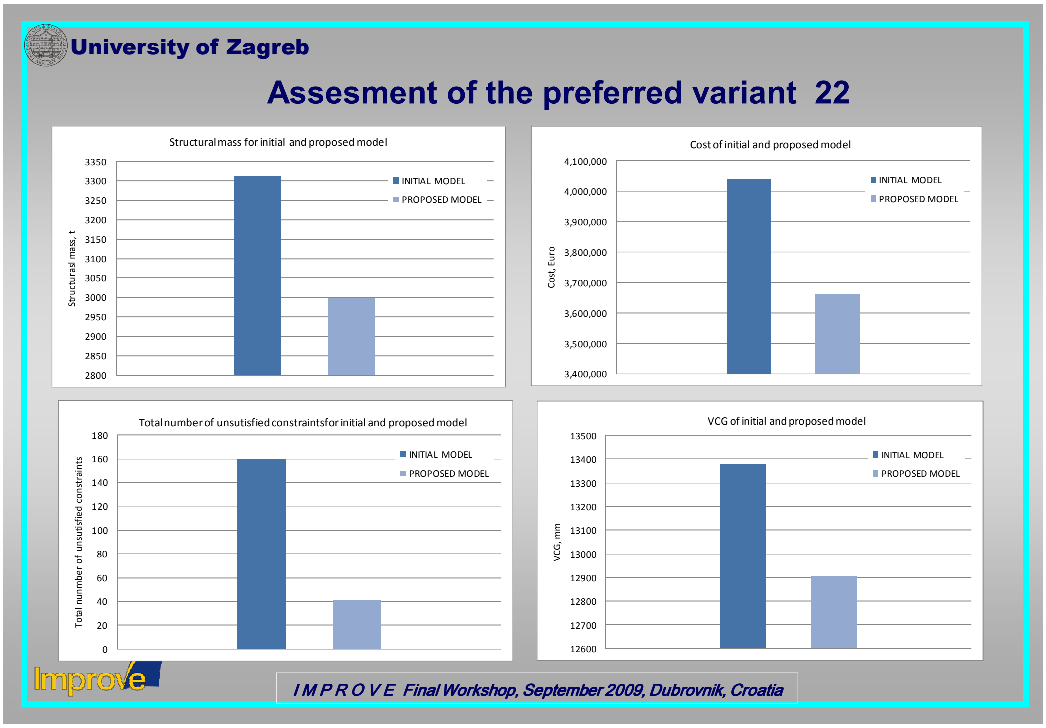


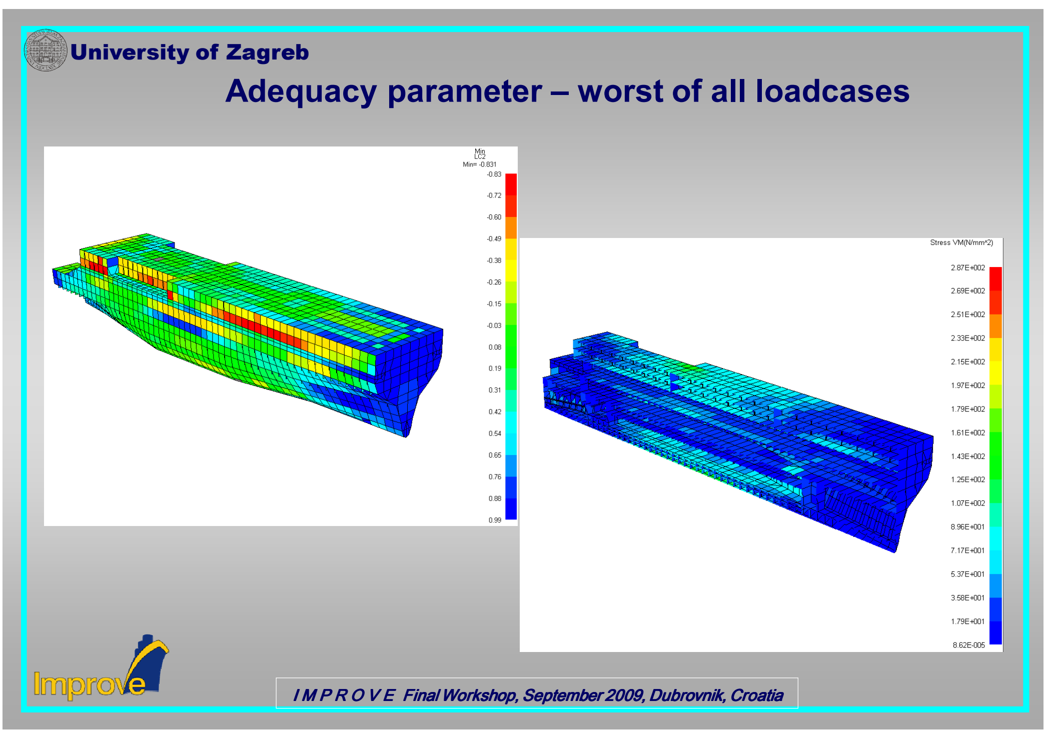
Improve

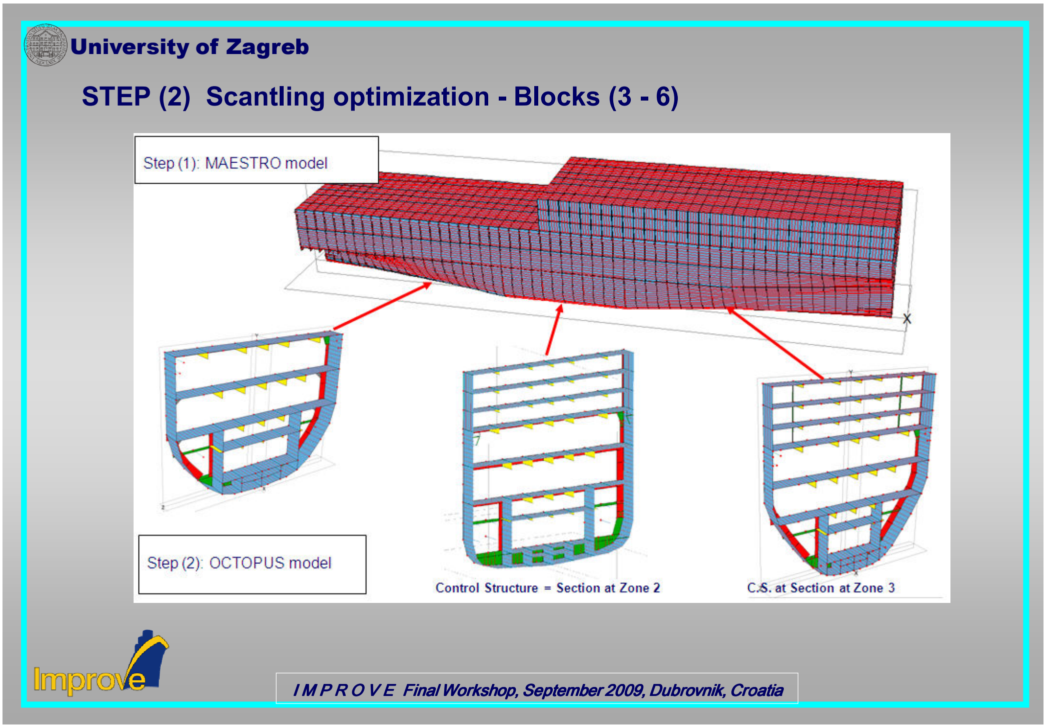
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

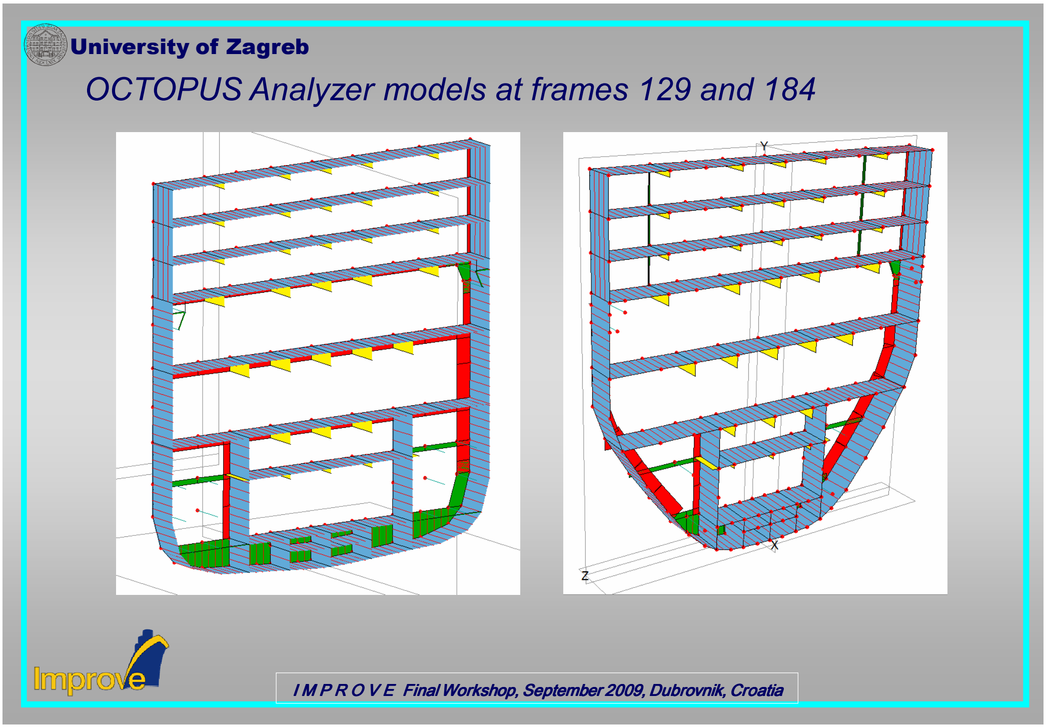

University of Zagreb
History of structural mass and total number of constraints with respect to number of cycle
Structural mass, t
Total number of unsatisfied constraints
MASS
TOTAL NUMBER OF UNSUTISFIED CONSTRAINTS
Optimization without proportionality constraints
Optimization with included proportionality constraints
3350.0
3300.0
3250.0
3200.0
3150.0
3100.0
3050.0
3000.0
2950.0
180
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10
Number of cycles
Improve
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

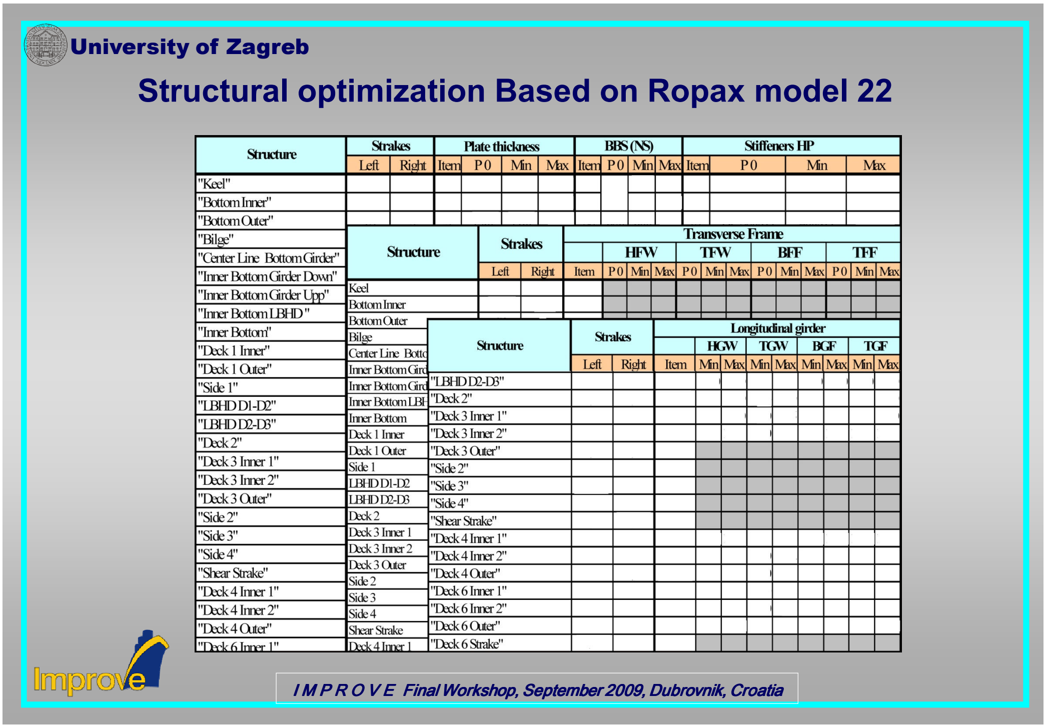

University of Zagreb
Relative adequaci index with respect to number of cycle
Relative adequacy index
Optimization without proportionality constraints
Optimization with included proportionality constraints
S1M1
S1M2
S1M3
0.9750
0.9700
0.9650
0.9600
0.9550
0.9500
0.9450
0.9400
0.9350
0.9300
0.9250
1 2 3 4 5 6 7 8 9 10
Number of cycles
Improve
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

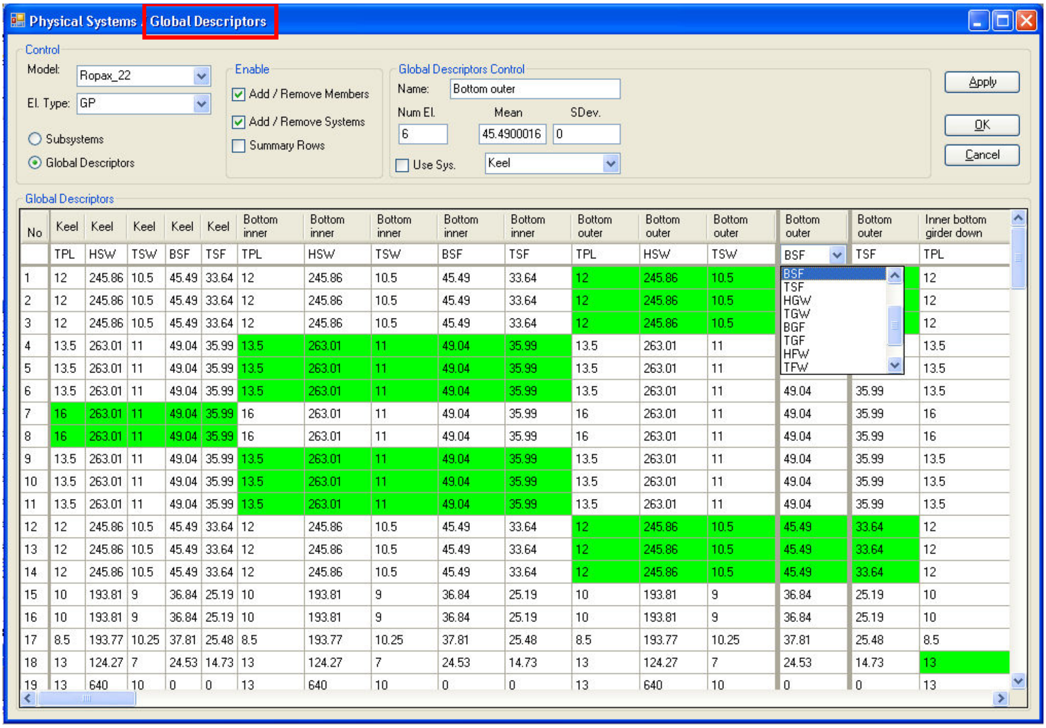

University of Zagreb
Assesment of the preferred variant 22
Structural mass for initial and proposed model
Structurasl mass, t
INITIAL MODEL
PROPOSED MODEL
Cost of initial and proposed model
Cost, Euro
Total number of unsutisfied constraintsfor initial and proposed model
Total nunmber of unsutisfied constraints
VCG of initial and proposed model
VCG, mm
Improve
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia


