GTT Membrane
Cargo Containment Systems
Alan Whitcher, Training Manager, GTT Training Ltd.
Agenda

- Introduction to GTT
- Introduction to membrane tanks
- MkIII Concept
- Building MkIII containment system
- NO96 Concept
- Building NO96 containment system
GTT in brief

- An engineering company with more than 50 years of experience in the design of the Membrane Cargo Containment Systems

- GTT is a public company listed on the Euronext Stock Exchange (Paris)

- More than 130 projects\(^{(1)}\) (LNGCs, FSRUs, FLNGs, GSTs and “LNG as a fuel”) currently on order

- 380 highly qualified people\(^{(1)}\) keeping on addressing new market requirements, such as:
  - Low BOR systems (particularly for spot)
  - Intermediate filling levels (particularly for offshore)
  - Small scale LNGCs (for retail LNG)
  - LNG as a fuel tanks (for bunkering)
  - Multigas vessels

\(^{(1)}\) As of December 31\(^{th}\), 2014
GTT History

Technigaz MkI System

• **1964**: Pythagore : 630 m³ (2 tanks)
• Converted fish carrier

*Figure 3: Pythagore LNG carrier; general overview and inside tank view*
GTT History

Gaztransport NO System

1969: Polar Alaska : 71,500 (4 tanks – NO82)
GTT History

Gaztransport → 1994 - GTT → NO96
Technigaz → 1994 - GTT → MkIII
GTT’s Contribution

**Pre-Design**
- Assistance to Shipowners, Shipyards and Engineering Companies for feasibility and optimization before contract
- Bill of materials, Equipment pre-sizing...

**Design**
- After contract, detailed engineering for Cargo Containment System (CCS) and Cargo Handling System (CHS)
- Material specification & homologation

**Construction**
- On-site supervision during construction
- Attendance to gas trials & commissioning

**Operations**
- Assistance and expert advice during operations

**Maintenance**
- Assistance and expert advice during ship life
Building Shipyards

- Technical Assistance and License Agreement
  - Non exclusive in terms of geography
  - Non exclusive in terms of technology
  - Access to new patents
  - Identical terms for all Licensee
  - Identical pricing whatever the technology, the country

- Presence on-site
  - Permanent office in shipyards

- Joint research programmes
  - Constantly working on common goals

26 shipbuilding groups\(^{(1)}\) are GTT partners for the construction of membrane LNG carriers

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\(^{(1)}\) As of June 2014
Ship Owners

- **Technical Services Agreement**
  - Advisory service for the maintenance and operation of the LNG fleet
  - Round the clock service on-site
  - Training
  - Engineering studies upon specific request
  - Assistance with statutory bodies

(1) As of May 2014
Repair Shipyards & Repair Service Providers

- Technical Assistance for the Maintenance of Membrane LNG Carriers
  - Training
  - Advisory service for the preparation of each maintenance operation
  - Round the clock service

- 16 repair shipyards and 2 repair services providers\(^{(1)}\) under contract on the world shipping routes
  - Europe (France, Germany, Italy, Portugal, Spain)
  - Middle East (Dubai, Qatar)
  - Asia (China, Japan, Malaysia, Singapore)

\(^{(1)}\) As of May 2014
GTT Technology Applications

LNG Carriers

(1) As of May 2014
GTT Technology Applications

Floating Storage & Regasification Vessels (FSRV)
Floating Production Storage and Unloading (FLNG)

**Dimensions**
- 488m long
- 74m wide
- 600,000 tns ballasted
- 3.6mtpa of LNG
- 1.3mtpa of condensate
- 0.4mtpa of LPG

**Storage**
- 220,000m³ LNG
- 90,000m³ LPG
- 126,000m³ condensate

As of May 2014
GTT Technology Applications

Land Storage Tanks
GTT Technology Applications

LNG as a Fuel – Bunker Barges

North America’s first LNG bunker barge
GTT Technology Applications

LNG as a Fuel – Vessel Fuel Tanks
Introduction to Membrane Tanks
Objective

• Regulatory requirements
• Design philosophy of Membrane systems
• Ship Design
• Liquid Motion

Enforced through SOLAS Chapter VII – Carriage of Dangerous Goods
Tank Types for LNG

IGC Code
Tank Classification

Independent Tanks

Type A
Pr < 700mb
Full Secondary Barrier

Type B
Pr < 700mb*
Partial Secondary Barrier

Type C
Pr > 2 bar
No Secondary Barrier

Membrane Tanks

Membrane
Pr < 700mb
Full Secondary Barrier

NO 96

Mk III

*For tanks with plane surfaces
NO96 & MkIII Technologies

NO96 Cargo Tank

MkIII Cargo Tank
Membrane Containment System
Basic Concept

Hull structure

Insulated lining
Membrane tanks are non-self-supporting tanks which consist of a thin layer (membrane) supported through insulation by the adjacent hull structure. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane.”

