GIGANTISM IN SHIPBUILDING
AND
CORRELATIVE SAFETY REQUIREMENTS

LE RENDEZ-VOUS DE L'ASSURANCE TRANSPORTS - CANNES
28 ET 29 AVRIL 2009

Jean-François SEGRETAINE
Bureau Veritas – Marine Division – Paris
THE GLOBAL PICTURE

- Economy of scale: less carrying cost per unit of cargo or passenger
- Imperative to ensure a sufficient filling ratio
- Reduced flexibility is a disadvantage:
  - Reduced number of port facilities
  - Shortage of docking facilities
  - Not allowed in Panama & Suez canals. Malacca strait in the future?
- Volume of casualties
SHEER SIZE

USS Enterprise - 341 m
Berge Stahl - 342 m
Queen Mary 2 - 345 m
Emma Maersk - 397 m
Knock Nevis - 458 m
CONCERNED SHIPS

1. Tankers
2. Bulk carriers
3. Container ships
4. Cruise-liners
Tankers built in France from 1935 to 1980
Maximum deadweight versus years

and studies for 1,000,000 tdw tankers
TANKERS

Bételgeuse : 120 000 tdw

Magdala : 211 000 tdw

L = 268.66 m  B = 38.92 m  D = 20.35 m  d = 15.087 m
Bottom thickness = 26 mm DH

L = 307.47 m  B = 47.17 m  D = 24.5 m  d = 17.68 m
Bottom thickness = 27 mm DH
TANKERS

Batillus: 550 000 t - CA 1976 for Shell
TANKERS

Batillus & Nordic Clansman
TANKERS

Batillus: 550,000 tdw

L = 414.22 m  B = 63 m  D = 35.9 m  d = 28.6 m

Bottom thickness = 27.5 mm  DH Side shell thickness = 25 m
TANKERS

Technical structural challenges

• Magdala: shear buckling during tank tests
  solved by measurements and stress computation (first time)

• 300,000 tdw with HS steel: early fatigue cracking
  solved by fatigue tests, detail new designs

• 550,000 tdw: springing phenomenon
  solved by ship behaviour and structural response computation
  verified by hull stress monitoring
TANKERS

550,000 tdw operational safety

Stop length > 2 miles - Turning circle diameter > 1 mile
TANKERS

550,000 tdw operational safety

two independant engine rooms  
two propellers, two rudders
BULK CARRIERS

Bulk carriers built from 1955 to 2007
Maximum deadweight versus years

Year


$\text{t dw}$

0 50000 100000 150000 200000 250000 300000 350000 400000

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
BULK CARRIERS

Berge Stahl 364,000 tdw (9 ships)
### Very Large Ore Carriers (VLOC)

**HE HENG**

Source NACKS SHIPYARD

<table>
<thead>
<tr>
<th>MAIN PARTICULARS:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L.O.A.</td>
<td>327.00m</td>
</tr>
<tr>
<td>B.MLD</td>
<td>55.00m</td>
</tr>
<tr>
<td>D.MLD.</td>
<td>29.00m</td>
</tr>
<tr>
<td>Summer Draft</td>
<td>21.40m</td>
</tr>
<tr>
<td>Gross Tonnage</td>
<td>152,305T</td>
</tr>
<tr>
<td>Net Tonnage</td>
<td>55,601T</td>
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<tr>
<td>Deadweight</td>
<td>297,592T</td>
</tr>
<tr>
<td>Speed</td>
<td>atb. 14.5Knots</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>MAIN ENGINE:</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>MAN B&amp;W 6S80MC-C Mk7</td>
<td>1set</td>
</tr>
<tr>
<td>M.C.O.</td>
<td>22,360kW(BHP)*73rpm</td>
</tr>
<tr>
<td>NOR.O.</td>
<td>19,000kW(BHP)*abt.69rpm</td>
</tr>
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</table>
Technical structural challenges

• First generation: lamellar tearing at bulkhead foot solved by steel plate testing requirement (Z grade plates)
• Hatchcoaming/hatchcover stiffnesses: hold tightness solved by hatchcoaming deformation computations
• Ballast in cargo tanks: sloshing and damages solved by model tests and upper tank shape design
• Fatigue cracks and domino effect: shell brittle fracture solved by stress computations, fatigue and crack propagation
• Fast loading by gravity (16,000 t/h): bottom pressure solved by R&D and impact structural response computation
BULK CARRIERS

