EXPERIMENTAL INVESTIGATION OF THE DYNAMIC ANGLE OF GRAIN SLIDING AND ITS IMPACT ON SHIP'S SAFETY.

FINAL DISSERTATION FOR THE DEGREE OF MASTER OF SCIENCE IN MARINE TECHNOLOGY

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STUDENT DECLARATION

I hereby declare that this dissertation contains only work completed by myself except for information obtained from written and online literature and university sources, which has been duly referenced and acknowledged in accordance with the university's policy on plagiarism.

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Montreal, October 18th 2018

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ABSTRACT

The carriage of grain by sea is one of the most regulated operations in the maritime industry given the risks of sliding accidents, Biran (2017) cites Arndt (1968) referring to 31 incidents involving sliding loads, 13 of them leading to sinking of vessels. The procedures and calculations for loading grain have been long established and are well known in the industry. Loading and carrying grain entails having as many cargo compartments loaded to their maximum capacity as possible to avoid the likelihood of shifting and the effect of heeling moments (IGC, 1991) . This is, in most occasions, not viable. Having several parcels with different grades to be segregated, loaded and discharged in different ports, results in going to the sea with a number of slack compartments.

There are various solutions to this dilemma, one of the most practical being the use of ballast to improve stability by increasing the displacement and reducing the vertical height of the center of gravity of the vessel. But even this solution has setbacks: the increase in draught or what is worse, the risk of exceeding the seasonal load line. To counteract for the former, the ballast is pumped out once the port limits are reached provided the ship's rolling is not near the angle of repose. This procedure has been widely performed without the benefit of experimental data on the dynamic angle of shifting of the grain (the only available data is the static angle of repose) and a reliable calculated safety margin. Moreover, no records were found of experimental physical measurements of the grain's angle of shifting in dynamic conditions on ships.

This project undertakes the construction of a typical bulk carrier cargo hold, suspended in a rotating mechanism, partially filled with samples of grain loaded in terminals, to perform the experimental measuring of the angle of shifting in dynamic conditions, and to determine its equivalence with the static angle of repose. It also performs a probabilistic analysis of the safety margins between the angle of rolling at sea and the angle of shifting at sea (dynamic), all in order to provide a tool to ship operators and masters for safe deballasting operations at sea when loaded with grain.

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ABREVIATIONS

AOR	Angle of repose
Ak	Bilge keel area
AOS	Angle of shifting
B	Breadth of the ship
bk	Bilge keel width
BM	Bending moment
Cb	Block coefficient
Cu	Upper deck area coefficient
D	Depth of the ship
FS	Free surface
GM	Metacentric height. Vertical distance from the centre of gravity to the transverse metacentre
GZ	Righting arm. Projection of G over the vertical from the new center of buoyancy after the inclination
H	Effective depth
HM ACT	Heeling moment actual (or transversal)
HM ALW	Heeling moment allowable
IGC	International Grain Code
im	Radio of gyration (Biran)
IMSBC	International Maritime Solid Bulk Cargoes code
K	Radio of gyration (Rawson and Tupper)
KG	Vertical distance from the keel to the centre of gravity
KM	Vertical distance from the keel to the metacentre
KN	Projection of centerline at base line over the vertical from the new center of buoyancy after the inclination
LBP	Length between perpendiculars
LCF	Longitudinal center of flotation, measured either from the midship or the aft perpendicular
LOA	Length overall
RAO	Response amplitude operator
SF	Stowage factor. Ratio of volume to weight. The inverse of the density
SF	Shear force
SOLAS	International Convention for the Safety of Life at Sea
T	Draught of the ship
$T\phi$	Natural period of roll

SYMBOLS

θ	Angle of heel
λ	Heeling moment arm
Δ	Displacement of the vessel
ϕ	Angle of roll
φ_f	Angle of flooding

1. INTRODUCTION

Grain and oilseeds, as main components of the food industry, are one of the pillars of the world trade and transportation. An estimated 371 million metric tons of grain (corn, wheat and rice) and 481 million metric tons oil seeds are exported worldwide every year for a total of 852 million metric tons, of which 80% is carried by sea, representing about 6% of the world seaborne trade, according to data from York Overseas Ltd .

Accordingly, all aspects related to the safety of carriage of grain, are of paramount importance.

The safety regulation of the grain transportation has, unequivocally, been crucial to the protection of seafarer's life at sea, and to the safety of navigation, but it has also brought operational and commercial challenges to shipowners and traders.

This project is a not only an empirical research on a parameter such as the angle at which the grain shifts in simulated rolling: the dynamic angle of shifting and how it is correlated to the angle of repose. By calculating safety margins between the angle of rolling and the dynamic angle of shifting it also constitutes a modest attempt to both easing such challenges and improving the safety of the grain carriage.

2. BACKGROUND AND LITERATURE REVIEW

Ships carrying grain have to comply with regulations and criteria as set out in SOLAS (1974) chapter VI and the IGC (1991). These criteria refer to minimum standards of intact stability and the vessel's response in the event of shifting of the grain. Sliding of grain is undesirable because of the heeling moment created which will cause the ship to experience large inclinations and loss of stability. Accordingly, any measure to prevent this would be aimed at preventing the shifting or minimizing the heeling moments.

As the shifting of grain is a consequence of cargo holds not being loaded in full, the first approach would be to fill up all or as many holds as possible. In the author's working experience of over 10 years, this could be limited by operational constraints such as number of grades, discharge port rotations, possibility or not of commingling, etc. When holds cannot be filled, the only other manner of preventing shifting is by securing (strapping) the grain . This is highly expensive and only specialized ports have the operational capability and know-how to perform it.

For reducing the heeling moments, either selecting the holds with taper end to be partially filled or trimming of the holds ends (for non-self-trimmers) is also considered, but the latter could be impractical due to availability restrictions or financial considerations and has limited effectiveness, also in the author's experience. If none of the above works, the only alternative is to increase the permissible heeling moments by augmenting the displacement or reducing the vessel's vertical center of gravity KG, or both. The reduction of free surface is a quick method of decreasing the KG but the most effective way of increasing the displacement and reducing the KG simultaneously thus improving the stability is by taking ballast in lower tanks.

This practice on the other hand has the issue of increasing the ship's draft sometimes beyond the available depth at then loading or discharging port. It is common practice in such cases to dump the ballast before entering or to take it after exiting it, subject to the vessel technically being within port limits or under local jurisdiction (i.e. not on an international voyage), and the weather conditions not being conducive to rolling motion in the region of the angle of repose (Kamal, 2016). The above has been done without a numerical tool for estimating at what angle of roll the grain might start sliding in dynamic conditions, based on the known angle of repose, and probabilistic methods for calculating a safety margin between the angle of rolling during de-ballasting operations and post-de-ballasted.

The literature and studies available related to grain stability are scarce, and most of them replicate the contents of the IGC (1991) or the booklet prepared by NCB (1994). Much of the above statements are based on the working experience of the author supervising the loading of grain. With respect to grain sliding, a wealth of articles and literature is available for measuring the angle of repose, or the study of the cohesive forces of granular material, but with respect to the sliding of grain in dynamic conditions, although experiments have been done to determine its angle of repose in systems like a rotating drum (Al-Hashemi and Al-Amoudi 2017), little could be found for a simulation of sliding in sea motion conditions, except for advanced studies done by Spandonidis and Spyrou (2015) about rolling on vessels carrying granular material where the granular behaviour under sea motion conditions was mathematically modeled and simulated. They recognized the lack of research on this subject.

2.1 - GRAIN DEFINITION AND PROPERTIES

2.1.1- Definition of grain

According to IGC (1991), the term grain applies to: wheat, maize or corn, oats, rye, barley, rice, pulses, seeds and processed forms thereof, whose behaviour is similar to that of grain in its natural state. The behaviour of interest is their property to shift once a specific angle of repose is reached and exceeded. Also, the following can be defined:

Angle of repose AOR: Means the maximum slope angle of non-cohesive - i.e. free flowing - granular material. It is measured as the angle between a horizontal plane and the cone slope of such material (IMSBC 2008).

Angle of shifting AOS: Not defined in the literature. We will use this term to refer to the angle of heel of the ship at which a particular grain with a certain angle of repose will shift in dynamic conditions, as measured in experimental tests. It is therefore a property intrinsic to the material on a certain ship in certain dynamic condition.

2.1.2- Other commodities be treated as grain

The forewords of the code IMSBC (2008) reads: The international maritime community recognized the challenges of the carriage of bulk cargoes in the 1960 International Conference on Safety of Life at Sea. At the time it wasn’t possible to define requirements for the carriage of bulk cargoes, except for grain, however, it did recommend the preparation of an international code for safe practices on bulk cargoes. From that effort, the chapter VI of SOLAS and the Grain Code saw the light, and subsequently, the Bulk Cargoes BC code, which transformed into The International Maritime Solid Bulk Cargoes Code (IMSBC code).

While it excluded the cargoes listed in the grain code, the IMSBC (2008) on the other hand defines Non-cohesive materials as dry materials that readily shift due to sliding during transport. The Dry materials with non-cohesive properties, therefore exhibit an angle of repose. In section 5 – Trimming procedures, the code stipulates that non-cohesive cargoes with an angle of repose less than or equal to 30 degrees, which flow freely like grain, shall be carried according to the provisions applicable to the stowage of grain cargoes. Example of these commodities are many fertilizers such as Ammonium Nitrate.

Although the above dry materials don’t have the use, biological and chemical properties of grains as defined in the Grain Code, for the purpose of transversal stability they share a common characteristic: they both are non-cohesive, both readily shift due to sliding during sea transport, both having an angle of repose. Accordingly, when it comes to compliance of intact stability, both grain cargoes and solid bulk cargoes which are non-cohesive and with AOR less or equal to 30 degrees, have to be treated same and the calculation for compliance of grain stability criteria performed.

2.1.3- Physics of grain cohesion

Granular friction is the main property responsible for granular cohesion. It was first described by Coulomb in 1776 (Sharan and Lee, 1970) and can be expressed as:

$$\tau = \sigma \tan \phi + C \qquad (2.1)$$

where
τ- Shear stress at failure
σ- Normal stress
ϕ - Angle of internal friction
C - Cohesion coefficient

For non-cohesive granular material such as wheat, C = 0.

According to the studies on compaction dynamics by Lumay et al. (2017), the complex behaviour of an assembly of particles depends on interparticle forces. Those forces are conditioned amongst others by:

- granular packing fraction: Increases with vibrations, tendency to form a denser system.
- shape, size, geometry, humidity: Polydispersity, cylindrical vs spherical, etc.
- friction / roughness: Texture of grain shell.
- cohesion: Van de Waal forces, changed if foreign particles are introduced.

Opposing these forces is the weight. In the paper Measuring the flowing properties of powders and grain (Lumay et al.,2012), to explain cohesion the authors use a heap of sugar, one with granulometry of about 0.5 mm, the other of 50 μm. While the former adopts the normal heap, the latter shows a cohesive heap as the cohesive forces related to the humidity, electric charges and Van der Waals forces are greater than the weight of the grain. SEE APPENDIX 12.

Accordingly, reducing the size of the grain as we did with the vessel would have changed size, geometry shape but more importantly: weight of grain and friction (the exposed cut off side would have a smaller roughness and friction).

2.2- COMPLIANCE WITH INTACT AND GRAIN STABILITY CRITERIA

Ships engaged in international voyages have to meet stability requirements as per intact and damaged stability codes and class rules (SOLAS 1974), but also, as per the above, when carrying grain or non-cohesive bulk cargoes with AOR less than or equal to 30 degrees, ships have to meet the requirements for carriage of grain as set out in the SOLAS (1974) and IGC (1991), as mentioned in the ISC (2008).

The stability criteria contained in the Intact Stability code ISC (2008) can be summarized as follows:

Criteria regarding the righting lever (GZ) curve:

1. $A(\varphi = 0 \text{ to } 30°) \geq 0.055$ meters-radians.
2. $A(\varphi = 0 \text{ to } 40° \text{ or } \varphi_f$, if less$) \geq 0.09$ meters-radians.

3. A(φ = 30° to 40° or 30° and φ_f, if less) ≥ 0.03 meters-radians
4. At $\varphi \geq 30°$ GZ ≥ 0.2 meters
5. $\mathrm{GZ_{max}}$ shall occur at $\varphi \geq 25°$
6. $\mathrm{GM_0} \geq 0.15$ m

Severe wind and rolling criterion: Considering a steady wind perpendicular to the centerline results in wind heeling lever l_{w1} and new position of equilibrium φ_0. Wave actions cause the ship to roll windward from φ_0 to φ_1 and then a wind gust results in a gust wind heeling lever l_{w2}:

7. $\varphi_0 \leq 16°$ or 80% of $\varphi_{\mathrm{deck\ inmersion}}$ (whichever is less)
8. $\mathrm{A_b} \geq \mathrm{A_a}$

where $\mathrm{A_b}$ area between GZ and l_{w2} up to φ_2, $\mathrm{A_a}$area between GZ and l_{w2} up to φ_1 and $\varphi_2 = \varphi_f$, 50° or φ_c (second intercept of GZ and l_{w2} curves). For better reference, see Figure 1:

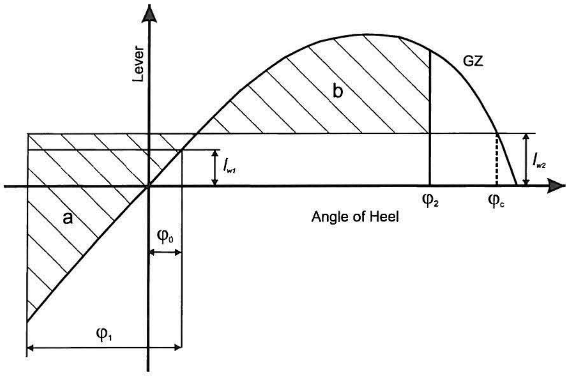


Figure 1: The weather criterion

Special criteria: For cargo ships carrying grain in bulk, the intact stability shall comply with the requirements of IGC (1991)

2.2.1 Grain stability criteria

In addition to the above criteria, when carrying grain ships have to meet minimum criteria with regards to the intact stability as per originally in SOLAS (1974) and subsequently IGC (1991). In this regard a vessel complying with the intact stability might not meet the grain stability. The correlation between the two criteria will be discussed below in Chapter 6.

The ISC Chapter 3 treats the grain stability as a special criteria for certain types of ships and in its chapter 3.4 - Cargo ships carrying grain in bulk, it reads: *The intact stability of ships engaged in the carriage of grain* *shall comply with the requirements of the International Code for the Safe Carriage of Grain in Bulk adopted by resolution MSC 23(59)* (ISC 1991).

SOLAS

The original text of SOLAS 1974, Chapter VI Carriage of Grain, consisted of the following:

Part A: General Provisions, Regulations 1 to 13.

Part B: Calculation of Assumed Heeling Moments, Sections I to V.

Part C: Grain Fittings and Securing, Sections I and II.

It was in Part A, Regulation 4 – Intact Stability Requirements, where these criteria are listed [5]:

1- *The angle of heel due to the shift of the grain not to exceed 12 degrees.*
2- *In the Statically Stability Diagram, the net or residual area between the heeling arm curve and the righting arm curve up to the angle of heel of maximum difference between the ordinates of the two curves, or 40 degrees or the "angle of flooding", whichever is the least, shall in all conditions of loading be not less than 0.075 metre-radians.*
3- *the initial metacentric height, after correction for the free surface effects of liquids in tanks, shall be not less than 0.30 metres.*

In the present text of SOLAS Convention (amended by 2002 Conference), chapter VI – Carriage of Cargoes, Part C – Carriage of Grain, Regulation 8 – Defines de Grain Code and the term Grain, Regulation 9 – Requirements for cargo ships carrying grain, the obligation to carry on board a document of authorization to carry grain.

IGC

The Grain Code consists of the following:

Resolution MSC.23 (59) adopted in May 23rd 1991 and entered in forced January 1st 1994, with revised part C of chapter VI of SOLAS and adopting the new IGC.

Annex Part A: Specific requirements, regulations 1 to 18.

Annex Part B: Calculation of assumed heeling moments and general assumptions.

Appendix: Incorporates the Part C of chapter VI of SOLAS.

It is in Part A, Regulation 7 – Stability Requirements A 7.1, where these criteria are listed. They replicated the same criteria as in the previous Chapter VI of SOLAS except for an amendment to the criteria related to the angle of heel:

1- *The angle of heel due to the shift of the grain not to exceed 12 degrees or the angle at which the deck edge is immersed, whichever is lesser.*
2- *In the Static Stability Diagram, the net or residual area between the heeling arm curve and the righting arm curve up to the angle of heel of maximum difference between the ordinates of the two*

curves, or 40 degrees or the "angle of flooding", whichever is the least, shall in all conditions of loading be not less than 0.075 metre-radians.

3- *the initial metacentric height, after correction for the free surface effects of liquids in tanks, shall be not less than 0.30 metres.*

2.2.2- Calculation of the grain stability criteria

1- The angle of heel after the shifting of the grain:

$$\text{Tan } \theta^{o} = \frac{\textbf{Sum of transversal heeling moments}}{\Delta \text{ X GM}} \text{ X } 57.3 \qquad (2.2)$$

2- The residual area between heeling arm and righting arm curves, from the angle of heel to the max ordinate or 40 degrees:

For the ordinates of the heeling arm curve.

$$\lambda_{o} = \frac{\textbf{volumetric heeling moments}}{\Delta \text{ X SF}} \qquad (2.3)$$

$$\lambda_{40^{o}} = 0.8 \text{ X } \lambda_{o} \qquad (2.4)$$

For the ordinates of the righting arm curve either use GZ curves or KN curves.

Where: $GZ = KN - (KG \sin \theta^{o})$

And θ^{o} is given values from 5^{o} to 45^{o}

Then the ordinates measured from the heeling arm to the righting arm curves are taken or calculated as: $Y = GZ - \lambda_{i}$

With the values of λ_{i} the area is resolved as a Simpson product:

$$A = \frac{\textbf{interval X } (\lambda_{1}+4\lambda_{2}+2\lambda_{3}+\cdots+4\lambda_{n}+\lambda_{n+1}}{3} \qquad (2.5)$$

3- The initial metacentric height corrected for free surface (fluid):

$$GM_{\circ} = KM - (KG + FS_{corr}) \qquad (2.6)$$

See in the Appendix 2 an example of the calculation sheet using the form from Transport Canada.

Also, in Part A, regulations 6.3.1 and 6.3.2 stipulate the ship shall have available information regarding assumed volumetric heeling moments of cargo compartments, filled or partly filled, as well as tables or curves of maximum permissible heeling moments for varying displacements and varying values of KG, allowing the Master to demonstrate compliance with the requirements of A 7.1 (only for ships built after the entry into force of the code). This is better explained in the National Cargo Bureau booklet General Information for Grain Loading NCB(1994):

"In lieu of calculating the actual GM, angle of heel, and residual area which will obtain for a given displacement, KGv and total grain heeling moment and then testing these values against the requirements of the Code, the naval architect pre-calculates the maximum heeling moment which will meet all three of these conditions for every combination of displacement and KGv within the range of the ship's operating conditions and lists them in curves or a table which is part of the data in the ship's approved Gain Loading Information".

As per the above paragraph, the criteria for grain stability compliance are reduced to calculate and compare the transversal heeling moments to the maximum permissible or allowable heeling moment (NCB 1994). The calculation of transversal heeling moment consists of taking the values of volumetric heeling moments from curves or tables and applying the SF and corrections, the total transversal heeling moment is calculated. The value of the maximum permissible or allowable heeling moment can be obtained from tables, with the vessels Displacement and KG as argument. Therefore, the Displacement and KG have to be calculated by listing the weights, the coordinates of their vertical center of gravity, and summing weights and vertical moments, as it is done for any cargo ship (NCB,1994). The below Figure 2 summarises the grain criteria:

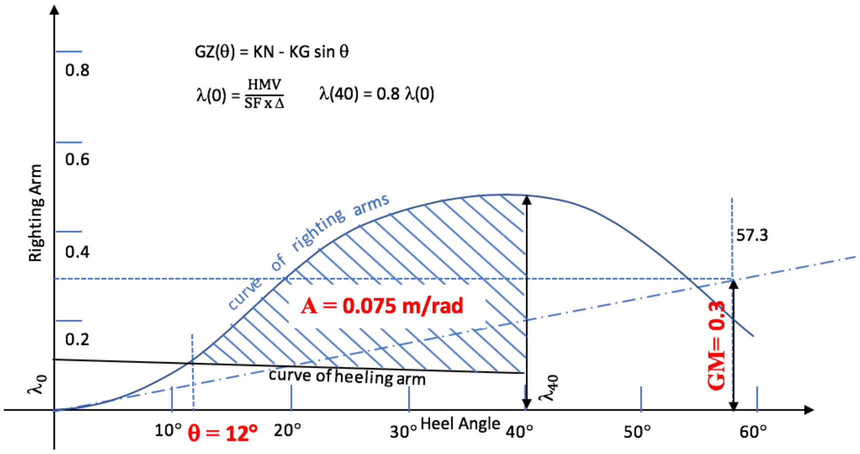


Figure 2: Stability curve and grain stability criteria

For further guidance on how the grain calculation is done and an actual example, SEE APPENDIX 1,2.

In this chapter we refer to the intact stability and the grain stability. There is a correlation between both as they both assess the vessel's response to inclinations: The intact stability examines the values of GZ and areas of the curve at different inclinations. It also considers a dynamic situation where the ship experiences a heel under the effect of a sustained wind and wind gust, from the rolled position on the opposite side, comparing the areas of residual stability under the curve of GZ for the effect of the wave pressure and to the area of residual stability under the curve of GZ for the effect of the wind pressure. It also considers the minimum GM and angle of heel from the sustained wind for a maximum value or percentage of the angle of deck immersion, whichever is less.

The grain stability on the other hand, evaluates the area of residual stability under the curve of GZ for the effect of shifting of the grain, and the resulting angle of heel. This heel is permanent regardless of the weather condition, heading, etc. The conditions for grain stability are more stringent. While the intact stability requires the angle of heel resulting from the sustained wind not to exceed 16° (or 80% of the angle of deck immersion),and the GM not to be less than 0.15 meters, the grain stability requires the angle of heel resulting from the shifting of the grain not to exceed 12° (or the angle of deck immersion) and the GM not to be less than 0.30 meters. It could be inferred, that a vessel complying the intact stability criteria not necessarily complies with the grain criteria, as this is the case for three out of six conditions in this work, but a ship complying with the grain stability criteria should meet the intact stability criteria (See Table 4 which compares the grain and intact stability parameters for all six conditions). While the intact stability criteria depend exclusively on the ship's design and loading condition, the grain stability also depends on the potential of shifting. Therefore, a ship may have a large initial GM and large values of GZ at different angles with all holds partially filled with grain and meet the intact stability criteria, but in the event of shifting, she would experience such heeling moment that she could list heavily or even capsize and hence fail the grain stability criteria.