- The membrane and hull behavior are intimately linked.
- The containment transmit the load whereas the hull takes the load
- The membrane should be flexible (thin) and/or should be suitable for cryogenic use (low contraction coefficient)
- The membrane should be flexible to absorb hull deformation
Membrane & Hull Intimately Linked

- Protect the hull structure from the low temperature
- Transfer the loads to the hull structure
- No loss of space, cargo volume maximized
- Accommodate any kind of hull form and size
- Large volumes
IGC 4.2.2.2 Membrane Tank Philosophy

“The design vapour pressure $P_0$ should not normally exceed 0.25 bar. If, however, the hull scantlings are increased accordingly and consideration is given, where appropriate, to the strength of the supporting insulation, $P_0$ may be increased to a higher value but less than 0.7 bar.”
IGC 4.3 Design Loads

4.3.1.1
Tanks together with their supports and other fixtures should be designed taking into account proper combinations of the following loads:

- Internal pressure
- External pressure
- Dynamic loads due to motions of the ship
- Thermal loads
- Sloshing loads
- Loads corresponding to ship deflection
- Tank and cargo weight with the corresponding reactions in way of supports
- Insulation weight
- Loads in way of towers and other attachments
Ship Deflections - Global

Hull Girder Deflection

Hogging
- Higher weight at ends
- Higher buoyancy in the middle part

Sagging
- Higher buoyancy at the ends
- Higher weight in the middle part
Ship Deflections – Local Ballast Pressure

Max ballast pressure ~ 4 bars
IGC 4.7.3 Secondary Barrier Requirement

Secondary barriers in relation to tank types should normally be provided in accordance with the following table.

<table>
<thead>
<tr>
<th>Cargo temperature at atmospheric pressure</th>
<th>-10°C and above</th>
<th>Below -10°C down to -55°C</th>
<th>Below -55°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic tank type</td>
<td>No secondary barrier required</td>
<td>Hull may act as secondary barrier</td>
<td>Separate secondary barrier where required</td>
</tr>
<tr>
<td>Integral</td>
<td>Tank type not normally allowed(^1)</td>
<td>Complete secondary barrier</td>
<td></td>
</tr>
<tr>
<td>Membrane</td>
<td>Complete secondary barrier</td>
<td>Complete secondary barrier(^2)</td>
<td></td>
</tr>
<tr>
<td>Semi-membrane</td>
<td>Complete secondary barrier</td>
<td>Complete secondary barrier</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>Partial secondary barrier</td>
<td>No secondary barrier required</td>
<td></td>
</tr>
<tr>
<td>Type A</td>
<td>Complete secondary barrier</td>
<td>Complete secondary barrier is incorporated</td>
<td></td>
</tr>
<tr>
<td>Type B</td>
<td>Complete secondary barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type C</td>
<td>Complete secondary barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Insulation</td>
<td>Complete secondary barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>Complete secondary barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>Complete secondary barrier</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.7.4 Secondary Barrier

The secondary barrier should be so designed that:

.1 it is capable of containing any envisaged leakage of the liquid cargo for a period of 15 days, unless different requirements apply for particular voyages, taking into account the load spectrum referred to in 4.3.4.4;

.2 it will prevent lowering of the temperature of the ship structure to an unsafe level in the case of leakage of the primary barrier as indicated in 4.8.2
Cofferdams

Cargo Tanks

Cofferdams
Ship Design Requirements
Objectives

▶ Basic design principles
▶ Reinforcement requirements
▶ Propulsion & reduced Boil Off Rate
▶ Thermal analysis
▶ Cofferdam heating
Membrane LNGC design rules: Tank layout

- Cargo capacity < 180,000M³: 3 + 1 Tanks
- Cargo capacity > 200,000M³: 4 + 1 Tanks
Design rules: geometrical requirements

Transverse section:

- Upper chamfer $\geq 30\%H$
- Lower chamfer $\geq 2.50\text{m.}$
- Angle of chamfer $\approx 135^\circ$
Reinforcement distribution

Adjusted to operational profile

Go through sloshing analysis for non conventional applications

- Evaluate the max. expected impact pressures
- Compare with the CCS strength and behavior

Large cargo capacity

Offshore loading or unloading
Reinforcement Distribution, Example for NO96
BOR & Propulsion Systems

BOR = 0.150%p.d.