Technical structural challenges

Resulting damage
Technical structural challenges

Fatigue cracks
Domino effect

Resulting damage

- Fatigue cracks
- Domino effect
- Resulting damage

- Bulkhead 4/5
- Bottom
- Bulkhead 3/4
- FR 188
- FR 217
- Deck
- Hole
- Welds at the origin of the failure
Technical structural challenges

Loading process

Plate dynamic response

16,000 t/h  h = 26 m

Amplification factor / static = 1.85
BULK CARRIERS

Operational safety

• Green water on fore deck: ship losses
  solved by R&D and new rules for fore part and monitoring

• Ballast water exchanges: stability, crew safety
  solved by computation, operational procedures
**BULK CARRIERS**

Water ballast exchange

Flow through

Sequential exchange
1. Hitting of a strong wave ahead
2. Shipping of green water
3. Damage of the first hatch cover, water ingress in hold
4. Negative trim, cargo fluidisation, sloshing
5. Damage of the hold nb 1 / nb 2 bulkhead
6. Flooding of the hold nb 2, stability loss
7. Ship capsizing
CONTAINER SHIPS

Container ship evolution from 1980 to 2007
Maximum capacity versus years

projects of 12,500 TEUs
Traffic TEUs worldwide (million TEUs)

Annual growth in the 9% order was expected before the economic downturn.
CONTAINER SHIPS

10,960 TEUS container ship

L = 346,5 m  B = 43,2 m  T = 15 m  V = 25 knots

(c) Boris Paulien
Big Box Ships

Ever Larger Vessels

-12.5 m
-14.5 m
-16 m

275 m
350 m
400 m

3500 TEU-vessel
8000 TEU-vessel
15000 TEU-vessel

15000 TEU
±25 wide 7 high

±23 TEU wide

8000 TEU
±17 wide 7 high

±15 TEU wide

3500 TEU
13 wide 4 high
# Representative ship dimensions

<table>
<thead>
<tr>
<th>Ship</th>
<th>Year</th>
<th>TEU</th>
<th>Loa (m)</th>
<th>Beam (m)</th>
<th>Draft (m)</th>
<th>Speed (kn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMA-CGM Hugo</td>
<td>2004</td>
<td>8 200</td>
<td>334.1</td>
<td>42.8</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>DSME</td>
<td>2009</td>
<td>9 000</td>
<td>347</td>
<td>45.2</td>
<td>15.5</td>
<td>24.3</td>
</tr>
<tr>
<td>HHI</td>
<td>2009</td>
<td>11 400</td>
<td>363</td>
<td>45.6</td>
<td>15.5</td>
<td></td>
</tr>
<tr>
<td>DSME</td>
<td>2009</td>
<td>13 000</td>
<td>365.5</td>
<td>51.2</td>
<td>14.0</td>
<td></td>
</tr>
</tbody>
</table>

*Power is about 72 000 kw to 80 000 kw with 2-stroke low rpm 12–14 cylinders Diesel engines*

*Operating draft between 14 m and 15 m*

*Air draft about 64.5 m*
M/V EMMA MAERSK
Implications for container terminals

In order to handle much larger vessels and consignment sizes, terminals must both expand and make better use of existing facilities.

In North Europe, consignment sizes are averaging nearly 2700TEU for 6000TEU+ sizes. For very large vessels, up to 5000TEUs have been handled at single port calls.

These increases will be noted in all major front rank ports.
ULCS*: The technical issue

- Large and slender hullform boxships have relatively small bending and torsional rigidity
- Therefore, the natural frequencies of hull girder vibrations are relatively small (large natural periods)
- High forward speed of container ships gives increases the wave encounter frequency (smaller wave encounter period)
- Consequently, dynamic phenomena which are second order for average size vessels may become of high importance for ULCS
- Main issue: vibratory structural response and associated fatigue damage caused by whipping and springing
- Extrapolation of existing designs to ULCS dimensions risky business?

