

**BUREAU
VERITAS**

Strength Assessment of LNG Membrane Tanks under Sloshing Loads

May 2011

**Guidance Note
NI 564 DT R00 E**

Marine Division
92571 Neuilly sur Seine Cedex – France
Tel: + 33 (0)1 55 24 70 00 – Fax: + 33 (0)1 55 24 70 25
Marine website: <http://www.veristar.com>
Email: veristarinfo@bureauveritas.com
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MARINE DIVISION

GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a Society the purpose of whose Marine Division (the "Society") is the classification ("Classification") of any ship or vessel or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

The Society:

- prepares and publishes Rules for classification, Guidance Notes and other documents ("Rules");
- issues Certificates, Attestations and Reports following its interventions ("Certificates");
- publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as "Certification".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1.2. and 1.3. are referred to as "Services". The party and/or its representative requesting the services is hereinafter referred to as the "Client". **The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.**

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit's valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Shipbuilder, Repair yard, Charterer or Shipowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraisal given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraisal is represented by a class entered on the Certificates and periodically transcribed in the Society's Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - It is incumbent upon the Client to maintain the condition of the Unit after surveys, to present the Unit for surveys and to inform the Society without delay of circumstances which may affect the given appraisal or cause to modify its scope.

2.4. - The Client is to give to the Society all access and information necessary for the safe and efficient performance of the requested Services. The Client is the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out.

ARTICLE 3

3.1. - The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.

Committees consisting of personalities from the Industry contribute to the development of those documents.

3.2. - The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society's intervention.

3.3. - The Services of the Society are carried out by professional Surveyors according to the applicable Rules and to the Code of Ethics of the Society. Surveyors have authority to decide locally on matters related to classification and certification of the Units, unless the Rules provide otherwise.

3.4. - The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not in any circumstances involve monitoring or exhaustive verification.

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- conducts surveys at the place of their construction;
- classes Units and enters their class in its Register;
- surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.

5.2. - The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for.

In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

5.3. - The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder, respectively.

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - If the Services of the Society cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one and a half times the above mentioned fee.

The Society bears no liability for indirect or consequential loss such as e.g. loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on were first known to the Client, and any claim which is not so presented shall be deemed waived and absolutely barred. Time is to be interrupted thereafter with the same periodicity.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice issued according to 7.2. here above subject to compliance with 2.3. here above and Article 8 hereunder.

7.4. - The contract for classification and/or certification of a Unit cannot be transferred neither assigned.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve, for the part carried out, the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. Overdue amounts are increased as of right by interest in accordance with the applicable legislation.

8.3. - The class of a Unit may be suspended in the event of non-payment of fee after a first unfruitful notification to pay.

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential. However:

- clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the **classification file** consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit;
- copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society, where appropriate, in case of the Unit's transfer of class;
- the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units, as well as general technical information related to hull and equipment damages, are passed on to IACS (International Association of Classification Societies) according to the association working rules;
- the certificates, documents and information relative to the Units classed with the Society may be reviewed during certifying bodies audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event not reasonably foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society's surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society's invoices by the Client are submitted to the Court of Nanterre, France.

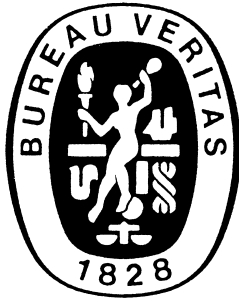
12.3. - Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.

ARTICLE 13

13.1. - These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether express or implied. They may be varied in writing by mutual agreement.

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.



GUIDANCE NOTE NI 564

NI 564

Strength Assessment of LNG Membrane Tanks under Sloshing Loads

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SECTION 3	COMPARATIVE STRENGTH ASSESSMENT
APPENDIX 1	PUMP MAST STRENGTH ASSESSMENT

May 2011

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SECTION 1

GENERAL

1 Introduction

1.1 Context

1.1.1 Sloshing became a very important practical problem in the last decade due to the increased activities in the LNG transport. Large numbers of LNG carriers were built or are under construction with the capacities which almost doubled as compared to the classical LNG carriers (from 138 000 m³ to 240 000 m³). The most common LNG carriers belong to the so-called membrane type. Within the membrane type concept, which is of main concern here, the LNG is kept at very low temperature (– 163°C) by means of a complex insulation system which is attached to the ship structure.