2.3- FAILURE TO COMPLY WITH THE GRAIN STABILITY CRITERIA

2.3.1- Grain stability criteria not met

When the above criteria are not met, it is obvious that there are two ways of improving the stability condition: by reducing the Total Heeling Moments or by increasing the Allowable Heeling Moment (NCB, 1994).

- Reducing the Total Heeling Moment:
    1- By planning a better distribution of the cargo: reducing the amount of slack holds and / or selecting for slack hold a smaller compartment or a compartment with taper end. These compartments have smaller heeling moments on account of reduced volume and width (volumetric moments are proportional to volume and transversal distance of the new position of the center of gravity to the centerline).
    2- In slack holds to avoid the grain surface to be at the greatest breadth level (normally at 50% for typical single skin bulk carrier with hopper and topside slopes), giving preference to slack holds almost empty or almost full.
    3- By reducing the void spaces of holds filled (trimming the ends).
    4- By securing the grain (strapping).

- Increasing the Allowable Heeling Moment:
    1- By increasing the Displacement (replenishing bunkers, loading more cargo if it is an option, taking ballast).

2- By reducing the vessels KG (avoiding tween-decks on MPPs, avoiding liquids on high tanks, reduction of free surface, taking ballast in double bottom tanks).

The above steps although not explicitly listed in the referred NCB booklet, can be inferred from the notes contained therein.

2.3.2- Preferred procedure to meet the grain stability criteria and setbacks.

The most common effective approach to deal with non-compliance of grain stability is the use of ballast in double bottom, after the amount of slack holds has been minimized, for the reasons explained above. However, the problem arises when there is a draft limitation at the loading or discharge port. Most commonly at the discharge port. The increase of displacement from the ballast taken causes the vessel’s sinking sometimes beyond the maximum permissible draft. This will result in either a change in the discharge port rotation, when possible, or a cancellation of the contract with the economic consequences.

A typical case of draft limitation at loading would be the American and Canadian grain ports along the Great Lakes and seaway system. For such cases where the weather conditions – especially from spring to fall when the seaway is opened for navigation – are fairly better than what can be expected in oceanic navigation, an alternative calculation has been implemented for the so called “sheltered waters”, but when this occurs at discharge ports, the sheltered water condition doesn't apply either because the ports are opened to the sea (West Africa) or because it hasn’t been instituted.

2.3.3 - Available solution when failing to comply with the grain stability criteria. Pros, cons and risks.

Organizations without personnel (ashore or at sea) with experience in the grain trade will take the shortest and more costly approach: refuse the contract or reduce the amount of cargo to fit in full holds with minimum slack holds. Both approaches have a substantial economic consequence: under present market conditions the loss of a contract means back to a pool of shipowners and operators looking for employment. A reduced freight or hire means a meagre revenue.

On the other hand, organizations with greater grain experience will ask the Master to take the full cargo and ballast to improve the grain stability condition, discharging the ballast once reaching port limits and before entering subject to safe weather conditions (usually rolling not exceeding the AOR). This is done on the premise that during roll, the mass of granular material stays in place until the angle of heel exceeds the angle of repose (Biran, 2003).

The Pros of this solution:

1- This procedure is not in contradiction with any regulation: SEE APPENDIX 3

2- The procedure is safe, as long as it is done while the rolling does not reach the angle of shifting of the cargo:

One of the requirements for loading grain or non-cohesive cargoes in bulk with an AOR of less than 30 degrees, is to level the surface horizontally. This has three goals:

- To reduce the heeling moment to a minimum according to the height of the grain (the tables of heeling moments are calculated for leveled grain on the basis of the void volume available for shifting, not considering any residual heeling moment due to a wedge on the surface of the not leveled grain)

- To attain the max AOR (for a grain with AOR 25 degrees, if the surface is inclined 2 degrees it will shift at 23 degrees of inclination of the vessel)
- To avoid a permanent list and with it a reduced intact stability of the vessel.

For a grain with a leveled surface, the ship's roll would have an effect equivalent to that of the slope of the tilting table (Ileleji and Zhou, 2007): the grain slides at the point when the inclination equals the AOR . Considering this in a static environment (no wind, heave, slamming shocks, accelerations, etc.) it is safe to say that as long as the rolling does not reach the declared AOR of the cargo, the grain will not shift, and the conditions calculated in the grain stability form, such as angle of heel after the shift, or area of residual stability will not be met.

The Cons of this solution and risks:

1- It lacks the support of a study on the dynamic behaviour of the grain and the effects of the ship's motion on the AOR. The open sea conditions met in some port limits (port access open to the ocean) are far from static, hence, a safety margin has to be considered. This has been done empirically without a consistent study or data available. In order to keep this procedure safe in view of the uncertainties on the ratio of AOR to angle of shifting resulting from the dynamic motions and forces, large margins are taken. There is no methodology on what those margins are or should be. Considering the responsibility for human life and property that the safety of the ship implies, every operator will seek to reduce risks that haven't been calculated. In my own experience, such margins are set as maximum 5- 10 degrees of rolling for wheat with AOR 25 degrees. The substantial safety margin covers uncertainties not only related to the dynamic angle of shifting of the grain, but also the angle of roll. Although the angle of roll is a piece of information available to the ship's staff (simply by reading the on-board inclination instrument) the input will be limited to a number of random readings which might miss larger values.

2- The economic cost: When weather conditions do not warrant a safe discharge of the ballast, the vessel has to keep it on board preventing her from entering the port. This could take hours or days until the weather improves (normally de-ballasting all double bottom tanks can take up to 10 hours or even more). As explained above in the absence of a complete study on this subject, the safety margins proposed are large and to be extra cautious the master might cancel the discharge of the ballast even with rolling of less than 10 degrees. This means that even in conditions that could be feasible for operating the vessel, the crew and operators will refuse to do so. The delay in entering the port will result in expenses equivalent to the time cost of the vessel or off hire.

3. OBJECTIVES

These experiments are based on the hypothesis that grains under dynamic conditions will exhibit a different cohesive behaviour and therefore the shifting will occur at angles smaller than the AOR, as suggested by Biran (2003): *The accelerations induced by the ship motions can cause load shifting at angles that are smaller than the angle of repose.* It is a premise of this work that the flaw in the procedure discussed in 2.3.3 is the lack of information available to ship masters and operators about the dynamic behavior of the grain in sea motion, and the influence of such motion in the actual angle of inclination when the sliding of the grain occurs (angle of shifting). The overall aim of this work is the research into this dynamic behaviour and how it correlates with the static behaviour of the grain, to use the values obtained experimentally for determining safety margins between the angle of rolling and the angle of shifting derived from the angle of repose, and using probabilistic methods, to calculate the probability of failure and reliability of the system.

The specific objectives of the project are:

1. To determine through experimental tests the angle of shifting of the grain under simulated dynamic conditions of sea rolling, and to compare them with the measured static angle of repose.
2. To collect readings from ocean going vessels of the angle of roll, in order to assess the dispersion of the data measured and to determine the standard deviations of those measurements.
3. To determine safety factors for calculating the maximum angle of roll for safe deballasting from the known angle of repose of the grain and to evaluate the reliability of the results. With these values to research on a possible methodology, as an example for a safe procedure of deballasting before entering ports (or ballasting after leaving) when the grain stability criteria and the draft cannot be simultaneously met.

4. METHODOLOGY

The methodology selected involves measuring the roll when the grain starts sliding or the angle of shifting, under dynamic conditions. It is to be simulated with the use of a scaled model of a bulk carrier's cargo hold suspended on a frame, therefore it also entails the design and construction of the model. These results will allow us to compare the measured angle of shifting with the previously measured static angle of repose of the grain, to establish a correlation between the two, to obtain the mean ratio and to propose a constant for conversion

4.1 - THE MATHEMATICAL MODEL

4.1.1. - Reference vessel.

The model is based on an actual bulk carrier vessel. The model vessel chosen is a handysize Laker with combined single hull transversally framed holds 2,3 and 5 with top side tanks and double bottom tanks with hopper slopes, and holds 1,4,6 with double skin side panels and smaller top side tanks. The transversal bulkheads are corrugated type.

The model vessel's particulars:

Vessel	Description	Units
Name	Nonesuch	N/A
L.O.A.	185.000	meters
L.B.P.	178.000	meters
Breadth (Extreme)	23.700	meters
Depth (Extreme)	14.644	meters
Draft (Summer)	10.416	meters
Displacement (Summer)	39,440.000	metric tons
Lightship	8,541.000	metric tons
Gross Tonnage	19,612.000	tons
Net Tonnage	10,162.000	tons

Table 1: The model vessel's particulars.

For General Arrangement Plan of the reference vessel, SEE APPENDIX 4.

4.1.2 - Loading condition and stability variables.

In order to make experimental measurements of the angle of heel at which the grain will shift, some variables are to be determined: vertical center of rotation (draft at LCF), GM, rolling period, etc. To establish these variables, a number of loading conditions were calculated for a cargo distribution and variations of consumables, on a model vessel in order to select the one with poorer stability results and more sensitive to inclinations for the experiment: ARRIVAL WITHOUT BALLAST.

4.1.2.1 - Cargo distribution.

The cargo condition chosen is a full load of grain wheat, grade 2 CWRS (Canadian Wheat Red Spring) with stowage factor SF 43.5 cf/mt. The following hypothetical constraints apply:

1. There are two grades to be separated by holds (grade A 5,200 MT + grade B 21,000 MT).
2. There is a draft limitation at the discharge (arrival) port of 9.40 (density 1.025).

The above constraints have the following consequences:

1. The separation results in slack holds, at least one per grade, unless the quantity to load has a tolerance and it fits the exact volume of the holds.
2. The draft limitation calls for two slack holds in order to adjust the trim for an even keel arrival.
3. The combination of 1 and 2 results in three slack holds.

The above is the most common scenario for shipments of grain.

In the loading condition chosen one grade is loaded in holds 1 and 4 and the other in holds 2,3,5,6.

The cargo plan:

Compartment	Cargo	Weight	Volume %
Hold No 1	Wheat CWRS Grade A	2400.00	62
Hold No 2	Wheat CWRS Grade B	6377.50	100
Hold No 3	Wheat CWRS Grade B	6149.00	100
Hold No 4	Wheat CWRS Grade A	2800.00	54
Hold No 5	Wheat CWRS Grade B	6146.50	100
Hold No 6	Wheat CWRS Grade B	2327.00	53
Total		26200.00	

Table 2- The cargo plan.

For the above cargo loading condition, a number of variants were checked:

- Departure condition, full bunkers, without ballast.
- Departure condition, full bunkers, ballasted.
- Intermediate condition, half bunkers, ballasted.
- Arrival condition, minimum bunkers, ballasted.
- Arrival condition, minimum bunkers, while de-ballasting.
- Arrival condition, minimum bunkers, without ballast.

4.1.2.2 - Bunkers, ballast and fresh water distribution and sequences:

The below table shows the maximum and minimum quantities of fuel and ballast for the selected conditions. The intermediate condition of fuel is the mean between the departure and arrival.

Compartment	BUNKERS				BALLAST			
	DEPARTURE		ARRIVAL		BALLASTED		DE-BALLASTED	
No 1 HFO	40.00	20	40.00	20				
No 2 HFO P	150.00	42	10.00	3				
No 2 HFO S	150.00	42	10.00	3				
No 3 HFO P	10.00	6	10.00	6				
No 3 HFO S	40.00	23	40.00	23				
No 4 HFO P LS	95.00	95	5.00	5				
No 4 HFO S LS	95.00	95	5.00	5				
No 2 HFO Sett	15.00	47	15.00	47				
No 2 HFO Serv.	15.00	50	15.00	50				
No 1 HFO Serv.	7.00	26	7.00	26				
No 1 HFO Sett.	7.00	22	7.00	22				
No 1 HFO Overflow	2.00	17	2.00	17				
Subtotal	**626.00**		**167.20**					
MDO Storage P	55.00	78	55.00	78				
MDO Storage S	55.00	78	55.00	78				
MDO Serv.	11.00	55	11.00	55				
MDO Sett. P	9.00	22	9.00	22				
Subtotal	**130.00**		**130.00**					
Fore Peak					2.00	0	2.00	0
No 1 WBT P					4.00	0	4.00	0
No 1 WBT S					4.00	0	4.00	0
No 2 DBWT P					3.00	1	3.00	1
No 2 DBWT S					3.00	1	3.00	1
No 2 TBWT P					1.00	1	1.00	1
No 2 TBWT S					1.00	1	1.00	1
No 3 DBWT P					552.20	100	5.00	1
No 3 DBWT S					552.20	100	5.00	1
No 3 TBWT P					1.00	1	1.00	1
No 3 TBWT S					1.00	1	1.00	1
No 4 WBT P					634.90	100	5.00	1
No 4 WBT S					634.90	100	5.00	1
No 5 DBWT P					4.00	2	4.00	2
No 5 DBWT S					4.00	2	4.00	2
No 5 TBWT P					1.00	1	1.00	1
No 5 TBWT S					1.00	1	1.00	1
No 6 BWT P					685.70	100	4.00	1
No 6 BWT S					685.70	100	4.00	1
No 7 DBWT P					3.00	1	3.00	1
No 7 DBWT S					3.00	1	3.00	1
After Peak					1.00	0	1.00	0
No 4 hold WB					0.00	0	0.00	0
Subtotal					**3,782.60**		**65.00**	
	FRESH WATER							
	DEPARTURE		ARRIVAL					
FWT P	45.00	59	45.00	59				
FWT S	100.00	68	100.00	68				
Distill WTK	5.00	11	5.00	11				
Cooling	20.00	75	20.00	75				

Table 3- Bunkers, ballast and fresh water distribution and sequences.

The reason for the different options with same cargo condition, is that the variation in the amount of liquids on board and the free surface moments when not full or empty, influence the values of KG, GM and GZ, as well as allowable heeling moments.

Below is a summary of the results of stability variables for the various loading conditions:

PARAMETERS		DEPARTURE WITHOUT BALLAST Δ = 35,731.71	DEPARTURE WITH BALLAST Δ = 39,449.31	INTERME-DIATE WITH BALLAST Δ = 39,219.31	ARRIVAL WITH BALLAST Δ = 38,989.31	ARRIVAL WHILE DE-BALLASTING Δ = 37,039.71	ARRIVAL WITHOUT BALLAST Δ = 35,271.71
DRAFT	FWD	9.44	9.89	9.87	9.84	9.62	9.40
	AFT	9.58	10.89	10.81	10.72	10.06	9.40
	MID	9.51	10.39	10.34	10.28	9.84	9.40
	LCF	9.51	10.40	10.35	10.30	9.84	9.40
KG SOLID		8.12	7.84	7.89	7.93	7.93	8.22
KMT		9.95	10.01	10.01	10.00	9.96	9.44
GM SOLID		1.82	2.17	2.12	2.07	2.03	1.72
FS CORRECTION		0.31	0.17	0.17	0.17	0.34	0.31
KG FLUID		8.43	8.02	8.06	8.10	8.27	8.53
GM FLUID		1.51	2.00	1.95	1.90	1.69	1.41
GM_{min} CURVES		0.86	0.86	0.86	0.86	0.86	0.86
INTACT STABILITY CRITERIA							
$A(\varphi\ 0\text{-}30°) \geq 0.055$		0.247	0.295	0.290	0.284	0.265	0.234
$A(\varphi\ 0\text{-}40°) \geq 0.09$		0.458	0.519	0.511	0.502	0.480	0.439
$A(\varphi\ 30\text{-}40°) \geq 0.03$		0.211	0.223	0.221	0.218	0.216	0.204
GZ φ 30° $\geq$ 0.2 m		1.034	1.115	1.101	1.085	1.063	1.000
$GZ_{max}\ \varphi \geq 25°$		49°	49°	49°	49°	49°	49°
$GM_0 \geq 0.15$ m		YES	YES	YES	YES	YES	YES
$A_b \geq A_a$		0.607 > 0.112	0.554 > 0.151	0.545 > 0.148	0.535 > 0.145	0.585 > 0.134	0.581 > 0.096
$\varphi_0 \leq 16°$		1.187°	0.761°	0.786°	0.814°	0.978°	1.299°
COMPLY		YES	YES	YES	YES	YES	YES
GRAIN STABILITY CRITERIA							
HM ALW > HM ACT		12,913 < 16,889	18,412 > 16,889	17,897 > 16,889	17,344 > 16,889	14,825 < 16,889	11,938 < 16,889
GRAIN $\theta \leq 12°$		14.8°	11.2°	11.4°	11.7°	13.3°	15.7°
COMPLY		NO	YES	YES	YES	NO	NO
LONGITUDINAL STRENGTH CRITERIA							
BM MAX < 100 (%)		72	78	75	72	63	58
SF MAX < 100 (%)		59	83	82	82	76	71
COMPLY		YES	YES	YES	YES	YES	YES

Table 4- Summary of the results of stability variables for the various loading conditions.

For each condition, (SEE APPENDIX 5-10):

- General information of stability (weight distribution, vertical and longitudinal moments, drafts and trim, GM corrected, longitudinal stresses, etc).

- Grain stability calculations using the form approved by the Canadian administration, seagoing and/or sheltered waters.
- GZ Curves.

4.1.3 - Period of roll.

The rolling for each vessel is a function of its beam and metacentric height in broad terms. The time required to complete a cycle of oscillations is termed the natural period of roll (To). In real dynamic conditions the dynamic response is also a function of the wave spectra and the response amplitude operator RAO, both depending on significant wave height, wave frequency and the latter on the ship's main and bilge keel dimensions (Frederic Deybach1997). However, as the prediction of sea conditions in certain areas, as well as certain ship responses are out of the scope of this work, it will not be calculated here.

During the experimental tests, it is important to simulate the accelerations that the cargo would be subjected to by trying to equate the frequency of the model's rolling to the frequency of oscillation for the To. As the experiment is conceived to determine the angle at which the grain slides, regardless of sea condition or vessel's type or response, only the natural period of roll was accounted for.

A substantial number of studies are dedicated for calculating the natural To.

- According to Rawson and Tupper (1968):

$$T_{\phi} = 2\pi \frac{K}{(g\,GM_T)^{\frac{1}{2}}} \qquad (4.1)$$

where GM_{FLUID} = 1.41 for the chosen condition at T = 9.4

And

$$\left(\frac{K}{B}\right)^2 = F\left[C_B C_U + 1.10 C_U \left(\frac{H}{T} - 2.20\right) + \frac{H^2}{B^2}\right] \qquad (4.2)$$

therefore

$$K = B\,x\sqrt{F\left[C_B C_U + 1.10 C_U \left(\frac{H}{T} - 2.20\right) + \frac{H^2}{B^2}\right]} \qquad (4.3)$$

Where

F = constant, 0.125.

T = Moulded draft = draft for condition - keel thickness.

A = Lateral area of deck and projections = $A_{DECK} + A_{ERECTIONS} + A_{FREEBOARD}$

A_{DECK} = L x W x cos Θ , (L = Length of deck, W = Camber = 0.5)

$A_{ERECTIONS}$ = L x W x cos Θ , L = Length of superstructure, W = Height of superstructure)

$A_{FREEBOARD}$ = L_{PP} * (D - T) - this data is inaccurate, as the ships side is not a rectangle

From the computer calculations, the windage area A was taken and the calculation done with this area also, with this data considered more reliable than that of the projected lateral area calculated.

H = Effective depth = D + A / L_{PP}

C_U = Upper deck area coefficient = $\frac{1}{LB}$

And K = radius of gyration.

- According to Biran (2003), the above formula can be reduced to:

$$T_\phi = \frac{cB}{\sqrt{GM}} \tag{4.4}$$

C = 2Im/B with values of im proposed B/3 (Costaguta 1981) or 0.35B (shipyards).

where Im = radius of gyration.

- According to ISC (2008) and Wawrzyński and Krata (2016) the coefficient C which relates the radius of gyration K or i_m to the breadth, can be calculated as:

$$T_\phi = \frac{2B}{\sqrt{GM}} \quad \text{where c = 0.373 + 0.023B/T - 0.043L/100} \tag{4.5}$$

Method	GM = 2.00 departure with ballast	GM = 1.41 arrival without ballast
Rawson and Tupper	12.0532	14.9560
Biran (mean)	11.4516	13.6387
ISC / Wawrzyński and Krata	11.8232	14.0813

Table 5: Summary of calculations of Period of Roll.

The two values of Biran and ISC / W&K are similar, and their mean value is around 12 - 14 seconds for the departure ballasted - arrival after deballasting condition. The value selected as reference is that for ISC. The Tϕ was also calculated with scaled dimensions using the above formulas resulting in 2.2737 - 2.7079 seconds for same conditions as a reference.

However, the right scaling of the model, simulating the accelerations taking place during the experiment vs sea rolling, are considered as per Bertram (2011). There are forces and accelerations involved in the period of roll, some related to velocities of fluids which are not applicable, hence we will concentrate on the forces only. Geometrical and kinematical similarity between the ship and the model results in the following scale factors for accelerations:

$$a_s = \frac{\lambda}{\tau^2} \text{ x } a_m \tag{4.6}$$

$$\nabla_s = \lambda^3 \text{ x } \nabla_m \tag{4.7}$$

The dynamical similarity means that the ratio of all forces acting on the full-scale ship to the corresponding forces acting on the model is constant:

$$F_s = k \, x \, F_m \tag{4.8}$$

Those forces can be inertial (F = m x a) and gravity (m = ρ x ∇) . Accordingly, the scale factor:

$$k = \frac{F_s}{F_m} = \frac{\rho_s}{\rho_m} \, x \, \frac{\nabla_s}{\nabla_m} \, x \, \frac{a_s}{a_m} \tag{4.9}$$

This equation (4.9) is the Newton's law of similarity.