BOR = 0.100%p.d.
Protecting the Inner Hull

- **Outer hull under IGC code requirement**
  - $T_{\text{air}} = 5^\circ \text{C}$,
  - no wind,
  - $T_{\text{sw}}=0^\circ \text{C}$
  - Primary barrier damaged

- **Inner hull under USCG requirement**
  - $T_{\text{air}} = -18^\circ \text{C}$,
  - Wind speed = 5 Knots,
  - $T_{\text{sw}}=0^\circ \text{C}$
  - Air inside cofferdam at $5^\circ \text{C}$
  - Primary barrier damaged
Cofferdam heating system

- Cofferdam heating system allow a temperature of +5°C inside cofferdam in damaged conditions, to comply with grade A steel.

- Fully redundant as per IGC Code (§ 4.8.4)

- It includes:
  - 2 redundant coils per cofferdam
  - Glycol water mixture
  - 2 equally sized heaters (steam heated, shell & tube type)
  - 1 expansion tank
  - 1 glycol storage tank
  - 1 water/glycol mixing tank

- 1 electric heater recommended (and designed) for normal conditions
Liquid Motion
Objectives

▶ What is sloshing?
▶ Calculating sloshing loads
▶ Reducing effects of sloshing
Sloshing – What is it?

High fillings: standing wave
Impacts located on tank discontinuities, i.e. bottom of upper chamfers and ceiling

Low fillings: progressive wave
Impacts located on lower chamfers and longitudinal walls
The effects of sloshing in tanks

- **EFFECTS OF SLOSHING**
  - On Pump Tower structure: *Drag force*
  - On Cargo Containment System: *Impact Pressure*

Pump Tower
Sloshing: Global and Local

Sloshing: global behaviour...
- Sea-waves & ship motions
- Tank geometry & filling level
- Change of momentum of the liquid avoiding obstacles

... and local behaviour
- Escape of the gas
- Compression of gas
- Condensation
- Shock waves
- Fluid / structure interaction

Courtesy of Sloshel consortium

Local effects induce high variability of loads
Examples of impacts
Cause of sloshing

Waves

Ship motions

Cargo motions

Hull Girder loads
Parametric rolling

Sloshing Impact Loads

Particular Phenomenon deriving from a Complex Reality
How to estimate sloshing loads?

- Several options
  - Use full scale loads and feedback at sea
    - Difficult because of low occurrence number
    - Restricts innovative designs
  - Numerical simulation
    - Difficult as global and local effects cannot be considered simultaneously due to CPU constraints
  - Model tests
    - The best compromise but induce scaling issues

Only MODEL TESTS considered relevant for CCS design against sloshing impacts
Tools to calculate loads

**DIODORE**
Sea keeping

**Ship motions**
6 d.o.f. time series

**DIVA 3 D**
numerical simulation

**HEXAPOD TEST RIG**
1/40 model tests

Impact pressures

Loads on pump tower
DIVA3D: loads on pump tower

- Fluid velocity and acceleration calculated at model nodes
- Hydrodynamic forces calculated

Load profiles for pump tower strength analysis
Model testing: Impact pressures on CCS

6 d.o.f. test rig, fully automated (3 different rigs)

Model tank at scale up to 1/25

Independent measurement system: trajectory checking

Independent actuators: high precision of motions

Up to 300 sensors completely synchronized, dispatched in “array of sensors”

Tests with the same density ratio at full and model scales

Large range of motions can be simulated

Pressures for CCS sloshing assessment
Means to reduce sloshing

1. **Tank design**

   ![Tank Design Diagram]

   - C1
   - C2
   - H1
   - 135° Angle or close value

2. **CCS design**

   ![CCS Design Diagram]

   - Primary box
   - Secondary box
   - Increased Risk
   - Approved range
   - Approved Filling Range
   - Buried Filling Range