University of Zagreb
Adequacy parameter – worst of all loadcases
Stress VM(N/mm^2)
Improve
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

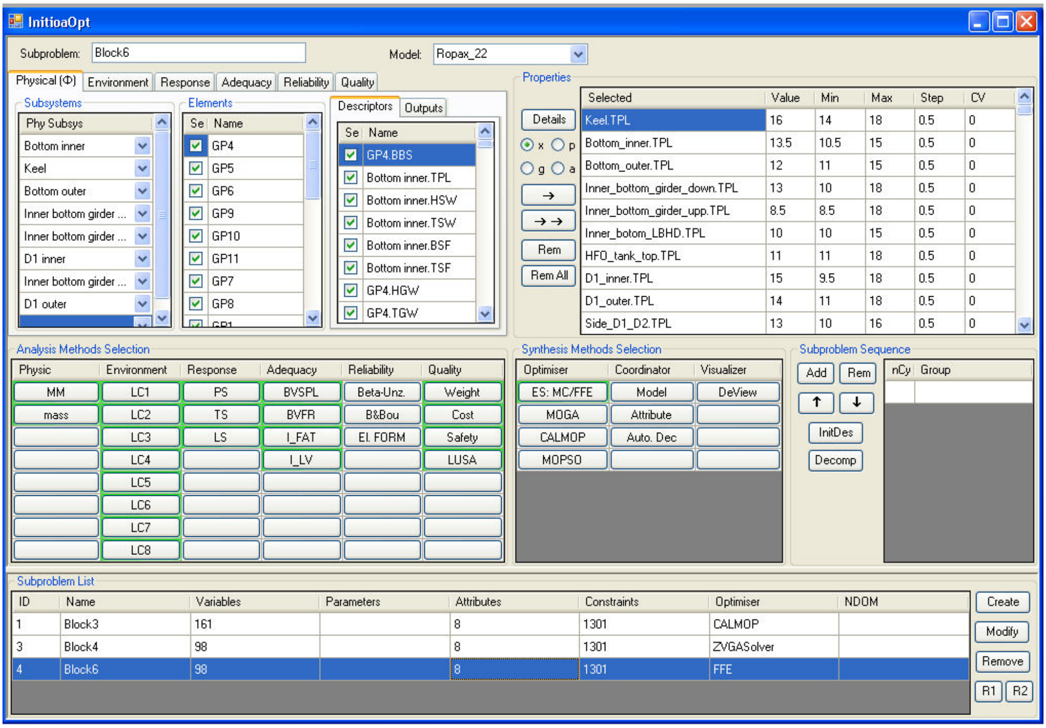

University of Zagreb
STEP (2) Scantling optimization - Blocks (3 - 6)
Step (1): MAESTRO model
Step (2): OCTOPUS model
Control Structure = Section at Zone 2
C.S. at Section at Zone 3
Improve
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

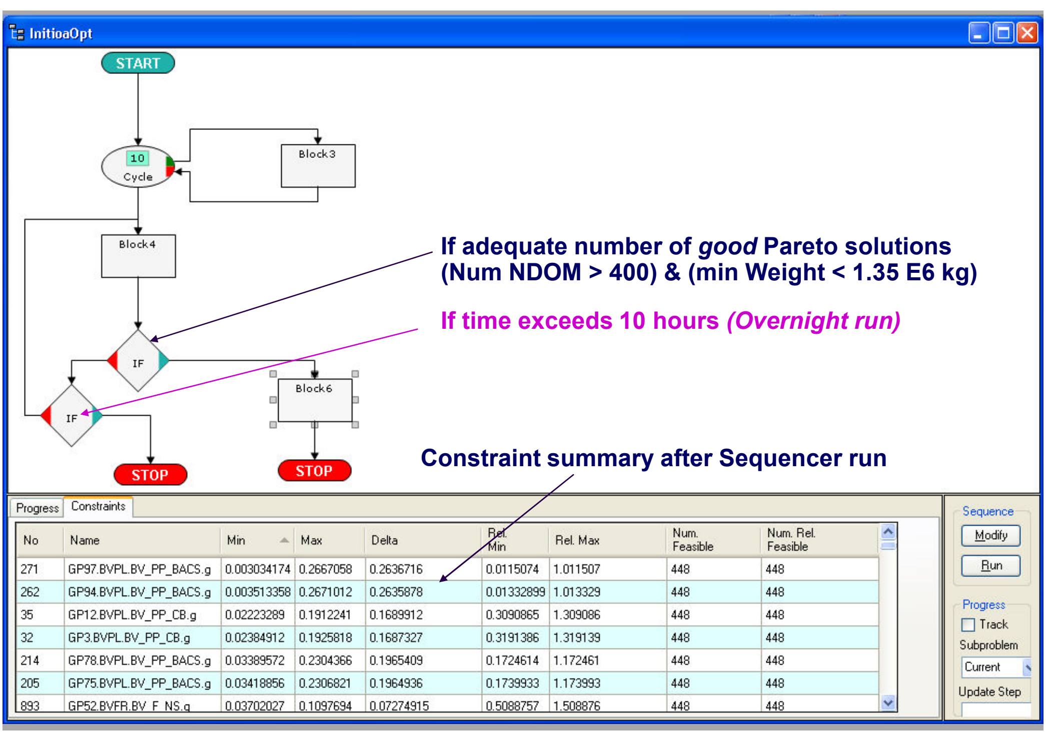

University of Zagreb
OCTOPUS Analyzer models at frames 129 and 184
Improve
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia





No	Keel	Keel	Keel	Keel	Keel	Bottom inner	Bottom inner	Bottom inner	Bottom inner	Bottom inner	Bottom outer	Bottom outer	Bottom outer	Bottom outer	Bottom outer	Inner bottom girder down
	TPL	HSW	TSW	BSF	TSF	TPL	HSW	TSW	BSF	TSF	TPL	HSW	TSW	BSF	TSF	TPL
1	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12	245.86	10.5			12
2	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12	245.86	10.5			12
3	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12	245.86	10.5			12
4	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5	263.01	11			13.5
5	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5	263.01	11			13.5
6	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5
7	16	263.01	11	49.04	35.99	16	263.01	11	49.04	35.99	16	263.01	11	49.04	35.99	16
8	16	263.01	11	49.04	35.99	16	263.01	11	49.04	35.99	16	263.01	11	49.04	35.99	16
9	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5
10	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5
11	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5	263.01	11	49.04	35.99	13.5
12	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12
13	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12
14	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12	245.86	10.5	45.49	33.64	12
15	10	193.81	9	36.84	25.19	10	193.81	9	36.84	25.19	10	193.81	9	36.84	25.19	10
16	10	193.81	9	36.84	25.19	10	193.81	9	36.84	25.19	10	193.81	9	36.84	25.19	10
17	8.5	193.77	10.25	37.81	25.48	8.5	193.77	10.25	37.81	25.48	8.5	193.77	10.25	37.81	25.48	8.5
18	13	124.27	7	24.53	14.73	13	124.27	7	24.53	14.73	13	124.27	7	24.53	14.73	13
19	13	640	10	0	0	13	640	10	0	0	13	640	10	0	0	13


InitioaOpt
Subproblem: Block6
Model: Ropax_22
Physical (Φ)
Environment
Response
Adequacy
Reliability
Quality
Subsystems
Elements
Descriptors
Outputs
Properties
Selected
Value
Min
Max
Step
CV
Keel.TPL 16 14 18 0.5 0
Bottom_inner.TPL 13.5 10.5 15 0.5 0
Bottom_outer.TPL 12 11 15 0.5 0
Inner_bottom_girder_down.TPL 13 10 18 0.5 0
Inner_bottom_girder_upp.TPL 8.5 8.5 18 0.5 0
Inner_botom_LBHD.TPL 10 10 15 0.5 0
HFO_tank_top.TPL 11 11 18 0.5 0
D1_inner.TPL 15 9.5 18 0.5 0
D1_outer.TPL 14 11 18 0.5 0
Side_D1_D2.TPL 13 10 16 0.5 0
Analysis Methods Selection
Synthesis Methods Selection
Subproblem Sequence
Optimiser
Coordinator
Visualizer
ES: MC/FFE
MOGA
CALMOP
MOPSO
Model
Attribute
Auto. Dec
DeView
Subproblem List
ID Name Variables Parameters Attributes Constraints Optimiser NDOM
1 Block3 161 8 1301 CALMOP
3 Block4 98 8 1301 ZVGASolver
4 Block6 98 8 1301 FFE
Create
Modify
Remove


InitioaOpt
START
Cycle
Block3
Block4
IF
IF
Block6
STOP
STOP
If adequate number of *good* Pareto solutions
(Num NDOM > 400) & (min Weight < 1.35 E6 kg)
If time exceeds 10 hours *(Overnight run)*
Constraint summary after Sequencer run
Progress
Constraints
No Name Min Max Delta Rel. Min Rel. Max Num. Feasible Num. Rel. Feasible
271 GP97.BVPL.BV_PP_BACS.g 0.003034174 0.2667058 0.2636716 0.0115074 1.011507 448 448
262 GP94.BVPL.BV_PP_BACS.g 0.003513358 0.2671012 0.2635878 0.01332899 1.013329 448 448
35 GP12.BVPL.BV_PP_CB.g 0.02223289 0.1912241 0.1689912 0.3090865 1.309086 448 448
32 GP3.BVPL.BV_PP_CB.g 0.02384912 0.1925818 0.1687327 0.3191386 1.319139 448 448
214 GP78.BVPL.BV_PP_BACS.g 0.03389572 0.2304366 0.1965409 0.1724614 1.172461 448 448
205 GP75.BVPL.BV_PP_BACS.g 0.03418856 0.2306821 0.1964936 0.1739933 1.173993 448 448
893 GP52.BVFR.BV_F_NS.g 0.03702027 0.1097694 0.07274915 0.5088757 1.508876 448 448
Sequence
Modify
Run
Progress
Track
Subproblem
Current
Update Step

University of Zagreb

Block 3: Fast MODM exploration of the design space

This block has generated 10 designs for each OCTOPUS Analyzer model, with proper distribution of material in the longitudinal structure, using SLP optimizer (CALMOP). Those designs were used as an initial designs for the next block

Note: 10 solutions are generated by changing load safety factors in each of the 10 cycles

Improve

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Block 4: Extensive scantling optimization with reduced analysis block using initial designs generated in block 3.

Notes:

Design Variables includes Complex Design variables (HP profiles)
(Num DV 161→98 + only standard HP profile used)

Constraints: BV Adequacy Criteria, Local Vibration of accommodation decks, Fatigue check of critical details, Maximal Weight

Objectives: Minimize Weight, Minimize Production Cost, Maximize Local Safety measure

Improve

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Permited HP profiles in Bottom Inner Group (Complex variable *HPBotIn*)

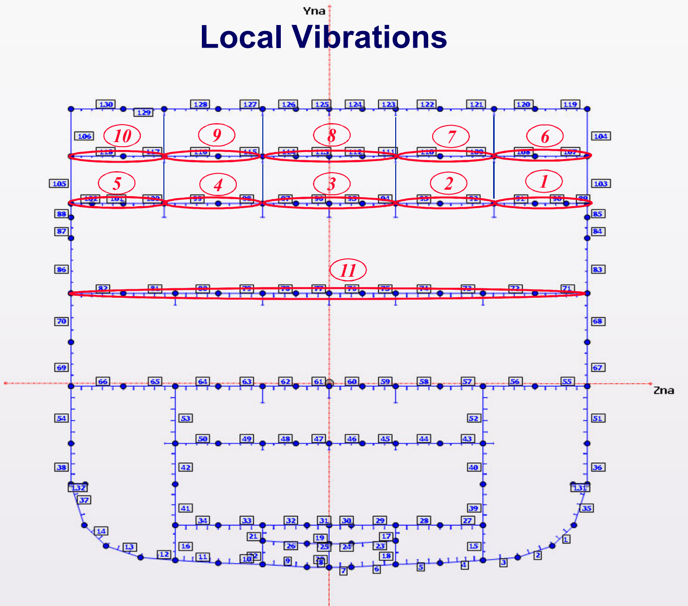
HP -No	Rbr	Name	HW	TW	BF	TF
31	1	HP240x10	212.44	9.00	39.68	26.56
32	2	HP240x11	210.76	10.00	40.07	28.24
33	3	HP240x12	210.76	11.00	41.05	28.24
34	4	HP260x11	227.48	10.00	42.51	31.52
35	5	HP260x12	228.13	11.00	43.70	30.87
36	6	HP260x13	227.35	12.00	43.93	31.65
37	7	HP280x11	245.86	10.00	45.49	33.14
38	8	HP280x12	245.27	11.00	46.27	33.73
39	9	HP280x13	244.79	12.00	47.08	34.21
40	10	HP300x11	261.86	10.00	47.71	37.14
41	11	HP300x12	263.01	11.00	49.04	35.99
42	12	HP300x13	262.56	12.00	49.86	36.44
43	13	HP300x14	261.69	13.00	50.02	37.31

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Local Vibrations



Note:

Group 11 Not used in Block 4 Due to high computing Cost

Improve

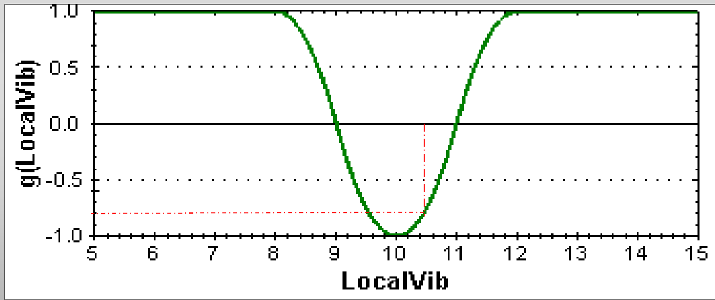
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Example - Vibration Group 2

Excitation Freq: 10 Hz   *Natural Freq: 10.31Hz*

g (VibGroup2, x) = -0.79

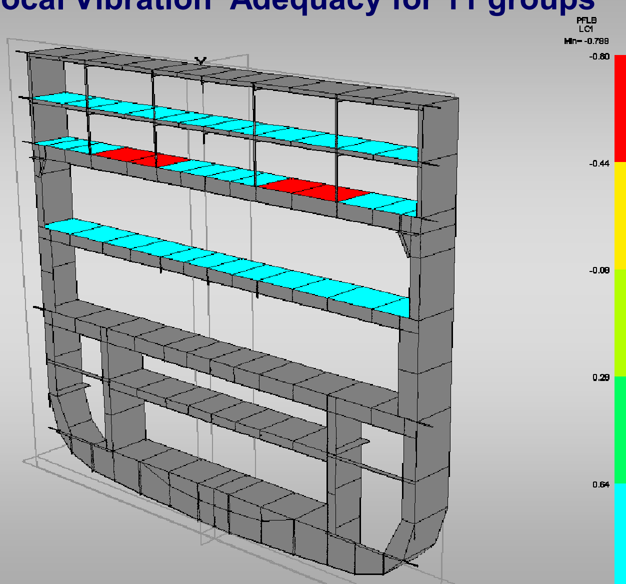


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Local Vibration Adequacy for 11 groups



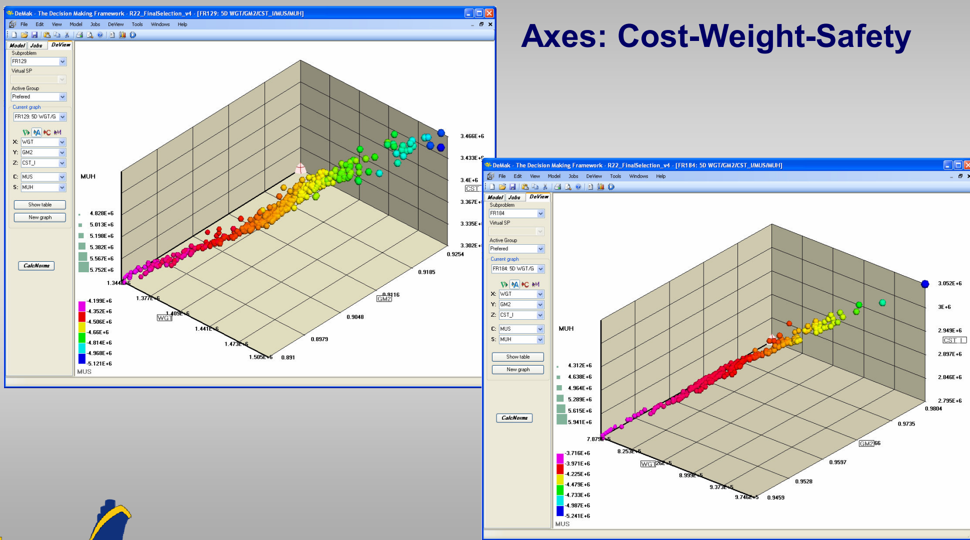
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Block 4- Obtained Pareto Frontier for model at Frams 129 -184

Axes: Cost-Weight-Safety



I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Block 5: Subjective selection of certain number of Pareto designs based on multi-stakeholder preferences using Saaty's inter-attribute preferences and fuzzy membership grade functions for intra-attribute preferences. Distance L_p-norms are used for selection of 20-30 preferred designs.