If we substitute the equation 4.6 and 4.7 in 4.9 we obtain:

$$k = \frac{\rho_s}{\rho_m} \, x \, \frac{\lambda^3 \, x \nabla_m}{\nabla_m} \, x \, \frac{\lambda \, x \, a_m}{\tau^2 \, x \, a_m} = \frac{\rho_s \, \lambda^4}{\rho_m \, \tau^2} \tag{4.10}$$

As for gravitational forces, the scale factor can be also applied as follows:

$$k_g = \frac{G_s}{G_m} = \frac{\rho_s}{\rho_m} \, x \, \frac{\nabla_s}{\nabla_m} = \frac{\rho_s}{\rho_m} \, x \, \lambda^3 \tag{4.11}$$

If dynamical similarity means that all scale factors are the same, then k = k_g, $\therefore$equating 4.10 and 4.11:

$$\frac{\rho_s \, \lambda^4}{\rho_m \, \tau^2} = \frac{\rho_s}{\rho_m} \, x \, \lambda^3 \; \therefore \; \tau^2 = \lambda \; \therefore \tau = \sqrt{\lambda} \tag{4.12}$$

Applying the equation in 4.12 to our calculated period of roll of the vessel for the arrival (worst) condition for the scale selected factor 40:

- ISC / Wawrzyński and Krata, τ_s = 14.0813, $\sqrt{\lambda}$ = 6.3245, τ_m = 2.2264 sec.

During the experiment the model was rolled at about 14, 10, 8 and 2 seconds, with the two first yielding similar results and the second different results. The final results were taken from the experiments with rolling at 8 seconds, for further results and explanation see Chapters 5 and 6.

For details of the calculations, SEE APPENDIX 11.

4.2 - THE PHYSICAL MODEL

4.2.1 - Scale applied to the original plans (from midship section and GA).

The cargo holds model and the supporting mechanisms were designed and assembled by the author. The scale was chosen based on the breadth of the ship for a feasible model's size: 1:40. No formulas were applied to the original vessel for scaling down. In studying model scaling it was noted the formulas with

Reynolds, Froude, Weber and Euler numbers are applied to models when tested in fluids at certain speed, according to Voraa and Bauge (2016). The cargo hold chosen was No 3 (center hold, typical self-trimming hold of a bulk carrier). The dimensions from Midship Section plan and General Arrangement plan are adjusted according to the scale selected as follows:

- Transversal plane: From the midship section plan, as per Figure 3 below.

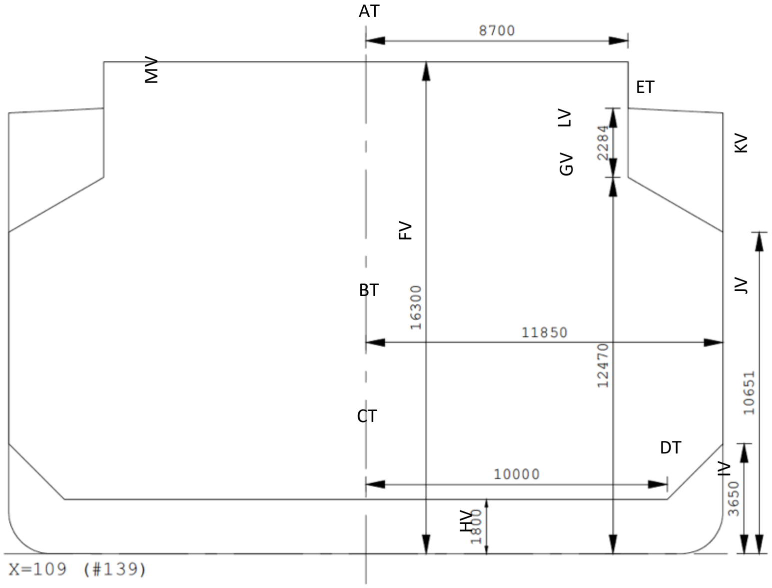


Figure 3: Transversal plane from midship section with dimensions.

AT	Width of Hatch opening	8,700 x 2 = 17,400	435.00 mm
BT	Width of cargo hold	11,850 x 2 = 23,700	592.50 mm
CT	Width of tank top	10,000 x 2 = 20,000	500.00 mm
DT	Width of hopper base	11,850 - 10,000 = 1,850	46.25 mm
ET	Width of Top side	11,850 - 8,700 = 3,150	78.75 mm
FV	Height BL to hatch cover	16,300	407.5 mm
GV	Height BL to main deck	12,470 + 2,284 = 14,754	368.85 mm
HV	Height BL to tank top	1,800	45.00 mm
IV	Height BL to top of hopper slope	3,650	91.25 mm
JV	Height from hopper slope to top side	10,651 - 3,650 = 7,001	175.02 mm
KV	Height of top side on side	12,470 + 2,284 = 14,754 - 10,651 = 4,103	102.58 mm
LV	Height of top side on hatch coaming	2,284	57.1 mm
MV	Height of hatch coaming	16,300 -12,470 + 2,284 = 1,546	38.65 mm

Table 6: Summary of symbols and dimensions from Figure 1.

- Longitudinal plane: From the General Arrangement plan, as per Figure 4 below.

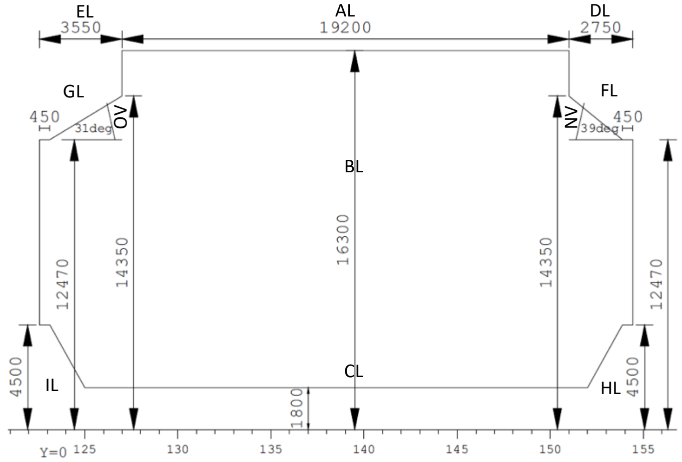


Figure 4: Longitudinal plane from midship section, with dimensions.

AL	Length of hatch opening	19,200	480.00 mm
BL	Length of cargo hold	19,200 + 3,550 + 2750 = 25,500	637.50 mm
CL	Length of tank top	Fr 125 - Fr 152 = 27 x 0.8 = 21.6 m = 21,600	540.00 mm
DL	Length of forward crossdeck	2,750	68.75 mm
EL	Length of aft crossdeck	3,550	88.75 mm
FL	Length of forward upper stool	2,750 - 450 = 2,300	57.50 mm
GL	Length of aft upper stool	3,350 - 450 = 2,900	72.50 mm
HL	Length of forward lower stool	Fr 152 - Fr 154 = 2 x 0.8 = 1.6 m = 1,600	40.00 mm
IL	Length of aft lower stool	Fr 123 - Fr 125 = 2 x 0.8 = 1.6 m = 1,600	40.00 mm
NV	Height of the forward upper stool	14,350 - 12,470 = 1,880	47.00 mm
OV	Height of the aft upper stool	14,350 - 12,470 = 1,880	47.00 mm

Table 7: Summary of symbols and dimensions from Figure 2.

4.2.2 - Sketch with scaled dimensions.

The dimensions above calculated are applied to the 3D sketch which serves as reference for preparing the cad drawings that feed the CNC machine. The sketch as shown in Figure 5.

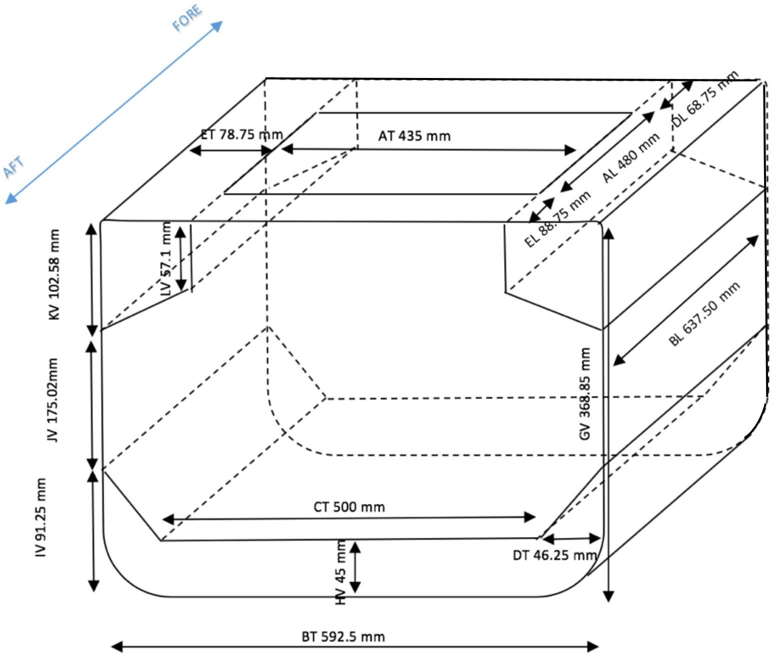


Figure 5: Sketch of physical model with scaled dimensions.

4.2.3 - CAD model based on exact dimensions scaled 1:40, as per Figure 6 below:

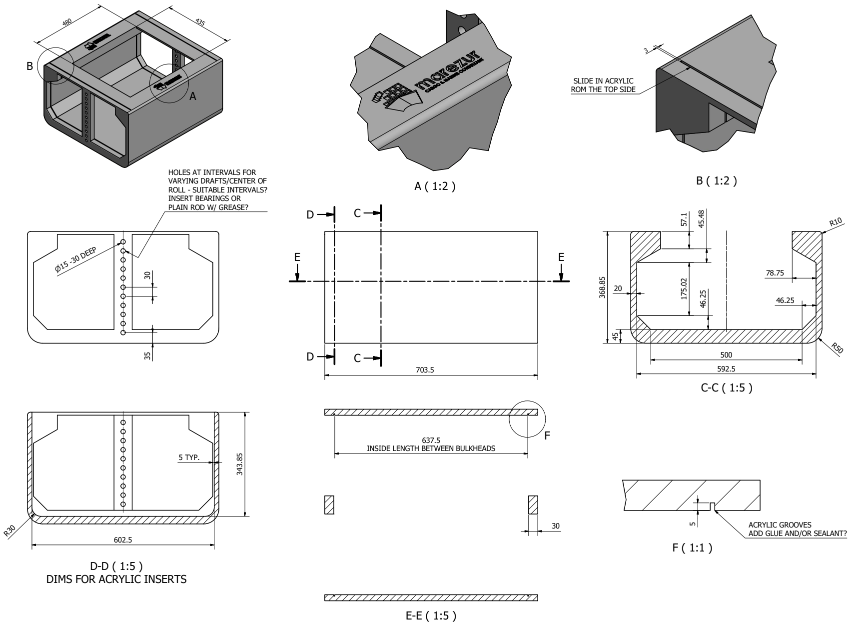
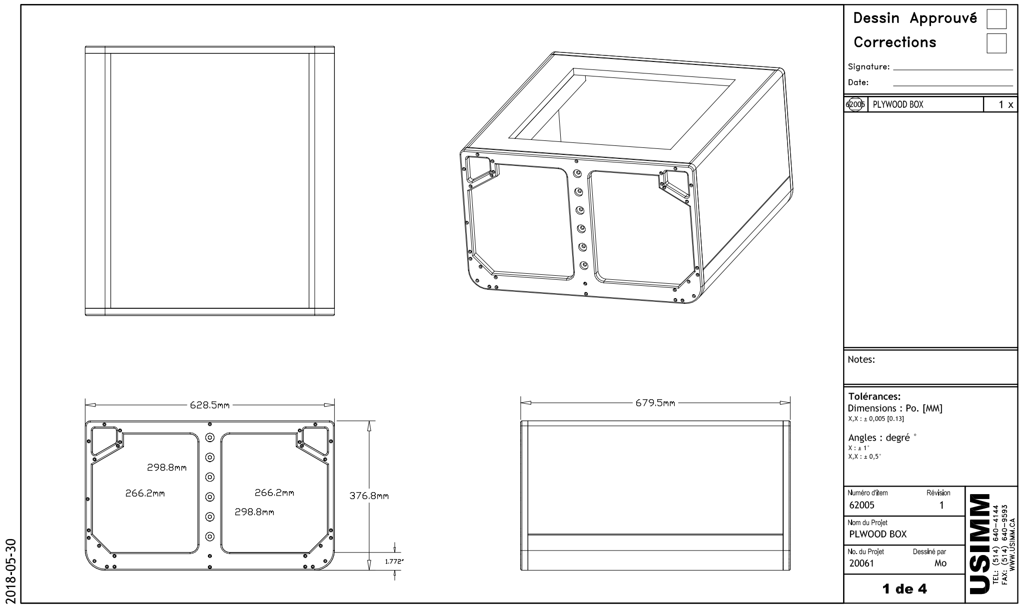
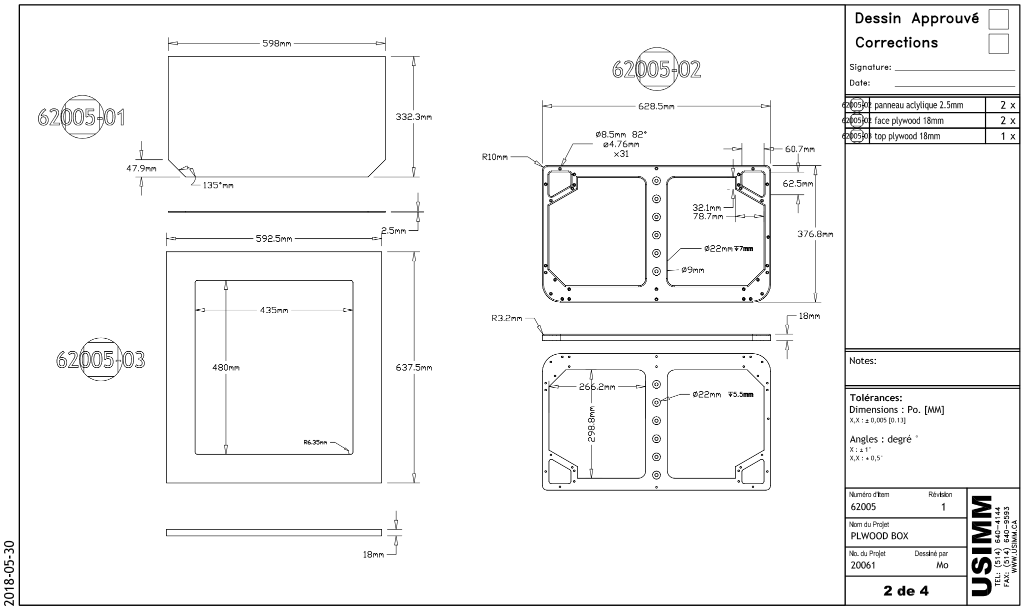


Figure 6: Rendering of the CAD model.

For the construction of the model the computerized machining method was selected considering the weight of grain to be placed inside (about 50 lbs). A local company USIMM in Pointe aux Trembles, Montreal (http://www.usimm.ca) with CNC Machines undertook the project, cutting out Russian plywood 18 mm for the frame and 2.5 mm acrylic inserts for the end panels, which allows the grain inside of the hold to be seen. The tolerances of the machined pieces were 0.005 inches or 0.13 mm.

4.2.4 - Final four sheets of drawings of the project by USIMM drawing desk as per Figure 7:





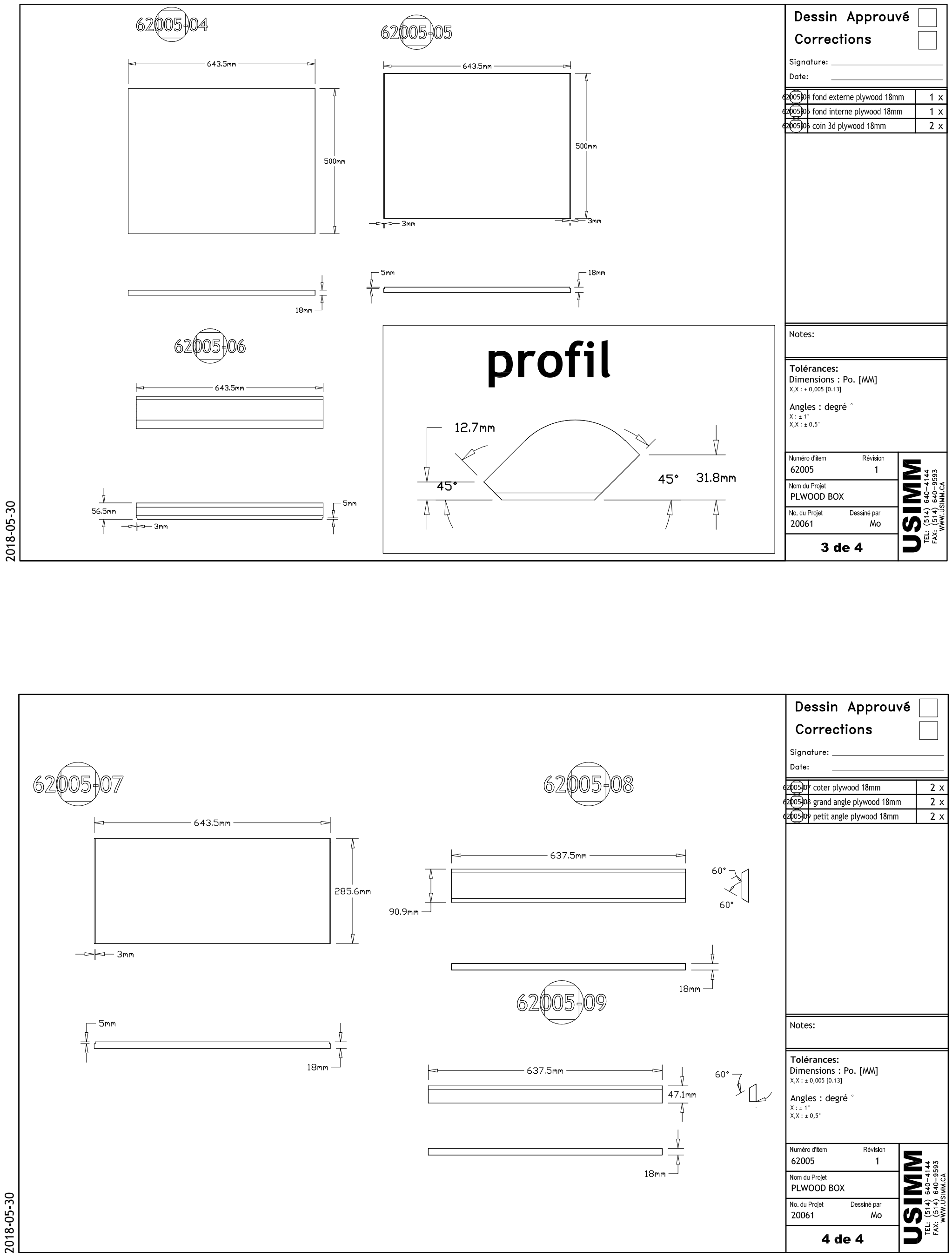


Figure 7: Sheets (4) of the design drawing and specs prepared by USIMM.

4.2.5 - Physical model assembled.

The parts cut by USIMM, including the acrylic panels, were assembled using carpenters glue and screws of the size recommended by them. The roller bearing was inserted in the slot corresponding to the scaled height of the LCF in the mathematical model. The result in Figure 8:

Figure 8: Photograph of the model, assembled

4.2.6 - Support and assembly.

The support was made of 2 mm thick aluminium angle bars of with transversal frames for supporting the weight of the model with cargo, all resting on an extended base for preventing longitudinal and lateral shifting (Figure 7). A vertical longitudinal reinforcement was used in way of the pivoting point where the load of the model and cargo is applied, thus, providing two supporting points for the pivoting axis at both sides. Subsequent to the experiments with the above set up, the fixed axis mechanism was replaced by springs in order to replicate the sea motion with all six degrees of freedom (see 4.3.7). The support was designed and assembled with materials acquired in hardware stores. The result in Figures 9-11:

Figure 9: Photograph of the support.

Figure 10: Photograph of the model and support assembly with fixed axis.

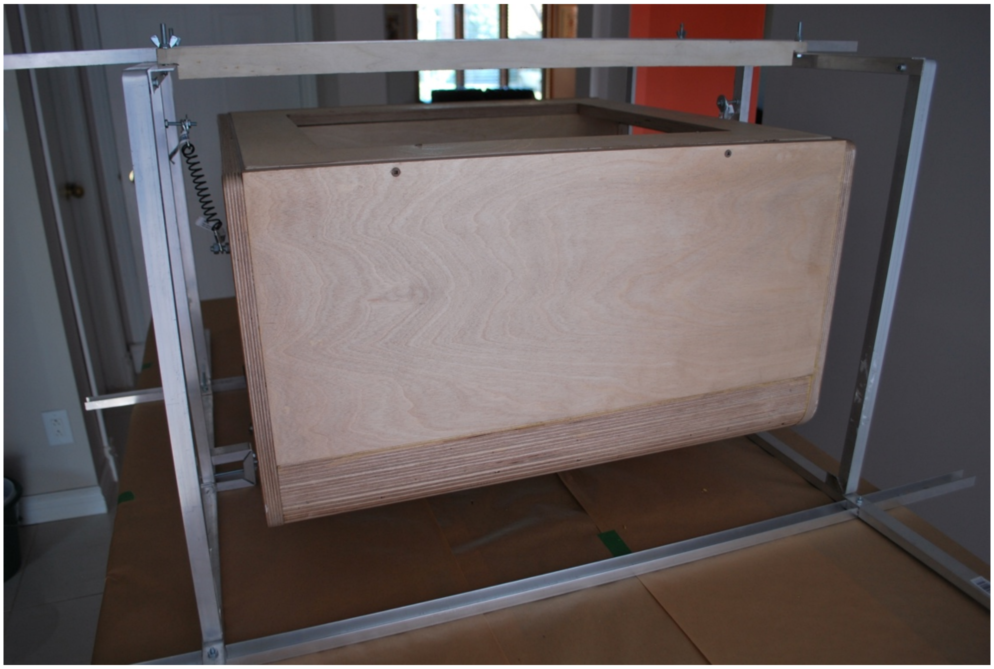


Figure 11: Photograph of the model and support assembly with springs.

4.2.7 - Mechanism for limiting the angle of roll and for damped oscillations.