* Ultra Large Container Ship: 10,000+ TEU
Whipping & Springing

- **Whipping** is a transient phenomenon characterised as hydrodynamic impact enforcing high frequency hull girder bending stresses (vibration)
  - Increased sagging and hogging wave bending moment (stress amplitude)
  - Increased fatigue loading (small range high frequency damped cycles and low frequency stress range)
- Whipping generally occurs in head seas when sailing severe sea states; main vibration mode is vertical bending
- **Springing** is a resonant phenomenon characterised as small range high frequent bending stresses which are added to the large range wave frequent bending stresses
  - Increased fatigue loading (small range high frequency cycles)
- Springing generally occurs in quartering seas when sailing in non-severe sea states (waves with small period have limited height); main vibration modes are torsional bending, vertical bending and horizontal bending
Full scale measurements: Lashing@Sea

CMA CGM Rigoletto – 9400 TEU – BV Class

Measurement of hull stresses and container accelerations

Transverse accelerations
Results:

<table>
<thead>
<tr>
<th>Mode</th>
<th>(Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>torsion</td>
<td>0.366</td>
</tr>
<tr>
<td>flexion</td>
<td>0.496</td>
</tr>
<tr>
<td>torsion</td>
<td>0.499</td>
</tr>
<tr>
<td>torsion</td>
<td>0.899</td>
</tr>
</tbody>
</table>
ULCS: What are the findings?

• Whipping can cause an increase in total vertical bending moment of about 20%
• The whipping induced increase in fatigue damage during the vessel lifetime has been found to be of the order of 3 to 5%
• The springing induced increase in fatigue damage during the vessel lifetime has been found to be of the order of 4 to 10%
• Consequences for the design of ULCS
  – The hull girder ultimate strength check will need to take into account the increase in dynamic hull girder loads
  – Increased attention required for the design of fatigue sensitive structural details (hatch corners, longitudinal connections, etc.)
• Effects of whipping and springing will become more important for new designs for container ships of over 400 m in length (over 13,000 TEU)
High quality user friendly tools for efficient design

MARS2000: longitudinal & ultimate strength, transverse bulkheads, torsion, fatigue

VeriSTAR LASHING: verification and optimisation of stackweight and lashing equipment
Direct Ship Analysis

- Necessary for large container ships…

13,000+ TEU
container ships

- Flexible hull structure due to open box holds (vertical bending and torsion) and weight optimisation (FE calculations)
- High power output for high sustainable service speed
- Main engine and crankshaft stiffness are relevant parameters due to specific architecture of main engine
- Hydrodynamic design aspects for single screw high powered ships (vibrations excitations, cavitation erosion)
- Direct coupling between line shafting and crankshaft
CONTAINER SHIPS

Technical structural challenges

• Large open deck: torsion, fatigue in hatch corners
  solved by measurements at sea, then stress computations

• Wave impacts: slamming, slapping, green water
  solved by hydrodynamic computations, hull monitoring

• Dynamic wave loads: hull girder springing, whipping
  solved by stress computation and fatigue verification

• Motion accelerations: on deck container lashing
  solved by load and stress computations, lashing design

• Propulsion power: shaft alignment, rudder erosion
  solved by elastic alignment, rudder shape and material
CONTAINER SHIPS

Structural critical areas

- HATCH COAMING/CASTLE CONNECTION
- LONGITUDINAL HATCH COAMINGS
- BOW FLARE (Slapping)
- HATCH CORNERS
- FORE BOTTOM (Slamming)
- TRANVERSE BULKHEAD CONNECTIONS
- CROSS DECK CONNECTIONS
CONTAINER SHIPS

Container lashing failure
CONTAINER SHIPS

Container lashing innovation

Lashing deck on 2 levels

Advantages:
- Short lashing lines
- 2 workers at the same time
- Easier working conditions

Inconvenient:
- Heavier equipment
CONTAINER SHIPS

Rudder erosion
CONTAINER SHIPS

Rudder erosion

Concerned areas

Proposed solutions

Horizontal plates

INOX

Rounded
CONTAINER SHIPS

Operational safety

• Fast speed: collision risk
  solved by manoeuvrability and navigation rules

• Containers on deck: visibility, green water
  solved by monitoring, bridge position

• Containers on deck: parametric rolling
  solved by R&D, computation and navigation rules
CONTAINER SHIPS