1.1.2 At the same time the size of LNG carriers increased, the operational requirements became more and more severe. Indeed, in the past, LNG carriers were allowed to operate either in full or in empty tank conditions, while today there is sometimes necessity to allow for operating at any filling level. This requirement introduces serious difficulties in the design of both the containment systems and the associated ship structure. Violent sloshing motions may occur and the direct consequence is the occurrence of different impact situations, which can induce the large structural loadings possibly damaging both the containment system and the ship structure.

1.1.3 The present Guidance Note:

- should apply to the LNG carriers and the offshore LNG floating units using the membrane technology
- focuses on the strength assessment of cargo containment systems and hull structure under sloshing impact loads. Strength assessment of pump mast and its supporting structure is described in App 1.

1.1.4 The determination of the sloshing impact loads is described in the separate Guidance Note NI554 “Design Sloshing Loads for LNG Membrane Tanks”. The analysis of navigation conditions, the sea-keeping calculations, CFD calculations and small-scale sloshing tests allow to define the design sloshing loads on the different areas of the tanks.

1.2 General methodology

1.2.1 When trying to reproduce the sloshing phenomenon, either experimentally or numerically, the complexity of the associated physics is emphasized:

- its stochastic nature
- its both local and global behavior
- the scaling from small to real scale
- the cryogenic environment
- the dynamics of the phenomenon
- the hydro-elastic effects occurring between the hydrodynamic loading and the structural response of the cargo containment system
- the non-linear structural response of the cargo containment system
- ...

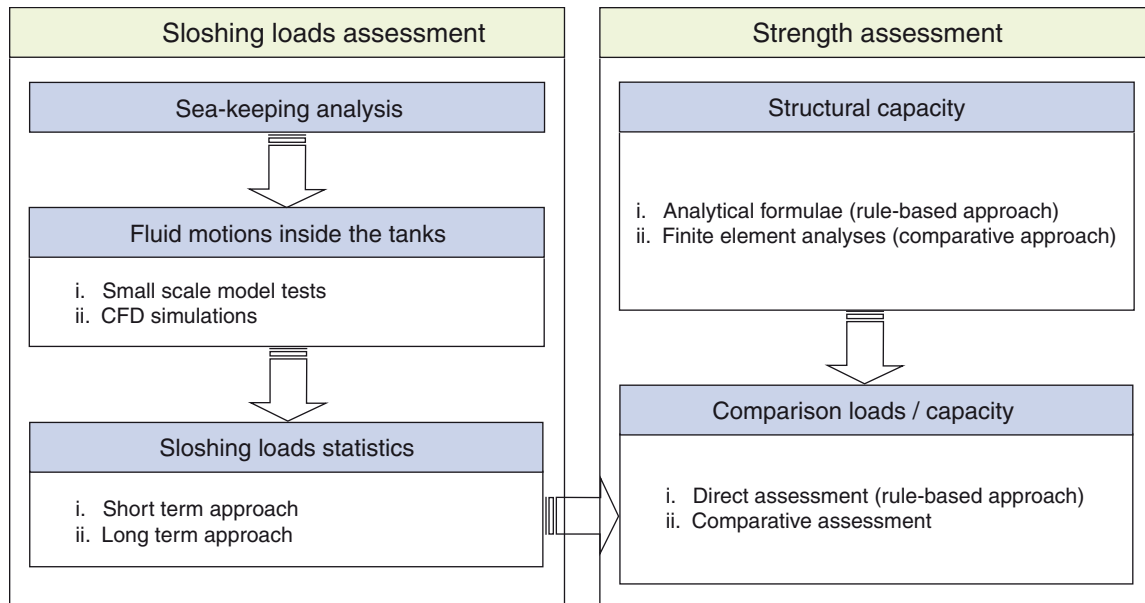
All these difficulties make it impossible to perform a direct evaluation of the strength of the insulation systems and hull structure, at least with the current knowledge and the numerical and material resources. Therefore, this Guidance Note proposes simplified procedures that can be applied. Whenever a simplification is needed, it is clearly stated and its effects are discussed.