To roll the model at pre-arranged angles, a set of longitudinal bars, which limit the angle of inclination was placed on top, with a scale indicating the position of the bars for each degree of inclination between 10 and 25 degrees. Also, a device consisting of a spring connected to a turnbuckle and with a cable to the bottom of the model through a sheave was arranged, in order to dampen the oscillations. This said mechanism caused the spring to elongate when the model was at the end of the roll, both sides. The mechanisms are shown in Figures 12-14.

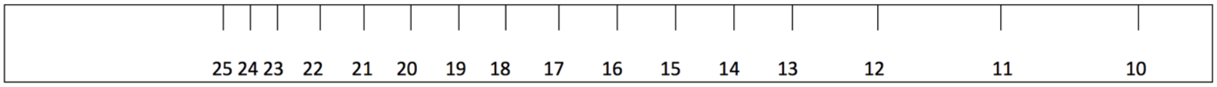


Figure 12: Scale for the angle limiting mechanism.

Figure 13: Photograph of the angle limiting mechanism with longitudinal sliding bars and scale.

Figure 14: The spring and cable assembly for damped oscillations.

4.3 - EXPERIMENT

4.3.1 - Hypothesis

These experiments are based on the hypothesis that grains under dynamic conditions will exhibit a different cohesive behaviour and therefore the shifting will occur at angles smaller than the AOR, as suggested by Biran (2003): *The accelerations induced by the ship motions can cause load shifting at angles that are smaller than the angle of repose.*

4.3.2 - Assumptions:

- That the rotating motion of the model is equivalent to the ship's rolling at sea, damped , with one out of six degrees of freedom: rotation over one axis, out of rotation and translation over three axes. This excludes longitudinal and vertical accelerations that take place during the complex motion at sea and assumes that it is the lateral accelerations that has a greater impact on sliding of granular material. The subsequent test of the model suspended on springs simulates the motion at sea with six degrees of freedom but undamped.

- That the effect of scale in measuring the AOR is the same as in measuring the angle of shifting, and by extension, that if a small pile has the same or similar AOR as a larger pile, the behaviour of the grain inside the model is the same as in the cargo hold, despite the difference in size. To account for that, multiple measurements of AOR were performed to small and larger piles for the same bag.

4.3.3 - Tolerances

The tolerances considered apply to the following:

- Scale: The model has a scale of 1:40 and the tolerances given by the manufacturer of the parts is 0.13 mm which is equivalent to 5.2 mm on the actual ship scaled. The ship has a beam of 23700 mm therefore the equivalent tolerance is of 0.000219 of its beam which is negligible.
- Rotational speed: The rotational speed was matched with the period of roll for the mathematical model with and without scaling down. In the case of rotating the model without scaling down the period of roll, it does it as a small section of the hold around the center of flotation would do.
- Rotational angle: The rotational angle was measured for every degree of inclination (1°). Objects scaled down of every axis keep angles unchanged therefore at real scale the tolerance continues to be 1°. To measure the angles a protractor scaled for every degree was used. For the purpose of this work, the relevance of the angles is connected to the ability to read angles of inclination on board ships which is in the range of 0.1-0.3° therefore the tolerance can be considered 1/10 or 0.1.
- Size of grain: While the model was scaled down the grain was not. This is because reducing the size of the grain would change its physical properties. This requires a separate analysis (see 2.1.3) and it is the customary procedure in tests done to soil and granular material in centrifuge for geotechnical purposes (Iglesia et al., 2011).

4.3.4 - Grain samples.

Supplied by York Overseas Ltd, obtained from grain terminals in Quebec while loaded on vessels and consisting of 14 bags of wheat CWAD & CWRS as follows. For original tags see APPENDIX 13.

BAG	TYPE	WEIGHT	SEAL No.	TERMINAL	VESSEL
1	1 CWAD	4.0 KG	00004728	G3 CANADA LTD	VEGA ROSE
2	2 CWRS	5.0 KG	00006804	CARGILL LTD	TAI HEALTH
3	2 CWRS	2.5 KG	00008010	LES SILOS PORTCARTIER	DESERT MOON
4	2 CWRS	5.0 KG	00008415	CARGILL LTD	TN DAWN
5	2 CWAD	2.5 KG	00008764	CARGILL LTD	DESERT OSPREY (H1)
6	2 CWRS	2,5 KG	00008763	CARGILL LTD	DESERT OSPREY (H 2,3,4,5)
7	2 CWRS	2.0 KG	00008661	CARGILL LTD	VEGA ROSE
8	2 CWRS	5.0 KG	00008666	CARGILL LTD	VEGA ROSE
9	3 CWAD	2.0 KG	00006914	LES SILOS PORT CARTIER	EQUINOX VOYAGER
10	1 CWRS	2.5 KG	00006934	LES SILOS PORT CARTIER	EQUINOX VOAYGER
11	1 CWAD	4.0 KG	00008775	CARGILL LTD	VEGA ROSE
12	1 CWRS	5.0 KG	00021021	RICHARDSON INT. LTD	JASMINE
13	2 CWRS	3.0 KG	NONE	NONE	NONE
14	2 CWRS	5.0 KG	NONE	NONE	NONE

Table 8: Summary of grain samples information.

4.3.5 - Measurements of the AOR of grain.

In the absence of lab resources for measuring the dimensions (height and radius) of the pile after spilling the grain from a funneling device, the tests were done spilling the contents of the bags at around 20 centimeters over the flat counter, allowing the free piling and sliding of the grain (cone lifting method, Rouse, P. 2014). A Kraft paper was used to line the flat granite counter in order to reduce sliding from the highly polished surface The measurements were done manually with a lever indicator or protractor (Figures 15-18), for which the estimated error in the measurement would be of about 1°. Further details of the proposed methods for measuring the AOR are discussed in this thesis. The mean values obtained are in the range of 25° ± 1°. The results were processed for small and large piles of individual bags and grades, and mean values calculated for each category.

Figure 15: Sample preparation: breaking seal and opening the bag.

Figure 16: Preparing the experiment, pouring the sample grain on the table.

Figure 17: Performing the measurements of AOR with level indicator.

Figure 18: Detail of measurement of AOR taken with the level indicator.

4.3.6 - Measurements of the AOS with fixed axis.

The measurements were taken for all the sample bags, plus the bags of same or similar grade combined. The reason for testing the bags of the same or similar grade combined was to test the AOS with a larger pile as each sample would barely take the volume of the bottom of the hold. The downside to this was that the same combinations of bags were not tested for AOR, but a mean value of their respective AOR calculated.

Tϕ: 2 sec

The rolling is started at 10 degrees of inclination but after several try outs it was seen that the grain only starts shifting at angles of 17 degrees or higher. The push (heeling force) was done from the port side, allowing the model to oscillate freely to starboard side. While the limiting angle was increased, as the model started to accumulate a permanent list resulting from the shifting of the grain, the oscillation to the opposite side was kept the same. Although the target Tϕ was 2 seconds, when the rolling was timed with a chronometer, it was noted to be about 1.40 seconds. The motion of the model was stable and natural. At this Tϕ, there was no visible sliding of the grain, probably because of the high frequency of the rolling. Snapshots of different moments of the measurements with fixed axis can be seen below in Figures 17-20.

Tϕ: 8 sec

Before managing to adjust the rolling to this frequency, several practice runs were done and timed with a chronometer. The motion was stable because the rotation axis is fixed, and there was an effort to maintain a synchronic motion during the rolling, with the deceleration that occurs at the end of the rolling, achieved through the damping mechanism of the small spring connected to the model with a cable. These were deemed the best tests because of the motion of the model. Initially tried at 14 and 10 seconds, the motion was deemed too biased, and at 2 sec too fast, without results. The grain was noted to slide at angles between 17 and 19°, in the region of the expected results. The first angle of shifting was computed, together with the permanent list accumulated for progressive increase of the rolling. Snapshots of different moments of the measurements with fixed axis can be seen below in Figures 19-22.

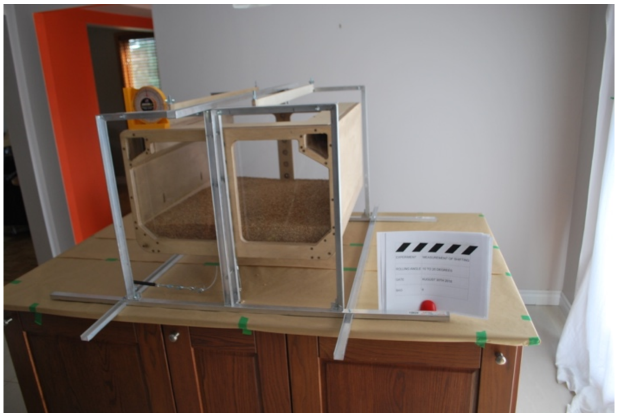


Figure 19: The set up for the tests, with fixed axis.

Figure 20: Rolling the model and measuring the AOS, with fixed axis.

Figure 21: Rolling the model and measuring the AOS, closer view, with fixed axis.

Figure 22: Detail of protractor with reading of the permanent angle of list after the shifting.

4.3.7 - Measurements of the AOS with model suspended on springs.

One of the assumptions (5.2.2) is that the rolling motion of the model is equivalent to that at sea but having only one out of six degrees of freedom. While the sea motion cannot be replicated with the model assembly, an approach to it was sought by suspending the model on springs, based on the below postulate from Rawson and Tupper (1968):

"...It is to be expected that the equation governing the motion of a ship in still water, which is subject to a disturbance in the roll, pitch and heave modes, will be similar to that governing the motion of a mass on a spring.."

The measurements were taken with the combined grains of same or similar grade. Values in excess of 18 degrees of inclination could not be taken, as the model hanging on springs sat lower over the counter.

Tϕ.: 2 sec

The model was rolled to one side and left to return to the opposite side. Although there was minimal intervention of the operator, just to give a push to one side to cause the inclination, the model was unstable, the push was noted to cause lateral displacement (in this case a surge fore-aft) and vertical displacement (in the form of heave), deemed excessive for the scale. Because of this, only the angle when the grain first slid was taken. That angle was noted to be similar to the ones measured for the fixed axis setup at 8 seconds, but no conclusive correlation between the two was sought as they were two different setups at different Tϕ. The damping mechanism was noted to be disabled for angles of inclination above 19 or 20° as the bilge strake of the model started hitting the counter. Snapshots of different moments of the measurements with springs can be seen below in Figures 21-24.

Tϕ.: 8 sec

The model was rolled in the same fashion as done with the fixed axis: the frequency was timed, and the motion controlled by hand. This time the disruption of the natural rolling of the vessel, and the bias of the operator was noted to be significative, as well as the side (sway), lateral (surge) and vertical (heave) displacement, with the damping mechanism not being very effective the motion was even more asynchronous. The grain started to slide at about 12° of inclination, which was deemed excessively low when contrasted with real life voyages, where such rolling has been reported but not shifting of cargoes. The reason for the sliding at smaller angles could be related to the disruptive effect of manually handling the model.. Snapshots of different moments of the measurements with springs can be seen below in Figures 23-26.

Figure 23: The set up for the tests, with springs.

Figure 24: Rolling the model and measuring the AOS, with springs.

Figure 25: Rolling the model and measuring the AOS, closer view, with springs.

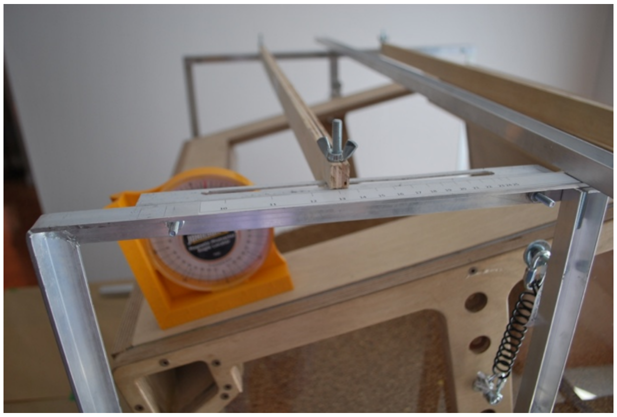


Figure 26: Detail of protractor with reading of the permanent angle of list after shifting.

4.4 - DATA PROCESSING.

4.4.1 - Comparison of values of AOR with AOS from the results.

The results of the AOS test for the model on fixed axis are consistent with AOS dynamic happening at angles of inclination smaller than AOR and the model's motion was stable. The values for AOS for model on springs at $T\phi$ = 8 seconds seem low, as if grain was to shift in sea motion condition at 12 degrees inclination, a large number of ships would report shifting during sea passage. As for the values of AOS for the model on springs, they are very similar to those of the model on fixed angles at 8 seconds, but it should not be regarded as a validation of the data, as the two tests were done with different setups and different frequencies. Accordingly, these values will be discarded, and the reading selected will be for fixed axis at $T\phi$ = 8 second, and the data gathered deemed reliable.

4.4.2 - Correlation between AOR and AOS and conversion constant.

Correlation coefficients are used in statistics to measure how strong a relationship is between two variables. For linear correlation the most common coefficient is Pearson's coefficient R, developed by Pearson (1896) according to Assuero et al. (2006). Given two sets of n number of variables x and y, the calculation of the Pearson's coefficient consists of listing those variables in columns, calculating XY, X^2, Y^2, calculating the summation of all the columns and the coefficient R as:

$$R = \frac{n(\sum XY)-(\sum X)(\sum Y)}{\sqrt{[n\sum X^2-(\sum X)^2][n\sum Y^2-(\sum Y)^2]}} \tag{4.13}$$

With values between -1 and 1, where -1 indicates a strong negative relationship and 1 a strong positive relationship.

This was done using Excel functions: Our variables X,Y are AOR and AOS. The function "Correl" (for correlation) was used returning a value of 0.5024 for the fixed axis which is not very strong. The causes for such low values can be related to the measuring techniques used and are discussed further in Chapter 7. Non linearity cannot be attributed to the cause, as the pattern of the scattered points is not indicative of any specific function. The graph showing the scatterplot of points around the mean line can be seen in Figure 27.

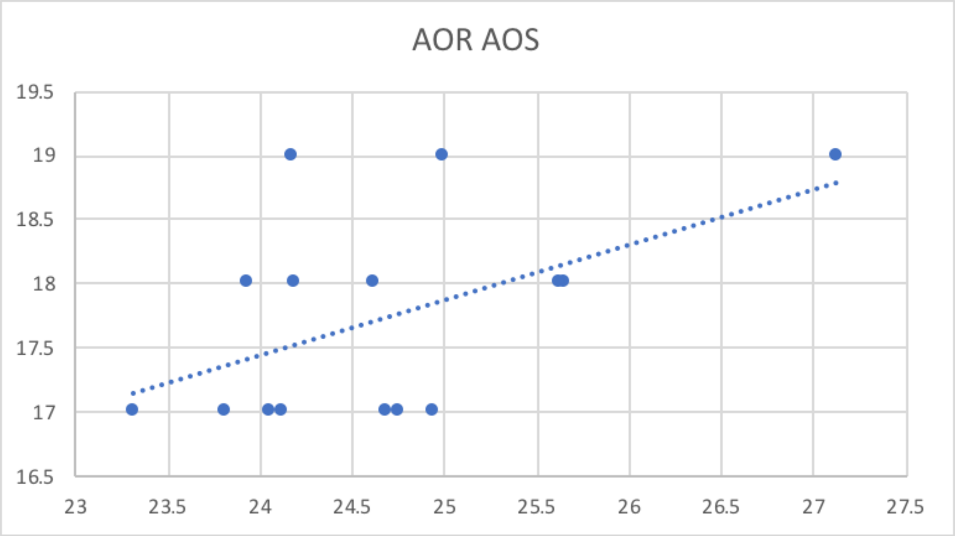


Fig 27: Pearson correlation graph AOR-AOS .

In order to assess the influence of errors on the correlation and to determine the sensitivity of the correlation to errors, we altered the readings by 0.5 degree either positive or negative, for AOR or AOS or both. That half degree of error is half the tolerance we believe our experiment has, given the methods used and one that is acceptable for the degree of accuracy needed. The new returned value of correlation was 0.8590, which is a strong positive correlation. This can be regarded as an arbitrary and biased procedure and will be discussed further in Chapter 6.

Of the points changed one was still off, which corresponds to the tests done to bags 2,3,4&6. As explained above, for these combined samples the AOR was calculated as the mean of the AOR for each respective bag, and not measured. Therefore, the accuracy of its value could be off by -1/+1. If the same point had been changed by -1/+1, the correlation afterwards would be 0.9273 and if it had been dismissed, the correlation would be 0.9266, which is a strong positive correlation. This illustrates that the calculation of the correlation for the amount of data gathered was very sensitive to errors even in the region of -0.5/+0.5, which is very small. The scatterplot of points after corrected by -0.5/+0.5 can be seen in Figure No 28.

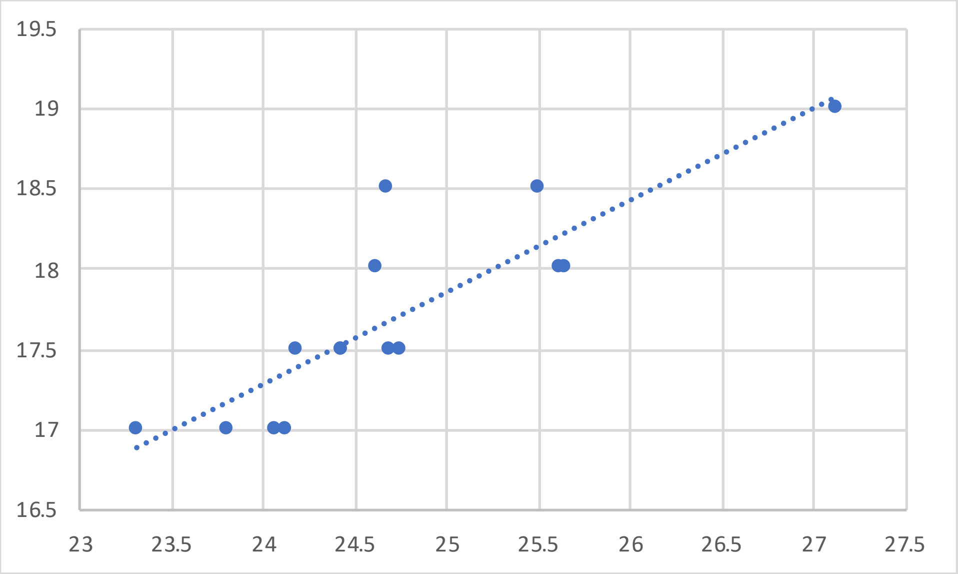


Figure 28: Pearson correlation graph AOR-AOS after changes by -0.5/+0.5.

With the data of AOR / AOS collected from the tests, as used for the calculation of correlation, we also calculated the ratio of AOS to AOR. The mean of all the calculated ratios was taken as a conversion constant. The conversion constant obtained was 0.719. As the validity of this constant could be questioned given the weak correlation between the values measured, the same was calculated for the data adjusted by -0.5/+0.5 as done above and the new correlation was noted to be 0.716.

Therefore, if the AOS was to be calculated with the first constant from AOR = 25°, the value would be 17°.975 ≈ 18°. If the same value was calculated with the second constant, the result would be 17°.9 ≈ 18°. Accordingly, the conversion constant between the AOR and AOS can be taken as 0.719 and the calculation can be done as follows:

$$\text{AOS} = \text{AOR} \times 0.719 \tag{4.14}$$

4.5 - USE OF PROBABILISTIC METHODS FOR PROCESSING THE DATA.

Probabilistic methods are used as a tool for calibrating safety margins against target safety levels and address the probability of an event occurring reflecting the uncertainties in the model chosen and variables considered. The calculations that will follow are based on the contents received during the MTEC module B3: Risk, Reliability and Safety, at the University of Strathclyde and the course notes (Baltrop and Hifi, 2012) and class noted from Dr. Evangelos Boulougouris.

4.5.1 - Readings of angle of roll ϕ

With the collaboration of sea masters and deck officers, readings of ϕ were collected in different types of sea conditions:

VESSEL TYPE			Bulk carrier handysize		
SEA CONDITION			swell, no wind		
DATE	TIME	VALUE	DATE	TIME	VALUE
15/09/18	6:07:35	8.1	15/09/18	15:40:40	7
	6:07:45	8		15:40:50	6.5
	6:07:52	6.3		15:40:59	7
	6:07:59	6		15:41:08	7
	6:08:05	7		15:41:18	7
	6:08:15	5.5		15:41:27	6.5
	6:08:23	4		15:41:36	5
	6:08:30	5.5		15:41:45	5
	6:08:38	4		15:41:55	7
	6:08:47	7		15:42:05	8
	6:08:56	5		15:42:14	8
	6:09:04	4		15:42:24	7
	6:09:13	4		15:42:33	6
	6:09:23	5.5		15:42:42	6
	6:09:33	5		15:42:52	5
	6:09:42	4		15:43:01	6
	6:09:52	5.5		15:53:10	6
	6:10:02	5		15:43:19	4
	6:10:12	5			

Table 9: Readings of angle of roll.

4.5.2 - Calculation of standard deviations of readings of angle of roll ϕ.

Using the formula:

$$\sigma = \sqrt{\frac{1}{K} \sum (X_i - \mu)^2} \tag{4.15}$$

where K - number of counts, X_i - each measurement, μ - mean.

The calculations yielded the following results :

For 15/09 AM $\mu = 5.4947$ and $\sigma = 1.3049$.

For 15/09 AM $\mu = 6.3333$ and $\sigma = 1.0701$.

As the readings were taken by different officers, and the standard deviations reflect their accuracy or lack of it in performing the measurements, I will select the highest value of $\sigma = 1.3049$, to account for inaccuracies and errors. In this case we take only the value of standard deviation, as the mean value of ϕ will be calculated from the mean value of AOS using safety factors (see below 4.5.4).

4.5.3 - Calculation of standard deviations of measured AOR - AOS.

Following the same procedure as above, the standard deviations of the measured values of AOR and AOS were calculated, separating the measurement by grades (CWAD and CWRS). The following results were obtained:

For CWAD AOR $\mu = 25.344$ and $\sigma = 1.127$, AOS $\mu = 18.2$ and $\sigma = 0.837$

For CWRS AOR $\mu = 24.330$ and $\sigma = 0.655$, AOS $\mu = 17.5$ and $\sigma = 0.707$

Here also in order to account for inaccuracies and errors, the highest value was selected: $\sigma = 1.127$. In this case we take only the value of standard deviation, as the mean value of AOR is given by shippers and the mean value of AOS is calculated from the angle of repose as per formula (4.9).

4.5.4 - Safety margin between ϕ and AOS - AOR.