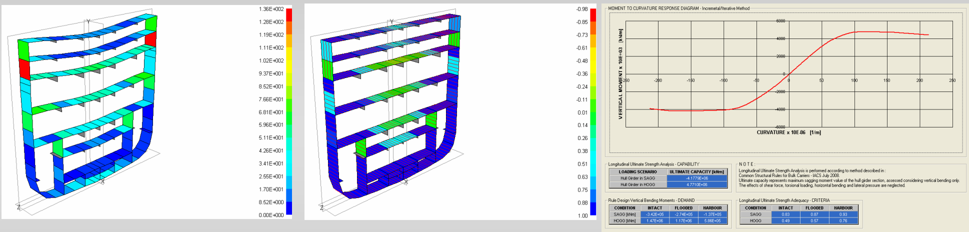
This block was actually omitted because the increased speed of LUSA module (from ~2 min to ~5 sec), have enabled ultimate strength calculation for all obtained Pareto Solutions

Block 6: Additional calculation of **complex design attributes** (Ultimate strength) - Complete analysis of the Pareto designs generated in block 4.

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Results of structural calculations performed on selected design using OCTOPUS Analyzer



(a) Fr. 129: Von-Mises Stress(b) Fr. 129: Adequacy BV-BACS criteria (c) Fr. 129 Ultimate Hull Bending Moment

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

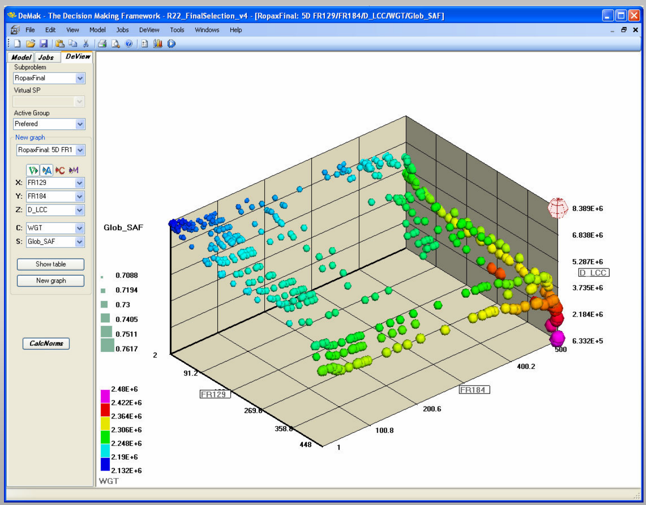
Block 7: Final selection of preferred designs.

- The main goal of this block was selection of a preferred design.
- Create ship designs based on the results from the models at Frame 129 and 184.
- Resultant Pareto frontier is obtained by generating all possible combinations of Pareto results from two models

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Cartesian product of Pareto designs from models 129 and 184 (After Pareto filtering)



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Design attributes for the final selection

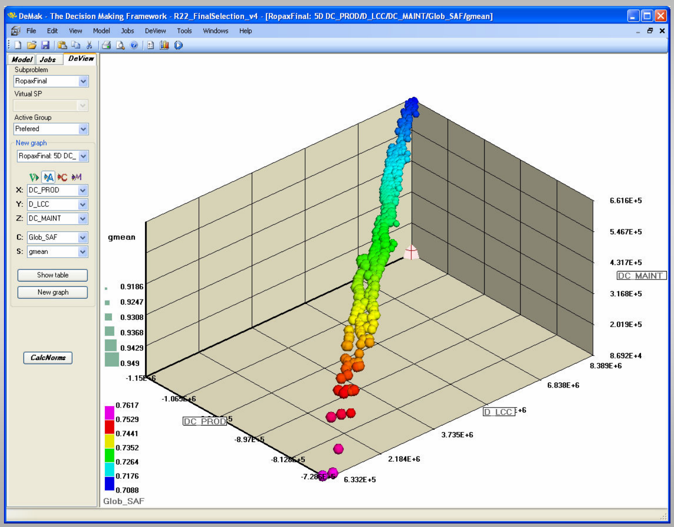
No	Acronym	Description
1	D_LWT	Delta Lightship weight
2	DC_PROD	Delta production cost
3	DC_MAINT	Delta Maintenance cost
4	DC_FUEL	Delta fuel cost
5	D_EARN	Delta earning
6	DP_DISM	Delta dismantling
7	D_LCC	Delta Life cycle cost
8	gmean	Local safety measure
9	SAF	Global (US) safety measure

Note:
D_LCC = D_EARN + DP_DISM- DC_FUEL- DC_MAINT-DC_PROD

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Resultant Pareto frontier (DC_PROD, D_LCC , D_MAINT

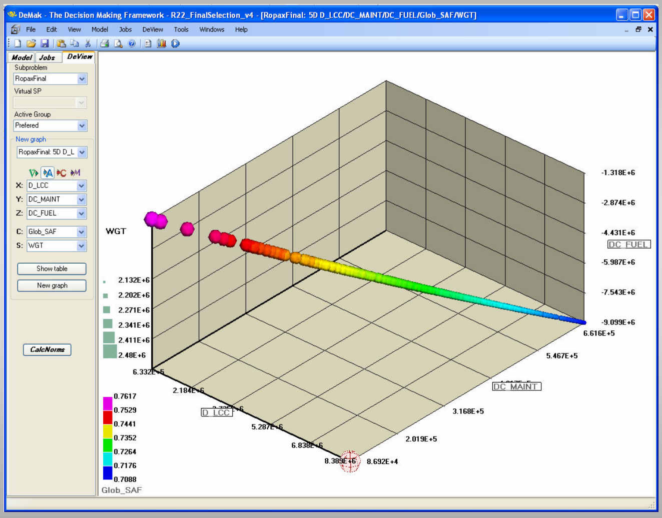


Improve

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Resultant Pareto frontier (D_LCC, DC_MAINT, DC_FUEL)



Improve

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Weight and Production cost Reference Values

Design\Module	S1M1	S1M2	S1M3	S1M4	LWT
Reference Weight	1515000	988000	810000	961000	12800000
Optimal Generic Weight	1407000	879000	714000	961000	12487000
Number of Bays	14	10	8	12	
Module Length	39.2	28	22.4	33.6	
Reference Cost	2398309	1556679	1282264	1514138	
Optimal Generic Cost	2227340	1384940	1130292	1514138	

Design\Octopus	FR_129 Long	FR_129_Trans	FR_183 Long	FR_184_Trans
Optimal Generic	96459.7	8831.643	94462.65	7429.2
K_Octopus		13.447		8.700

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Characteristics of the selected design according to LCC module (with respect to reference RoPax 22 Yard Design variant)

No	Acronym	Value	%
1	D_LWT	**-504** t	**-3.9 (gain)**
2	DC_PROD	**- 1.144·10^6 €**	**-16.9**
3	DC_MAINT	0.666·10^6 €	17.6
4	DC_FUEL	**-9.086·10^6 €**	**-4.0**
5	DP_DISM	-0.2286·10^6€	-4.0
6	D_LCC	**8.376·10^6 €**	**3.4 (gain)**

* minus sign denotes reduction of physical value,
** **bolded** values denote aspired changes

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

STEP (3) : Problem Solution - RoPax Preliminary Design Phase

Preliminary design phase includes:

Block 8 - Final structural optimization based upon refined loads model and full ship 3D FEM model obtained by merging and refining ship generic model and bay models with optimal scantlings.

Block 9 - Final Analysis of the selected preferred design (from Block 8) including forced vibration analysis, building cost simulation, LCC analysis, final check of panel safety measures, ultimate strength and fatigue life of critical details.

Improve

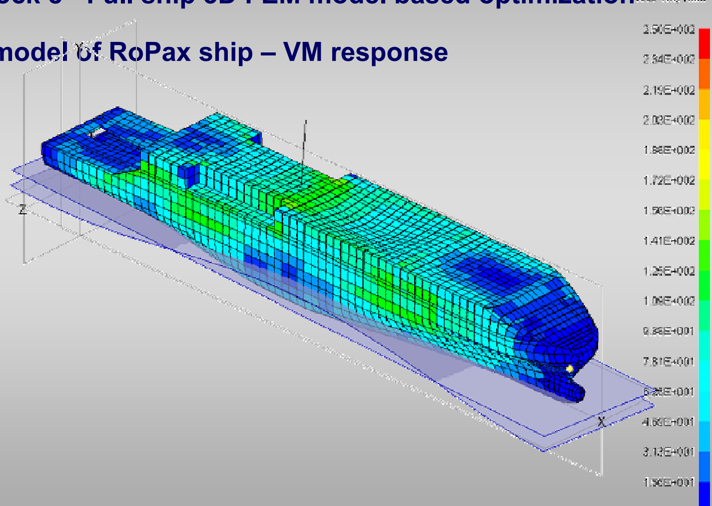
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

STEP (3) Preliminary design phase

Design Block 8 - Full ship 3D FEM model based optimization

Full-ship model of RoPax ship – VM response



Improve

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

STEP (3) Preliminary design phase

Block 9: Full ship MAESTRO + OCTOPUS **analysis of the final design.**

Key Performance Indicators of the final design are determined.

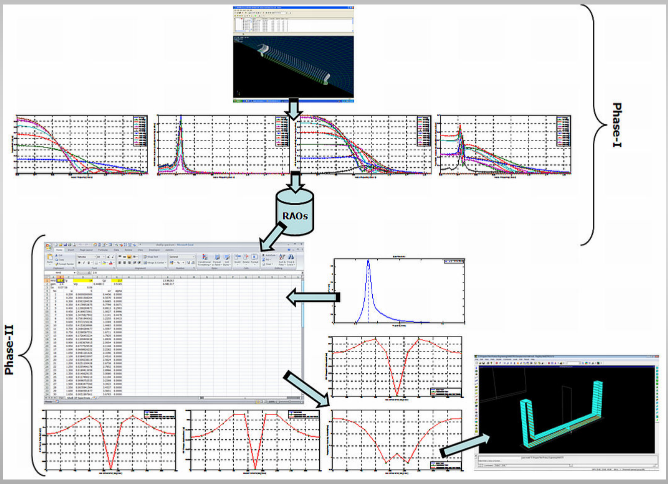
Additional analysis steps are performed (vibration, etc.)

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

Wave induced hydrodynamic load calculation by NAME

Schematic diagram of WILC



I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

GLOBAL VIBRATIONS OF THE ROPAX **(by SDG)**

Noise and vibration problems tend to become an important part of the ship design optimization process. Vibrations often affect the passengers comfort on board, and may damage the ship and its cargo. They are also important in the structural design for the following design trends:

- light-weight construction (with low stiffness and mass, ex. openwork structures);

- high propulsion power;

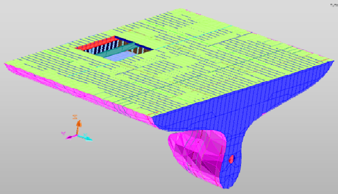
- arrangement of living space and working quarters near the propeller to optimize stowage space;

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

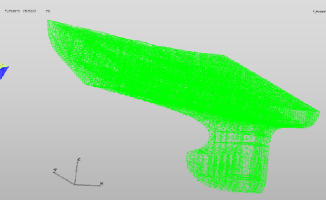
University of Zagreb

VIBRATION CALCULUS OF ROPAX AFT PART

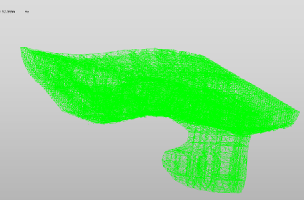
- ACAD drawings (Uljanik)→ the aft part ROPAX structure modeled
- The CAD model was imported in COSMOS. The model was clamped in fore part, in the section of the ER aft bulkhead.
- Details on weight distributions in the aft part are not known, only structure mass was consideres in the free vibration calculus. For the FEM model, shell3T elements from COSMOS/M were used.
- The first 150 natural vibration were determined.



Aft part – 3D CAD model



Mode 1 global bending vibration (10.03 Hz)



Mode 2 (52 Hz)

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

CONCLUSIONS:

- decision support problem for ROPAX ship was formulated
- sets of design variables constraints and objectives were identified
- relative quality measures were used during generation of the non-dominated Pareto frontier
- novel design procedure was developed including coordinated cascade of structural models (generic, one bay and full ship model)

1st DESIGN STEP-COMPARISON BETWEEN SIX GENERIC MODELS:

- total mass of every model is successfully decreased for approximately 200 to 300 t (depending on a model).
- cost and VCG are successfully decreased.
- safety is increased due to smaller number of unsatisfied constraints and greater relative adequacy index.
- height of all model was increased for 300 mm due to greater height of frame web of decks 2 and 3.

Improve

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

2nd and 3rd DESIGN STEP:

After ULJANIK head designer detailed interactive analysis of the resultant Pareto frontier, in OCTOPUS Designer DeView the following conclusions have been made based on the IMPROVE LCC module:

- The designs with low weight had simultaneously the low production cost and fuel cost while the maintenance cost is high

- Influence of the maintenance cost on the total life cycle cost is significantly smaller then influence of a fuel cost

- The preferred designs for both the shipyard and the ship-owner were actually the same: designs with the low weight offered smallest Production Cost (important for shipyard) and highest Profit (important for ship-owner).

Improve

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

University of Zagreb

CONCLUSIONS

- Relative quality measures (enabling correct ordering of design variants) were used as objectives in building of the preference structure needed in generation of the non-dominated Pareto frontier.

- Interactivity in *DeView* module was instrumental for comfortable work with Yard head designer.

