RO/RO Ships

Manuel Ventura

Ship Design I

MSc in Marine Engineering and Naval Architecture

Summary

• Definition
• Types of RO/RO Ships
• Profile and evolution of the fleet
• Relevant aspects of design
  - Arrangement of the accesses and garage zone
  - Cargo types and characteristics
  - Specific equipment for securing of roll-on/roll-off cargo
  - Damaged Stability: Criteria and assessment
  - Safety (SOLAS): Prevention and extinguishing of fire in the garage zone
• Annex A. Significant Ships
• Annex B. Relevant Non-IMO Standards
Roll-On/Roll-Off Ships - ships where the cargo is wheeled or is loaded/unloaded on board in vehicle or platforms equipped with wheels

• The first ships of this type were the Ferry, equipped with railways to allow the transport of train carriages between the margins of the rivers that were too wide for bridges

• One of the first ferry ships was the Forfarshire, across the Firth of Forth, in Scotland, built in 1861

The WWII has motivated the development of this type of ships for the landing of military equipment.

After the war many of those military ships were converted for operation as merchant ships, such as the LST (Landing Ship Tank) MV Virginia Beach
The use of the RO/RO concept in merchant ships started in the late 1940's, early 1950's, mainly in short-sea routes.

Types of RO/RO Ships

- Ferries
- Freight
- Ro-Pax
- Pure Car Carriers
- Combined carriers
  - Container Ro/Ro
  - Ro/Ro Lo/Lo
Ferry

Carriage of Passengers and Vehicles

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Ferry - Typical General Arrangement

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Freight Ro/Ro

Transport of Wheeled Cargo

Ro-Pax

Mixed Transport of Passengers, Vehicles and Wheeled Cargo
Pure Car Carrier (PCC)

Car Transport

- Ships quite sensitive to the side winds due to the large exposed area
- Present a large number of ventilators on the exposed deck due to the SOLAS requirements for the garage zone

The largest PCC currently in service is the MV Mignon (1999), from Wallenius Lines, which after a lengthening of 28 m (2005) has the capacity to carry about 7,200 cars.

Pure Car Truck Carrier (PCTC)

Transport Cars and Trucks

Courageous Ace (2003)
6400 cars

Loa = 198 m
Lpp = 188 m
B = 32.20 m
D = 14.60 m
T = 8.80 m
DW = 16,957 t
**Container Ro/Ro (ConRo)**

**Combined Ship, Container Carrier and Ro/Ro**

ConRo Trader (1978)
Loa = 109.60 m
DW = 4,550 t

Generally carries stacks of containers on the upper deck and wheeled cargo under deck

**Ro/Ro Lo/Lo**

CEC Oceanic (1997)
Loa = 100.90 m
DW = 5,150 t

Ship that can carry and load wheeled cargo, but that also has lifting equipment to load/unload through the hatches
Profile and Evolution of the Fleet

World Fleet of Ro/Ro Ships

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2006</th>
<th>Change [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Fleet</td>
<td>8172</td>
<td>7522</td>
<td>7520</td>
</tr>
<tr>
<td>Added to Fleet</td>
<td>70</td>
<td>32</td>
<td>19</td>
</tr>
</tbody>
</table>

Notes:
- Only Ro/Ro cargo ships
- Units: [1,000 tdw]

Source: ISL Market Review 2006 - Merchant Fleet Data

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Recent Evolution of the Fleet

### Evolution of the Capacity Ro/Ro

<table>
<thead>
<tr>
<th>Route Type</th>
<th>2003</th>
<th>2006</th>
<th>Absolut Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra European NW</td>
<td>522</td>
<td>573</td>
<td>+ 51</td>
</tr>
<tr>
<td>Intra Mediterranean</td>
<td>394</td>
<td>447</td>
<td>+ 53</td>
</tr>
<tr>
<td>Intra Asian (exc. ferries)</td>
<td>27</td>
<td>60</td>
<td>+ 33</td>
</tr>
<tr>
<td>Intra Americas</td>
<td>108</td>
<td>109</td>
<td>+ 1</td>
</tr>
<tr>
<td>Inter-continental</td>
<td>199</td>
<td>222</td>
<td>+ 23</td>
</tr>
<tr>
<td><strong>Total all routes</strong></td>
<td>1291</td>
<td>1473</td>
<td>+ 182</td>
</tr>
</tbody>
</table>