In structural engineering, safety factors that account for uncertainties are calculated, without being excessive while yielding low probabilities of failure. Normally those safety factors are associated to loads and resistance or applied load versus design load, where the former exceeding the latter would result in structural failure. In this particular problem of transversal stability, an homology with the above concept can be established, where ϕ and AOS are the two variables to compare, and the former exceeding the latter would result in system failure, in this case, shifting of the grain.

As the angle of shifting (AOS) is a parameter not known to grain producers and terminals (it was the main objective of this work to obtain it and it was measured with the experiments), a factor or constant will be used to convert AOR into AOS having established the correlation between the two and the mean ratio or conversion constant as per formula (4.9). This constant C is valid only for wheat. As the correlation was weak, resulting from possible errors in the measurements during the tests, such errors can be offset by choosing the highest values of Standard deviations for measuring AOR and AOS, and by increasing the safety factor. When choosing a safety factor, a target value of probability of failure should be considered (Tsimopoulou et al., 2011). Goal based Safety Level Approach could be used as reference. In this particular case, where the risks are associated with cargo damage, structural damage, commercial losses, but most of all, personal injury or loss of life, even though it can be quantified and compared to the costs of not taking the cargo or waiting outside for better weather conditions, we will select a target probability of failure.

Example:

AOR for wheat, according to shippers = 25°

AOS = AOR x C = 25 x 0.719 = 17.975 = 18

The safety factor:

$$Y = \frac{\mathbf{AOS}}{\phi} \tag{4.16}$$

For Y = 1.5, then

$\phi = \frac{\mathbf{AOS}}{\mathbf{Y}} = \frac{\mathbf{18}}{\mathbf{1.5}} = 12°$

We have set the safety factor at 1.5 with a target probability of failure $P<0.0006$ (see discussion in Chapter 6).

4.5.5 - Montecarlo simulation for random ϕ and AOR, and probabilities of shifting.

The safety factor chosen may or may not be sufficient to warrant a low or the targeted probability of failure: shifting. If the probability of shifting remains above the targeted limits, then the safety factor has to be increased. If the probability is zero or too low and the safety factor deemed excessive, it can be reduced.

A feasible way to check the reliability of the safety factor chosen is by running a crude Montecarlo simulation using the two mean values of the variables to compare (AOS = 18 and $\phi = 12$), and the highest values of standard deviation obtained from the readings (for ϕ and for AOR-AOS). This will generate or simulate a number of random variables, and compare for failure, where the probabilities of failing is the ratio of failures to the number of simulations.

Values

Mean value of the ϕ $\mu_{A_{\text{roll}}}$ = 12°, standard deviation of the ϕ $\sigma_{A_{\text{roll}}}$ = 1.3049

Mean value of the AOS $\mu_{A_{\text{shifting}}}$ = 18°, standard deviation of the AOS $\sigma_{A_{\text{shifting}}}$ = 1.1270

The Montecarlo simulation returned the following values after 1,000,000 simulations:

Mean of 1,000,000 angles of roll ϕ, Aormean: 12.0004

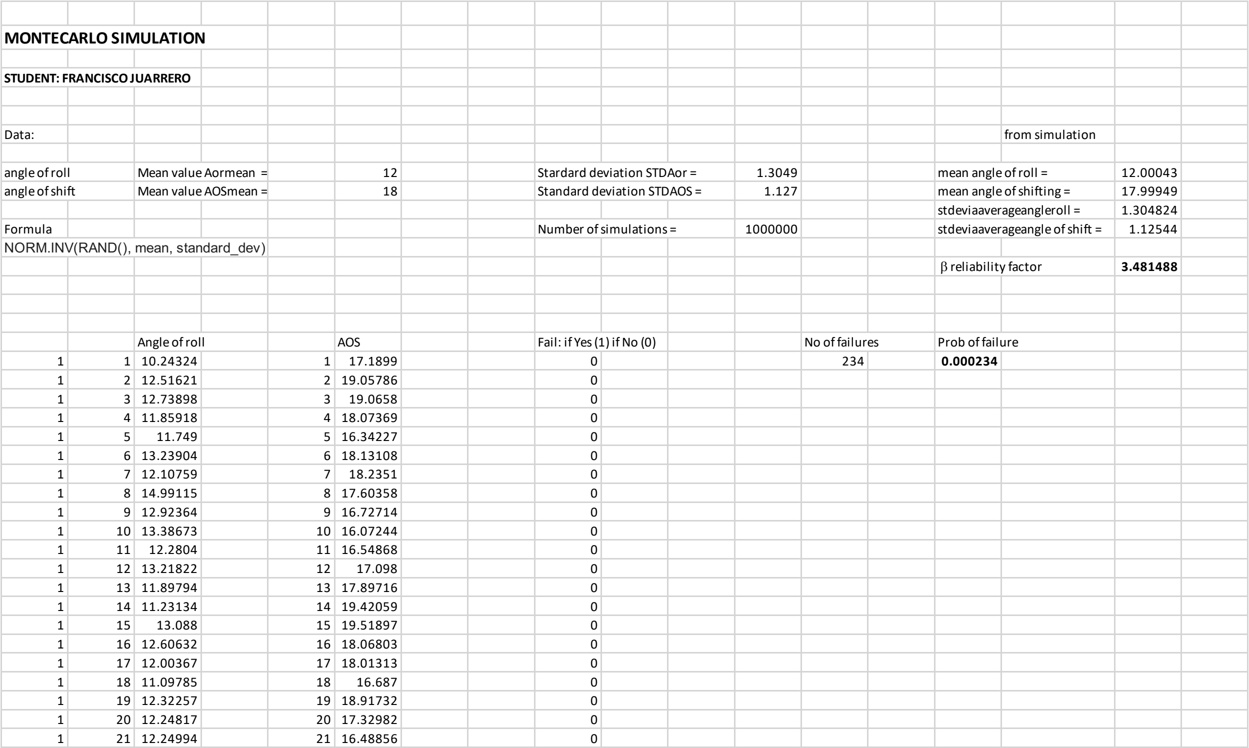
Mean of 1,000,000 angles of shifting, AOSmean: 17.9995.

Standard deviation of the mean of 1,000,000 angles of roll ϕ, STDAor: 1.30482.

Standard deviation of the mean of 1,000,000 angles of shifting, STDAOS: 1.12544.

The number of failures in 1,000,000 simulations: 234.

The probabilities of failure: 0.00023 .



MONTECARLO SIMULATION

STUDENT: FRANCISCO JUARRERO

Data:					from simulation	
angle of roll	Mean value Aormean =	12	Stardard deviation STDAor =	1.3049	mean angle of roll =	12.00043
angle of shift	Mean value AOSmean =	18	Standard deviation STDAOS =	1.127	mean angle of shifting =	17.99949
					stdeviaaverageangleroll =	1.304824
Formula			Number of simulations =	1000000	stdeviaaverageangle of shift =	1.12544
NORM.INV(RAND(), mean, standard_dev)						
					β reliability factor	**3.481488**

		Angle of roll		AOS	Fail: if Yes (1) if No (0)	No of failures	Prob of failure
1	1	10.24324	1	17.1899	0	234	**0.000234**
1	2	12.51621	2	19.05786	0		
1	3	12.73898	3	19.0658	0		
1	4	11.85918	4	18.07369	0		
1	5	11.749	5	16.34227	0		
1	6	13.23904	6	18.13108	0		
1	7	12.10759	7	18.2351	0		
1	8	14.99115	8	17.60358	0		
1	9	12.92364	9	16.72714	0		
1	10	13.38673	10	16.07244	0		
1	11	12.2804	11	16.54868	0		
1	12	13.21822	12	17.098	0		
1	13	11.89794	13	17.89716	0		
1	14	11.23134	14	19.42059	0		
1	15	13.088	15	19.51897	0		
1	16	12.60632	16	18.06803	0		
1	17	12.00367	17	18.01313	0		
1	18	11.09785	18	16.687	0		
1	19	12.32257	19	18.91732	0		
1	20	12.24817	20	17.32982	0		
1	21	12.24994	21	16.48856	0		

Figure 29: Montecarlo simulation calculation in Excel.

As the resulting probability of failure is less than 0.0006 (0.00023), the calculations can be repeated to reach the target probability chosen. It should be noted though that as the computer is generating random numbers that match the criteria of mean value and standard deviation, for both variables, the results vary slightly. Moreover, when tried for Y = 1.3 the number of failures was 1861 for P = 0.00186, and for Y = 1.4 the number of failures was 10195 for P = 0.0102, therefore, the value of safety factor chosen 1.5 is finally selected.

5. RESULTS

Following are the results of the experiment and processing of data:

- The measurements of the AOR yielded the following results:

BAG	AOR										
	SMALL PILE					LARGE PILE					MEAN OF MEAN
	1	2	3	4	MEAN	1	2	3	4	MEAN	
1	26.5	26.5	26.5	26.5	26.500	27.5	27.0	28.5	28.0	27.750	27.125
2	24.0	24.5	23.5	23.5	23.875	25.0	25.0	24.5	23.5	24.500	24.188
3	22.5	23.5	25.5	23.5	23.750	25.0	24.0	25.0	24.0	24.500	24.125
4	24.0	23.5	24.0	23.5	23.750	24.0	24.5	24.5	24.5	24.375	24.063
5	24.0	24.5	25.0	25.5	24.750	25.0	23.5	24.5	25.5	24.625	24.688
6	24.5	25.0	23.5	25.5	24.625	23.5	22.5	23.5	22.5	23.000	23.813
7	24.5	23.0	23.0	23.5	23.500	23.5	25.0	25.0	24.0	24.375	23.938
8	23.5	23.5	22.5	23.5	23.250	22.0	25.5	22.5	23.5	23.375	23.313
9	25.0	23.5	23.5	25.5	24.375	24.5	26.5	26.5	25.0	25.625	25.000
10	24.5	25.0	25.0	25.5	25.000	25.5	23.5	23.5	24.5	24.250	24.625
11	24.0	24.5	23.5	24.5	24.125	26.5	25.0	25.0	25.0	25.375	24.750
12	25.0	25.0	25.0	24.5	24.875	25.5	23.5	26.5	24.5	25.000	24.938
13	25.5	25.5	24.5	26.5	25.500	25.5	24.5	26.5	26.5	25.750	25.625
14	25.5	25.5	25.5	25.0	25.375	26.0	26.0	25.5	26.0	25.875	25.625

Table 10: Measured angle of repose AOR of samples and average values.

- The summary of the above measurements by grades:

GRADE	AOR		
	SMALL PILE	LARGE PILE	MEAN OF MEAN
	MEAN.	MEAN	
1 CWAD	25.313	26.563	25.938
2 CWAD	24.750	24.625	24.688
3 CWAD	24.375	25.625	25.000
1 CWRS	24.938	24.625	24.782
2 CWRS	24.203	24.469	24.336

Table 11: Summary of the AOR measured.

- The measurements of AOS with fixed axis, at To = 2 seconds:

No tests	Bag No	Grade	Angle of Shifting	Permanent angle of list after the roll								
				17	18	19	20	21	22	23	24	25
1	1	1 CWAD		-	-	-	-	-	-	-	-	-
2	5	2 CWAD		-	-	-	-	-	-	-	-	-
3	1+5	CWAD		-	-	-	-	-	-	-	-	-
4	2	2 CWRS		-	-	-	-	-	-	-	-	-
5	3	2 CWRS		-	-	-	-	-	-	-	-	-
6	4	2 CWRS		-	-	-	-	-	-	-	-	-
7	6	2 CWRS		-	-	-	-	-	-	-	-	-
8	2+3+4+6	CWRS		-	-	-	-	-	-	-	-	-
9	7	2 CWRS		-	-	-	-	-	-	-	-	-
10	8	2 CWRS		-	-	-	-	-	-	-	-	-
11	9	3 CWAD		-	-	-	-	-	-	-	-	-
12	10	1 CWRS		-	-	-	-	-	-	-	-	-
13	11	1 CWAD		-	-	-	-	-	-	-	-	-
14	12	1 CWRS		-	-	-	-	-	-	-	-	-
15	13	2 CWRS		-	-	-	-	-	-	-	-	-

Table 12: Measured angle of shifting AOS of samples with fixed axis assembly (Tϕ 2 sec).

- The measurements of AOS with fixed axis, at To = 8 seconds:

No tests	Bag No	Grade	Angle of Shifting	Permanent angle of list after the roll								
				17	18	19	20	21	22	23	24	25
1	1	1 CWAD	19	-	-	1.0	3.0	4.0	6.0	8.0	9.0	9.5
2	5	2 CWAD	18	-	1.5	2.5	4.0	5.0	6.5	8.0	8.5	9.0
3	1+5	CWAD	18	-	1.5	3.0	4.5	5.5	6.5	8.5	9.5	10.0
4	2	2 CWRS	17	1.5	2.0	4.0	5.0	5.5	7.0	8.0	8.5	10.0
5	3	2 CWRS	17	1.5	2.0	2.0	4.5	5.0	6.0	7.5	8.0	8.5
6	4	2 CWRS	17	1.0	2.5	2.5	4.5	6.0	6.5	8.5	10.0	10.0
7	6	2 CWRS	17	1.5	2,5	4.0	4.5	6.5	7.5	7.5	8.3	8.5
8	2+3+4+6	CWRS	19	-	-	1.5	3.0	4.0	5.0	6.5	7.0	8.0
9	7	2 CWRS	18		2.0	2.5	3.5	5.0	6.0	6.5	7.5	8.0
10	8	2 CWRS	17	1.5	3.5	4.5	5.5	6.5	8.0	8.5	9.5	10.5
11	9	3 CWAD	19	-	-	2.0	3.0	3.5	5.0	5.5	6.0	8.5
12	10	1 CWRS	18		1.0	2.5	3.5	4.5	6.0	6.5	6.5	8.0
13	11	1 CWAD	17	2.5	3.0	4.5	6.0	7.5	8.0	9.0	9.5	10.0
14	12	1 CWRS	17	1.5	2.5	3.0	4.0	4.5	5.0	6.0	8.0	8.5
15	13	2 CWRS	18	-	1.5	2.5	3.5	4.5	5.0	5.5	7.0	8.0
16	14	2 CWRS	-	-	-	-	-	-	-	-	-	-

Table 13: Measured angle of shifting AOS of samples with fixed axis assembly (Tϕ 2 sec).

- The measurements of AOS with springs, at To = 2 seconds:

No tests	Bag No	Grade	Angle of Shifting	Permanent angle of list after the roll								
				15	16	17	18	19	20	21	22	23
1	1+5	CWAD	18	-	-	-	2.5					
2	2+3+4+6	2 CWRS	19	-	-	-	-	4.0				
3	8	2 CWRS	19	-	-	-	-	4.5				
4	11	1 CWAD	18	-	-	-	3.5					
5	12	1 CWRS	19	-	-	-	-	2.5				
6	14	2 CWRS	19	-	-	-	-	2.0				

Table 14: Measured angle of shifting AOS of samples with model on springs (Tϕ 2 sec).

- The measurements of AOS with springs, at To = 8 seconds:

No tests	Bag No	Grade	Angle of Shifting	Permanent angle of list after the roll								
				12	13	14	15	16	17	18	19	20
1	1+5	CWAD	12	1.0	4.0	6.5	7.5	9.0	10.0	11.5		
2	2+3+4+6	2 CWRS	13	0.0	1.5	2.5	4.5	6.5	9.5	11.0		
3	8	2 CWRS	12	2.5	5.0	7.0	9.0	10.0	12.0	13.5		
4	11	1 CWAD	12	3.0	5.0	6.0	7.5	8.5	10.5	11.5		
5	12	1 CWRS	12	1.5	3.5	5.5	6.5	8.0	10.0	10.5		
6	14	2 CWRS	13	0.0	1.5	3.5	4.5	6.0	9.0	10.0		

Table 15: Measured angle of shifting AOS of samples with model on springs (Tϕ 8 sec).

- The results of the tests for AOR and AOS for the different grades can be compared as follows:

No Test	BAG - GRADE	AOR (mean of mean)	AOS FIXED (8 sec)	AOS FIXED (2 sec)	AOS SPRING (8 sec)	AOS SPRING (2 sec)
1	1 - 1CWAD	27.125	19	-		
2	5 - 2CWAD	24.188	18	-		
3	1&5 - CWAD	25.656	18	-	12	18
4	2 - 2CWRS	24.125	17	-		
5	3 - 2CWRS	24.063	17	-		
6	4 - 2CWRS	24.688	17	-		
7	6 - 2CWRS	23.813	17	-		
8	2,3,4&6 - 2CWRS	24.172	19	-	13	19
9	7 - 2 CWRS	23.938	18	-		
10	8 - 2 CWRS	23.313	17	-	12	19
11	9 - 3 CWAD	25.000	19	-		
12	10 - 1 CWRS	24.625	18	-		
13	11 - 1 CWAD	24.750	17	-	12	18
14	12 - 1 CWRS	24.938	17	-	12	19
15	13 - 2 CWRS	25.625	18	-		
16	14 - 2 CWRS	25.625	-	-	12	19

Table 16 : Comparison of values of AOR and AOS from the experiments.

- The results of the calculations for correlation and ratio, with the data from AOR and AOS:

No Test	BAG - GRADE	AOR (mean of mean)	AOS FIXED (8 sec)	RATIO
1	1 - 1CWAD	27.125	19	0.700
2	5 - 2CWAD	24.188	18	0.744
3	1&5 - CWAD	25.656	18	0.702
4	2 - 2CWRS	24.125	17	0.705
5	3 - 2CWRS	24.063	17	0.706
6	4 - 2CWRS	24.688	17	0.689
7	6 - 2CWRS	23.813	17	0.714
8	2,3,4&6 - 2CWRS	24.172	19	0.786
9	7 - 2 CWRS	23.938	18	0.752
10	8 - 2 CWRS	23.313	17	0.729
11	9 - 3 CWAD	25.000	19	0.760
12	10 - 1 CWRS	24.625	18	0.731
13	11 - 1 CWAD	24.750	17	0.687
14	12 - 1 CWRS	24.938	17	0.682
15	13 - 2 CWRS	25.625	18	0.702
CONSTANT FOR CONVERSION				0.719
CORRELATION				0.5024

Table 17: Data and results of AOR to AOS ratio and correlation.

- The results of the calculations for correlation and ratio, with the data from AOR and AOS, with adjustments:

No Test	BAG - GRADE	AOR (mean of mean)	AOS FIXED (8 sec)	ADJUSTMENT	RATIO
1	1 - 1CWAD	27.125	19	-	0.700
2	5 - 2CWAD	24.188	17.5	0, -0.5	0.744
3	1&5 - CWAD	25.656	18	-	0.702
4	2 - 2CWRS	24.125	17	-	0.705
5	3 - 2CWRS	24.063	17	-	0.706
6	4 - 2CWRS	24.688	17.5	0, + 0.5	0.689
7	6 - 2CWRS	23.813	17	-	0.714
8	2,3,4&6 - 2CWRS	24.672	18.5	+0.5, -0.5	0.786
9	7 - 2 CWRS	24.438	17.5	+0.5, -0.5	0.752
10	8 - 2 CWRS	23.313	17	-	0.729
11	9 - 3 CWAD	25.500	18.5	+0.5, -0.5	0.760
12	10 - 1 CWRS	24.625	18		0.731
13	11 - 1 CWAD	24.750	17.5	0, +0.5	0.687
14	12 - 1 CWRS	24.438	17.5	-0.5, +0.5	0.682
15	13 - 2 CWRS	25.625	18		0.702
CONSTANT FOR CONVERSION					0.716
CORRELATION					0.8590

Table 18: Data and results of AOR to AOS ratio and correlation , with adjustments.

- The values of mean and standard deviation for the readings of angle of roll were calculated as follows:

VESSEL TYPE	DATE	TIME UTC	SEA CONDITION	ROLL	
				MEAN VALUE μ	STD DEV σ
Bulk carrier handysize	15/9/18	06:07	swell, no wind	5.4947	1.3049
Bulk carrier handysize	15/9/18	15:40	swell, no wind	6.3333	1.0701

Table 19: Calculation of mean values and standard deviations of angle of roll.

- The values of mean and standard deviation for the measurements of AOR and AOS were calculated as follows:

No Test	BAG - GRADE	AOR (mean)	AOR variance	AOR STD DEV	AOS FIXED (8 sec)	AOS variance	AOS STD DEV
1	1 - 1CWAD	27.125	3.173		19.000	0.640	
2	5 - 2CWAD	24.188	1.336		18.000	0.040	
3	1&5 - CWAD	25.656	0.097		18.000	0.040	
4	9 - 3 CWAD	25.000	0.118		19.000	0.640	
5	11 - 1 CWAD	24.750	0.353		17.000	1.440	
Mean CWAD		25.344	1.269	1.127	18.200	0.700	0.837
6	2 - 2CWRS	24.125	0.042		17.000	0.250	
7	3 - 2CWRS	24.063	0.071		17.000	0.250	
8	4 - 2CWRS	24.688	0.128		17.000	0.250	
9	6 - 2CWRS	23.813	0.267		17.000	0.250	
10	2,3,4&6 - 2CWRS	24.172	0.025		19.000	2.250	
11	7 - 2 CWRS	23.938	0.154		18.000	0.250	
12	8 - 2 CWRS	23.313	1.034		17.000	0.250	
13	10 - 1 CWRS	24.625	0.087		18.000	0.250	
14	12 - 1 CWRS	24.938	0.370		17.000	0.250	
15	13 - 2 CWRS	25.625	1.677		18.000	0.250	
Mean CWRS		24.330	0.428	0.655	17.500	0.500	0.707

Table 20: Calculation of mean values and standard deviations of AOR and AOS.

- The number of failures and probability of failure returned after generating 100,000 random variables or the selected parameters ϕ and AOS:

Number of failures: 23

Probability of failure: 0.00023

6. DISCUSSION

The experiment was performed for a number of samples. Before doing the tests and measuring the angle of shifting, each sample was tested for the angle of repose. Such test was performed on a flat table, allowing a vertical flow of grain from the bags to pile up and form a slope until the sliding started to occur. The measurements were done with a lever indicator measuring over the base of the pile every 90 degrees, similar to the cone lifting method described by Rouse, P. (2014). Other more sophisticated methods described by Rouse and others (Al-Hashemi and Al-Amoudi 2017) entail measuring the base of the heap and height and calculating the slope with trigonometric functions or using tilting boxes. The method used can also be categorized as Piling Angle of Repose, as opposed to the Sliding Angle of Repose (Eleleji and Zhou, 2008), which is an approach to determining the dynamic angle of repose, using tilting or movable tables. Al-Hashemi and Al-Amoudi also refer to the dynamic angle of repose being between 3 to 10° less than the static angle of repose using the revolving cylinder method, but again, no reference was found of doing the same on board rolling vessels or models. The values measured in smaller and larger piles show that the changes in the surface area available to the grain caused a slight variation of the AOR but in both directions (increase or decrease), therefore, not conclusive (not systematic). We have considered that the observed differences may be errors of measurements (casual errors) and not cause-effect related. The average values of AOR measured are similar to those customarily presented to the industry by grain shippers.