- The OCTOPUS / MAESTRO decision support system included specially developed, fast and balanced collection of analysis and synthesis modules/methods. Part of those modules was only developed under this EU FP6 IMPROVE project, using full synergy of the consortium.

I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

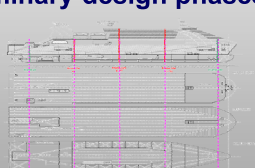
University of Zagreb

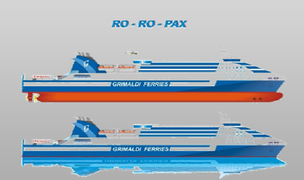
CONCLUSIONS

- Novel design procedure used for multi-deck ships like RoPax, with complex distribution of primary stresses, included coordinated cascade of structural models: (1) tapered generic ship models, (2) fast one bay ‘control structures’, and (3) their synthesis in full ship model.

- Problem sequencer and OCTOPUS / MAESTRO modeling environment enabled seamless transfer between models and efficient design work.

- The design environment for new Euro-ships deigns is believed to be a flexible and robust tool of fidelity required in the concept and preliminary design phases.

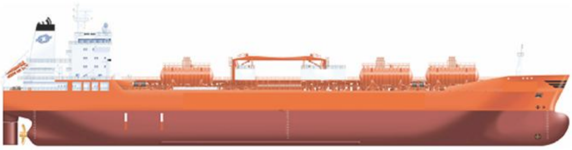




I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia


University of Zagreb
Improve
EURO FERRIES
THANK YOU!
Improve
I M P R O V E Final Workshop, September 2009, Dubrovnik, Croatia

Product Presentation: Chemical Tanker (WP8)



IMPROVE

The IMPROVEd chemical tanker

S. Ehlers, A. Klanac, H. Remes
Helsinki University of Technology, Finland
K. Kapuścik
Szczecin New Shipyard, Poland
H. Naar
MEC, Estonia
J. Andric, V. Zanic, M. Grgic
University of Zagreb, Zagreb, Croatia
E. Pircalabu
Design Naval & Transport, Belgium
F. Bair
University of Liège, Liège, Belgium
I.Lazakis, O. Turan
Universities of Glasgow & Strathclyde, Glasgow, United Kingdom

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Contents

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Owner's main design requirements

- General design objectives:
  - Maximize cargo volume per ship dimensions by reducing the void spaces, by using sandwich spaces instead of voids where possible and by reducing the internal subdivisions (non-cargo tanks) in number and in volume;
  - Increase carrying capacity by reducing the steel mass;
  - Minimize the cost of the main engine and machinery;
  - Improve the vessels' operational performance and efficiency;
  - Maximize the operational flexibility (no. of different types of cargo that can be carried simultaneously, no. of allowed loading conditions, efficient loading/discharging/stowage of cargo etc.);
- Structural Design Objectives:
  - Minimize the use of DUPLEX steel;
  - Decrease the cost of structural steel (including optimization of the geometry of corrugations);
  - Maximize structural safety by maximizing both global and local safety measures;
  - Minimize probability of the foreseeable structural failures by means of inspection focusing and repair prioritization; Maximize the fatigue life (FL > 45 years should be ensured);
- Operation, Maintenance and Repair Objectives:
  - Minimize maintenance and other operational costs by minimizing the need for tank inspection, by minimizing painted surface, especially in the ballast tanks and by maximizing the maintainability of the ship structure;
  - Maximize the reliability of the ship's machinery;

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

	Key Performance Indicators (KPI)	STAKEHOLDERS		YARD PROTOTYPE SHIP LEVEL 1	PROTOTYPE CONCEPT + OWNER'S REQUIREMENTS LEVEL 2a *(GAIN : LEVEL 2a vs. LEVEL 1)*	ASSOCIATED DESIGN VARIABLES	OBJECTIVES	IMPROVE PROJECT SHIP OWNER AND YARD EXPECTATIONS		GAIN (%) *LEVEL 3 vs. LEVEL 2a or LEVEL 3 vs. LEVEL 2b *)*
		Shipyard SSN	Owner TPZ					INITIAL DESIGN LEVEL 2b *(GAIN : LEVEL 2b vs. LEVEL 1)*	LEVEL 3 *(GAIN : LEVEL 3 vs. LEVEL 1)*	
1.0	SHIP FUNCTIONS -PERFORMANCES OTHER THEN COST & SAFETY									
1.1	MASSES, SPACES, CAPACITIES									
	Hull structure mass [t]	HI		10500		hull structure total	Minimize			3%
	Volume of ballast tanks [m^3]	MID	MID	16080		GA	Minimize	16080	16080	
	Number of ballast tanks [#]	MID	MID	21		GA	Minimize	17 (19 %)	17 (19 %)	
1.2	STRUCTURE									
	DUPLEX steel mass [t]	HI		2900		scantlings, structural layout	Minimize			3 – 5 %
	Fatigue life [years]	MID	HI	45	45	detail design		45	45	
	Use of MS (% of black steel mass)	HI	HI	34%		Material type	Maximize	60%		26%
	Painted surface [m^2]	HI	HI			structural layout, scantlings	Minimize			1.5%
	Longitudinal spacing [mm]	HI		various	various	structural layout	optimized	optimized		

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The interviews

- Two interviews with each stakeholder (owner and yard)
  - Semi-structured interviews
- First interviews were performed to confirm the indicated design drivers, the KPIs and also get a better insight into what is expected from the improvements in hull structure through optimization.
- Second set of interviews followed after structural optimization was made, and after several alternatives were identified as the potential good compromises for both stakeholders.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The interviews (2)

- 1st interviews

1. What is your role in the Shipyard? Could you please explain your duties and professional experiences?
2. What is a 'good' ship for you?
3. Observing the General Arrangement of the tanker, how would you describe it in short?
4. What would you indicate as its advantages and what as deficiencies?
5. In previous activities you have indicated certain priorities which are indicated here in the APPENDIX. Do you consider that this design will fulfill these priorities? Please explain.
6. Have the main objectives and KPIs changed for you?
7. What technical details do you see relevant for fulfilling the objective of design? Which features in your opinion could be improved through optimization study?
8. If I were to ask you to rank several design alternatives of this ship, do you think you would be able to do this? On what information or features would you base your ranking?
9. In your daily work how much are your decisions based on formalized information, and how much are they based on experience, hear say, experience of others, brainstorming and meetings?
10. Would you say that in your work (ship design) you make consistent decisions? If yes, please explain. If not, what contributes to the inconsistencies?

- 2nd interviews

1. How fatigue, costs, and weight are preferred?
   a) Is a unit of equivalent change dependent on the magnitude of the attribute
   b) Are they equally preferred even though the values of other attributes differ
   c) Is a unit of equivalent change dependent on the value of other attributes
2. Both owner and yard engage in value exchange, meaning that costs induced by the desire to increase benefits will be shared.
   a) We employ for this reason two realistic compensation factors p12 and p21 where first is the added ship price for the owner for the increased fatigue life, and it is based on the increased production costs for the yard.
   b) The second factor, p21, is the penalty for the lost deadweight caused by the weight increase.
3. The amount the owner is willing to pay to increase the fatigue life of this ship by 1year.
   a) Let us consider three values for the moment: 0, 100k€ and 1M€.
   b) Find the actual value

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The findings – 1st interviews

- Owner does not take part in the conceptual structural design of the vessel, but is interested in her characteristics. Specifically, that the vessel in operation is safe, that there are no cracks in the structure and that there is no need for repainting.
- Other characteristics related to safety, e.g. ultimate strength is of no relevance to the owner, but it is covered with the previous statement that the vessel should be safe.
- The lightship mass of the vessel is also of no particular concern for the owner since vessels are usually purchased as existing projects which guarantees their capacity, or deadweight.
- Due to the requirements for cargo capacity and safety (chemicals), yard is specially interested in controlling the mass of the hull and in its fatigue characteristics to maintain a higher reliability of ship structure.
- Fatigue is typically controlled trough design of structural details since loss of cargo capacity is not preferred
- Loosing 1000t of capacity for a vessel is huge!
- In case that owner is interested in increased vessel's structural safety, this is reflected in the ship price. The ship price is not standard but is based on the calculations founded on observed vessel design

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The findings – 2nd interviews

- Owner expresses no interest to increase the fatigue life beyond required minimum, set by class, since it becomes difficult to find cargo for the vessel older than 15 years.
- On the other hand, it makes sense to increase the reliability of the vessel, but the vessel's capacity should not be sacrificed, and it should not cost any significant amount. The re-design should concentrate on the structural details, and on painting.
- The yard mentions, from the experience of dealings with chemical tanker owners, that the fatigue life of this chemical tanker should be 30 years (40 years is too long, and 25 too short). There is a special class for a 30-year fatigue life vessel.
- Chemical tanker owners are in principle not selling for the reasons to avoid creation of competition. Thus they maintain and use their vessels until the scraping
- Yard estimates the upper value of investment into one year of fatigue life to be 100 000 EURO.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Conclusion on stakeholder preferences

- Some interesting (unexpected) results
  - The aspect of fatigue life increase
- Chemical tanker is designed in the 'small' market, meaning that there are no firm market prices established for the vessel type, and also that there are no direct competitors involved in the process of negotiation
- All positive (increased lifetime of the vessel) and/or negative (loss of capacity) aspects of increasing the fatigue life are summed up through the following three scenarios:
  - High returns are expected from the increase in fatigue life. One year of fatigue life is valued at 1M€.
  - Low returns are expected from the increase in fatigue life. One year of fatigue life is valued at 100k€.
  - Fatigue is not to be increased. Value of one year of additional fatigue life equals 0€.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

- This section presents
  - expertise of the Szczecin Shipyard (SSN) with respect to chemical and product tankers
  - choices of improvements and their evaluations
  - The purpose of the improved design is to lower the amount of duplex steel due to its significant influence on the total cost

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

- ┼40 000 DWT CHEMICAL TANKER
  - B588-iii tzpe ND
- During 2003 - 2007 eight (8) fully Duplex stainless steel chemical tankers were delivered by SSN for Norwegian owner Odfjell ASA, the one of the biggest chemical tanker operators.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

- The main data of these vessels are as follows:
- Length o.a. - 182.88 m,
- Length b.p. - 175.25 m,
- Breadth - 32.20 m,
- Depth - 17.95 m,
- Draught - 11.50 m,
- Deadweight - 40 000 DWT,
- Cargo tanks capacity - 52 126 m3,
- Number of cargo tanks - 34 + 6 /deck tanks/,
- Service speed - 15.5 kn,
- Class - DNV.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

- These vessels are the biggest in the world fully Duplex stainless steel tankers with all cargo tanks / center, wing and deck tanks / made of solid Duplex stainless steel
- The vessels have been designed for the niche between product and chemical tankers and as compared to standard chemical tanker have cargo tanks capacity bigger by about 15%
- This allows operating the vessels in CPP market utilizing the full deadweight
- From the operation point of view the vessels are very flexible thanks to cofferdam bulkheads between center and wing tanks, arrangement of center tanks and deck tanks

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

- As consequence of such design, building costs for such vessels are very high, mainly due to:
  - high lightship weight of the vessels,
  - amount of Duplex steel equal to 3 000 t per vessel,
- amount of cargo tanks and associated piping systems
- In 2007, with very high material cost, building cost of such vessel was on the level 140 mil. USD, that was far above market expectation

Improve

Basic design (SSN)

- Because the chemical tankers are considered as one of SSN's specialization, Shipyard decided to redesign the B588-III vessel to get the building cost which could be accepted by the market.
- Alternative 1
  - main dimensions as in original design B588-III,
  - wing cargo tanks made of mild steel instead of Duplex steel,
  - reduction of number of center cargo tanks from eighteen to twelve,
  - reduction of service speed to 15.0 kn,
  - deleting of shaft generator.

Improve

Basic design (SSN)

- Alternative 2
  - reduction of cargo tanks capacity to abt. 45 000 m3,
  - deleting of cofferdam bulkheads and replacing them by vertically corrugated bulkheads,
  - reduction of depth of the vessel to 15.0 m,
  - using of Duplex steel for center tanks only,
  - deleting of six deck tanks,
  - reduction of service speed to 15.0 kn,
  - deleting of shaft generator.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

- Alternative 3
  - As Alternative 2 except the arrangement of Duplex tanks which are arranged in the middle part of the vessel / wing and center tanks /.
- Calculation of building cost done for 2007 condition shows that the most effective cost reduction is Alternative 3, and Shipyard decided to develop this design and optimize it using the IMPROVE tools

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

- The IMPROVE design is based on the following assumptions:
  - specific gravity of sulfuric acid varies between abt.1.55 - 1.85 t/m3,
  - capacity of Duplex stainless steel tanks should allow to carry acid with 50% of consumables, utilizing full deadweight of the vessel,
  - total number of Duplex stainless steel tanks to be eighteen with different capacities
  - Duplex stainless steel cargo tanks to be separated from the mild steel cargo tanks by cofferdams,
  - longitudinal bulkheads to be vertically corrugated,
  - transverse bulkheads to be vertically or horizontally corrugated
    - Connection between longitudinal vertically corrugated bulkheads and transverse horizontally corrugated bulkheads to be subject of FEM analyses
  - propulsion system consists of slow speed ME driving directly FP propeller,
  - service speed to be 15.0 kn.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

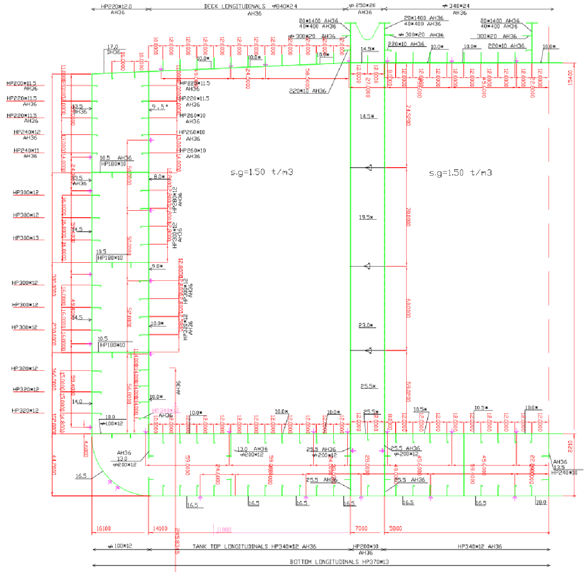
- Calculation of cargo tanks capacity and arrangements for three different specific gravities of acid 1.50, 1.65, and 1.85 t/m3 has been performed
  - For further optimization, cargo tanks arrangement for specific gravity 1.50 t/m3 was taken. The main target for optimization was reducing of quantity of Duplex steel due to a very high price of this material.

- The following structures are subject to optimization:
  - scantling as shown on drawing Midship Section,
  - transverse bulkheads, horizontally corrugated,
  - longitudinal bulkheads, vertically corrugated.