1.2.2 The first level of assessment, very simplified, uses a rule-based approach to derive extreme values of allowable sloshing pressures; it is currently available for NO96 containment system only. This method relies on analytical formulae, and thus, considers many simplifying hypotheses. It should therefore only be used in a screening phase: if some areas of the LNG tank present design sloshing loads (impact pressures) larger than, or of the same order of magnitude as, the allowable values analytically calculated, then a more refined analysis should be performed.

1.2.3 Then, given the very large feedback available, a comparative approach may be considered. The philosophy of this approach is that, if a target ship is more resistant than a reference ship and if the latter has never sustained damages due to sloshing impact loads, then the target ship will not sustain damages either. This approach is characterized by the use of non-linear and dynamic finite element analyses, which allow to take into consideration most of the physics involved in the structural response of cargo containment systems under sloshing impacts.

1.2.4 The global sloshing assessment procedure is summarized in Fig 1.

Figure 1 : Sloshing assessment procedure



1.2.5 During the review of a new concept or in case of substantial modification of a containment system, the Society requests wet drop tests or equivalent tests are performed.

A wet drop test consists in letting a sample of the analyzed containment system fall onto calm water. It should be carried out for different drop heights (to get different impact velocities) and drop incidences (relative angles between the surface of the containment system and the liquid surface). The principal advantage of the wet drop test is the representation of the fluid/structure impact interaction in realistic conditions with real cargo containment system.

Drop tests have been investigated several times in the past, by containment system designers and by shipyards, with the support of the Society. The aims of these tests were different, depending on their characteristics. Some of them were carried out to define a relation between the pressure and the fluid velocity, others were carried out in a comparative way to determine the best insulation system regarding sloshing impacts.

1.2.6 This note is a guidance note and, as such, proposes only a method and gives the corresponding recommendations on the procedure to be applied. It is the designer's responsibility to opt either to use the methodology proposed in this guidance note, or to propose any other procedure. In any case, this choice should be discussed with the Society.

2 Description of cargo containment systems

2.1 General

2.1.1 The two major containment systems - NO96 and MarkIII, designed by GTT - are covered here and described respectively in [2.2] and [2.3].

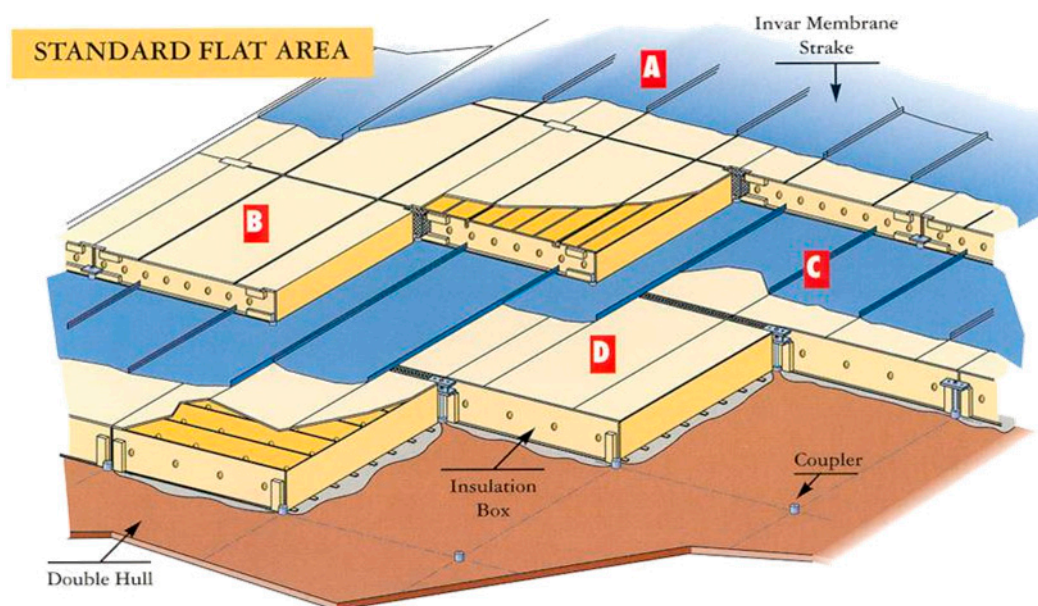
2.1.2 They both consist in a two-layer system, insulating the hull structure from the cryogenic temperature of the LNG. They only differ in the way the insulation is achieved.