- Global growth of abt. 14% in 3 years
- Increase of capacity concentrated in established markets
Comparison of Ships Ro/Ro Cargo - Ropax

- Increasing trends to build Ropax ships
  - Market of passenger ferries declining due to the low cost air transport companies
  - Ropax ships present a larger increase in the intra-European low cost transport

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2006</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ropax</td>
<td>185</td>
<td>235</td>
<td>+ 27%</td>
</tr>
<tr>
<td>Only Cargo</td>
<td>67</td>
<td>74</td>
<td>+ 10%</td>
</tr>
</tbody>
</table>

Source: MDST Containerhip Databank
Arrangement of Access Way and Garage Zones

Dimensions of Access Ways
External Access Ramp

Ramp angle < 12°

Internal Access Ways

- Capacity expressed in total lane length
- Parking space requirements:

<table>
<thead>
<tr>
<th></th>
<th>length [m]</th>
<th>width [m]</th>
<th>height [m]</th>
<th>Load [t/axis]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>4.0 ~ 5.5</td>
<td>2.2 ~ 2.5</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Trucks</td>
<td>10.0, 12.0, 15.0</td>
<td>2.8 ~ 3.1</td>
<td>4.7</td>
<td>15.0 (double wheels)</td>
</tr>
</tbody>
</table>

(*) Minimum free height, must add margin for upper deck structure
Parking Spaces

- For road trailers, semi-trailers and roll trailers the width of the lane is typically 2.90 m
- The width of the cargo space should be a multiple of 2.90 m

Internal Ramps

- The slope of the internal ramps is normally between 1:7 to 1:10 (abt. 8° – 6°) and the width should be carefully selected in relation to the cargo stowed at each deck.
- Widths between 7 and 12 meters are used in the large ships
- Anti-skid surfaces are important.
### Initial Dimensioning Guidelines

<table>
<thead>
<tr>
<th>Ro/Ro Cargo Ships</th>
<th>Ro/Ro Passenger Ships</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{pp} = 110 + \frac{(L_m - 1000)}{25}$</td>
<td>$L_m = \text{Lane length [m]}$</td>
</tr>
<tr>
<td>$N_{cars} = \text{max. Number of cars}$</td>
<td>$N_{cars} = \text{max. Number of cars}$</td>
</tr>
<tr>
<td>$L_{pp} = 30 + (N_{cars} - 15)(10/17)$</td>
<td>$N_{cars} &lt; 100$</td>
</tr>
<tr>
<td>$L_{pp} = 80 + (N_{cars} - 100)(5/22)$</td>
<td>$100 &lt; N_{cars} &lt; 320$</td>
</tr>
<tr>
<td>$L_{pp} = 130 + (N_{cars} - 320)/9$</td>
<td>$320 &lt; N_{cars} &lt; 500$</td>
</tr>
<tr>
<td>$L_{pp} = 150 + (N_{cars} - 500)/10$</td>
<td>$N_{cars} &gt; 500$</td>
</tr>
</tbody>
</table>

Deck Configuration

- The number of decks increases with ship size.
- For ships up to about 15000 tdw, 2 decks are most common.
- Bigger ships have often 3 permanent decks.
- Movable car decks are frequently installed in between the permanent decks.
Ro/Ro Deck Configurations (1)

RoRo Ferry

RoPax Ferry

Ro/Ro Deck Configurations (2)

PaxCru Ferry

Cruise Ferry
Trailers - Stowage in Lanes

Ro/Ro for Carriage of Trailers (Semi-Reboques) - Stowage

Cargo Equipment for Ro/Ro Ships
RO/RO ships require a wide range of access equipment.
Cargo Equipment for Ro/Ro Ships (2)

- Bow doors
- Bow ramps
- Internal doors
- Hoistable car decks
- Hoistable car ramps

Ramps/Bow Access Doors

- Stern ramps, for ships that attend Ro/Ro terminals
Quarter ramp, which allows access with the ship in a peer (without Ro/Ro terminal)

- Bow ramp "Folding Frame Type"
- Allows a complete separation of the door in the collision bulkhead from the remainder of the ramp
Opening sequence of the bow ramp.