Improve

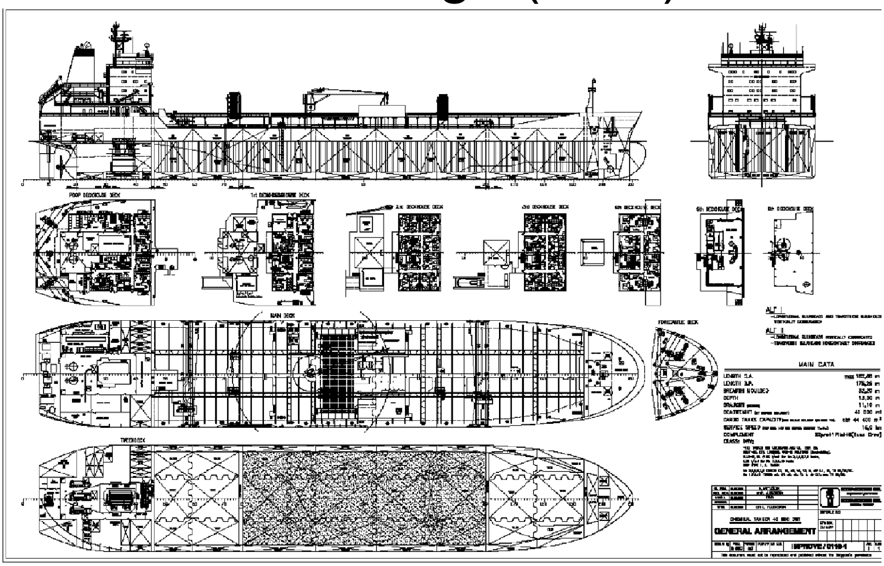
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Basic design (SSN)

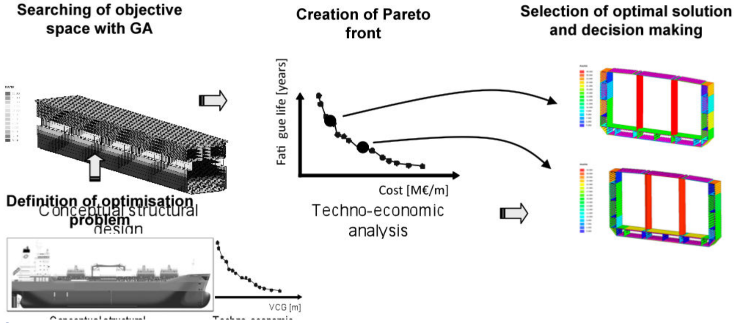
- The Propulsion system
  - single diesel main engine, low speed, two stroke type,
  - driving directly FP propeller.
  - Main engine type 6S50 - ME -B9 is chosen for this project.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)

- cost, weight and fatigue life was included as objectives into structural optimization
- The knowledge of the relationship between these different objectives was required to obtain reliable techno-economical evaluation of tanker structures



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)

- The relationship between the objectives was determinate using optimization method and “multiple run” approach. In this approach, several optimisation models with fixed and specified weight factors for objectives were run, and as results the Pareto surface was created including all potential candidates for optimum design alternative

Model	Cost	Weigth	Fatigue
1 Tanker_II_C	1	0	0
1 Tanker_II_W	0	1	0
1 Tanker_II_CW	1	1	0
1 Tanker_II_CWF	1	1	1
1 Tanker_II_CF	1	0	1
1 Tanker_II_WF	0	1	1

Structural optimization (ConStruct)

- The constraints of the optimization were strength criteria and production requirements according to shipyard specification
  – Production requirements were considered as minimum and maximum values of the design variable ranges
- The tanker structure included totally 22 different stiffened panels, which each have three design variables:
  – plate thickness of a panel
  – number of stiffeners of panels
  – stiffener type
  – In the case of corrugated panel, panel 23, the stiffener was not applied, but shape and height (H) of corrugations was varied.

Structural optimization (ConStruct)

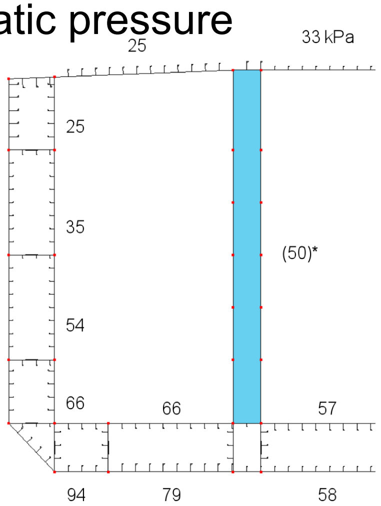
- The loading included the vertical bending moment as a global load and dynamic pressure loads as a local load. These loads are specified according to the Shipyard load manual and classification rules (DNV Classification notes No.30.7.)
- For quasi-static strength evaluation the vertical bending moments were
  - M_hog = - 2 410 000 kNm
  - M_sag = + 2 933 000 kNm
- and for fatigue loading
  - M_hog = +1 593 000 kNm
  - M_sag = - 1 708 600 kNm
- The fatigue loading corresponded to probability level 10^{-8}, and Weibull shape parameter equal to 1.034 was applied describing the long-term stress distribution during ship life.
- The pressure includes the loads due to wave-induced external pressure and the deck load due to ship motions.
- The pressure loads were modeled as uniform pressure acting at each stiffened panel
- Quasi-static and dynamic pressure loads were applied strength and fatigue analysis

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)

- Quasi-Static pressure

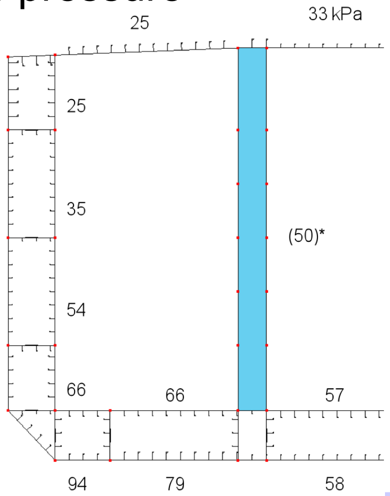


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)

- Dynamic pressure



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)

- Optimization of longitudinal structure
  - The response is divided into two parts:
    - global and local analysis
    - global analysis was carried out ConStruct tool using CB-method (Naar et al., 2004)
      - This analysis determines the boundary forces of stiffened panel, which were used in the local analysis.
    - The local analysis was carried out using the fast analytical approaches (Mantere, 2007) and IMPROVE Fatigue module, see Deliverable T3.3.
      - The analysis covered yielding and buckling of the plate and stiffener as well as fatigue strength

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)

- The IMPROVE Fatigue module is based on linear damage rule, long-term stress distribution defined by a Weibull distribution, and notch stress method
- Fatigue strength is described by one-slope S-N curve.
- The selection to design S-N curve is based on IIW recommendation (Hobbacher 2007)
- An additional safety factor equal to 1.6 is included.
- Thus, the parameters of S-N curve are
  - C = 5.75E+12 and m = 3, which equal to the classification guidelines with allowed value for accumulated damage ratio equal to D = 1 (DNV 2005).

Improve

Structural optimization (ConStruct)

1. The global response of the hull girder is evaluated based on wave loading and still water bending within existing design tools
2. The local nominal stress is evaluated in fatigue-critical locations
3. The notch stress is obtained based on the hot-spot and notch stress factors

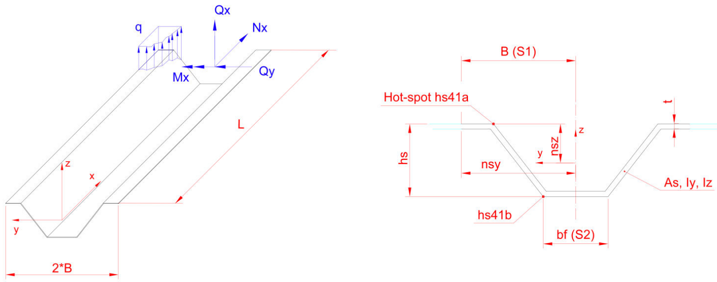
The second and third level of the response analysis in carried out within the fatigue module using fast analytical formulae based on plate or beam theory

Improve

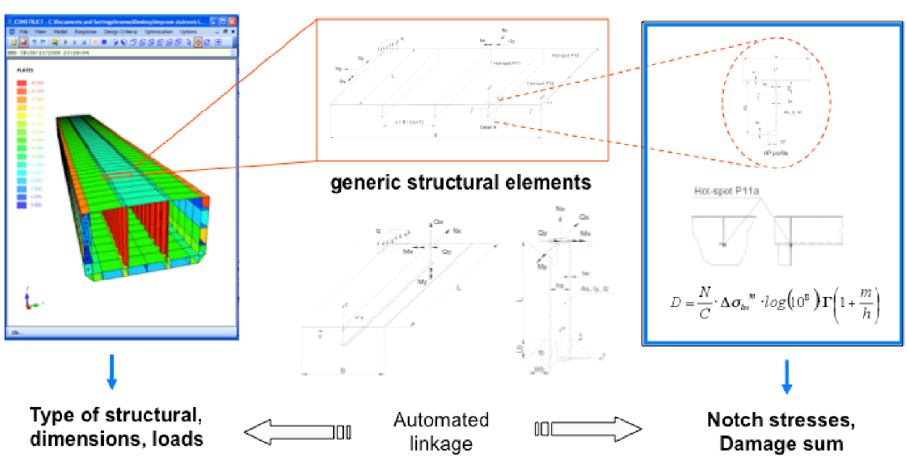
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)

- Data transforming between the existing design tool and the Fatigue module is done using generic structural elements:
  - stiffened plate, girder and pillar
    - Plus an additional element of a corrugated bulkhead is used for the tanker structure



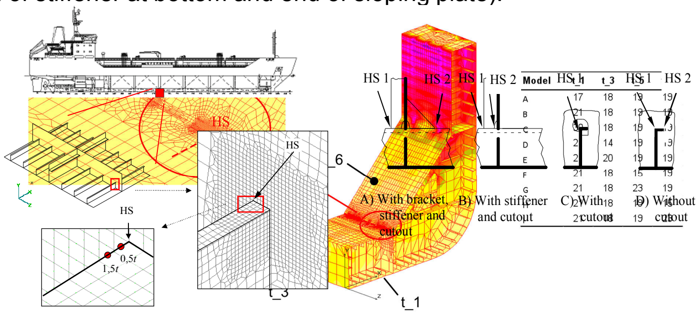
Structural optimization (ConStruct)



Structural optimization (ConStruct)

- Validation of the Fatigue module:
  - The preliminary validation of the Fatigue module is done in Task 3.3, and it indicates good accuracy in nominal stress level
  - Further validation of the Fatigue module is based on the stresses in hot-spot points of the selected fatigue critical structural details

    (end of stiffener at bottom and end of sloping plate):



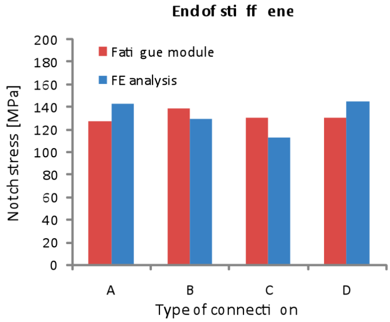
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

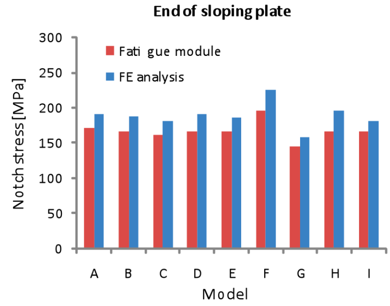
Validation of the Fatigue module

- The FE -analyses of the first validation case is carried out by TKK and the second case by SDG according to Hobbacher (2007)
- The both analysis applies parabolic shell elements, which size in the hot-spot area is half of the plate thickness t
- The hot-spot stress is multiplied by factor 1.5 to get notch stresses, which include the stress increase due to weld shape.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Validation of the Fatigue module





Difference= 10% and 15%

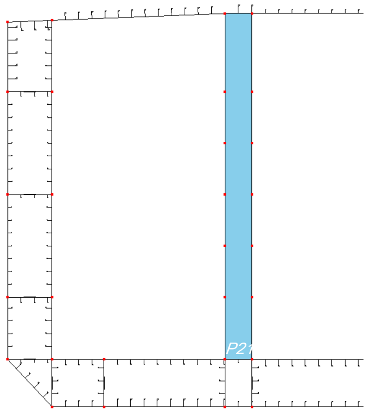
-10%

slight underestimation

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)



Objectives

- Min Weight (ton/m)
- Min Cost (ton/m)
- Min Fatigue Damage

Variables

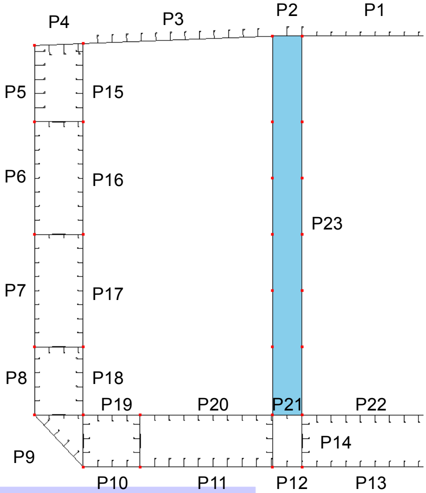
- Normal steel
  - Thickness t = 5...36
  - Spacing s= 450 - 800
  - Profile height 75 – 400
- Duplex steel
  - Thickness t = 6 – 32
  - Spacing s = 450 – 800
  - Profile height h = 75 - 400

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Range of variables

Panel	Mat	t	NoS	h
P1	Dublex	6-37	13-20	100-300
P2	Dublex	6-37	1-2	100-300
P3	Dublex	6-37	9-16	100-300
P4	EH36	5-36	2-3	100-300
P5	EH36	5-36	4-7	100-300
P6	EH36	5-36	6-9	140-400
P7	EH36	5-36	6-9	140-400
P8	EH36	5-36	3-6	140-400
P9	EH36	5-36	3-6	140-400
P10	EH36	5-36	3-4	140-400
P11	EH36	5-36	5-12	140-400
P12	EH36	5-36	1-2	140-400
P13	EH36	5-36	8-11	140-400

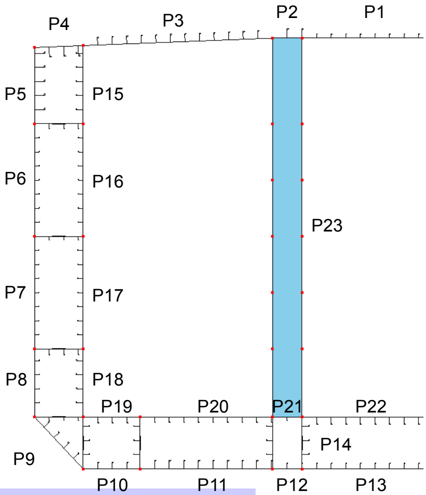


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Range of variables

Panel	Mat	t	NoS	h
P14	EH36	5-36	2-3	100-300
P15	Dublex	6-37	4-7	100-300
P16	Dublex	6-37	6-9	140-400
P17	Dublex	6-37	6-9	140-400
P18	Dublex	6-37	3-6	140-400
P19	Dublex	6-37	3-4	140-400
P20	Dublex	6-37	5-12	140-400
P21	Dublex	6-37	1-2	140-400
P22	Dublex	6-37	8-11	140-400
P23	Dublex	6-37*	-	800-1400



Improve

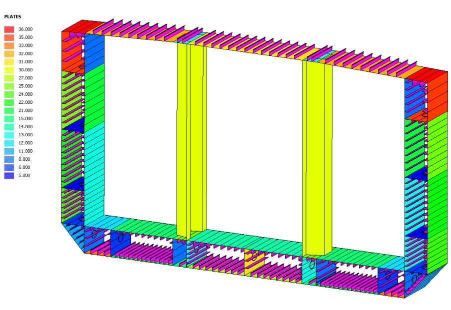
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

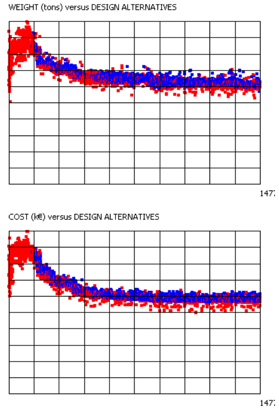
Structural optimization (ConStruct)