3. **Operational limits**
Objectives

- Mark III design concept
- System description
- Mark III Flex
- Mark V
MkIII Tank
Mark III Design Concept

The corrugated stainless steel primary barrier:

- Standard pitch: 340mm
- Thickness: 1.2mm
- Material: Stainless Steel 304L
The insulation panel components are made out of:

- **Secondary barrier: composite material named "Triplex"**
  - Material: aluminum foil bonded between two glass clothes
  - Versions: flexible band (named ‘Flexible Secondary Barrier’ or ‘FSB’) or rigid foil (named ‘Rigid Secondary Barrier’ or ‘RSB’)

- **Insulating material:**
  - reinforced polyurethane foam ("R-PUF")
  - Density: 120 / 130 Kg.m-3
  - Reinforcement: 10% glass fiber, in weight
Mark III Design Concept

The insulation panel

- it is a prefabricated component integrating the two insulation layers and the secondary barrier and on top of which the primary barrier is welded.
Mark III design concept

- **Thickness of the insulation**
  - Dedicated part for Mark III Flex at the end of the presentation

**MARK III**

270mm
Mark III design concept

- The Mark III components are:
  - highly standardized: low number of part references
  - highly prefabricated in workshop: ready-to-use

- The Mark III containment system mounting procedure is highly automated: reduced number of manual operations
System description – the flat wall area

- The flat wall area
  - The flat wall area is everywhere in the tank, except for the corners and the special areas.
System description – the flat wall area

- The main component of the flat wall area is the "Flat Panel".
  - It represents about 90% of all insulation panels used in a tank.
System description – the flat wall area

- The flat panel is a sandwich of several layers

- Two plywood boards at the top and the bottom of the sandwich

- Two R-PUF boards as insulating material

- RSB foil as secondary membrane

- All these components are bonded together in workshop with PU glue
System Description – The Flat Wall Area

- The flat wall area: flat panels in their context
System description – the dihedron

- The dihedron
  - It's the intersection of 2 tank faces
There are several different dihedron angles (90deg, 135deg, 108.4deg…)

The two more common angles being 90deg and 135deg.
System description – the dihedron

The insulation panel of the dihedron is called the "Corner Panel"

Typical 90° corner panel

Typical 135° corner panel
The corner panel structure is slightly different from the flat panel one.

Typical 90° corner panel, exploded view.
System description – the dihedron

- The primary level of the corner panel is a bolted assembly of 3 parts:
  - 1 thick stainless steel folded sheet (the "Steel Corner")
  - 2 thick plywood pieces

Steel corner bolted and tack welded
System description – the dihedron

- The dihedron: corner panels in their context

- 135° corner panels
- Bottom of the tank
- 90° corner panels
- Transverse bulkhead (fore or aft)
System description – the trihedron

- The trihedron
  - It's the intersection of 3 tank faces
The insulation panel in the trihedron area is called a "Trihedron" or "Three-way panel".

- The trihedron panel structure is very similar to the one of a corner panel,
- The parts are bonded using the same glues as for a corner panel.
System description – the trihedron

- Exploded view of a trihedron

Typical trihedron, exploded view
System description – the trihedron

- The trihedron: three-way panel in its context

![Trihedron diagram](image)

- Trihedron
- Transverse bulkhead (fore or aft)
- Bottom of the tank
System description – completion of the insulation

- Secondary barrier completion
  - The secondary barrier is closed by bonding FSB between panels
Triplex Flexible Secondary Barrier

Sandwich of Glass Cloth and Aluminium Foil
System description – completion of the insulation

- The top bridge pad has the same structure as the primary level of a flat panel:
  - Top plywood board
  - R-PUF board
  - Anchoring strip, riveted to the plywood
System description – completion of the insulation

- The primary insulation is completed by bonding "top bridge pads"
System description – primary barrier

- Membrane sheets are welded on anchoring strips
- The membrane sheets overlap one another
System description - reinforcements

- When needed, several types of containment system reinforcements are available.