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Side Shell Doors

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Internal Ramps

Internal ramps typically have inclination of abt. 7°

Internal Doors

Watertight door designed for the subdivision of the cargo spaces with a minimum of interference
Movable Car Decks

- Intermediate decks of lightweight construction that allow the stowage of cars inside the deck for heavy vehicles

Moveable Car Decks

- There are 2 types of moveable car decks:
  - **Hoistable Car decks** - with integrated lifting device, electrically or hydraulically driven
  - **Liftable Car Decks** - do not have integrated lifting mechanism, they are moved by lifts of the scissors type
**COREX Cardecks**

- Stainless steel sandwich panels from MacGreggor
- A 3D truss-core is built-up between top and bottom panels
- Compared with conventional steel cardecks they have about 1/3 of the depth and about ½ of the weight

**TYPICAL CAR DECK CONSTRUCTION MATERIALS**

<table>
<thead>
<tr>
<th>material</th>
<th>profile</th>
<th>weight (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COREX panel deck</td>
<td>100mm</td>
<td>45</td>
</tr>
<tr>
<td>Conventional steel deck</td>
<td>350mm</td>
<td>85</td>
</tr>
<tr>
<td>Aluminium deck</td>
<td>350mm</td>
<td>35</td>
</tr>
</tbody>
</table>

**COREX PANEL CAR DECK CHARACTERISTICS**

- Total structure depth: 100mm
- Total structure depth with clearance in stowed position: 100-140mm
- Total structure depth with deflections in working position: maximum 140mm
- Steel weight for fixed car deck: 45 kg/m²
- Complete weight with fittings and hydraulic cylinders for hoistable deck: 52 kg/m²
- Maximum distributed cargo load on deck: 200 kg/m²
- Free span at maximum load: 7m

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**Cargo Lifts**

- Lifts to carry vehicles between decks, in ships where the longitudinal space is limited
- There are configurations in which the platform itself works as watertight hatch cover when secured in its lower position

- Types of cargo lifts:
  - Scissors
  - Telescopic
  - Chain driven
Cargo Handling

MAFI Trailer

Used to move containers on chassis in the terminals

Connection System

MAFI Tractor

Axle loads:
- Front axle: 4,000 kg (8,800 lbs.)
- Rear axle: 2,600 kg (5,700 lbs.)
- Total: 6,600 kg (14,300 lbs.)
### Truck and Semi-Trailer

<table>
<thead>
<tr>
<th></th>
<th>Overall Height</th>
<th>Semi-Trailer</th>
<th>Overall Width</th>
<th>Length</th>
<th>Overall Length</th>
<th>Width</th>
<th>Wheelbase</th>
<th>Tandem axle spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck Tractor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheelbase</td>
<td>6.2 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tandem axle spread</td>
<td>1.2 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### Semi-Trailers

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Trailer horse
Trailer Trestle

- A terminal trailer trestle is a device which releases the towing truck for more productive use while the semi-trailer is loaded or unloaded in a terminal.

Cassettes for Containers

- The cassettes are detachable steel platforms, which containers can be loaded on for transporting.
- The containers can be double-stacked so that either 2x40ft or 4x20ft containers can be moved. This cassettes are able to handle 80 tons (there are examples of 120-ton versions used in the steel industry).
- One of the advantages of using cassettes is that they act as a "floating" buffer, since containers can be placed on the cassettes with or without being coupled to a vehicle.
**Cassettes**

A translifter is a steerable lifting trailer which can be used with pallets or trestles. It has soft wheels.

**Translifter**

- A translifter is a steerable lifting trailer which can be used with pallets or trestles.
- It has soft wheels.
Types of Cargo (1)

- **Road Trailer** - Including tractor and the trailer with the container on top. The dimensions, including allowances, are 12.5 m x 3.0 m x 4.5 m. Weight of 30 - 35 t and centre of gravity at 3.0 m height.
  
  **Load:** 15.0 t/axle, 1.3 m distance between axis.

- **MAFI trailer** - Platforms for cargo towing, moved by tractors designated by Tugmasters.
  
  **Load:** 18.0 t/axle, 0.7 m distance between axis.

- **Tugmaster** - Tractor for moving cargoes in the terminals and in the ship.
  
  **Load:** 21.0 t/axle.

Types of Cargo (2)

- **Palette** - Rectangular shaped structure where the cargo is stowed. Many different sizes, with rectangular shapes whose sides vary in a range from 0.8 m to 1.5 m. The size currently more used is 1.25 m x 1.0 m. The height of the cargo depends from the stowage conditions but can be assumed a value of 1.8 m to 2.0 m from the base, including the pallette.