- ConStruct limitations
  - Assessement of the longitudinal strength
    - it includes only the vertical bending for the response evaluation of the hull girder
    - Therefore, torsion and horizontal bending were neglected in the present analysis

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

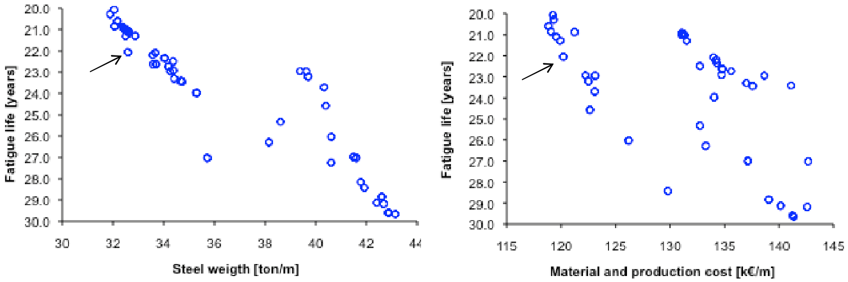
Results





IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural optimization (ConStruct)

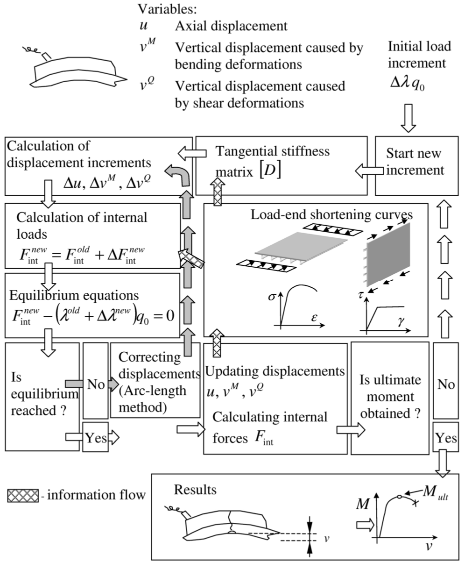


Pareto optimal solutions showing the relationship between fatigue, cost, and weight

Structural optimization (ConStruct)

- The ultimate strength of the final selected IMPROVE design alternative according to the structural optimisation is investigated using non-linear coupled beam method (Naar, 2006)

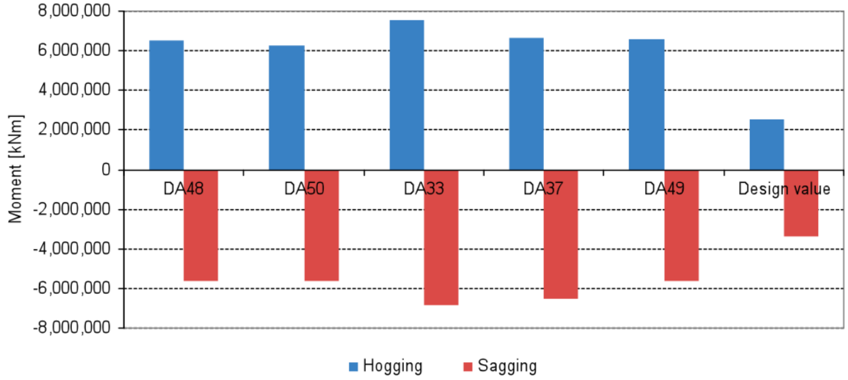
Structural optimization (ConStruct)



Structural optimization (ConStruct)

- Ultimate strength results
  - The ultimate strength of the selected candidates was evaluated with non-linear CB methods
  - Values of ultimate strength are compared to design moment in hogging and sagging condition
  - In the case of minimum weight and cost design the margin of ultimate strength to design moment is about two
  - For design alternative with 30 years fatigue life, the ultimate strength is increased having value 2.5.

Structural optimization (ConStruct)



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Transverse bulkhead optimization (UZ)

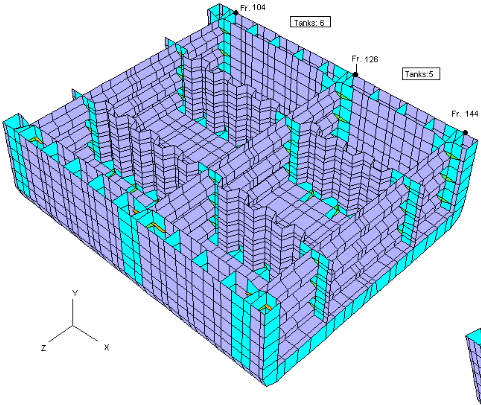
Objectives:

- **TWO VARIANTS WERE EVALUATED:**
  - ***1. HORIZONTAL CORRUGATIONS (HC)***
  - ***2. VERTICAL CORRUGATIONS (VC)***
- **GEOMETRY OF CORRUGATIONS KEEP FIX**
- **DESIGN VARIABLE: PLATE THICKNESS**
- TBHD at **Fr.126** was chosen (as the characteristic bulkhead) to be optimized

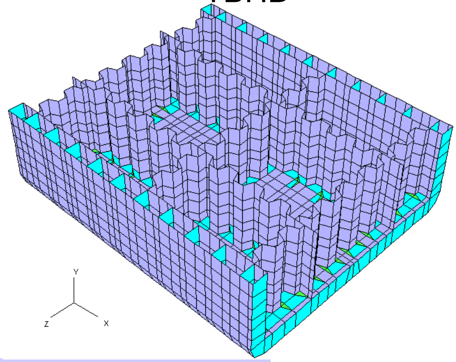
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Structural FE MAESTRO models:



VC-Vertical corrugated TBHD



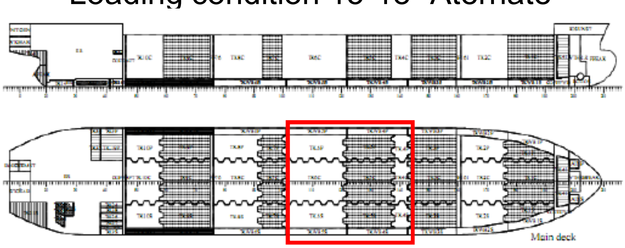
HC-Horizontal corrugated TBHD

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Twelve load cases were formed from two critical loading conditions (alternate and chessboard loading) using BV load case requirements (upright “a”, “b” and inclined “d” case).

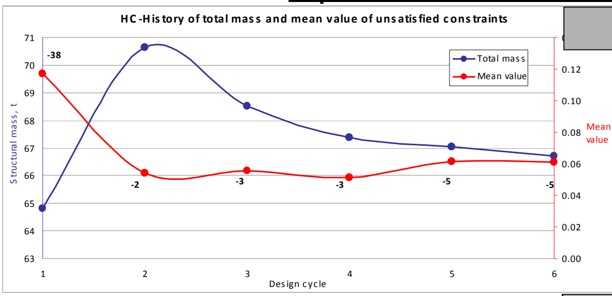
Loading condition 11-14 Chessboard

Loading condition 15-18- Aternate

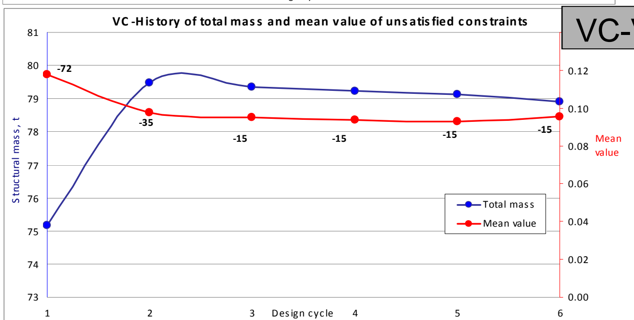


Optimization results

HC-Horizontal corrugated



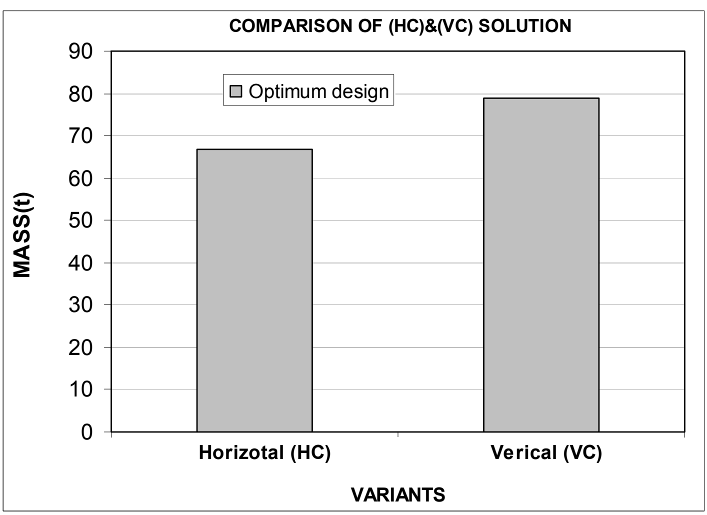
VC-Vertical corrugated



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Comparison of HC and VC variants:

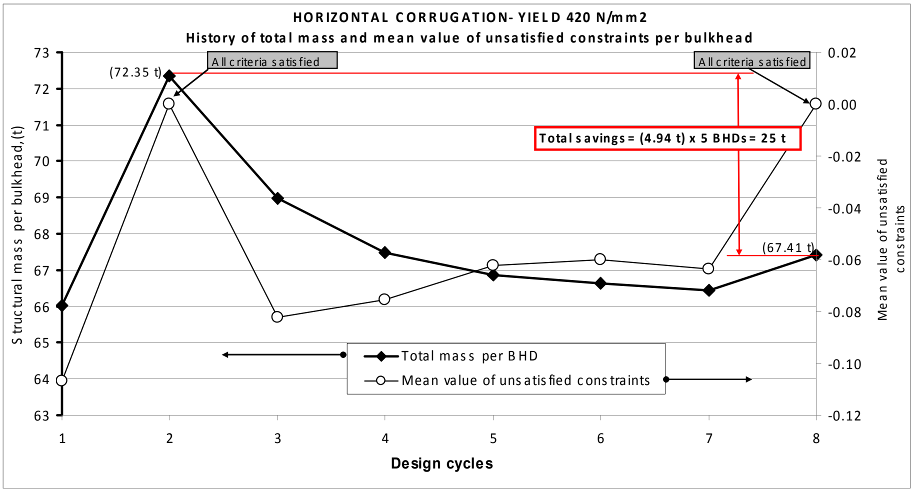


Optimization was preformed using MAESTRO dual SLP optimizer.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Optimization results of preferred variant: HORIZONTAL CORRUGATION (HC)



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

FE strength assessment

Modelled structure with the length of 73.4 m

Considerde loads

external water pressure

cargo pressure,

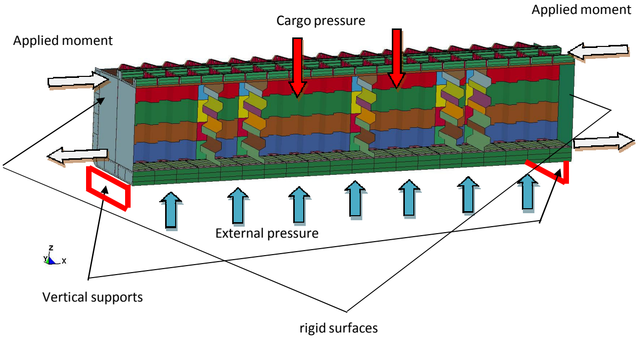
boundary moments.

accelerations

Boundary conditions

Simply supported

boundaries



IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

FE-model

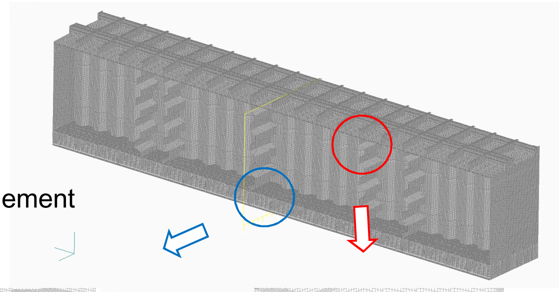
plating and T-profiles

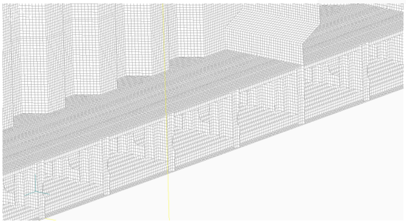
four node shell elements

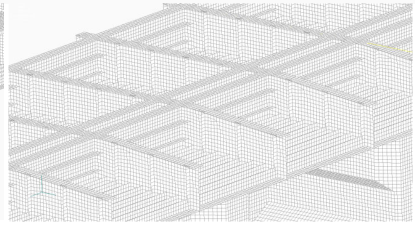
HP-profiles

web -> four node shell element

flange -> beam elements



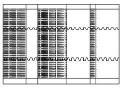
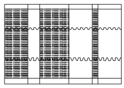
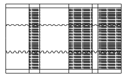
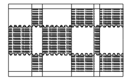
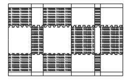
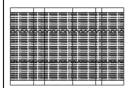
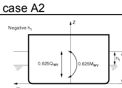
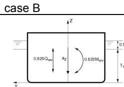
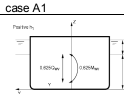
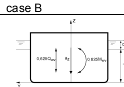
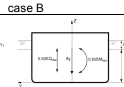
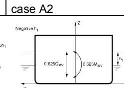




Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Loading cases

No	LC1(17) A2 Case 1	LC1(17) B Case 2	LC2(15) A1 Case 3	LC3(11) B Case 4	LC4(13) B Case 5	LC5 (6) A2 Case 6
Loading case nr from loading manual	15	15	15	11	13	6
						
	Still water shear force (sagging): 30656 kN Wave shear force (sagging): 10538 kN Still water bending moment (sagging): 641476 kNm Vertical wave bending moment (sagging): 967500 kNm	Still water shear force (sagging): 30656 kN Wave shear force (sagging): 10538 kN Still water bending moment (sagging): 641476 kNm Vertical wave bending moment (sagging): 967500 kNm	Still water shear force (hogging): 15206 kN Wave shear force (hogging): 10538 kN Still water bending moment (hogging): 1100376 kNm Vertical wave bending moment (hogging): 901875 kNm	Still water shear force (sagging): 1226 kN Wave shear force (sagging): 10538 kN Still water bending moment (sagging): 310016 kNm Vertical wave bending moment (sagging): 967500 kNm	Still water shear force (hogging): 8829 kN Wave shear force (hogging): 10538 kN Still water bending moment (hogging): 361646 kNm Vertical wave bending moment (hogging): 901875 kNm	Still water shear force (sagging): 70632 kN Wave shear force (sagging): 10538 kN Still water bending moment (sagging): 2408920 kNm Vertical wave bending moment (sagging): 967500 kNm
Accelerations a_x, a_y, a_z		a_{x1} = 0.61 m/s² (z = 2.21 m) a_{x1} = 1.22 m/s² (z = 15.4 m) a_{z1} = 1.65 m/s²		a_{x1} = 0.63 m/s² (z = 2.21 m) a_{x1} = 1.25 m/s² (z = 15.4 m) a_{z1} = 1.65 m/s²	a_{x1} = 0.62 m/s² (z = 2.21 m) a_{x1} = 1.24 m/s² (z = 15.4 m) a_{z1} = 1.65 m/s²	
Reference value of the relative motion	h_l = 5.98 m	h_l = 2.99 m	h_l = 5.98 m	h_l = 2.99 m	h_l = 2.99 m	h_l = 5.98 m
	Wave loads in load case A2	Wave loads in load case B	Wave loads in load case A1	Wave loads in load case B	Wave loads in load case B	Wave loads in load case A2
						