The experiment is an approximation or simulation of the conditions the grain is exposed to during rolling at sea, i.e. dynamic conditions. Rolling motion is a complex phenomenon. Even in a simplified mathematical model, it depends on many factors, such as transverse ship's inertia, moment of added mass of water dragged by the hull, linear roll damping coefficient, righting moment or stiffness, external heeling moment and frequency of waves (Wawrzyński and Krata, 2016). In terms of frequency of the roll, it is understood that the rolling periods calculated are representative of this vessel for this cargo in specific loading conditions. There can be as many values of period of roll as there are vessels in different loading conditions, and it is therefore impossible to analyze each one of them. The natural period of roll, for the mathematical model ship rounded up were 12 and 14 seconds for the departure and arrival condition. These two values were recalculated scaling down the dimensional elements of the expression, i.e. only applying the scale to the dimensional variables with mean result of 2 seconds. The calculations are in appendix 6. The right scaling down of the period was done considering the geometrical and kinematical similarity requirements, as expressed in Newton's law of similarity, considering only the forces and accelerations that are relevant to the model (gravity and acceleration) and none that would apply to hydrodynamic test models (velocity of fluids, viscosity)(Bertram 2011). All calculations can be seen in 4.1.3.

The tests were done using the model suspended on fixed axis and on springs. The model was initially tried and rolled, aiming at various frequencies approximately: 14,10,8 and 2. The rolling at period of roll of 2 seconds was done by pushing the model from one side, then allowing the return roll with its own restoring forces, with the spring acting as a damper of the oscillations and the angle limiting bars setting the maximum angle of roll (it was in reality about 1.40 sec this rolling). In the model set up with fixed axis this appeared to be natural and stable, the rolling motion well simulated although it lacked 5 out of 6 degrees of freedom. In the model with the spring set up we noted vertical (surge) and lateral (sway) displacements to be too large for the scale. A possible reason for this was the excessive elasticity of the springs.

The rolling at 14 and 10 seconds was firstly done with the operator controlling the frequency of oscillations by hand, after timing the cycle with a chronometer. This disrupted the synchronism and the symmetry of the motion, and the operator bias was deemed excessive. The rolling was done at 8 seconds and the results were similar to that at 14 and 10, therefore, the tests were not pursued at 10 or 14 seconds and instead done at 8 seconds. In the set up with springs, the handling of the rolling introduced even more longitudinal and lateral displacements. Accordingly, in terms of motion and simulation of oscillations, the best performance was done at 2 seconds (1.4 seconds) for the model on fixed axis, then the model on spring at 2 seconds (1.4 seconds) and model on fixed axis at 8 seconds. The period of roll of 14 seconds (2 seconds scaled down) can be categorized as "comfortable" according to the Kempf factor as mentioned by Norby (1962) according to Biran (2003) which is calculated and assessed as follows:

$$\text{Kf} = T\sqrt{\frac{g}{B}} \tag{6.5}$$

Where

Kf < 8 = vessel stiff

Kf > 8 <14 = comfortable roll

Kf >14 = vessel tender

for T = 2 seconds, Kf = 9.00 - comfortable

for T = 8 seconds, Kf = 5.14 - stiff

8 seconds is not the true period of roll for the model or the vessel; 2 and 14 seconds are. However, as the former did not yield results in the fixed axis model and the latter made the motion too disruptive and biased, the tests at 8 seconds on the fixed axis model are chosen as the reliable results, prioritizing the stability of the motion over the period of roll for a single condition, keeping also in mind the tests were done to find a general methodology for different ships in different loading conditions with different period of roll.

The model on springs yielded shifting angles at period of roll of about 2 seconds (1.40) in the region of 18-19 degrees of inclination. At period of roll of 8 seconds, the grain sliding occurred at angles of inclination in the region of 12 degrees. The results at 8 seconds are not reliable, firstly because in the experience of the author, many voyages with grain are performed in winter season where such angles of rolling are recorded, and if grain were to shift, a substantial amount of shifting reports would have been received, secondly because at 8 seconds the motion of the model with the intervention of the operator was exceedingly unstable, as mentioned above. As for the model on fixed axis, it did not show any sliding at period of roll of 2 seconds. It is possible that the frequency of the sliding of the grain is such compared to that of the rolling, that when the sliding starts to occur, the vessel is already in the return roll, thus nullifying the event, in a similar fashion as free surface in roll damping tanks occur. At period of roll of 8 seconds the grain sliding occurred at angles of about 18 degrees and these results were deemed reliable and taken for calculations of the methodology.

For each of the mentioned period of roll, the model was rolled at increasing angles until there was visual indication of granular slide and there was some permanent list measured with the protractor to one side.

The limiting bar set for the angle of roll when the first sliding was noted to occur, was taken as the angle of shifting. One common result was that the smaller the period of roll, which is indicative of greater stability (GM), the greater the angle at which the shifting occurs. While greater GM and shorter periods of roll for which the ship might be termed as "stiff" could be undesirable and even counterproductive for certain cargoes such as steel due to tangential forces (Biran, 2003), for grain cargoes a greater GM could prevent the shifting of the grain at lesser angles. During the experiments we tried to establish a threshold of period of roll where the grain stops shifting at some angles. It was difficult to establish as the frequency of the roll is adjusted manually but it was noted there was no sliding at 15°, at 18° roll the threshold T ≈ 3 sec. ($f \approx 0.333\overline{3}$ Hz) at 21° roll the threshold T ≈ 2.1 sec. ($f \approx 04762$ Hz) and at 25° the threshold T ≈ 1.5 sec. (($f \approx 0.666\overline{6}$ Hz). The measuring was done by starting at high frequencies and decreasing them until sliding was noted to occur, measuring the corresponding period of roll with a chronometer.

A strong correlation between the measured AOR and AOS could not be established, however, after further verification it was found that the correlation calculation was highly sensitive to errors in measurements. As an exploratory exercise, the angles of repose and shifting measured that were more scattered in the scatterplot were altered by ± 0.5° and following this, the correlation changed to almost 0.9. Accordingly, it would be fair to say that there is a correlation and it is positive and linear; and the low correlation coefficient was due to the lack of precision of the methods and instruments for measuring the angle of repose and the angle of shifting: limited to visual indication of sliding and shifting and a protractor. This of course can be deemed arbitrary and biased, and there is a mathematical way of correcting the low values of correlation due to measurement errors, called Attenuation, as described by Spearman C. (1094) which will not be done here as it is not within the scope of this work.

The experiments would have benefited also from a motor coupled with a mechanism for adjusting the speed for better simulating a controlled rolling motion at exact periods of roll. The accuracy in establishing when the grain first slides enough to accumulate a list, depended on the accuracy and the position of the protractor (which could not be placed in the centerline thus adding weight to one side) and also on the attention and perception of the observer. These are limitations given by the lack of access to lab resources or sophisticated techniques and instruments, however, such limitations do not impair the use of the results or affect their accuracy beyond the tolerances established initially, and the possible errors introduced are covered by the safety factor chosen. We did not find reference to methods for measuring shifting of grain in cargo hold models, or even references to previous tests of this kind. However, the methods presented in this report could be improved based on methods used in geotechnical engineering. Prof. François Duhaime and Mr. Pouyan Pirnia from the Construction engineering department at École de technologie supérieure, in Montreal, suggested for instance to measure the static AOR based on methods proposed by Ileleji and Zhou (2007), to use the discrete element method to model grain displacements (Pirnia et al. 2016), and to use the digital image correlation technique to measure grain displacements behind the transparent surface of the model (Dumberry et al. 2018).

Although Spandonidis and Sryrou (2015) did model the shifting of granular materials in beam seas with computers, there is lack of information on how the shifting of grain in cargo holds occurs physically. These experiments provided an opportunity also for observing the process of grain sliding in an oscillating enclosed compartment and for attempting to describe the possible scenario of grain shifting and listing of a rolling vessel: At certain values of inclination during the rolling, the granular cohesive forces are exceeded, and the grain commences to slide. As indicated by the physics of grain cohesion (5.2.3.1), there are frictional forces opposing to the weight causing sliding. In this case there are frictional forces between grains or layers of grain and frictional forces between the pile and the surface of the compartment (hold tank top and hopper slopes). During the experiment, we noticed the laminar sliding occurring between layers of grain, with the upper layers shifting in greater proportion than the subsequent layers, in a staggered fashion, and the pile sliding with respect to the surface of the model interior (Figure 26). Both the grains and model surface have different frictional coefficient, and that of the model (varnished wood) is certainly less than that of the grain, but also the fact that the model is varnished results in greater sliding of the pile with respect to the surface of the model, compared to that of grain in the surface of a real cargo hold. To better understand the phenomenon observed, the work done by Sharan and Lee (1969) is of great relevance. They measured the friction coefficient of wheat grain on grain (internal friction) and wheat on steel, for a pile of wheat with certain depth in a steel bin. The results of their experiment demonstrate the increase of the internal friction with the increase of the depth of the grain, and the internal friction coefficient being greater than that of grain on steel. The former explains the laminar sliding and the latter explains the small piles sliding faster than large piles.

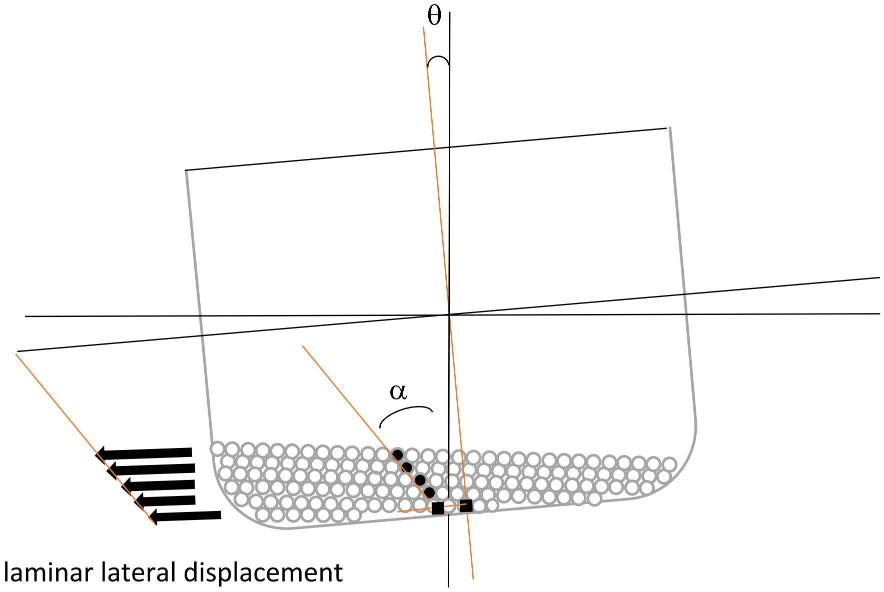


Figure 30 - Laminar sliding of the grain

Let's call θ - angle of list and α - angle of laminar sliding, then it was observed that $\theta > \alpha$

The depth of the pile has an effect not only on the friction coefficient and hence the cohesion forces, but also leads to compression. It is well known by grain terminal operators and superintendents that when the grain is loaded, the stowage factor (the ratio of total volume of a cargo hold to weight of same hold fully loaded) is smaller than the test weight (ratio of total volume of a test box to weight of the same box filled) due to compression.

As the grain shifts, a new slope will form requiring more inclination to cause sliding and the sliding will stop. This new slope will cause a transverse shifting of the center of gravity of the pile. As the center of gravity of that (and any other slack hold where the grain slid) shifted, the center of gravity of the whole vessel has shifted too and it is off the vertical with the center of buoyancy, the two opposing forces - gravity and buoyancy - at certain distance creating a moment (heeling moment). As the vessel starts listing, the centre of buoyancy shifts towards the side the hull is sinking until it is in the same vertical with the center of gravity, the new position of equilibrium, where the heeling arm and moment are null and the vessel rests in that position of permanent list. The vessel now rolls around the new position of equilibrium, meaning that the new rolling will be increased due to the permanent list. This phenomenon can be seen in videos of the towing of the Modern Express, which listed heavily in the North Atlantic on January 26th 2016: the ship rolled around the new position of equilibrium at 40 degrees to the port side (gCaptain, 2016). The increased roll will be able to exceed the cohesive forces of the pile, causing it to shift, until the newly formed slope stops the shifting again. There will be a new increased permanent list, and the process is repeated with the vessel rolling around the new position of equilibrium until the grain surface reaches the boundaries of the cargo hold and cannot shift anymore. Accordingly, it can be said it is a progressive effect. With respect to the limit of shifting, the IGC (1991) establishes that limit at 25° of slope, and ship's curves and tables for heeling moments are calculated for that number, that is, the permanent angle of heel and the residual stability between the curve of righting arm (GZ) and the curve of heeling arm (λ) after the shifting, are calculated based on the surface of the grain shifting 25° for partially filled holds (15° for filled holds).

In order to test the above, the model was set at max 18° both sides with the limiting angle mechanism, then pushed to roll to one side to 18° and let return freely, which happened at 16°.5. Then the rolling slowed down to let slide happening and the return controlled to 16.5 with 1° permanent list. The limiting bars were then set for max 20° one side and 19°, and the return freely although never reached that point. Then, repeated controlling the speed. With the accumulated shift of grain, the new list was 3°. Same repeated at 23° one side, return to 19° and both rolling and return controlled to allow for sliding. The new list was 8.5°. Finally, the test was done at 25° one side, return 19° (at this point with the free rolling the return roll didn't even reach 10°) and the permanent list was 11°. The last test was performed mixing many samples of different grades to fill up the model. When the test was run, the shifting was noted to occur at angle of inclination of 23°. There is a number of reasons for this: the storage condition of these samples (the samples had been stored in a temperature controlled room whereas these ones after the use had been stored in a garage) and the depth of the pile increasing the friction over the surface of the model and the internal friction of grain on grain. While this test was not computed for results given that the sample was of mixed grades and probably accumulated humidity, it sheds some light on the increase of the angle of shifting for larger piles, and this compounded with the findings of Sharan and Lee about increase of friction with the depth of the pile and the internal friction of grain on grain prevailing over friction with the steel tank top and sloping plates of ship holds, we can conclude that holds mostly empty will shift earlier than fuller holds.

One of the objectives of this work was to research on a possible methodology for a safe procedure of deballasting before entering ports (or ballasting after leaving), when the grain stability criteria and the draft cannot be simultaneously met. The said methodology starts with the known data: angle of repose and the required data: angle of roll. The angle of repose is given by terminals when loading the grain. Enquiries were made with local grain terminal managers (G3 in Quebec, Les Silos de Port Cartier, Cargill in Baie Comeau) and they referred to having such data as statistical value. During the experiment a number of samples were tested for both angle of repose and angle of shifting, thus allowing us to find their ratio and with the mean ratio establishing a conversion constant. Such factor for the grain used (wheat) was found to be 0.719. Applying this factor to the AOR given by shippers / terminals, the expected or estimated angle of shifting is obtained. Then the maximum permissible ϕ can be calculated, so as to prevent shifting. The minimum requirement or what could be called Limit State Function would be:

$$g(x) = AOS - \phi \text{ where failure } F = \{g(x) <= 0\} \quad (6.6)$$

where failure means shifting of the grain.

Any condition where AOS - $\phi > 0$ satisfies the criteria that avoid the shifting of the grain, however, such condition is not enough to be deemed safe. The values involved in the calculation are subject to errors: The value of AOR given by shippers is statistical and one value will fit different parcels with different grains, even if of the same grade, exposed to different environment, thus having different size, humidity, etc. The value of AOS and the conversion factor was obtained from tests for a single value of period of roll, with specific grades of wheat, and with instruments of limited accuracy. To account for possible errors in the readings, we introduced a safety factor: one that reduces the probability of failure below minimum acceptable limits. We are applying basic principles of probabilities, as presented to us in the MTEC module B3, Risk, Reliability and Safety by the University of Strathclyde (course notes) used for structural design.

$$AOS = Y \times \phi \quad (6.7)$$

To check the degree of reliability with this safety factor, the Montecarlo simulation was run, after the mean values for AOS (from AOR) and standard deviations σ of the various readings of AOS were calculated, selecting the highest of all values of σ for different grades. As for the mean value of the angle of rolling ϕ, it was calculated from the AOS with the safety factor, and the standard deviations from a number of readings done by deck officers on board ships and sent to us. The simulation was done in Excel, using the function NORM.INV, for a 100,000 and 1,000,000 simulations. Ideally, it would have been done in the professional version of MathCad. The simulation was tried for various safety factors Y = 1.3, 1.4 and 1.5 against a target probability of failure.

With respect to the target probability of failure, the information found mostly relates to structural failure. Duckett (2004) refers to an annual probability of failure for bridges (collapse and impacted by ships) in the range of 10^{-4} yearly target, as per ISO/ DIS 10252 (bases for design of structures, accidental actions) norms. This results in 1% probability of failure for a 100 years life of the structure.

In the same paper, he presents a formula for calculating a rational target probability as follows:

$$P(f) = \frac{10^{-4}}{N_r} K_s N_d \quad (6.8)$$

Where $N_r$is the number of people at risk (considered 20), N_d the number of years of service (considered 25) and $K_s$is 5 for towers and offshore structures.

the calculated target probability is:

$$P(f) = \frac{10^{-4}}{20} \text{ x } 5 \text{ x } 25 = 0.000625$$

The safety factor Y = 1.5 ($\phi = 12°$) yielded a probability of failure of 0.00023 which is the one that meets the target set. At Y = 1.4 (($\phi = 13°$) it yielded a probability of failure of 0.00186 and at Y = 1.3 (($\phi = 14°$) the probability of failure was 0.0102. While the 100,000 simulations gave variable results of failures ranging from 7 to 30 (P = 0.00007 to 0.00030), at 1,000,000 simulations there was a better convergence and the number of failures were all in the range of 200. The reliability factor β was calculated as 3.55.

The said methodology and possible safety procedures, subject to further research and studies, could be summarized as follows (as an example only):

- To ensure the angle of repose of the wheat is provided by shippers.
- To calculate the probable angle of shifting of the grain by applying the ratio or constant for conversion. If wheat C = 0.719 (AOS = AOR x 0.719).
- To calculate the maximum permissible angle of roll ϕ by applying a safety factor of 1.5 to the angle of shifting (ϕ = AOS / 1.5).
- To determine the actual ϕ before deballasting, by performing a number of readings, taking the greatest value. If the value taken exceeds the value calculated, DO NOT proceed with the deballast.
- To estimate the time needed for deballasting, if possible including transit to the berth or place where the limitation applies. To commence the deballasting operation allowing enough time to reach such point without ballast, but without unnecessary delays.
- To check the weather conditions and reports, and if there is any suspicion of deterioration of sea conditions, to postpone. In case of a sudden deterioration of the weather during the process of deballasting beyond the calculated limits, to ballast again and cancel until the weather conditions warrant a safe deballasting and passage to the port.
- To check with the pilot and port authorities to prevent cancellations in entering the port. If such is the case, to ballast again without delay.
- When all the above conditions are met, to perform the deballasting operation.

It cannot be stressed enough that this methodology is not applicable for sea passages when the vessel doesn’t meet the grain stability criteria, only for a vessel technically within port limits or under local jurisdiction (i.e. not on an international voyage) and a lapse of time needed to deballast tanks to the draft of the entry port (or ballast the tanks outside the exiting port), time lapse in which it is not believed the weather conditions will deteriorate to the point that such maximum angle of roll will be exceeded. It is also understood that the researched methodology should benefit from further studies and investigation as well as experimental results including studies of influence of sea condition (sea spectra) and ship's dynamic response (RAO) on the dynamic angle of sliding of grains, before being considered for modifying or adding to existing regulations and practices.

Nonetheless, this work represents to our knowledge a first known attempt to research the dynamic angle of sliding of the grain through experimental tests with a physical model of a ship's cargo hold, and to elaborate a much needed methodology of calculation for determining the maximum angle of roll at which the vessel can deballast (or ballast) in open waters when both the grain stability and the draft limits cannot be met.

7. CONCLUSIONS

1. The experimental tests confirmed the hypothesis that under dynamic conditions the grain shifts at angles of inclination smaller than the static angle of repose.
2. The experimental tests revealed the dynamic angle of shift is not only a function of the cohesive properties of the grain, but also the frequency of oscillations (period of roll), in that the higher the frequency (smaller period of roll), the greater the angle at which the grain slides. It was also found that at the scaled roll frequency the grain didn’t even slide at large angles of inclination probably due to the absence of lateral and vertical accelerations of the fixed axis model ($f \approx 0.333\overline{3}$ Hz or higher).
3. The experimental test revealed that smaller piles in the cargo compartment have less weight and hence less internal friction in the pile and less friction with the boundary structure (tank top and sloping steel plate). It was also seen how the internal friction of grain on grain prevails over the friction of grain on structure, as the displacement over the bottom was greater than the laminar displacement of the various layers of grain.
4. The accuracy of the measurements and results are limited by the instruments and methods employed, but nonetheless they shed valuable information. The use of a level protractor - angle locator and hands to regulate the frequency of oscillation can introduce errors to the measurements and results, highlighting the need for greater resources: computer-based techniques for capturing sliding and mechanisms for controlling the frequency and amplitude of balance.
5. The results obtained in this thesis are only applicable to wheat, and for other types of grain, it is necessary to carry out a similar comparative study of angle of repose versus angle of shifting, to determine the conversion constant (ratio) and to calculate safety factors and probability of failure.
6. The determination of the probability of failure and reliability of the results are only an example of a possible methodology, subject to further studies and research, that could in the future lead to approved procedures for safe operation of deballasting before entering ports (or ballast after leaving), for ships loaded with wheat which are constrained by the draft and grain stability.