- **Car** - Change a lot, but for European cars, average values of 4.5 m x 2.0 m x 1.7 m can be assumed, with an average weight of 1.0 t and max. of 2.0 t.

- **SECU** - *(Storabox unit)* specialized container for the carriage of paper, with dimensions 13.8 m x 3.6 m x 3.6 m and weight of 90t.
### Types and Characteristics of Cargo (1)

<table>
<thead>
<tr>
<th>Cargo</th>
<th>Type</th>
<th>Length [m]</th>
<th>Width [m]</th>
<th>Height Max. [m]</th>
<th>Weight Max. [t]</th>
<th>Load/axis [t]</th>
<th>Slope Max. [%]</th>
<th>Speed Max. [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container</td>
<td>20'</td>
<td>9.0</td>
<td>3.2</td>
<td>4.4</td>
<td>57.0</td>
<td>54.0</td>
<td>12.5</td>
<td>30</td>
</tr>
<tr>
<td>Palettes</td>
<td>4 t</td>
<td>4.0</td>
<td>1.3</td>
<td>2.2</td>
<td>10.0</td>
<td>8.0</td>
<td>16.0</td>
<td>30</td>
</tr>
<tr>
<td>Truck</td>
<td></td>
<td>11.0</td>
<td>2.5</td>
<td>4.4</td>
<td>24.0</td>
<td>10.0</td>
<td>16.0</td>
<td>80</td>
</tr>
<tr>
<td>Truck (articul.)</td>
<td></td>
<td>15.0</td>
<td>2.5</td>
<td>4.4</td>
<td>38.0</td>
<td>10.0</td>
<td>16.0</td>
<td>80</td>
</tr>
<tr>
<td>Trailer</td>
<td>20'</td>
<td>6.1</td>
<td>2.5</td>
<td>4.5</td>
<td>22.0</td>
<td>10.0</td>
<td>14.0</td>
<td>80</td>
</tr>
<tr>
<td>Trailer</td>
<td>40'</td>
<td>12.3</td>
<td>2.5</td>
<td>4.5</td>
<td>35.0</td>
<td>10.0</td>
<td>11.0</td>
<td>80</td>
</tr>
<tr>
<td>Car EU</td>
<td></td>
<td>4.0</td>
<td>1.6</td>
<td>1.4</td>
<td>2.0</td>
<td>1.0</td>
<td>20.0</td>
<td>100</td>
</tr>
</tbody>
</table>

### Types and Characteristics of Cargo (2)

<table>
<thead>
<tr>
<th>Cargo</th>
<th>Type</th>
<th>Length [m]</th>
<th>Width [m]</th>
<th>Height Max. [m]</th>
<th>Weight Max. [t]</th>
<th>Load/axis [t]</th>
<th>Slope Max. [%]</th>
<th>Speed Max. [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wagon w/ container</td>
<td>40'</td>
<td>14.0</td>
<td>4.7</td>
<td>3.4/6.0</td>
<td>52.0</td>
<td>2 x 13.0</td>
<td>14.0</td>
<td>15</td>
</tr>
<tr>
<td>Tractor LUFmaster</td>
<td>8 TEU/2 layers</td>
<td>18.8</td>
<td>4.9</td>
<td>5.9</td>
<td>247.0</td>
<td>48.0</td>
<td>11.0</td>
<td>15</td>
</tr>
<tr>
<td>Side carrier</td>
<td>1 TEU</td>
<td>9.0</td>
<td>3.7</td>
<td>4.6</td>
<td>60.0</td>
<td>30.0</td>
<td>14.0</td>
<td>30</td>
</tr>
<tr>
<td>Straddle carrier</td>
<td>1 TEU</td>
<td>6.0</td>
<td>3.9</td>
<td>4.5</td>
<td>40.0</td>
<td>10.0</td>
<td>11.0</td>
<td>30</td>
</tr>
</tbody>
</table>
Vehicle Securing