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Results for loading case 4

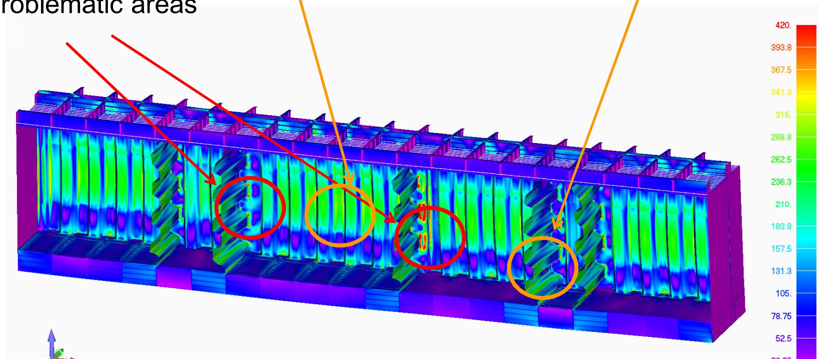
local bending stress 296 MPa

buckling stress 325 MPa

local bending stress 282 MPa

buckling stress 289 MPa

problematic areas



Equivalent Von-Mises stress in longitudinal bulkhead [MPa]

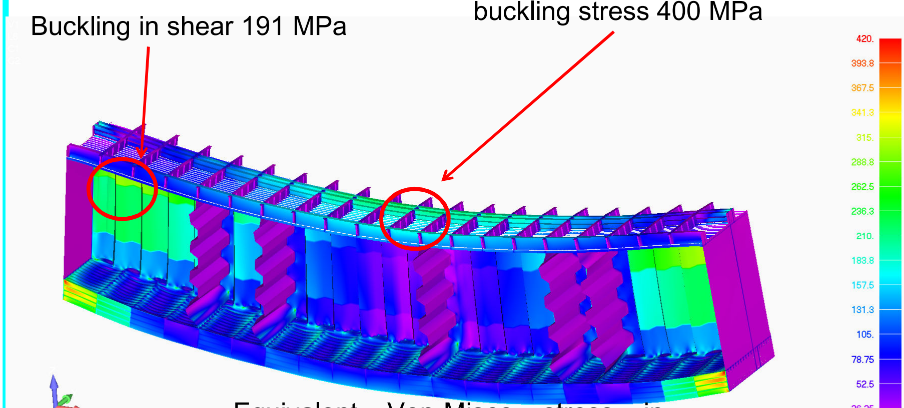
Results for loading case 6

Shear stress 173 Mpa

Buckling in shear 191 MPa

Compression in plate 164 MPa

buckling stress 400 MPa

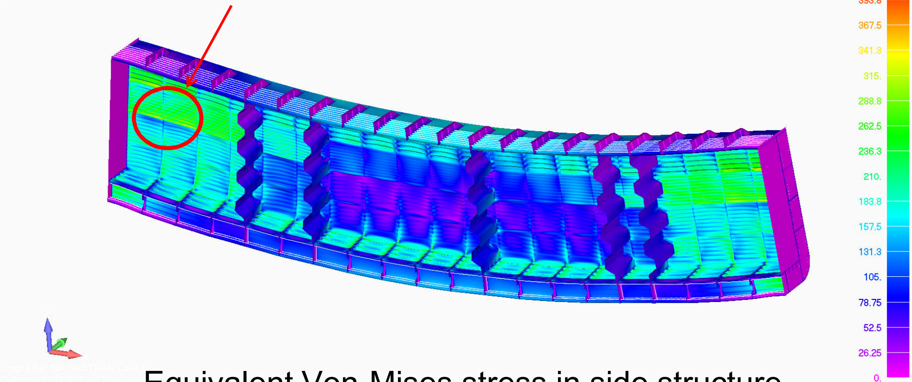


Equivalent Von-Mises stress in longitudinal bulkhead [MPa]

Results for loading case 6

shear stress 147 Mpa

buckling in shear 151 MPa



Equivalent Von-Mises stress in side structure

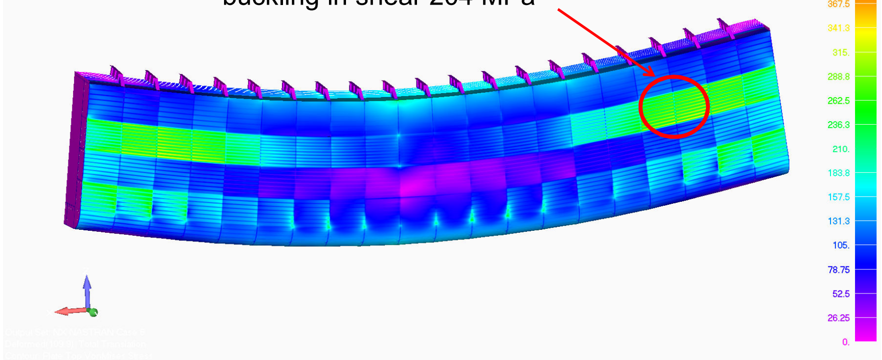
(internal plating)

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Results for loading case 6

shear stress 187 Mpa

buckling in shear 204 MPa



Equivalent Von-Mises stress in side structure

(external plating)

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Ultimate strength assessment

Designs that have been studied with non-linear FE-method

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Ultimate strength assessment

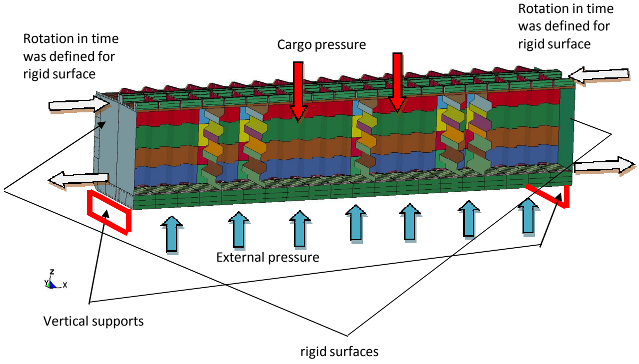
Methods used for analysis

CB-method and FE method

FE-model

loading conditions (from loading manual)

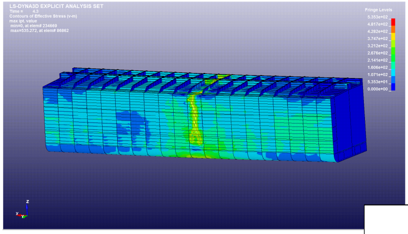
- 006 for sagging
- 003 for hogging

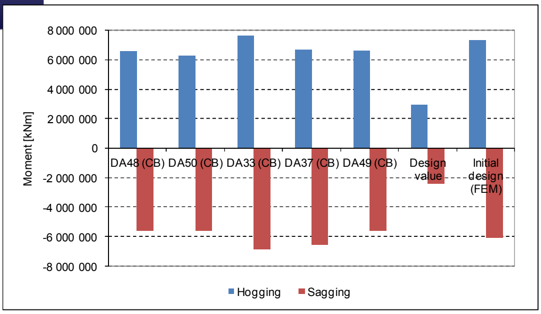


IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Ultimate strength assessment

Results

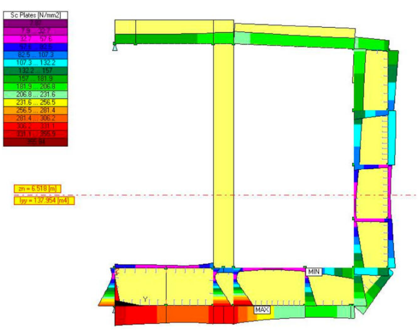


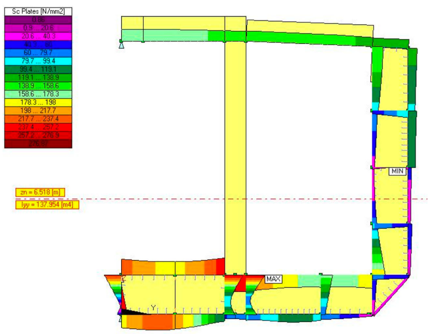


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Validation of the pareto optima with LBR-5 (ANAST/DN&T)





Critical areas are globally the same for ConStruct concept load and for Bureau Veritas loads

The stresses indicate that the design, and thereby the optimization procedure, is feasible

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Life cycle cost evaluation (ANAST/DN&T)

- Life Cycle Cost (LCC) estimates the life cycle cost
- The module has been implemented into the LBR-5 software to be used as new objective function
- As a result, this evaluation shows that the life cycle cost is not influenced significantly by the optimised structural design

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Life cycle cost evaluation (ANAST/DN&T)

	Displacement constant	Deadweight constant
Cost of the periodic maintenance	- 1.7%	+ 0.1%
Cost of fuel consumption	0%	+1.0%
Exploitation revenue	- 1.9%	0%
Dismantling revenue	+ 6.3%	+ 6.3%
Total Life Cycle Cost (= 1 + 2 – 3 – 4)	- 2%	- 0.1%

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Seakeeping and Stability (NAME)

- The regular and stochastic real sea analyses
  - 2D strip theory based numerical code
- In general, the vessel is expected to exhibit good seakeeping characteristics as most of the worst response modal periods are either far off from the dominant wave periods of operational area or wave headings may be adjusted to avoid severe responses
- The calculations show that the IMPROVE Chemical Tanker satisfies the stability requirements of applicable rules and regulations.

Improve

Improve

Sixth Framework Programme

IMPROVE

IMPROVEd chemical tanker

Optimization for crashworthiness

16th September 2009

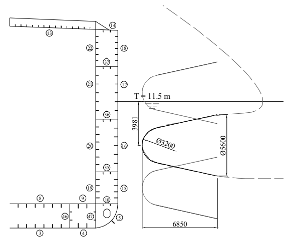
DUBROVNIK, *CROATIA*

Improve

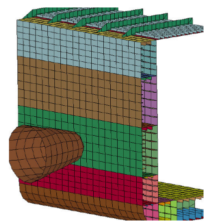
IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Description of the study

- Design the ship structure so to increase the crashworthiness of the vessel considering the standard service loads and functions



- Numerical simulations are applied to evaluate the capacity of the hull to tolerate crash avoiding the breach

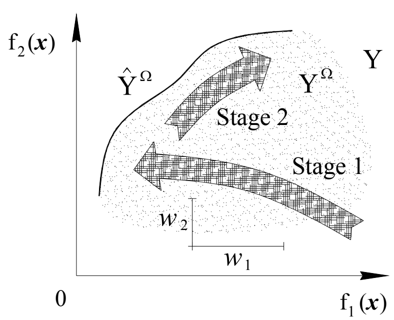


Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Optimization for crashworthiness

- Very time-expensive problems
- Design objectives (3)
  - Crashworthiness
  - Hull mass (total and duplex steel)
- Variables (92)
  - Thicknesses and profile sizes
- Constraints (300+)
  - Structural stability



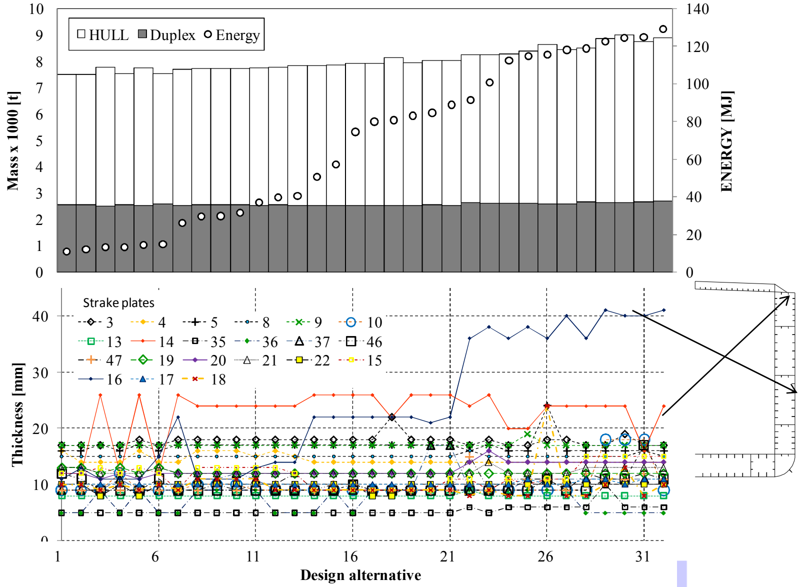
$$\min_{x \in X} \left\{ f_1(\boldsymbol{x}), \ldots, f_M(\boldsymbol{x}), f_{M+1}(\boldsymbol{x}), \ldots, f_{M+J}(\boldsymbol{x}) \right\}.$$

- Optimization method
  - Vectorization of the optimization problem
  - 1st optimize mass (optimization difficult problem)
  - 2nd add to optimization the crashworthiness (time expensive)

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Results



Implications

- Crashworthiness can be raised by 10 times with approx. 25% increase in hull mass
- The crashworthiness is most efficiently raised by only local stiffening of the side structure
  - Thicken the plates around the expected location of collision
  - Keep the remaining structure scantling around minimal allowed scantlings
- Effect of risk reduction for the crashworthy ship could be expected in the range of 20 to 40%

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

IMPROVE

IMPROVEd chemical tanker

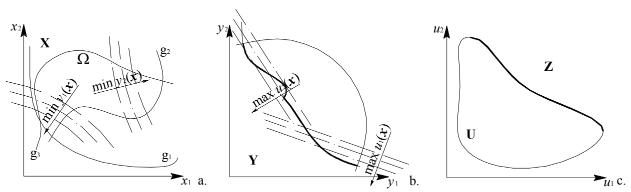
Design selection

16th September 2009

DUBROVNIK, *CROATIA*

Design selection

- From the created set of Pareto optimal alternatives, select one design alternative as a recommendation for stakeholders as the best compromise for their preferences.
- The multi-stakeholder decision-making approach is applied for this purpose
- Combines data on stakeholder preferences, obtained through semi-structured interviews with stakeholders, with formal assessment of stakeholder utility functions.
- Once the stakeholder utility functions are established, utilities of Pareto optimal design alternatives are conflicted in the utility space.
- In the end, the alternative which is the best compromise for both stakeholders is identified using the concept of *Competitive optimum*.



Assessment of stakeholder preferences

- Identify relevant design drivers (Key Performance Indicators – KPIs) for both stakeholders,
  - minimize the mass of duplex steel,
  - maximize fatigue life, etc.
- These KPIs are the key for defining the formal preference of a stakeholder towards a design alternative.
- Instead of observing its descriptors, i.e. the design variables, stakeholders effectively observe design characteristics, and based on this performance determine their preference.
- Preferences are elicited through semi-structured interviews
- After performing interviews and their transcription, a formal design framework is established through which stakeholder multi-attribute utility functions could be determined.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The interviews

- Two interviews with each stakeholder
  - Semi-structured interviews
- First interviews were performed to confirm the indicated design drivers, the KPIs and also get a better insight into what is expected from the improvements in hull structure through optimization.
- Second set of interviews followed after structural optimization was made, and after several alternatives were identified as the potential good compromises for both stakeholders.