2.2 NO96 system

2.2.1 NO96's basic element consists in two plywood boxes corresponding to the two insulation layers: the primary box (tank side) and the secondary box (double hull side). They are filled with an insulation material called perlite. Each box covers a 1-m² surface and is stiffened by internal bulkheads. All plywood parts are fixed one to another by staples.

The secondary box is fixed to the inner hull structure at its four corners by couplers and lays on mastic ropes. It is separated from the primary box by an invar (steel-nickel alloy) membrane and the primary box is separated from the inside of the tank (i.e. the LNG) by another invar membrane. The global arrangement is shown in Fig 2.

Figure 2 : NO96 system general arrangement (courtesy of GTT)



- A : Primary invar membrane
 B : Primary box
 C : Secondary invar membrane
 D : Secondary box.

2.2.2 Plywood primary and secondary boxes exist in four levels of reinforcement (standard, reinforced, super reinforced and ultra reinforced), differences consisting mainly in the thickness of the plywood sheets and the number and height of bulkheads. The main dimensions of the plywood boxes and the characteristics of each reinforcement level are detailed in Tab 1.

Table 1 : Reinforcements of NO96 primary and secondary boxes

Reinforcement level	Dimensions of the primary box (mm)							
	h	S	t_c	t_{w_i}	t_{w_e}	h_{comb}	t_{comb}	b
Standard	209	116	1 x 12	9	9	30	12	1132
Reinforced	209	113	2 x 12	12	9	30	12	1132
Super reinforced	209	113	2 x 12	12	12	30	12	1135
Ultra reinforced	209	110	2 x 12	15	15	30	12	1135

Reinforcement level	Dimensions of the secondary box (mm)							
	h	S	t_c	t_{w_i}	t_{w_e}	h_{comb}	t_{comb}	b
Standard	300	166	9	9	9	30	12	981
Reinforced	300	166	9	12	9	30	12	981
Super reinforced	300	166	9	12	12	200	12	485
Ultra reinforced	300	166	9	15	15	200	12	334

Note 1:

- b : Length of the bulkheads (distance between sidewalls or, in case of 200-mm combs, between sidewall and comb or between combs)
 S : Cell width (spacing between two primary bulkheads)
 h : Height of the box
 t_c : Thickness of the cover plate. When two cover plates are indicated, they are stapled together.
 t_{w_i} : Thickness of the internal primary bulkheads
 t_{w_e} : Thickness of the external primary bulkheads
 h_{comb} : Height of the comb(s)
 t_{comb} : Thickness of the comb(s).

Primary and secondary boxes are stiffened by the following bulkheads:

- Primary bulkheads
 - external bulkheads: 2, at the edges of the boxes
 - internal bulkheads: 7 for primary boxes (the 2nd and the 6th being always 24 mm thick) and 4 for secondary boxes.