IMO Guidelines - Securing Points

- **Guidelines for Securing Arrangements for the Transport of Road Vehicles on Ro-Ro Ships.**
- Apply to Ro-Ro ships which carry road vehicles on either long or short international voyages in unsheltered waters
- Are applicable to:
  - Road vehicles with an authorized total mass of vehicle and cargo between 3.5 and 40 t
  - Articulated road trains with an authorized total mass not more than 45 t
- The decks shall be provided with securing points with:
  - Longitudinal spacing < 2.5 m
  - Transverse spacing 2.8 < S < 3.0
  - Minimum strength without permanent deformation: 20 KN
Securing Points on Decks

- Flush Latchpoints
- Ramped Latchpoints

Securing Points on Decks (Cars)

- Min. breaking load tension 60 kN
- Approval from any classification society
- Standard height 64 mm
- Thickness of top plate 6 mm
- Weldable inorganic zinc or epoxy shop primer
- Made of high tensile steel
- Counter part in hook

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IMO Guidelines - Lashing

- Lashing shall consist of chain or any other device made of steel or other material with equivalent strength and elongation characteristics.
- The strength of lashing without permanent deformation should not be less than 120 KN.
- Lashings should be attached to the securing points with hooks or other devices.
- Lashings should only be attached to the secure points.
- The angle between the lashings and the horizontal and vertical planes shall be preferably between 30° and 60°.

Car Lashing Equipment

- MODEL 2909-1453: ROPE AUTOMOBILE TIEDOWN
  - MIN. 10’ / 3.05 M
  - MAX. 10’ / 3.05 M
  - WORKING LOAD LIMIT (WLL): 1,050 LBS / 479 Kg
  - BREAK STRENGTH (BBS): 2,000 LBS / 907 Kg
  - WEIGHT: 1.9 LBS / 0.86 Kg
  - TYPICALLY USED ON RO/RO SHIPS FOR SECURING AUTOMOBILES
  - NOT FOR LIFTING. LOAD SECURING ONLY.

- MODEL 2909-6014: RATCHET STRAP ASSEMBLY
  - 1’ x 7’ WITH S-HOOKS
  - WORKING LOAD LIMIT (WLL): 1,050 LBS / 479 Kg
  - BREAK STRENGTH (BBS): 3,100 LBS / 1,406 Kg
  - WEIGHT: 1.75 LBS / 0.78 Kg
  - NOT FOR LIFTING. LOAD SECURING ONLY.
Trailer and Truck Lashing

Chain lashing

<table>
<thead>
<tr>
<th>Art. No.</th>
<th>SWL</th>
<th>MSL</th>
<th>Take-up</th>
<th>Material</th>
<th>Riss-out</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>123456</td>
<td>30</td>
<td>20</td>
<td>5.0 m</td>
<td>Steel</td>
<td>25</td>
<td>7.5 kg</td>
</tr>
</tbody>
</table>

Accidents due to Improper Lashing

Accident due to an articulated vehicle being only lashed at the 4 corners
(www.shipownersclub.com)
Scantlings of Decks for Wheeled Cargo (BV)

The thickness of plate panels submitted to wheeled cargoes shall not be less than the following, in [mm]:

\[ t = C_{wh}(nP_k)^{0.5} - t_c \]

with:

- \( C_{wh} \): Coefficient to be taken equal to:
  \[ C_{wh} = 2.35 \left( \frac{0.05L}{s} + 0.02 \left( 4 - \frac{s}{L} \right) \right)^{1.73} \]
  where \( s \) is to be taken not greater than 3
- \( n \): Number of wheels on the plate panel, taken equal to:
  - 1 in the case of a single wheel
  - the number of wheels in a group of wheels in the case of double or triple wheels
- \( A_r \): Tyre print area, in \( m^2 \), in the case of double or triple wheels, the area is that corresponding to the group of wheels
- \( P_k \): Wheeled force, in kN, taken equal to:
  \[ P_k = 2.0F_1 + 3.0F_2 \]

\( t_c \): The thickness of plate panels submitted to wheeled cargoes
Scantlings of Decks for Wheeled Cargo (BV)

When the tyre print area, \(A_T\), is not known, can be used the value in \([\text{m}^2]\) computed by the expression:

\[
A_T = 9,8 \left( \frac{nQ_A}{n_W P_T} \right)
\]

with:
- \(n\) - number of wheels on the plate panel
- \(Q_A\) - load in t/axis
- \(n_W\) - number of wheels in the axis considered
- \(P_T\) - pressure of the tyres \([\text{kN/mm}^2]\)

(When the value is not known, use the ones from Table 6)