For insulation panels

For membranes sheets
Reinforcements include

- Denser mastic ropes depositing
- Thicker bottom plywood (12mm instead of 9mm) for corner panels and three-way panels
System description – reinforcements for membrane

- Ribs are dents on the large corrugation to increase the buckling strength

View of a large corrugation with a rib
System description – reinforcements for membrane

- Plywood wedges are placed below large corrugations, small corrugations and sheets junctions
MkIII Overview
Mark III Flex: Requirements & Developments

Strength Increase
- The main evolution retained consists in increasing the foam density which provides higher compressive strength
- The Mark III Flex project will take benefit from the “all PU” bonding development

Insulation performance
- The thickness of insulation panels will have to be increased to comply with the conventional 0.15%V/day BOR in case of higher density foam
- The increase of insulation thickness will also provide lower BOR in case of standard density foam use in order to reach an objective of 0.1%V/day BOR
MkIII & MkIII Flex

MARK III
270mm

MARK III FLEX
400 mm
Mark V
Basis of the development

A new Cargo Containment System

- Based on the Mark III concept
  - Mark III corrugated primary membrane (304L, 1.2mm thickness)
  - R-PUF insulation panels
  - No anchoring of the membranes to the hull
  - Hull requirements consistent with actual Mark III hull scantling

- With new elements
  - Invar secondary membrane
  - Welded secondary membrane

- With improved performances
  - Target Boil-Off Rate: 0.075%V/day
General description

Corrugated Invar secondary membrane

Corrugated primary membrane identical to Mark III

No crossing of membranes

Anchoring to the hull with mastic identical to Mark III
MkIII Building
Objectives

1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. Primary membrane installation and testing
9. Final erection steps
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. Primary membrane installation and testing
9. Final erection steps
Scaffolding
Scaffolding

- Retractable scaffolding legs
- Retractable edges platforms
- Feet distribution according to panels arrangement
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. Primary membrane installation and testing
9. Final erection steps
Panels and studs positioning

- Step 3: Marking of flat panel axes

1. Preliminary mesh
2. Final mesh 3060x1020
3. Intermediate point
Panels and studs positioning

- Template for studs location marking out
- Studs welded using a welding gun
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. Primary membrane installation and testing
9. Final erection steps
Determination of the reference surface

- Using another GTT software (GTT-LISS)
  - Flatness measurements of all bulkheads: input of GTT-LISS software
  - Computing thickness of wedges and ropes of mastic
  - Flatness defaults corrected with wedges installation in way of studs

1. Measuring of the DZ values
2. Computing of the data / sizing of wedges and ropes
3. Installation on bulkheads
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. Primary membrane installation and testing
9. Final erection steps
Mastic application

Insulation panel / Inner hull bonding
load bearing epoxy mastic
Mastic application

- Sizing of mastic ropes according to reference surface calculation

**Typical depositing plan**

<table>
<thead>
<tr>
<th>Gap “G”</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e \leq 7$</td>
<td>C1</td>
</tr>
<tr>
<td>$7 &lt; e \leq 12$</td>
<td>C2</td>
</tr>
<tr>
<td>$12 &lt; e \leq 15$</td>
<td>C3</td>
</tr>
<tr>
<td>$15 &lt; e \leq 20$</td>
<td>C4</td>
</tr>
<tr>
<td>$20 &lt; e \leq 25$</td>
<td>C5</td>
</tr>
</tbody>
</table>
Mastic application

- Mastic depositing machine
- Application beneath panels
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. Primary membrane installation and testing
9. Final erection steps
Panel installation
Panel installation
Panel installation

- R-PUF + glass wool between corner panels and flat panels
- Glass wool between flat panels
- Cylindrical plugs above studs
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. Primary membrane installation and testing
9. Final erection steps
Manual & automatic bonding

FSB / RSB bonding
epoxy glue
or polyurethane glue
Manual & automatic bonding

- **Typical sequences of FSB strips installation**
  - Automatic or manual bonding of FSB strips between flat panels (purple)
  - Manual bonding of curved FSB strips between corner panels (red/brown)
  - Manual bonding of variable width FSB strips between flat panels and corner panels (green)
Manual & automatic bonding

- Automatic bonding machine (ABM) overview

- Protection tape
- Gluing income
- The chassis
- FSB roll
- Bonding direction
- Calibrating roller
- Displacement motorisation
- Heating skates
Manual & automatic bonding

▶ Manual bonding process
  ▶ FSB strip cutting
  ▶ Surface cleaning
  ▶ Adhesive tape application
  ▶ Spreading of thin layer of glue on RSB of panels
  ▶ Unrolling of FSB strip
  ▶ Rolling FSB surface to remove air bubbles
  ▶ Hold in position the bonded joint using pressure pads
Controls and secondary barrier global testing