8. RECOMMENDATIONS

1. To continue the study of the dynamic angle of sliding compared to the static angle of repose of other types of grain, namely: Corn, barley, soybean, rye, rice, seeds (sunflower seeds, rapeseeds, cottonseeds, etc.) and others whose behaviour is similar to that of grain in its natural state: other cargoes with non-cohesive properties and angles of repose of less than 30° such as fertilizers (ammonium nitrate, urea, etc.).
2. To perform these other experiments with more sophisticated techniques for rolling the model and capturing and measuring the sliding. The model to be engaged to a motor with a speed and direction controlling mechanism to simulate the oscillations without disturbances. To perform more tests per type of grain in order to have more data to compare.
3. To use more elaborated probabilistic techniques when assessing the safety factor and probability of failure. When performing the Montecarlo simulation, to incorporate all uncertainties derived from the dynamic situation the vessel might encounter in open seas, including the variables from wave or sea spectra and vessel's response amplitude operator. To use Mathcad or similar software allowing more simulations and easier calculations.
4. The subsequent studies and research should be aimed to calculating reliable conversion factors or ratio of AOR to AOS, which would give sea masters a very useful information about the maximum rolling conditions under which the deballasting before entering (or ballasting after leaving) the port can be undertaken, when both the draft and grain stability criteria cannot be met simultaneously.
5. It would be also desirable that with the numeric results from further research, guidelines or procedures are elaborated and presented to competent authorities in charge of revising the regulations for their perusal, approval and implementation.

9. BIBLIOGRAPHY

Al-Hashemi, H and Al Moudi, O (2017) *A review on the angle of repose of granular material*. Dhahran, Saudi Arabia. King Fahd University.

Arndt, R (1968). *Schüttgut und Kentersicherheit*. Hansa. 105.

Assuero et al. (2006) *The correlation coefficient: An overview*. Sevilla, Spain. Taylor and Francis Group LLC. Available at URL: https://pdfs.semanticscholar.org/80cc/d0790a6889ea4517b378d 7ddf5eb49db5da9. pdf

Baltrop and Hifi (2012) *Reliability based Marine Structural Design*, course notes. Glasgow, UK. University of Strathclyde.

Bertram, V (2011) *Practical Ships Hydrodynamics*. Oxford, UK. Butterworth-Heinemann.

Biran, A.B. (2003) *Ship Hydrostatics and Stability*. Oxford, UK. Butterworth-Heinemann.

Dumberry, et al. (2018). *Erosion monitoring during core overtopping using a laboratory model with digital image correlation and X-ray microcomputed tomography*. Montreal, Canada. Revue Canadienne de Géotechnique. Available at URL: http://www.nrcresearchpress.com/doi/10.1139/cgj-2016-0684#.W8kM6S8ZPB

gCaptain (2016) Video: The Spectacular Salvage Operation to Save the Modern Express. Blog. Available at URL: https://gcaptain.com/video-the-spectactular-salvage-operation-to-save-the-modern-express/

Gifford, Will Duckett (2004), *Risk Analysis and the Acceptable Probability of Failure*, Risk Analysis. Available at URL: https://www.istructe.org/iabse/files/henderson04/paper_06.pdf

IGC (1991*). International Code for the Safe Carriage of Grain in Bulk*. London, UK. International Maritime Organization.

Iglesia et al. (2011) *Validation of centrifuge model scaling for Soil systems via Trapdoor tests*. Massachusetts, US. American Society of Civil Engineers.

Ileleji, K and Zhou B (2007) Th*e angle of repose of bulk corn stover particles.* West Lafayette, USA. Elsevier, Available at URL: https://engineering.purdue.edu/ABE/people/Papers/klein.ileleji.1/bulkcorn

IMSBC, code (2008) *International Maritime Solid Bulk Cargoes Code*. Edition 2013. London, UK. International Maritime Organization.

ISC (2008) *International Code on Intact Stability*. London, UK. International Maritime Organization.

Kamal, A (2016) *Guidance to Deck Officers while loading grain*. Marine Study. Available at URL: https://marinestudy.net/guidance-to-deck-officers-while-loading-grain/

Lumay et al. (2017) *The influence of grain shape, friction and cohesion on granular compaction dynamics*. Liege, Belgium. European Physical Journal.

Lumay et al. (2012) *Measuring the flowing properties of powders and grain*. Liege, Belgium. Elsevier. Available at URL: http://www.grasp.ulg.ac.be/article/2012_lumay_PT.pdf

NCB (1994) *General Information for Grain Loading*. Edition 2002. New York, US. National Cargo Bureau Inc.

Norby, R. (1962).*The stability of coastal vessels*. Trans. RINA, 104, 517-44.

Pirnia et al. (2016). *Development of a multiscale numerical modelling tool for granular materials*. Montreal, Canada. 69th Canadian Geotechnical Conference.

Rawson, K and Tupper E (1968) *Basic Ship Theory*. Edition 2001. Oxford, UK. Butterworth-Heinemann.

Rouse, P. (2014) *Comparison of methods for the measurement of the angle of repose of granular materials, pascal rouse*, Geotechnical testing journal.

Sharan, G and Lee, J (1970). *Coefficient of friction of wheat grain on grain and steel*. Ontario, Canada. Canadian Agricultural Engineering.

SOLAS (1974). International Convention for the Safety of Life at Sea, 1974 and protocols 1988. Edition 2009. London, UK. International Maritime Organization.

Spandonidis and Sryrou (2015) *Coupled granular material and vessel motion in regular beam seas*. Glasgow, UK. STAB2015.

Spearman, C (1904) *The proof and measurement of association between two things*. Leipzig, Germany. American Journal of Psychology. Available at URL: https://academic.oup.com/ije/article/39/5/1137/806468

Tsimopoulou et al. (2011) *Rationalization of safety factors for breakwater design in hurricane-prone areas*. Delft, Netherlands. Delft University of Technology. Available at URL: http://edepot.wur.nl/207202

Voraa, E and Bauge K (2016) *Development and design of a ship model for use in education and research*. Gothenburg, Sweden. Chalmers University of Technology

Wawrzyński, W and Krata, P (2016) *Method for ships rolling period prediction with regards to non-linearity of GZ curve*. Warsaw, Poland. Journal of Theoretical and applied mechanics. Available at URL: https://www.researchgate.net/publication/309839271_Method_for_ship%27s_rolling_period_prediction_with_regard_to_non-linearity_of_GZ_curve

10. APPENDIX

10.1- APPENDIX 1

METHODOLOGY FOR CALCULATING GRAIN STABILITY

NCB Part I and II / TC Table II and III

1- The cargo and liquid compartments, weights, VCGs and FS moments are listed. The Vertical Moments are calculated as a product of the weight x VCGs

2- The lightship weight and constants are also listed with their respective VCGs. The Vertical Moments are calculated as a product of the weight x VCGs.

3- The weights of cargo and liquid compartments, LS and constant are added to obtain the Displacement. The Vertical Moments of compartment, LS and constant are added to obtain the total Vertical Moment. The FS moments are added to obtain the total FS moment

4- The total Vertical Moment is divided by the Displacement to obtain the vessel's KG

5- The total FS moment is divided by the Displacement to obtain the FS correction to the KG

6- The vessel's corrected KG is calculated by subtracting the KG – FS correction

7- With the transversal metacentric height over the keel KM, the GM for the loading condition can be obtained by subtracting the KM – Kg corrected.

NCB Part III / TC Table IV, V, VI

1- The cargo compartments, ullage or height, stowage factor and volumetric heeling moments are listed. The transversal heeling moments are calculated dividing the volumetric heeling moment by the stowage factor SF

2- The transversal heeling moments for filled compartments is corrected for vertical shifting of the center of gravity by multiplying it for a constant 1.06, unless already accounted for in the ship's data

3- The transversal heeling moments for partially filled or slack compartments is corrected for vertical shifting of the center of gravity by multiplying it for a constant 1.12, unless already accounted for in the ship's data

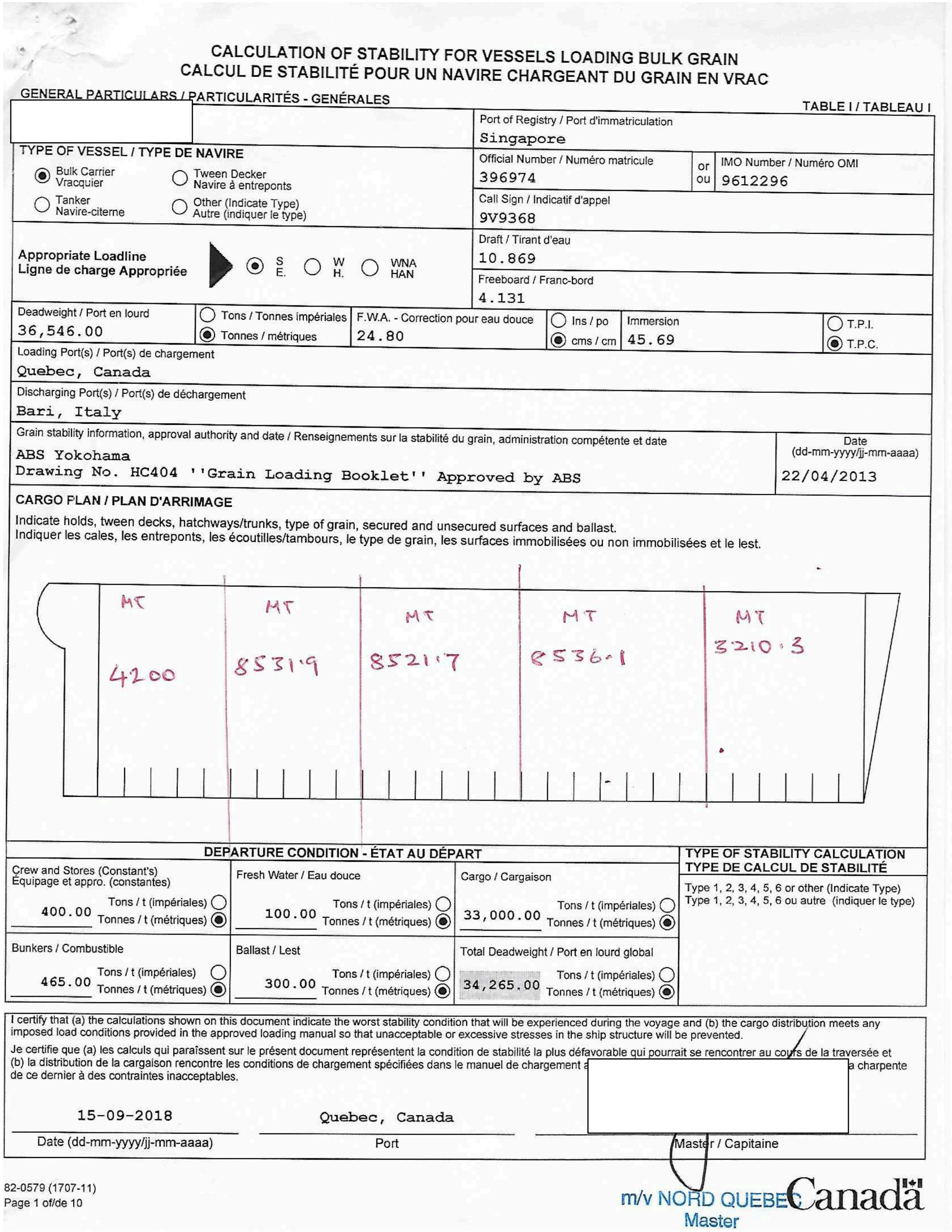
4- The value of the Total Heeling Moment is calculated by adding the transversal heeling moments for filled and for slack compartments.

5- The value of Allowable or Maximum Permissible Heeling Moment is obtained from tables with the Displacement and KG corrected above calculated

6- The two values of Total Heeling Moment and Allowable Heeling Moment, and if the latter exceeds the former, the Grain Stability Criteria is met.

10.2- APPENDIX 2

ACTUAL GRAIN CALCULATION AS PERFORMED BY PORT WARDEN ON A CANADIAN PORT



CALCULATION OF STABILITY FOR VESSELS LOADING BULK GRAIN
CALCUL DE STABILITÉ POUR UN NAVIRE CHARGEANT DU GRAIN EN VRAC

GENERAL PARTICULARS / PARTICULARITÉS - GÉNÉRALES

TABLE I / TABLEAU I

[redacted]

Port of Registry / Port d'immatriculation: Singapore

Official Number / Numéro matricule: 396974 or / ou IMO Number / Numéro OMI: 9612296

Call Sign / Indicatif d'appel: 9V9368

Draft / Tirant d'eau: 10.869

Freeboard / Franc-bord: 4.131

TYPE OF VESSEL / TYPE DE NAVIRE
● Bulk Carrier / Vracquier ○ Tween Decker / Navire à entreponts
○ Tanker / Navire-citerne ○ Other (Indicate Type) / Autre (indiquer le type)

Appropriate Loadline / Ligne de charge Appropriée ▶ ● S / E. ○ W / H. ○ WNA / HAN

Deadweight / Port en lourd: 36,546.00 ○ Tons / Tonnes impériales ● Tonnes / métriques

F.W.A. - Correction pour eau douce: 24.80 ○ Ins / po ● cms / cm

Immersion: 45.69 ○ T.P.I. ● T.P.C.

Loading Port(s) / Port(s) de chargement: Quebec, Canada

Discharging Port(s) / Port(s) de déchargement: Bari, Italy

Grain stability information, approval authority and date / Renseignements sur la stabilité du grain, administration compétente et date:
ABS Yokohama
Drawing No. HC404 ''Grain Loading Booklet'' Approved by ABS

Date (dd-mm-yyyy/jj-mm-aaaa): 22/04/2013

CARGO PLAN / PLAN D'ARRIMAGE

Indicate holds, tween decks, hatchways/trunks, type of grain, secured and unsecured surfaces and ballast.
Indiquer les cales, les entreponts, les écoutilles/tambours, le type de grain, les surfaces immobilisées ou non immobilisées et le lest.

MT 4200	MT 8531.9	MT 8521.7	MT 8536.1	MT 3210.3

DEPARTURE CONDITION - ÉTAT AU DÉPART

Crew and Stores (Constant's) / Équipage et appro. (constantes): 400.00 ○ Tons / t (impériales) ● Tonnes / t (métriques)	Fresh Water / Eau douce: 100.00 ○ Tons / t (impériales) ● Tonnes / t (métriques)	Cargo / Cargaison: 33,000.00 ○ Tons / t (impériales) ● Tonnes / t (métriques)
Bunkers / Combustible: 465.00 ○ Tons / t (impériales) ● Tonnes / t (métriques)	Ballast / Lest: 300.00 ○ Tons / t (impériales) ● Tonnes / t (métriques)	Total Deadweight / Port en lourd global: 34,265.00 ○ Tons / t (impériales) ● Tonnes / t (métriques)

TYPE OF STABILITY CALCULATION / TYPE DE CALCUL DE STABILITÉ
Type 1, 2, 3, 4, 5, 6 or other (Indicate Type)
Type 1, 2, 3, 4, 5, 6 ou autre (indiquer le type)

I certify that (a) the calculations shown on this document indicate the worst stability condition that will be experienced during the voyage and (b) the cargo distribution meets any imposed load conditions provided in the approved loading manual so that unacceptable or excessive stresses in the ship structure will be prevented.

Je certifie que (a) les calculs qui paraîssent sur le présent document représentent la condition de stabilité la plus défavorable qui pourrait se rencontrer au cours de la traversée et (b) la distribution de la cargaison rencontre les conditions de chargement spécifiées dans le manuel de chargement a[redacted]a charpente de ce dernier à des contraintes inacceptables.

15-09-2018 — Date (dd-mm-yyyy/jj-mm-aaaa)
Quebec, Canada — Port
[redacted] — Master / Capitaine

m/v NORD QUEBEC
Master

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Canada

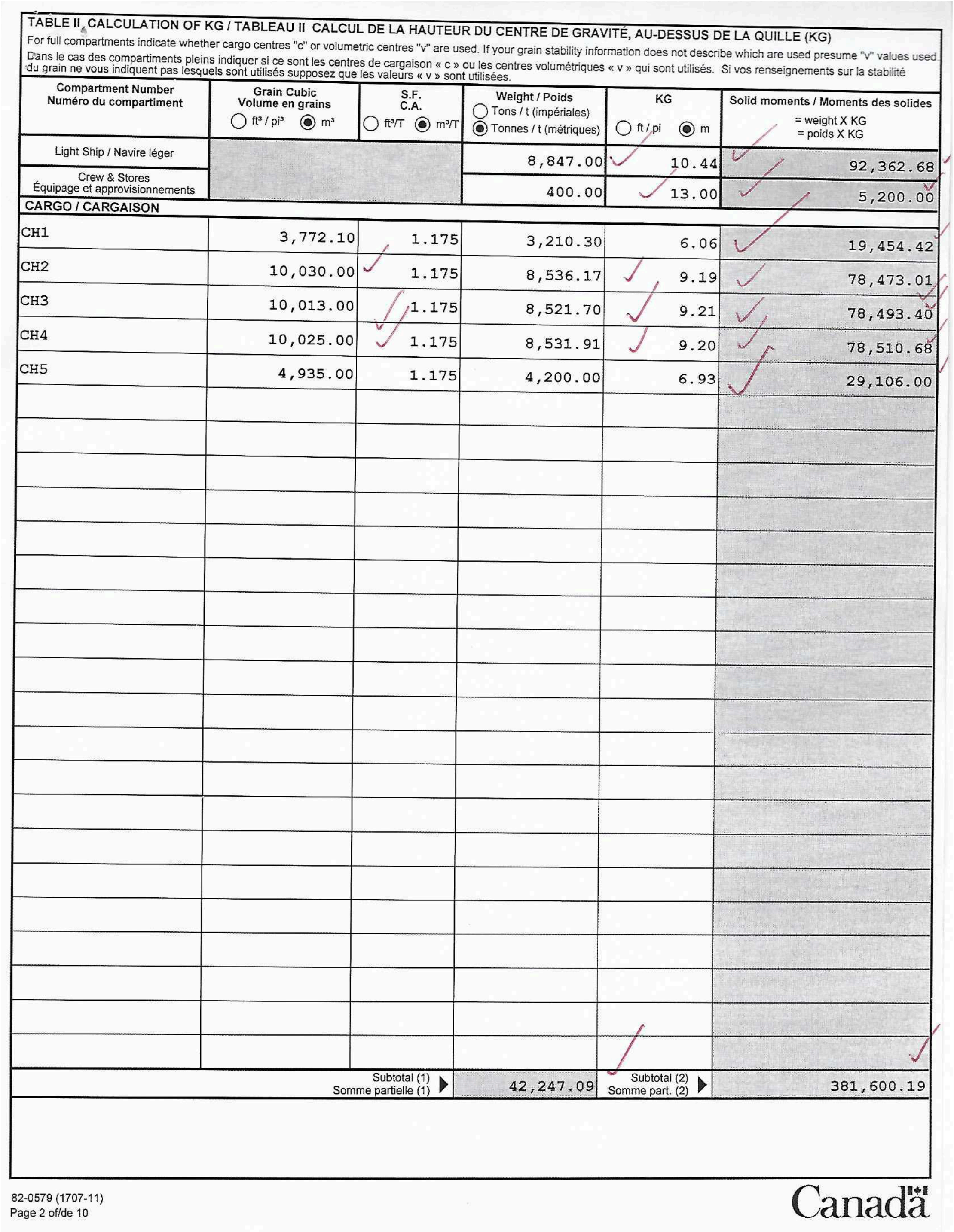

TABLE II CALCULATION OF KG / TABLEAU II CALCUL DE LA HAUTEUR DU CENTRE DE GRAVITÉ, AU-DESSUS DE LA QUILLE (KG)

For full compartments indicate whether cargo centres "c" or volumetric centres "v" are used. If your grain stability information does not describe which are used presume "v" values used.

Dans le cas des compartiments pleins indiquer si ce sont les centres de cargaison « c » ou les centres volumétriques « v » qui sont utilisés. Si vos renseignements sur la stabilité du grain ne vous indiquent pas lesquels sont utilisés supposez que les valeurs « v » sont utilisées.