### Table 6: Tyre pressures \(P_t\) for vehicles

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Tyre pressure (P_t) in (\text{kN/m}^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumatic types</td>
<td>Solid rubber types</td>
</tr>
<tr>
<td>Private cars</td>
<td>250</td>
</tr>
<tr>
<td>Vans</td>
<td>600</td>
</tr>
<tr>
<td>Trucks and trailers</td>
<td>800</td>
</tr>
<tr>
<td>Handling machines</td>
<td>1100</td>
</tr>
</tbody>
</table>

In the vehicles where the 4 wheels of the axis are on the plate panel (Figure 1) the plate thickness shall be the largest of the values obtained from the following expressions:

\[
t = t_1 = t_2(1 + \beta_3 + \beta_5)
\]

with:
- \(t_1\) - Net thickness obtained, in mm, from (4.3.1) for \(n = 2\), considering one group of two wheels located on the plate panel
- \(t_2\) - Net thickness obtained, in mm, from (4.3.1) for \(n = 1\), considering one wheel located on the plate panel
- \(\beta_3, \beta_5\) - Coefficients obtained from the following formula, by replacing \(i\) by 2, 3 and 4, respectively (see Fig. 1):
  - For \(x_i/b < 2\):
    \[
    \beta_i = 0.6 \left(1.2 - 2.02 w_i + 1.17 w_i^2 - 0.21 w_i^3\right)
    \]
  - For \(x_i/b \geq 2\):
    \[
    \beta_i = 0
    \]
- \(x_i\) - Distance, in \(m\), from the wheel considered to the reference wheel (see Fig. 1)
- \(b\) - Dimension, in \(m\), of the plate panel side perpendicular to the axle

\(t_i = \frac{t_i}{b}\)

Figure 1: Four wheel axle located on a plate panel
Damaged Stability

Accidents with Ro/Ro Ships

- Princess Victoria (1953), 135 casualties
- Estonia (1994), 852 casualties
- Herald of Free Enterprise (1987), 193 casualties
Damaged Stability (1)

- The shipwreck of the "Harald of Free Enterprise", in 1987, called the attentions for the damaged stability of Ro/Ro ships, which are characterized for NOT having watertight subdivision above the main deck.
- In a first approach R&D has focused on the residual stability of existing ships and in the identification of the main causes of the shipwrecks.
- The sinking of the "Estonia" has increase the urge to find solutions.

- Measure of Survivability - Critical height of the water on deck. Based in probabilistic concepts.
- The total probability of survival has 2 factors:
  - The probability that a given compartment is flooded
  - The probability that the ship survives to that flooding

Damaged Stability (2)

- The probability of survival can be divided in 2 factors:
  - The probability of surviving the pure lost of stability, moments of heel, displacement of the cargo and angle of heel.
  - The probability of surviving the effect of the water accumulated on deck due to the action of the waves.
- The computation of this last factor designated by survival factor with water on deck, $s_w$, is based in the concept of the critical height of the wave at which capsize (sossobrar) occurs, and so $s_w$ is just the probability that this wave height is not exceeded.
Static Equivalent Method (SEM)

- Based on the results from experimental tests it was determined that the capsizing happens at an heeling angle close to \( \Theta_{\text{Max}} \), the angle corresponding to the maximum value of the righting moment.
- \( \Theta_{\text{Max}} \) is determined by the traditional constant displacement method, allowing the progressive flooding of the car deck until the immersion of the deck at side.
- Based in these assumptions, it was developed the Static Equivalent Method (SEM), that allows the calculus of the critical amount of water accumulated on deck from the results of static stability computations.

**Static Equivalent Method**

- It is considered a flooding scenario in which the ship has a only a damage under the car deck, but there is a quantity of water accumulated on the deck, considered intact.
- The critical amount of water is the one that takes the ship to assume an equilibrium heeling angle equal to \( \Theta_{\text{Max}} \).

\[
h_{\text{crit}} = f(H_s) = 0.085 (H_{S\text{crit}})^{1.3}
\]

with:

- \( h_{\text{crit}} \) - difference in height between the internal and external waterlines
- \( H_{S\text{crit}} \) - critical significative wave height
In Ro/Ro ships, the closed decks for wheeled cargo shall have levels of protection equivalent to machinery spaces:
- Must be limited by class A boundaries (in steel or equivalent material)
- Closed spaces to be protected by a fixed fire extinguishing system, typically CO2 in cargo ships and sprinklers (DeLuge system) in car ferries
- Smoke detection system
- Open cargo decks do not require a fixed fire extinguishing system
- Portable systems and hoses
**Ventilation of Cargo Spaces for Vehicles**

- The ventilation system of the cargo spaces shall be completely segregated from the others ventilation systems.