- Vacuum Box control
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. **Primary insulation completion**
8. Primary membrane installation and testing
9. Final erection steps
Primary insulation completion

- Top Bridge Pads (TBP)
Top bridge panels held in place with temporary anchor bars
Primary insulation completion
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. **Primary membrane installation and testing**
9. Final erection steps
Primary membrane installation & testing

- **Marking of the membrane axes**
  - To fulfill the continuity of corrugations between all bulkheads
  - **Perpendicular lines**
    - Maximum deviation 1mm/1m
  - **Junction of lines**
    - Max misalignment 2mm

Laser equipment
Primary membrane installation & testing
Primary membrane installation & testing
Primary membrane installation & testing
Primary membrane installation & testing

- **Ammonia test**
  - Tightness testing of all welds of the tank membrane
  - Mixture injection NH3/N2 in IBS maintained at +20 mbarg
  - Visual detection of potential leaks by reactive paint application
  - Paint color change when NH3 passing through the leak
1. Scaffolding
2. Panels and Studs positioning
3. Determination of the reference surface
4. Mastic application
5. Panels installation
6. Secondary barrier completion
7. Primary insulation completion
8. Primary membrane installation and testing
9. Final erection steps
Final erection steps

- Pump tower installation
Final erection steps

- Scaffolding removal
- Side opening closing
- Final tests
NO96 System Components
Objectives

- 1. NO96 design concept
- 2. System description
- 3. NO96 Evolution
1. NO96 design concept
NO96 Tank
1. NO96 design concept

- The NO96 system is a membrane containment system for LNG transportation as defined by the IGC Code, including:
  - Tight thin metallic membranes.
  - Two layers of insulation.

- The NO96 design concept lays on two pillars:
  - A membrane made out of Invar®
  - Plywood boxes filled with an insulating material

- A fully redundant membrane and insulating system.
1. NO96 design concept

- **The Invar® membrane:**
  - Thickness: 0.7mm
  - Material: Invar® (36% Nickel-Steel Alloy)
1. NO96 design concept

- The insulation boxes:
  - Made of birch plywood or foam panel
  - Filled with insulating material (perlite or GW)

Secondary insulating boxes
2. System description
Agenda

▶ 1. NO96 design concept
▶ 2. System description
  ▶ 2.1. The flat wall area
  ▶ 2.2. The transverse corner
  ▶ 2.3. The longitudinal corner
  ▶ 2.4. The oblique corner
  ▶ 2.5. The trihedron
2.1 System description – the flat wall area

- The flat wall area: standard boxes in their context.
2.1 System description – the flat wall area

- The secondary boxes cannot be rigidly fixed to the inner hull:
  - The secondary boxes lay on mastic ropes instead of directly onto the hull.
  - Those mastic ropes are used to allow a good bearing of the loads.
  - The secondary boxes are not glued to the hull thanks to a sheet of kraft paper put between the mastic and the hull.
2.1 System description – the flat wall area

- Due to the ballast pressure, the hull deforms up to several millimeters between the stiffeners:
  - The secondary boxes *cannot be rigidly fixed* to the inner hull.
  - The anchoring device of the insulation system must allow for *degrees of freedom* to compensate for hull deformations.
2.1 System description – the flat wall area

- The anchoring device of the insulation system must allow degrees of freedom to compensate hull deformations:
  - The anchoring device is named “coupler”
  - The coupler is fixed to the inner hull through a ball-joint.
  - The coupler is elastic thanks to spring washers.
2.1 System description – the flat wall area

- Detail view of a coupler and its ball-joint base socket:

Coupler base socket welded on hull
2.1 System description – the flat wall area

- Coupler deformation under ballast conditions:

![Diagram](image)

Spring washers
2.1 System description – the flat wall area

- Coupler and mastic ropes in their context, detail view:
2.1 System description – the flat wall area

- The insulation of the cargo is completed by filling the gap between insulation boxes:
  - At secondary level, using rigid poly-urethane foam
  - At primary level, using glass wool
2.1 System description – the flat wall area

- NO96 membranes:
  - U-shaped 500mm wide Invar strakes
  - Running from one corner of the tank to the other following some specific directions.
2.1 System description – the flat wall area

- This membranes are fixed to:
  - Each other through seam welds along raised edges
  - The insulation boxes with an invar element named “tongue”
2.1 System description – the flat wall area

- The membrane strakes have to cope with two different kinds of constraint:
  - **Thermal strain** due to the low temperature of the cargo
  - **Mechanical strain** due to the movements of the ship.