The primary bulkheads of the primary boxes are oriented perpendicularly to those of the secondary boxes

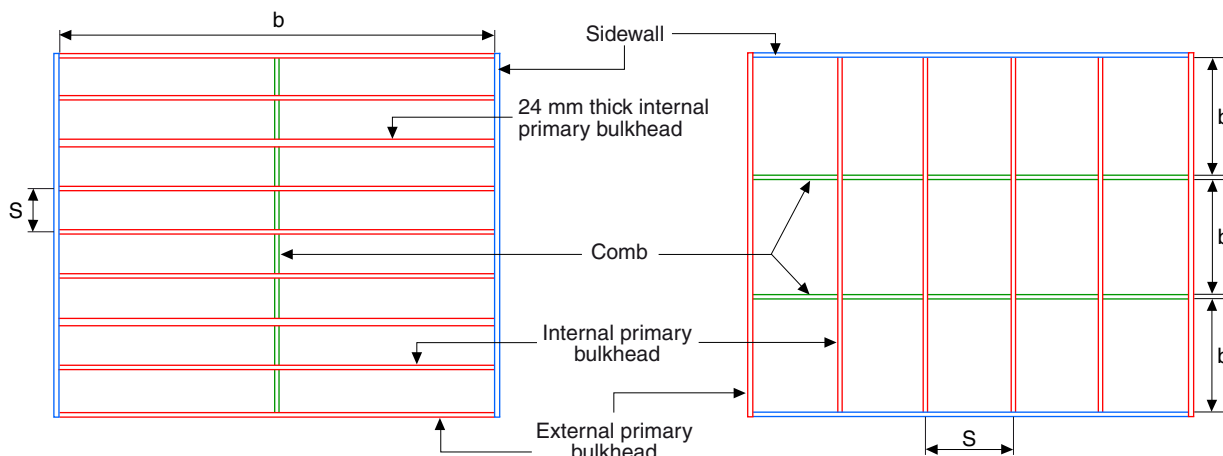
- Additional bulkheads perpendicular to the primary ones

These additional bulkheads are called combs and their height h_{comb} is equal to:

- either 30 mm (standard height): such combs (at mid-span of primary bulkheads) are only used to make the manufacturing easier and are not taken into consideration for the stiffening. It is the case for all the primary boxes and the standard and reinforced levels of secondary boxes, or
- 200 mm: in this case, the combs have a stiffening role. It is the case for super reinforced secondary boxes (one 200-mm comb, at mid-span of primary bulkheads) and ultra reinforced secondary boxes (two 200-mm combs, at 1/3 and 2/3 of the span of primary bulkheads).

Examples of a primary box and an ultra reinforced secondary box are shown in Fig 3.

Figure 3 : NO96 primary box (left) and ultra reinforced secondary box (right) - Top view



2.3 MarkIII system

2.3.1 MarkIII system ensures the insulation, using two layers of reinforced polyurethane foams separated one from the other by a membrane, called secondary barrier, consisting in a triplex membrane (composite material made of an aluminum sheet between two glass fiber sheets). The secondary foam layer (double hull side) is made in one continuous block, whereas the basic primary foam layer (tank side) presents slots. A plywood sheet is fixed on the top of the primary foam layer (called "top plywood"), and another is fixed on the back of the secondary foam layer (called "back plywood"). All components are glued together, and the whole system is fixed to the hull structure using mastic ropes positioned between the back plywood and the hull.

Unlike NO96 containment system that uses 1 m² boxes, MarkIII system is based on larger pre-assembled panels: a basic flat panel approximately covers a surface of 3 m².

The global arrangement of the MarkIII system is shown in Fig 4.

2.3.2 A corrugated stainless steel membrane, called primary barrier, is fixed on the top plywood. Three types of membranes can be used, depending on the level of reinforcement: standard membrane and membrane with ribs, with or without wooden wedges devices inside the corrugations.