- In ships with a number of passengers $N$, the system shall guarantee:
  - $N > 36 \rightarrow 10$ renewals/hour
  - $N \leq 36 \rightarrow 6$ renewals/hour

*Source: SOLAS Chap. II-1 Regulation 38 - Cargo Spaces for Motor Vehicles*

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**Conclusions from the Analysis of the Fires**

- In accordance to SOLAS, the large fires are rare in ships and the casualties are generally related with situations when the passengers are in the interior of the vehicle during the voyage (which is no longer acceptable by SOLAS and by the ISM code).

- Many of the big fires started when the ship is in port, during load or unload. The detection system is often temporarily switched off and the CO2 can not be released quickly by the system because the ramps (internal and external) are still open.

- The reliability of the low pressure CO2 systems for cargo space is generally quite low.

- The sprinkler systems for Ro/Ro decks in Ferries have shown good results.

*Source: DNV, "Fires on Ro-Ro Decks", DNV Technical Paper, 2005*
### Fires in Ro/Ro Ships (1990-2003)

<table>
<thead>
<tr>
<th>Ship name</th>
<th>Incident year &amp; place</th>
<th>Cause</th>
<th>Fire extinguished</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.Ventura</td>
<td>1998 In port</td>
<td>While jumpstarting and refuelling car</td>
<td>(Burst out) (4th?) (CO2 released after 1:02h)</td>
<td>Total loss of cargo and ship</td>
</tr>
<tr>
<td></td>
<td>2001 At sea</td>
<td>Started in second hand car</td>
<td>CO2 released after 2:25h, first attempt after 1:35</td>
<td>100s of cars damaged. Also some structural damage to the ship</td>
</tr>
<tr>
<td></td>
<td>2001 At sea</td>
<td>-</td>
<td>Extinguished after 3 days (open deck?)</td>
<td>136 tons steel renewed. Note: container / ro-ro ship</td>
</tr>
<tr>
<td>Silver Ray</td>
<td>2002 In port</td>
<td>-</td>
<td>(Burst out after 9 days)</td>
<td>Total loss of cargo and ship</td>
</tr>
<tr>
<td></td>
<td>2002 At sea</td>
<td>Started in new car</td>
<td>CO2 released</td>
<td>20 cars damaged, heat damage to deck</td>
</tr>
<tr>
<td></td>
<td>2003 At sea</td>
<td>-</td>
<td>CO2 released after 25 minutes – failed</td>
<td>1,425 cars smoke damaged 4 deck heat damaged</td>
</tr>
</tbody>
</table>

Source: DNV, “Fires on Ro-Ro Decks”, DNV Technical Paper, 2005

### Fires in Ferries (1990-2004)

<table>
<thead>
<tr>
<th>Ship name (built year)</th>
<th>Incident year &amp; place</th>
<th>Cause</th>
<th>Fire extinguished</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pegasus (1975)</td>
<td>1991 In port</td>
<td>-</td>
<td>Deluge and fire hoses?</td>
<td>List and partly submerged</td>
</tr>
<tr>
<td>Falster Link (1969)</td>
<td>1994 At sea</td>
<td>Engine in recently parked truck</td>
<td>By deluge (released after 10 minutes, confirmed out / under control within 90 minutes)</td>
<td>1 truck driver died – slept in truck cabin (passengers are to leave car deck during voyage)</td>
</tr>
<tr>
<td>Superfast III (1998)</td>
<td>1999 At sea</td>
<td>-</td>
<td>-</td>
<td>14 illegal immigrants died (had inside car deck trucks). Damage to steel, cables, etc. on ship.</td>
</tr>
<tr>
<td>* * (1991)</td>
<td>1999 At sea</td>
<td>Coal briquettes (auto ignition?)</td>
<td>-</td>
<td>Minor</td>
</tr>
<tr>
<td>Joseph and Clara Smallwood (1989)</td>
<td>2003 At sea</td>
<td>Trailer caught fire</td>
<td>Confirmed extinguished (probably by deluge / fire hoses)</td>
<td>Deck heated up – passengers and crew evacuated</td>
</tr>
<tr>
<td>Knoxoss Palace (2000)</td>
<td>2003 At sea</td>
<td>Trailer caught fire</td>
<td>Quickly extinguished by the deluge system</td>
<td>Minor. Some problems in evacuating passengers upon arrival in port</td>
</tr>
<tr>
<td>Vincenzo Florio (1999)</td>
<td>2004 At sea</td>
<td>Cargo shifted and caught fire</td>
<td>Controlled after a few hours?</td>
<td>32 cars on car deck died. Heavy seas. Power black out.</td>
</tr>
</tbody>
</table>