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The interviews (2)

- 1st interviews

1. What is your role in the Shipyard? Could you please explain your duties and professional experiences?
2. What is a 'good' ship for you?
3. Observing the General Arrangement of the tanker, how would you describe it in short?
4. What would you indicate as its advantages and what as deficiencies?
5. In previous activities you have indicated certain priorities which are indicated here in the APPENDIX. Do you consider that this design will fulfill these priorities? Please explain.
6. Have the main objectives and KPIs changed for you?
7. What technical details do you see relevant for fulfilling the objective of design? Which features in your opinion could be improved through optimization study?
8. If I were to ask you to rank several design alternatives of this ship, do you think you would be able to do this? On what information or features would you base your ranking?
9. In your daily work how much are your decisions based on formalized information, and how much are they based on experience, hear say, experience of others, brainstorming and meetings?
10. Would you say that in your work (ship design) you make consistent decisions? If yes, please explain. If not, what contributes to the inconsistencies?

- 2nd interviews

1. How fatigue, costs, and weight are preferred?
   a) Is a unit of equivalent change dependent on the magnitude of the attribute
   b) Are they equally preferred even though the values of other attributes differ
   c) Is a unit of equivalent change dependent on the value of other attributes
2. Both owner and yard engage in value exchange, meaning that costs induced by the desire to increase benefits will be shared.
   a) We employ for this reason two realistic compensation factors p12 and p21 where first is the added ship price for the owner for the increased fatigue life, and it is based on the increased production costs for the yard.
   b) The second factor, p21, is the penalty for the lost deadweight caused by the weight increase.
3. The amount the owner is willing to pay to increase the fatigue life of this ship by 1year.
   a) Let us consider three values for the moment: 0, 100k€ and 1M€.
   b) Find the actual value

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The findings – 1st interviews

- Owner does not take part in the conceptual structural design of the vessel, but is interested in her characteristics. Specifically, that the vessel in operation is safe, that there are no cracks in the structure and that there is no need for repainting.
- Other characteristics related to safety, e.g. ultimate strength is of no relevance to the owner, but it is covered with the previous statement that the vessel should be safe.
- The lightship mass of the vessel is also of no particular concern for the owner since vessels are usually purchased as existing projects which guarantees their capacity, or deadweight.
- Due to the requirements for cargo capacity and safety (chemicals), yard is specially interested in controlling the mass of the hull and in its fatigue characteristics to maintain a higher reliability of ship structure.
- Fatigue is typically controlled trough design of structural details since loss of cargo capacity is not preferred
- Loosing 1000t of capacity for a vessel is huge!
- In case that owner is interested in increased vessel's structural safety, this is reflected in the ship price. The ship price is not standard but is based on the calculations founded on observed vessel design

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

The findings – 2nd interviews

- Owner expresses no interest to increase the fatigue life beyond required minimum, set by class, since it becomes difficult to find cargo for the vessel older than 15 years.
- On the other hand, it makes sense to increase the reliability of the vessel, but the vessel's capacity should not be sacrificed, and it should not cost any significant amount. The re-design should concentrate on the structural details, and on painting.
- The yard mentions, from the experience of dealings with chemical tanker owners, that the fatigue life of this chemical tanker should be 30 years (40 years is too long, and 25 too short). There is a special class for a 30-year fatigue life vessel.
- Yard transfers all the costs of increasing fatigue life to the owner
- Chemical tanker owners are in principle not selling for the reasons to avoid creation of competition. Thus they maintain and use their vessels until the scraping
- Yard estimates the upper value of investment into one year of fatigue life to be 100 000 EURO.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Conclusion on stakeholder preferences

- Some interesting (unexpected) results
  - The aspect of fatigue life increase
- Chemical tanker is designed in the 'small' market, meaning that there are no firm market prices established for the vessel type, and also that there are no direct competitors involved in the process of negotiation
- All positive (increased lifetime of the vessel) and/or negative (loss of capacity) aspects of increasing the fatigue life are summed up through the following three scenarios:
  - High returns are expected from the increase in fatigue life. One year of fatigue life is valued at 1M€.
  - Low returns are expected from the increase in fatigue life. One year of fatigue life is valued at 100k€.
  - Fatigue is not to be increased. Value of one year of additional fatigue life equals 0€.

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Stakeholder utilities

- Three attributes are considered here: the mass of hull, the costs required to produce it and the estimated fatigue life
  - The yard:
    - Minimize production costs, but with intention that all extra production costs to that of the standard minimum mass design are transferred to the owner
    - Do not significantly decrease the cargo capacity
  - The owner:
    - Increase fatigue life
    - Do not significantly decrease the cargo capacity
- Both owner and yard engage in value exchange, meaning that costs induced by the desire to increase benefits will be shared.
- We employ two probabilities p_{12} and p_{21}
  - First is the chance that the owner will accept the added ship price for the increased fatigue life, and it is based on the increased production costs of the yard.
  - The second p_{21} is the chance that the yard accepts the penalties for the lost deadweight caused by the mass increase.

$$u_j(\boldsymbol{x}) = k_{financial,j} \cdot r_{financial,j}(\boldsymbol{x}) + k_{fatigue,j} \cdot r_{fatigue,j}(\boldsymbol{x})$$

$$r_{financial,YARD}(\boldsymbol{x}) = \langle\langle (1-p_{12})\Delta P_{production} - p_{21}\Delta P_{capacity\,loss} \rangle\rangle$$

$$r_{fatigue,YARD}(\boldsymbol{x}) = \langle\langle \Delta FL \rangle\rangle$$

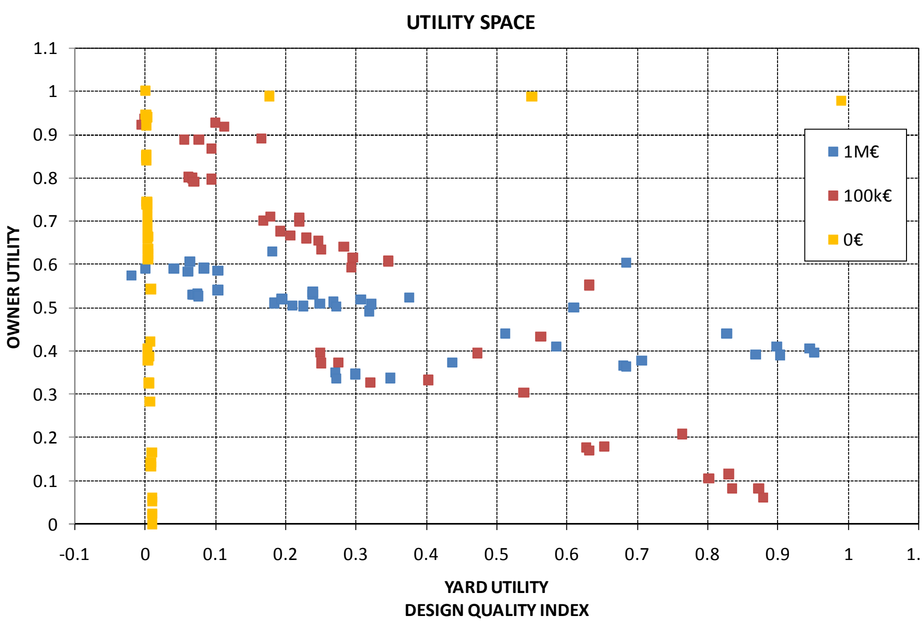
$$r_{financial,OWNER}(\boldsymbol{x}) = \langle\langle p_{12}\Delta P_{production} - (1-p_{21})\Delta P_{capacity\,loss} \rangle\rangle$$

$$r_{fatigue,OWNER}(\boldsymbol{x}) = \langle\langle \Delta FL \rangle\rangle$$

Design scenario	Scaling constants	YARD	OWNERS
1	$k_{financial}$	0.644	0.730
	$k_{fatigue}$	0.356	0.270
2	$k_{financial}$	0.847	0.787
	$k_{fatigue}$	0.153	0.213
3	$k_{financial}$	0.99	1
	$k_{fatigue}$	0.01	0

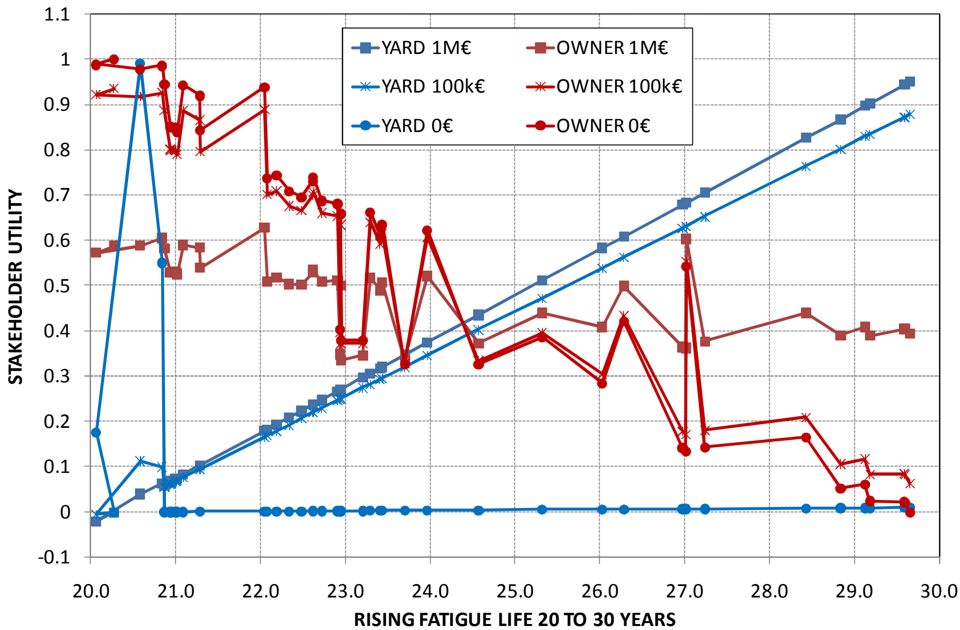
Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Multi-stakeholder decision-making

- Condition 1 – Compromise

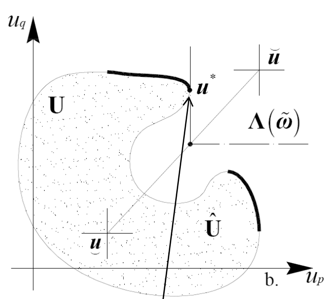
...if $\nexists \boldsymbol{u} \in \mathbf{U} \mid \underset{\smile}{\boldsymbol{u}} < \boldsymbol{u}^* < \boldsymbol{u},$

- Condition 2 – Efficiency

...if $\nexists \boldsymbol{u} \in \mathbf{U} \mid u_j^* = u_j, \forall j \in m \setminus i$ and $u_i^* < u_i, i \in m,$

- Condition 3 – Maximal stakeholders' satisfaction in the competitive relationships (MaSSCoR).

...if $\boldsymbol{u}^* \geq \left\{ \tilde{\boldsymbol{u}} \mid \tilde{u}_1 = \ldots = \tilde{u}_m \text{ when } \forall \boldsymbol{u} \in \mathbf{U}, \mathbf{P}(\boldsymbol{u}) \in \mathbf{U} \right\}$

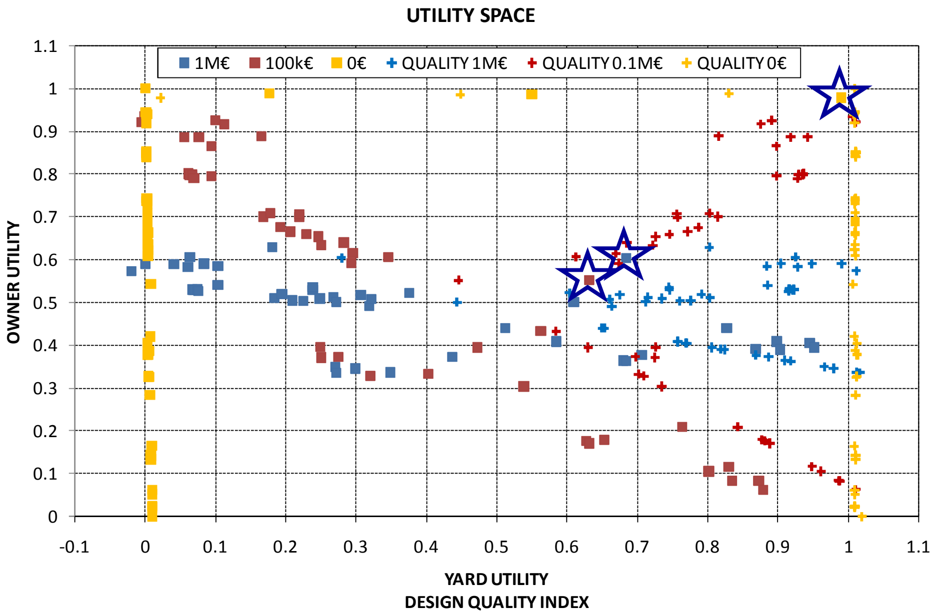


!!!The solution!!!

Minimum uniformly weighted Chebyshev metrics

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia



Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Proposed alternatives

- Fatigue life is not important
- Design alternative '48'
  - Low weight design
  - No additional investments
  - Some financial gains for both stakeholders due to production cost reduction
  - Present day optimized solution

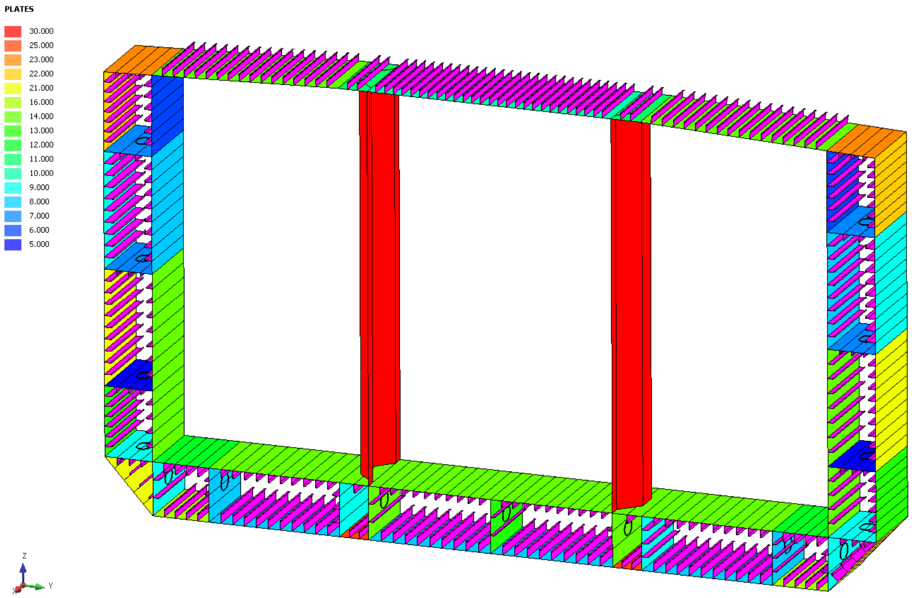
- High and low value of fatigue life
- Design alternative '4'
  - 6.75 extra years of fatigue life
  - abt. 700 tons of extra steel

Design scenario	Value of 1 year of fatigue life increase [k€]	DA	Quality index	P12	P21	Added fatigue life [year]	Deadweight loss [t]	Yard's financial loss [M€]	Owner's financial loss [M€]
1	1000	4	0.28	0	1	6.75	684	0	6.4
2	100	4	0.45	0	1	6.75	684	0	6.4
3	0	48	0	0	1	0	0	-0.05	0.1890

Improve

IMPROVE Final Workshop, September 2009, Dubrovnik, Croatia

Proposed alternative – min. costs DA-48



Proposed alternative – Fatigue efficient DA-4