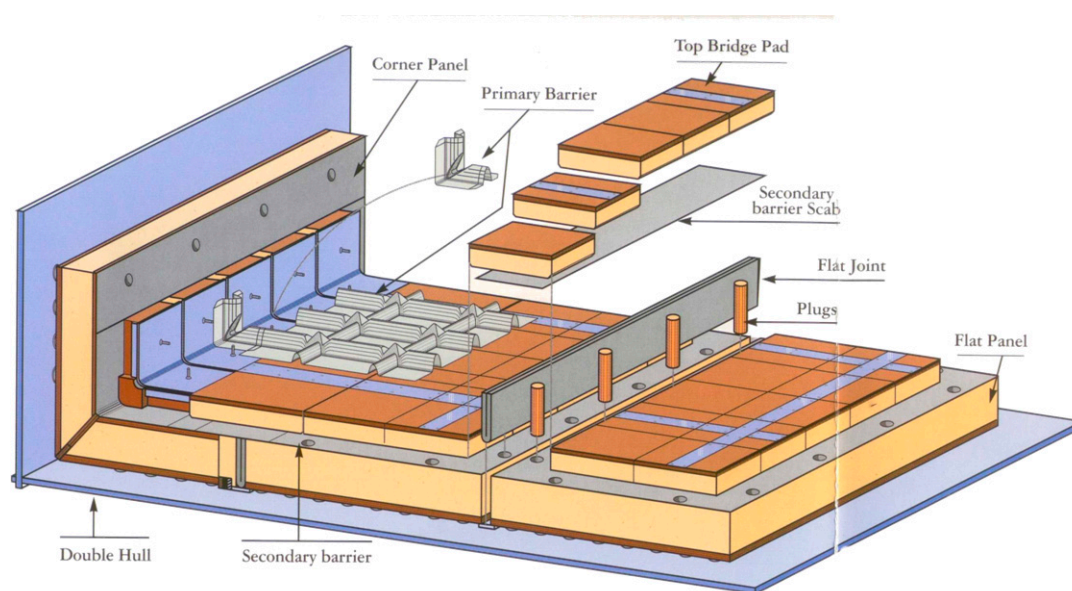
2.3.3 The MarkIII panel can be reinforced by reducing the gap between mastic ropes from 140 mm to 100 mm. The main dimensions of the containment system and the corresponding scantlings are detailed in Tab 2.

Table 2 : Reinforcement of MarkIII panel

Reinforcement level	Dimensions of the panel (mm)				
	L_{prim}	L_{sec}	t_{top}	t_{back}	G
Standard	90	160	12	9	140
Example of reinforcement	90	160	12	9	100

Note 1:

L_{prim} : Thickness of the primary foam layer
 L_{sec} : Thickness of the secondary foam layer
 t_{top} : Thickness of the top plywood
 t_{back} : Thickness of the back plywood
G : Gap between two mastic ropes.

Figure 4 : MarkIII system general arrangement (courtesy of GTT)

SECTION 2 RULE-BASED STRENGTH ASSESSMENT

Symbols

$S, b, h, t_{w_i}, t_{w_e}, t_c$: Dimensions and thicknesses of the NO96 box, as defined in Sec 1, Tab 1. These symbols may concern primary or secondary boxes, this indication being, if necessary, specified in index (e.g.: $S_{\text{primary}}, t_{c, \text{secondary}}$).

1 Strength assessment NO96 system

1.1 Pressures

1.1.1 The pressures to be taken into account are:

P_p : Peak pressure, in kPa, corresponding to the maximum statistical pressure given by small scale model tests (at scale 1:50 or 1:40) in a unique sensor (with diameter 5mm)

P_{qs} : Quasi-static pressure, in kPa, corresponding to the maximal pressure to be taken in the numerical simulations.

1.1.2 Alternatively, if there is no model test result (and so P_p is not known explicitly) or no numerical simulation result (and P_{qs} is not known explicitly), the following relation may be used:

$$P_p = 7 \cdot P_{qs}$$

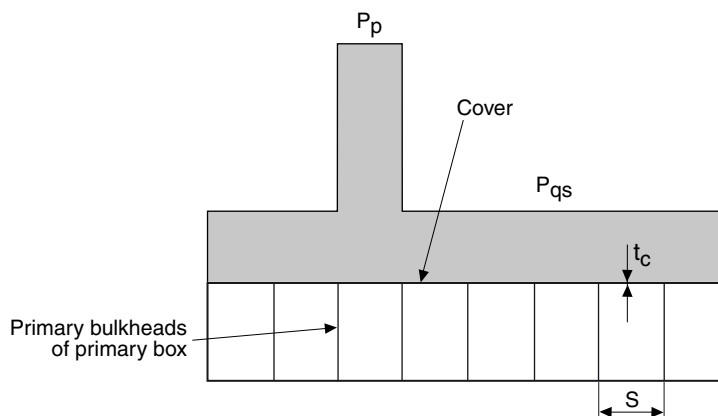
Factor 7 is coming from the analysis of wet drop tests and impact full scale tests.