Source: DNV, “Fires on Ro-Ro Decks”, DNV Technical Paper, 2005
Bibliography (1)

- DNV, "Fires on RoRo Decks", DNV Technical Paper, 2005

Bibliography (2)

Relevant IMO Guidelines and Codes

- IMO Resolution A.533(13) - Elements to be taken into account when considering the Safe Stowage and Securing of Cargo Units and Vehicles in Ships
- ✓ IMO MSC.1/Circ.1355 (2010) - Amendments To The Guidelines For Securing Arrangements For The Transport of Road Vehicles on Ro-Ro Ships (Resolution A.581(14))

Relevant Links

Suppliers of Ro/Ro Equipment
- www.macgregor-group.com
- www.nordana.com
- www.tts-technology.no

Other
- www.shipownersclub.com
Annex A. Significant Ships

Ro/Ro Ferry (1)
Ro/Ro Ferry (2)

Ro/Ro Ferry (3)

Basic loading conditions:
100 passenger cars (4.4 m x 1.8 m) and 790 passengers, or 48 passenger cars, 8 trailers (of 40 t each) and 790 passengers, or 10 passenger cars, 10 trailers (of 40 t each) and 790 passengers.

Capacity:
- Number of passengers in enclosed saloons: 610
- Number of passengers on the open deck: 180
- Total number of passengers: 790
- Number of European standard passenger cars (4.4 m x 1.8 m) - basic layout:
  - on the main deck: 78
  - hoistable side ramps: 22
- Total number of passenger cars: 100
- Number of crew members: 20

Vehicle loading/unloading equipment:
Hydraulically effected access ramps at bow and stern have to be large enough to enable a quick and efficient flow of vehicles onto and from the ship.

The bow access ramp at the main deck level shown in Figure 2 is a watertight, two-part folding ramp with:
- driving width: 4.0 m, approximately
- length (excluding flaps): 31.0 m, approximately
- height of clear opening: 5.1 m

Clear height of decks/platforms:
- Above the main deck (amidships): 4.70 m
- Below the side car platforms: 2.30 m
- Above the side car platforms: 2.10 m

The stem ramp at the level of the main deck is a watertight, one-piece ramp with:
- clear driving width: 6.5 m, approximately
- length (excluding flaps) of the hull: 7.0 m, approximately
- height of clear opening (at the hull): 4.6 m
- operational slope of: + 5 to -8 degrees

Hoistable side ramps/platforms (2) on the car deck (garage) consist of three hydraulically effected sections (each):
- clear driving width: 2.2 m
- maximal operational slope (lowered position): 8 degrees

During sailing, the loaded ramps are lifted into horizontal position at the level of the platform deck.
Ro/Ro Ferry (4)

Tor Petunia

M.Ventura RO/RO Ships
MV Tamesis

TECHNICAL SPECIFICATIONS

Length overall 240.65 m
Beam 52.26 m
Air Draft 46.0 m
Depth to upper deck 19.45 m
Draft, design/loaded 13.07/11.78 m
Deadweight at maximum draft 38,406 MT
Gross tonnage 87,141 MT
Net tonnage 24,570 MT
Main engine width 39.0 m
Main engine capacity 120,000 kW

M.Ventura RO/RO Ships

Annex B. Relevant Non-IMO Standards

Engine: BWMC 6L 716HC (MTU) 2641502B4
Basic complement 100
Built: 2006, Daewoo Heavy Industries Ltd., Korea
Call Sign: LA971
IMO No: 9333558
Owner: Wilhelmshaven Lloyd Shipowning AG, Germany
Flag: NL
Some Relevant ISO Standards