  - **Invar material** & lateral flexibility through raised edges
  - **Connection to the ship structure**
2.1 System description – the flat wall area

- Compensation of thermal strain:
  - Raised edges ensure lateral flexibility to the membrane.

Thermal strain absorbed by raised edges lateral flexibility
2.1 System description – the flat wall area

- Compensation of mechanical strain: transmission to ship structure.
  - Membranes are connected to the ship structure (inner hull) through a component named “tube”.

![Diagram showing Invar® tube and Inner hull connection]
Agenda

1. NO96 design concept
2. System description
   2.1. The flat wall area
   2.2. The transverse corner
   2.3. The longitudinal corner
   2.4. The oblique corner
   2.5. The trihedron
2.2 System description – transverse corner

- Different angles for TC
  - Cylindrical tank (n°2, 3 and 4) → 90° angle TC
  - Tank n°1 (special shape): non 90° angle TC
2.2 System description – transverse corner

- The main component of the TC is the membrane component named “tube”, linking the primary and secondary membrane to the hull.
2.2 System description – transverse corner

- Standard Transverse Corner arrangement:

![Diagram showing Thermal strain, Mechanical strain, Invar® tube, Invar® strips, and Anchoring flat bars.]
Agenda

▶ 1. NO96 design concept
▶ 2. System description
  ▶ 2.1. The flat wall area
  ▶ 2.2. The transverse corner
  ▶ 2.3. The longitudinal corner
  ▶ 2.4. The oblique corner
  ▶ 2.5. The trihedron
2.3 System description – longitudinal corner

- Along the Longitudinal Corner, the membrane loads are low (limited bending effect).
2.3 System description – longitudinal corner

- The Longitudinal Corner arrangement:

- Boxes
- Insulation
- Invar® strake
- Invar® Angle bar
- Fasteners
Agenda

1. NO96 design concept
2. System description
   2.1. The flat wall area
   2.2. The transverse corner
   2.3. The longitudinal corner
   2.4. The oblique corner
   2.5. The trihedron
2.4 System description – the oblique corner

- The Oblique Corner (OC) is the junction between the upper/lower faces and the chamfers in tank nr. 1.
2.4 System description – the oblique corner

- From the membrane loads point of view, it is a mix of a Longitudinal Corner and a Transverse Corner.

On the lower/upper faces, similar to a Transverse Corner: high membranes loads.

On chamfers, similar to a Longitudinal Corner: low membranes loads.
2.4 System description – the oblique corner

- The anchoring device of the Oblique Corner designed to sustain the membranes loads is named “pillar”.

![Diagram of Oblique Corner with brackets highlighted]
2.4 System description – the oblique corner
Agenda

1. NO96 design concept
2. System description
   ▶ 2.1. The flat wall area
   ▶ 2.2. The transverse corner
   ▶ 2.3. The longitudinal corner
   ▶ 2.4. The oblique corner
   ▶ 2.5. The trihedron
2.5 System description – the trihedron

- Trihedron arrangement:
  - Anchoring flat bars
  - Trihedron
  - Insulation
  - Boxes
NO96 Overview
3. NO96 Evolution – NO96 Max
The Market Drivers

CCS reinforcement

- LNG Carriers
  - Less restrictive for increased flexibility
- Small scale / Bunker vessels
  - All fillings operations are needed for partial loading/unloading
- Offshore (FPSO, FSRU, Ship-To-Ship Transfer)
  - All fillings conditions required by offshore operations are susceptible to generate high sloshing impacts

CCS Low BOR

- BOG needs for propulsion is continuously reduced:
  - Progress made in hull design and propulsion efficiency
  - Flexibility in operation (lower speed, spot market...)

GTT Training

Safety Excellence Innovation Teamwork Transparency
The Market need

Low BOR / CCS reinforcement?
- A compromise based on the shipowner’s need
Concept breakthrough
Based on an efficient structure...

- **The pillar geometry** offers a better strength than **bulkhead geometry**.
  - The bulkhead is subject to **buckling**.
  - The pillar is only limited by the **compressive strength of material**.