1.1.3 In this simplified procedure, no amplification factor due to dynamic characteristic of the load (rise time) is taken into account.

1.2 Structural assessment of the cover plate

1.2.1 The load is to be applied according to Fig 1.

Figure 1 : Load distribution for the cover plate assessment



1.2.2 Bending

As the cover is cut by grooves for membrane fixation, it may be assumed semi clamped. Then, the moment M is given by:

$$M = \frac{P_p \cdot S^2}{10}$$

Therefore the bending stress σ in the cover plate is equal to:

$$\sigma = \frac{6 \cdot P_p \cdot S^2}{10 \cdot t_c^2}$$

Finally, the allowable peak pressure corresponding to bending failure is equal to:

$$P_{p, \text{allowable}} = \sigma_{\text{allowable}} \cdot \frac{10 \cdot t_c^2}{6 \cdot S^2}$$

with:

$\sigma_{\text{allowable}}$: Allowable bending stress, determined from material mechanic tests in cryogenic environment.

1.2.3 Shear

The shear stress τ in the cover plate is given by:

$$\tau = \frac{P_p \cdot S}{2 \cdot t_c}$$

Therefore, the allowable peak pressure corresponding to shear failure is equal to:

$$P_{p, \text{allowable}} = \frac{2 \cdot \tau_{\text{allowable}} \cdot t_c}{1,5 \cdot S}$$

where:

$\tau_{\text{allowable}}$: Allowable shear stress, determined from material mechanic tests in cryogenic environment.

1.3 Buckling assessment of the primary boxes

1.3.1 The load is to be applied according to Fig 2.

Test results show that the peak pressure P_p applies to a small surface. The considered surface to determine P_p being a cell surface, the same surface is used for the buckling verification. The strength of the internal and external primary bulkheads of the primary boxes is to be assessed according to the following load per unit length, as shown in Fig 3:

- for the internal primary bulkheads:

$$P = P_p \cdot S$$

- for the external primary bulkheads:

$$P = P_p \cdot \frac{S}{2}$$

Figure 2 : Load distribution for the primary bulkhead assessment

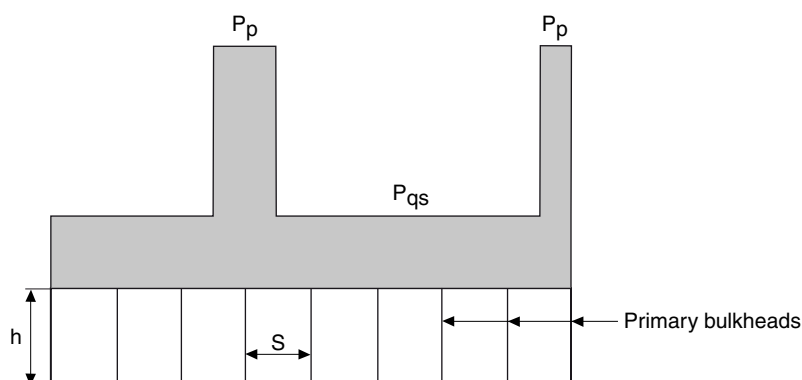
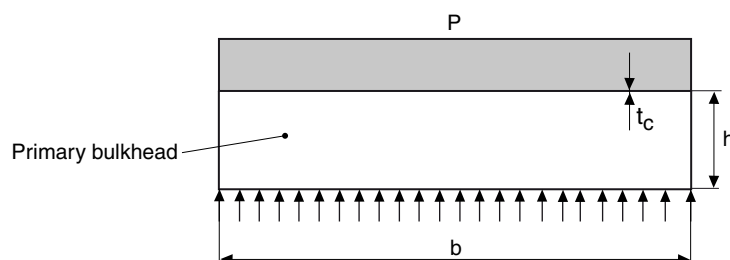