Visibility from bridge
CONTAINER SHIPS

Visibility from bridge

- 5900 TEU
- 8200 TEU
- 12500 TEU

Dimensions:
- 275 M
- 335 M
- 360 M
CONTAINER SHIPS

Shipping of green water
CONTAINER SHIPS

Shipping of green water effects
CONTAINER SHIPS

Parametric rolling effects
CONTAINER SHIPS

Parametric rolling computation

Roll
time history

Forced roll simulation (fixed axis)
CONTAINER SHIPS

Parametric rolling risk prediction

Hs_1
Tp_1

parametric rolling

“normal” rolling

Hs_2
Tp_2
CRUISE LINERS

Cruise liner evolution from 1970 to 2006

Maximum passenger number versus years

project of 5,600 passengers
CRUISE LINERS

Norway: 2000 passengers $L = 315$ m

Queen Mary II
3080 passengers
$L = 345$ m
CRUISE LINERS

Genesis project: 5600 passengers L = 360 m
Technical structural challenges

• **Superstructures**: hull girder deformation loads solved by structural stress computations

• **Large wide spaces**: structural discontinuities solved by structural behaviour computations

• **Large shell opening**: structural discontinuities solved by structural behaviour computations

• **Passenger comfort**: reduced vibration, noise solved by structural behaviour computations

• **Propulsion**: large flexibility needed solved by PODS
CRUISE LINERS
Large superstructures submitted to hull girder deformations

MSC SERENATA 133.000 GT 1.650 Pax Cabins Over-Panamax size - May 2009
CRUISE LINERS

Wide space: commercial centre
CRUISE LINERS

Wide open spaces

Carnival Elation - Theater

Main stair

Carnival Elation - Main stairway
CRUISE LINERS

Passenger comfort

Cabin room

Bar and Restaurant
CRUISE LINERS

FE model for vibration and noise prediction computation
CRUISE LINERS

Propulsion flexibility

Queen Mary II PODS
CRUISE LINERS

Operational safety

• **Stability**: ship capsize
  solved by damage stability computations

• **Health**: air conditioning, water, food
  solved by procedures, maintenance, audits

• **Environment**: garbage and sewage
  solved by design and equipment

• **Fire**: detection, protection, fighting
  solved by specific rules and fire propagation computations

• **Evacuation**: number of passengers and panic
  solved by specific equipment and computer simulations
CRUISE LINERS

Lost of stability consequences

RoRo/Ferries losses from 1987 to 2002

- accidents: 9
- capsizings: 7
- victims: 3,644
CRUISE LINERS

Contamination by air conditioning

Risk of legionella
CRUISE LINERS

Contamination by water

- warm water legionella
- cold water pseudomonas
CRUISE LINERS

Contamination by foods
### CRUISE LINERS

#### Waste quantities

Cruise liner of 3,000 passengers

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>kg or liter/person/day</th>
<th>tons or m³/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic</td>
<td>0.1</td>
<td>2.1 t</td>
</tr>
<tr>
<td>Paper and pasteboard</td>
<td>1.0</td>
<td>21.0 t</td>
</tr>
<tr>
<td>Glass</td>
<td>1.0</td>
<td>21.0 t</td>
</tr>
<tr>
<td>Food garbage</td>
<td>0.7</td>
<td>14.7 t</td>
</tr>
<tr>
<td><strong>Total solid</strong></td>
<td><strong>2.8</strong></td>
<td><strong>58.8 t</strong></td>
</tr>
</tbody>
</table>

**Black water** (conventional system)

- **100** t
- **2 100 m³**

**Black water** (void system)

- **12**
- **252 m³**

**Grey waters**

- **160**
- **3 360 m³**

**Wash houses**

- **80**
- **1 680 m³**

**Kitchens**

- **90**
- **1 890 m³**

**Total liquid**

- **430 / 342**
- **9 030 / 7 182 m³**
CRUISE LINERS

Fire propagation simulation
CRUISE LINERS

Salvage crafts and evacuation training
CRUISE LINERS
Evacuation computer simulation
SYNTHESIS

• SINCE MAGDALA TANKER (1969)
  All ship structures are verified by structural computations

• SINCE YEARS 70s
  All ship types have increased in size thanks to R&D and computer progresses

• TODAY
  Ship designers and operators have efficient tools for calculations and simulations
SYNTHESIS

Global and local hull stresses
END

Thank you for your attention
LE RENDEZ-VOUS DE L’ASSURANCE TRANSPORTS

Cannes

28th and 29th April 2009