**Bulkhead failure**: buckling

**Pillar failure**: compression

- **Strength increased by 150%**
- **Low inertia → Buckling**
- **High inertia → No Buckling**
The optimized design

Based on NO96 philosophy & sea proven materials

- Invar
- Densified plywood
- Glass wool
- Resin

![Diagram showing various components such as Pillar, Stiffener, Bottom, NO Max coupler, Resin patch, Primary invar membrane, and Upper top.]
Increased flexibility

Possibility to reach low BOR...
...Or higher strength!

NO96 cross section

Bearing structure = 10% of box volume

NO96 Max reinforced cross section (Offshore, heavier gas, partial fillings...)

Bearing structure = 10% of box volume

NO96 Max Low BOR cross section

Bearing structure = 3% of box volume
NO96 Erection Sequence
Objectives

- Scaffolding
- Marking of Inner Hull
- Flatness treatment
- Erection of
  - Insulation
  - Membrane
  - Tests and Controls
- Scaffolding
- Marking of Inner Hull
- Flatness treatment
- Erection of
  - Insulation
  - Membrane
  - Tests and Controls
Scaffolding erection during block assembly
Installation of scaffolding: Bottom part

Normal load : 2.5 bar
Max load : 5 bar
Scaffolding erection
Objectives

- Scaffolding
- **Marking of Inner Hull**
- Flatness treatment
- Erection of
  - Insulation
  - Membrane
  - Tests and Controls
Positioning of coupler sockets
Coupler base socket installation

Can be performed at block stage
Objectives

- Scaffolding
- Marking of Inner Hull
- **Flatness treatment**
- Erection of
  - Insulation
  - Membrane
  - Tests and Controls
Hull flatness allowance

Proper bearing of the secondary insulation with limited resin consumption
Determination of the reference surface

a) Measuring of the DZ value

b) Computing of the data sizing of wedges and mastic ropes

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Determination of the reference surface

Reference surface is not necessary flat

Reference wedges

Laser beam

Coupler number

dz measurement

Reference surface obtained

Hull deformation
Wedging and stopper clip

Piling type wedges made by molded injected plastic

Machine plywood or hard wood type
Wedges
Distribution of resin ropes on a typical bulkhead
Objectives

- Scaffolding
- Marking of Inner Hull
- Flatness treatment
- **Erection of**
  - Insulation
  - Membrane
  - Tests and Controls
Transverse corner anchoring bar erection

Marking operation

Welding operation
Boxes delivered to vessel
Typical resin depositing machine
Securing the boxes onto the inner hull
Erection of the transverse corner

**Transverse corner sequences**

a) Glass wool +5B box
b) Invar tube + 6B box
c) Welding on anchoring bars + tests (visual + DPT)
d) Boxes 7B, 8B and 9B
e) Primary strips welding on anchoring bars and tube + tests
Insulation along the longitudinal corner

The Longitudinal Corner arrangement:

- Invar® strake
- Angle Invar® bar
- Boxes
- Insulation
- Fasteners
Secondary membrane

Anchoring on secondary boxes

- Invar strip «L tongue»
- Invar strake 1
- Invar strake 2
- Box
- Cover
- Seam weld

Local control
Remote control
Uncoiling of invar strakes

Uncoiling machine
A very modern method....
Secondary membrane testing

- Initial vacuum test at -800mb
- Helium injected and its presence checked at locations around the tank
- All welds tested with a gas detector
- Helium injection and sample point sealed
- Tested again at -800mb
- Held at -800mb during installation of primary boxes to show if there is any damage to the membrane during this process
Helium Sampling Point
Gas Detection Test
Securing of primary boxes

- Self locked nut
- Spring washer
- Collar stud
- 80 x 40 x 6 plate
Installation of the continuous invar strip

Anchoring on primary boxes

- Invar strip
- Invar strake 1
- Invar strake 2
- Invar Clip anchored in internal bulkhead
- Seam weld
- Box Cover

Steps:
1. Step 1
2. Step 2
3. Step 3
Primary membrane testing

- Similar to secondary membrane testing
- Initial vacuum test at -800mb
- Helium injected and its presence checked at locations around the tank
- All welds tested with a gas detector (Repeated 2 times)
- Helium injection and sample point sealed
- Tested again at -800mb
- Held at -800mb during the removal of the scaffolding from the tank to detect any damage to the membrane