Figure 3 : Buckling assessment



1.3.2 Assuming that the bottom part of the bulkhead is fully supported, the buckling limit load is given in NR467 Rules for Steel Ships, Pt B, Ch 7, Sec 1, [5.3]:

$$P_{\text{allowable}} = \sigma_{\text{allowable}} \cdot t_w = \frac{\pi^2}{12} \cdot \frac{E}{(1 - \nu^2)} \cdot \left(\frac{t_w}{b}\right)^2 \cdot K \cdot \varepsilon \cdot t_w$$

with:

t_w : $t_{w,i}$ or $t_{w,e}$, depending on the bulkhead under consideration

K : Factor, to be taken as:

$$K = 4 \quad \text{for } \alpha = \frac{h}{b} \geq 1$$

$$K = \left(\alpha + \frac{1}{\alpha}\right)^2 \quad \text{for } \alpha = \frac{h}{b} < 1$$

ε : Factor to be taken equal to 1,30

E : Young modulus of the bulkhead in the direction of the load (strong direction of the plywood).

1.3.3 Assuming a safety factor of 1,5, the allowable peak pressure corresponding to the failure of the primary bulkheads is defined as:

- for the primary external bulkheads:

$$P_{p,\text{allowable}} = \frac{2}{3} \cdot \frac{\pi^2}{12} \cdot \frac{E}{(1 - \nu^2)} \cdot \left(\frac{t_{w-e}}{b}\right)^2 \cdot K \cdot \varepsilon \cdot \frac{t_{w-e}}{S/2}$$

- for the primary internal bulkheads:

$$P_{p,\text{allowable}} = \frac{2}{3} \cdot \frac{\pi^2}{12} \cdot \frac{E}{(1 - \nu^2)} \cdot \left(\frac{t_{w-i}}{b}\right)^2 \cdot K \cdot \varepsilon \cdot \frac{t_{w-i}}{S}$$

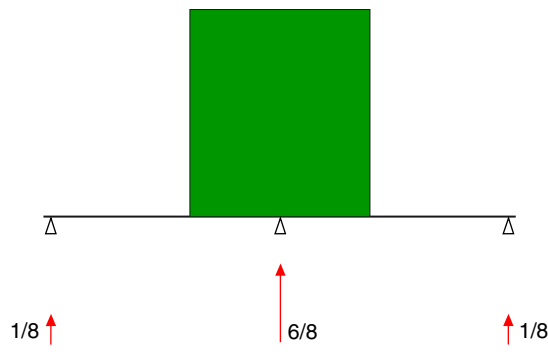
1.4 Buckling assessment of the secondary boxes

1.4.1 Damping effect

For the analysis of the buckling of the secondary boxes, the following damping effect is to be taken into account: the peak pressure on the primary box is distributed on the two primary bulkheads of the secondary box as shown in Fig 4.

A quarter of the total reaction force is distributed on the two adjacent primary bulkheads. Consequently, a coefficient of damping on the load on the most loaded primary bulkhead of the secondary box may be applied. This coefficient may be taken equal to 3/4. However, this damping coefficient is applicable to the internal primary bulkheads, but not always to the external primary bulkheads.

Figure 4 : Damping effect for secondary boxes



1.4.2 Case of lower filling levels

This requirement aims at the assessment of the boxes located in way of the foot of longitudinal and cofferdam bulkheads. In this case, the pressure from the wave is as given in Fig 5.

The critical stress is multiplied by a proportionality factor k , equal to:

$$k = \frac{S_{\text{primary}}}{S_{\text{primary}} + h_{\text{secondary}}}$$

and the critical load calculated using formulae in [1.3.3] is multiplied by $1/k$.