Compartment Number Numéro du compartiment	Grain Cubic Volume en grains ○ ft³ / pi³ ● m³	S.F. C.A. ○ ft³/T ● m³/T	Weight / Poids ○ Tons / t (impériales) ● Tonnes / t (métriques)	KG ○ ft / pi ● m	Solid moments / Moments des solides = weight X KG = poids X KG
Light Ship / Navire léger			8,847.00	10.44	92,362.68
Crew & Stores Équipage et approvisionnements			400.00	13.00	5,200.00
CARGO / CARGAISON					
CH1	3,772.10	1.175	3,210.30	6.06	19,454.42
CH2	10,030.00	1.175	8,536.17	9.19	78,473.01
CH3	10,013.00	1.175	8,521.70	9.21	78,493.40
CH4	10,025.00	1.175	8,531.91	9.20	78,510.68
CH5	4,935.00	1.175	4,200.00	6.93	29,106.00
		Subtotal (1) Somme partielle (1) ▶	42,247.09	Subtotal (2) Somme part. (2) ▶	381,600.19

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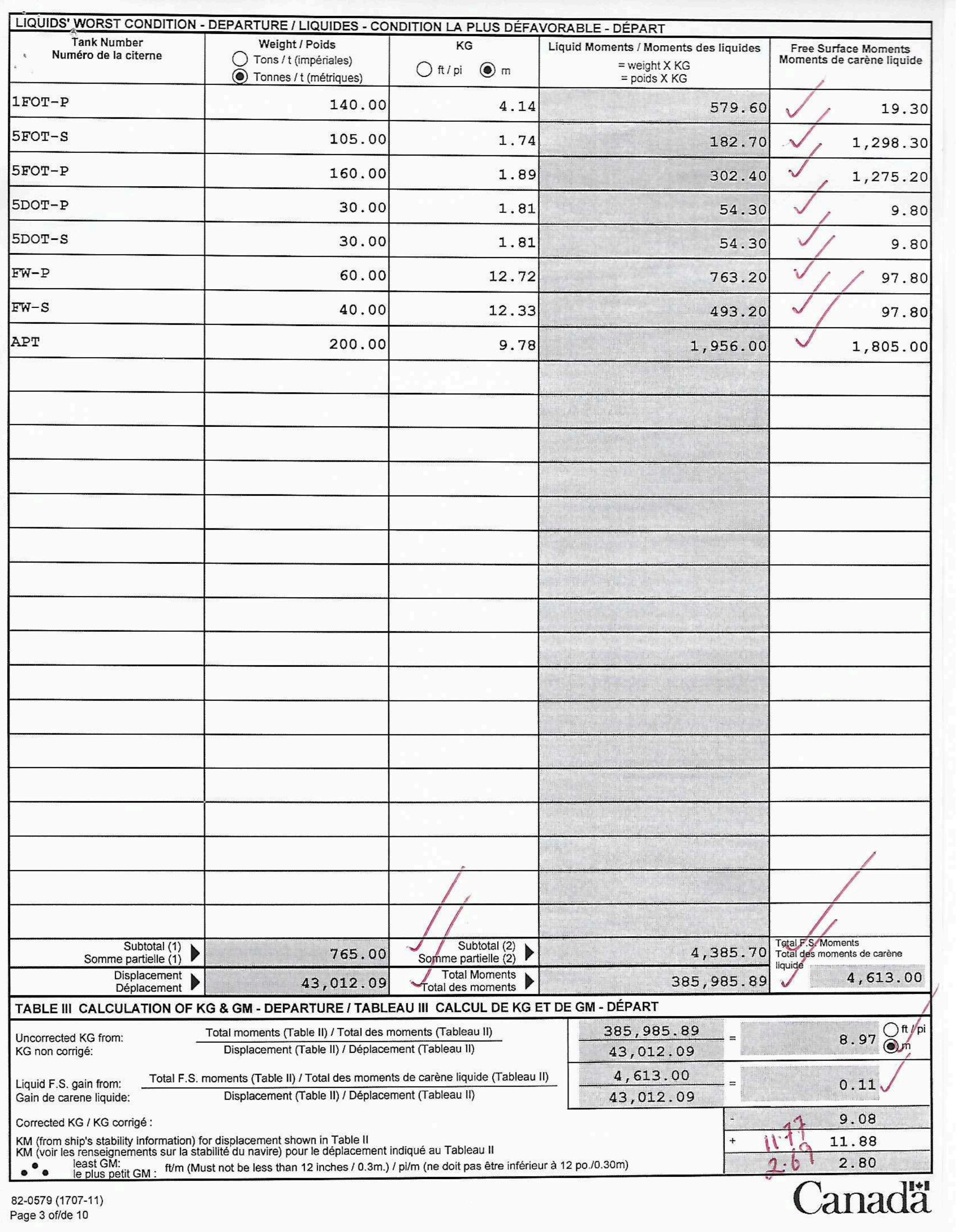
Canada



LIQUIDS' WORST CONDITION - DEPARTURE / LIQUIDES - CONDITION LA PLUS DÉFAVORABLE - DÉPART

Tank Number Numéro de la citerne	Weight / Poids ○ Tons / t (impériales) ● Tonnes / t (métriques)	KG ○ ft / pi ● m	Liquid Moments / Moments des liquides = weight X KG = poids X KG	Free Surface Moments Moments de carène liquide
1FOT-P	140.00	4.14	579.60	✓ 19.30
5FOT-S	105.00	1.74	182.70	✓ 1,298.30
5FOT-P	160.00	1.89	302.40	✓ 1,275.20
5DOT-P	30.00	1.81	54.30	✓ 9.80
5DOT-S	30.00	1.81	54.30	✓ 9.80
FW-P	60.00	12.72	763.20	✓ 97.80
FW-S	40.00	12.33	493.20	✓ 97.80
APT	200.00	9.78	1,956.00	✓ 1,805.00
Subtotal (1) Somme partielle (1) ▶	765.00	✓ Subtotal (2) Somme partielle (2) ▶	4,385.70	Total F.S. Moments Total des moments de carène liquide ✓ 4,613.00
Displacement Déplacement ▶	43,012.09	✓ Total Moments Total des moments ▶	385,985.89	

TABLE III CALCULATION OF KG & GM - DEPARTURE / TABLEAU III CALCUL DE KG ET DE GM - DÉPART

Uncorrected KG from: KG non corrigé:	Total moments (Table II) / Total des moments (Tableau II) Displacement (Table II) / Déplacement (Tableau II)	385,985.89 43,012.09	=	8.97 ○ ft / pi ● m ✓
Liquid F.S. gain from: Gain de carene liquide:	Total F.S. moments (Table II) / Total des moments de carène liquide (Tableau II) Displacement (Table II) / Déplacement (Tableau II)	4,613.00 43,012.09	=	0.11 ✓
Corrected KG / KG corrigé :			-	9.08
KM (from ship's stability information) for displacement shown in Table II KM (voir les renseignements sur la stabilité du navire) pour le déplacement indiqué au Tableau II			+ 11.77	11.88
least GM: le plus petit GM :	ft/m (Must not be less than 12 inches / 0.3m.) / pi/m (ne doit pas être inférieur à 12 po./0.30m)		2.69	2.80

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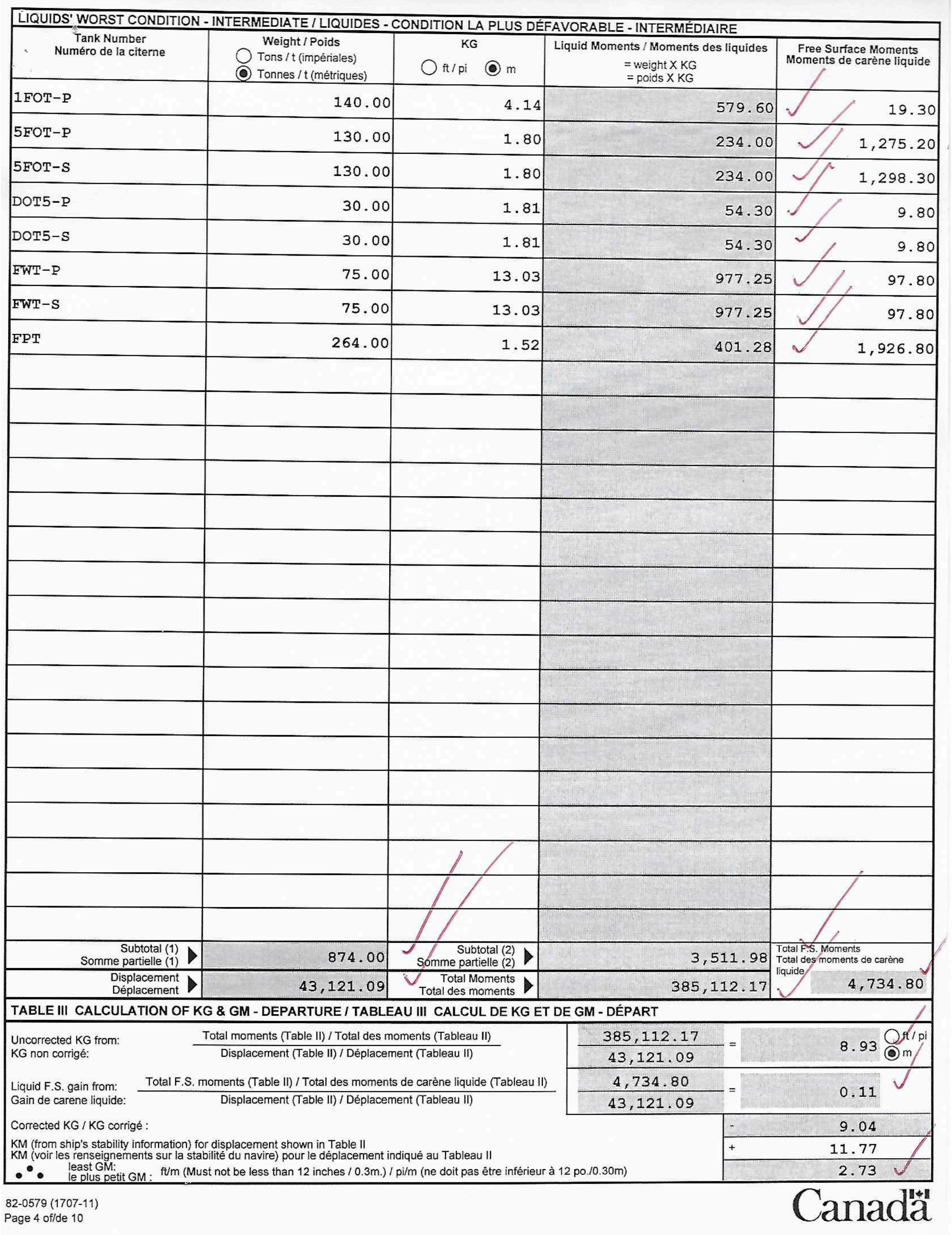
Canada



LIQUIDS' WORST CONDITION - INTERMEDIATE / LIQUIDES - CONDITION LA PLUS DÉFAVORABLE - INTERMÉDIAIRE

Tank Number Numéro de la citerne	Weight / Poids ○ Tons / t (impériales) ● Tonnes / t (métriques)	KG ○ ft / pi ● m	Liquid Moments / Moments des liquides = weight X KG = poids X KG	Free Surface Moments Moments de carène liquide
1FOT-P	140.00	4.14	579.60	19.30
5FOT-P	130.00	1.80	234.00	1,275.20
5FOT-S	130.00	1.80	234.00	1,298.30
DOT5-P	30.00	1.81	54.30	9.80
DOT5-S	30.00	1.81	54.30	9.80
FWT-P	75.00	13.03	977.25	97.80
FWT-S	75.00	13.03	977.25	97.80
FPT	264.00	1.52	401.28	1,926.80
Subtotal (1) Somme partielle (1) ▶	874.00	Subtotal (2) Somme partielle (2) ▶	3,511.98	Total F.S. Moments Total des moments de carène liquide 4,734.80
Displacement Déplacement ▶	43,121.09	Total Moments Total des moments ▶	385,112.17	

TABLE III CALCULATION OF KG & GM - DEPARTURE / TABLEAU III CALCUL DE KG ET DE GM - DÉPART

Uncorrected KG from: KG non corrigé:	Total moments (Table II) / Total des moments (Tableau II) Displacement (Table II) / Déplacement (Tableau II)	385,112.17 43,121.09	=	8.93	○ ft / pi ● m
Liquid F.S. gain from: Gain de carene liquide:	Total F.S. moments (Table II) / Total des moments de carène liquide (Tableau II) Displacement (Table II) / Déplacement (Tableau II)	4,734.80 43,121.09	=	0.11	
Corrected KG / KG corrigé :			-	9.04	
KM (from ship's stability information) for displacement shown in Table II KM (voir les renseignements sur la stabilité du navire) pour le déplacement indiqué au Tableau II			+	11.77	
least GM: le plus petit GM :	ft/m (Must not be less than 12 inches / 0.3m.) / pi/m (ne doit pas être inférieur à 12 po./0.30m)			2.73	

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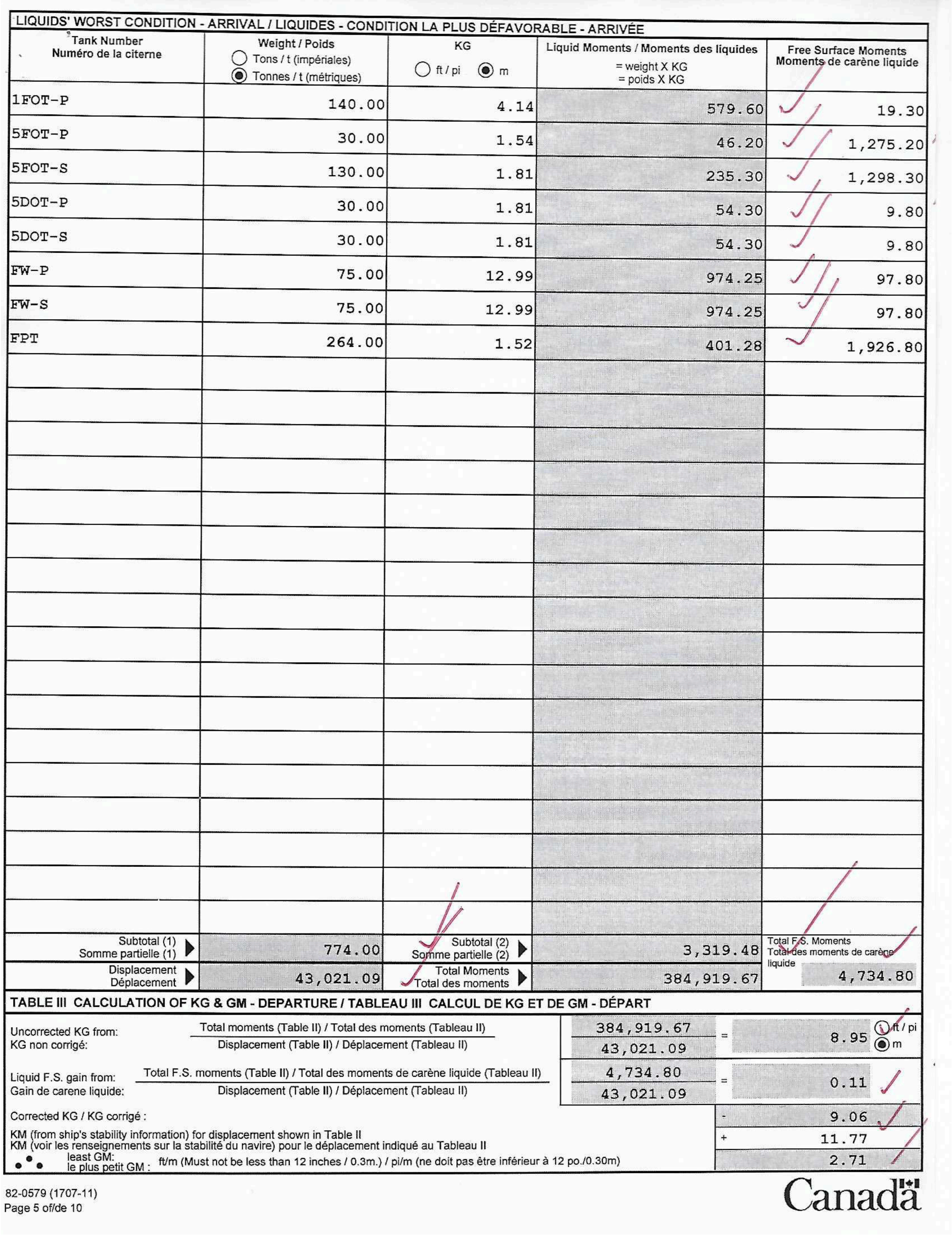

LIQUIDS' WORST CONDITION - ARRIVAL / LIQUIDES - CONDITION LA PLUS DÉFAVORABLE - ARRIVÉE

Tank Number Numéro de la citerne	Weight / Poids ○ Tons / t (impériales) ● Tonnes / t (métriques)	KG ○ ft / pi ● m	Liquid Moments / Moments des liquides = weight X KG = poids X KG	Free Surface Moments Moments de carène liquide
1FOT-P	140.00	4.14	579.60	19.30
5FOT-P	30.00	1.54	46.20	1,275.20
5FOT-S	130.00	1.81	235.30	1,298.30
5DOT-P	30.00	1.81	54.30	9.80
5DOT-S	30.00	1.81	54.30	9.80
FW-P	75.00	12.99	974.25	97.80
FW-S	75.00	12.99	974.25	97.80
FPT	264.00	1.52	401.28	1,926.80
Subtotal (1) Somme partielle (1) ▶	774.00	Subtotal (2) Somme partielle (2) ▶	3,319.48	Total F.S. Moments Total des moments de carène liquide 4,734.80
Displacement Déplacement ▶	43,021.09	Total Moments Total des moments ▶	384,919.67	

TABLE III CALCULATION OF KG & GM - DEPARTURE / TABLEAU III CALCUL DE KG ET DE GM - DÉPART

Uncorrected KG from: KG non corrigé:	Total moments (Table II) / Total des moments (Tableau II) Displacement (Table II) / Déplacement (Tableau II)	384,919.67 43,021.09	=	8.95	○ ft / pi ● m
Liquid F.S. gain from: Gain de carene liquide:	Total F.S. moments (Table II) / Total des moments de carène liquide (Tableau II) Displacement (Table II) / Déplacement (Tableau II)	4,734.80 43,021.09	=	0.11	
Corrected KG / KG corrigé :			-	9.06	
KM (from ship's stability information) for displacement shown in Table II KM (voir les renseignements sur la stabilité du navire) pour le déplacement indiqué au Tableau II			+	11.77	
least GM: le plus petit GM :	ft/m (Must not be less than 12 inches / 0.3m.) / pi/m (ne doit pas être inférieur à 12 po./0.30m)			2.71	

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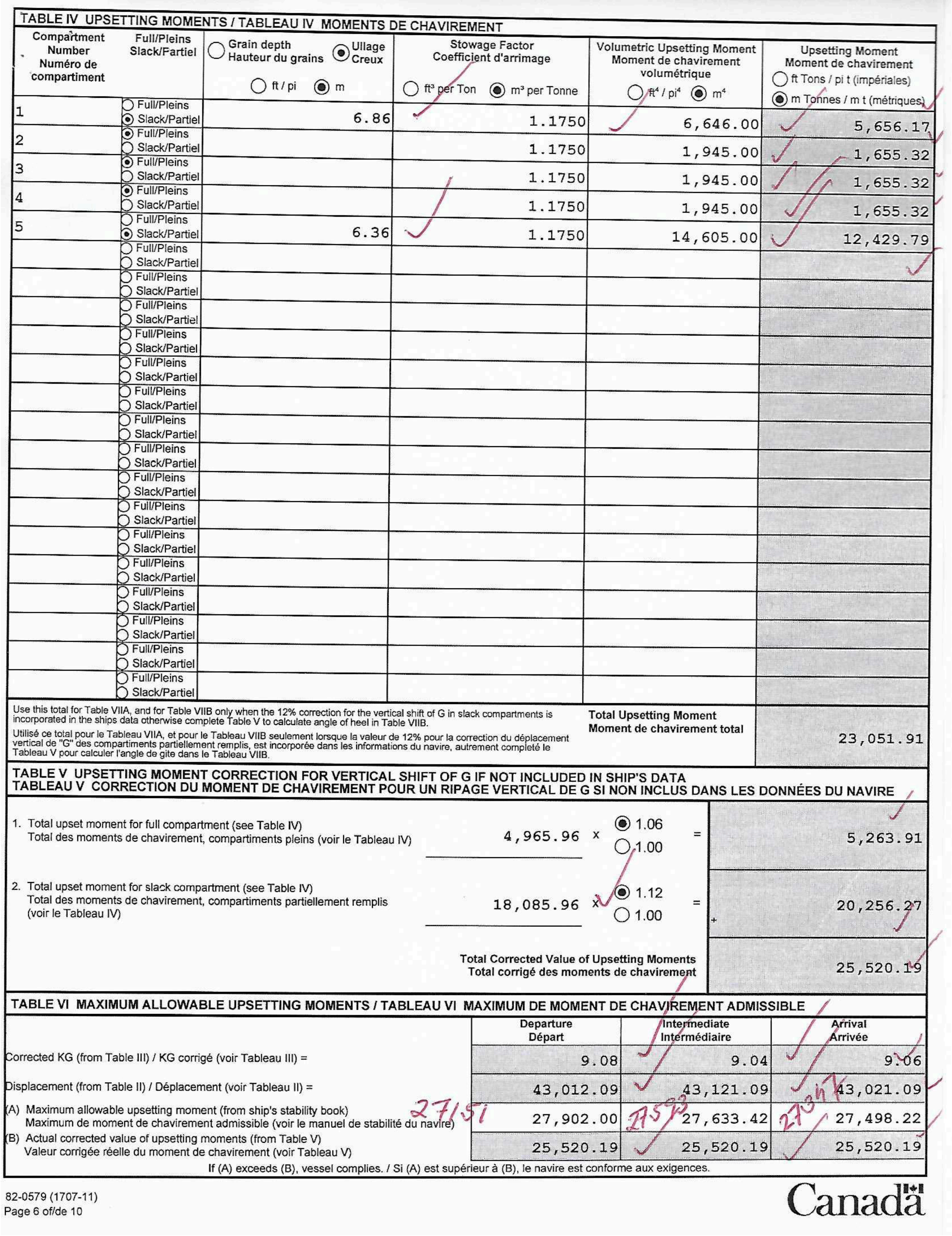

TABLE IV UPSETTING MOMENTS / TABLEAU IV MOMENTS DE CHAVIREMENT

Compartment Number Numéro de compartiment	Full/Pleins Slack/Partiel	○ Grain depth / Hauteur du grains ● Ullage / Creux ○ ft / pi ● m	Stowage Factor / Coefficient d'arrimage ○ ft^3 per Ton ● m^3 per Tonne	Volumetric Upsetting Moment / Moment de chavirement volumétrique ○ ft^4 / pi^4 ● m^4	Upsetting Moment / Moment de chavirement ○ ft Tons / pi t (impériales) ● m Tonnes / m t (métriques)
1	○ Full/Pleins ● Slack/Partiel	6.86	1.1750	6,646.00	5,656.17
2	● Full/Pleins ○ Slack/Partiel		1.1750	1,945.00	1,655.32
3	● Full/Pleins ○ Slack/Partiel		1.1750	1,945.00	1,655.32
4	● Full/Pleins ○ Slack/Partiel		1.1750	1,945.00	1,655.32
5	○ Full/Pleins ● Slack/Partiel	6.36	1.1750	14,605.00	12,429.79
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				
	○ Full/Pleins ○ Slack/Partiel				

Use this total for Table VIIA, and for Table VIIB only when the 12% correction for the vertical shift of G in slack compartments is incorporated in the ships data otherwise complete Table V to calculate angle of heel in Table VIIB.

Utilisé ce total pour le Tableau VIIA, et pour le Tableau VIIB seulement lorsque la valeur de 12% pour la correction du déplacement vertical de "G" des compartiments partiellement remplis, est incorporée dans les informations du navire, autrement complété le Tableau V pour calculer l'angle de gîte dans le Tableau VIIB.

Total Upsetting Moment / Moment de chavirement total: 23,051.91

TABLE V UPSETTING MOMENT CORRECTION FOR VERTICAL SHIFT OF G IF NOT INCLUDED IN SHIP'S DATA
TABLEAU V CORRECTION DU MOMENT DE CHAVIREMENT POUR UN RIPAGE VERTICAL DE G SI NON INCLUS DANS LES DONNÉES DU NAVIRE

1. Total upset moment for full compartment (see Table IV) Total des moments de chavirement, compartiments pleins (voir le Tableau IV)	4,965.96	x	● 1.06 ○ 1.00	=	5,263.91
2. Total upset moment for slack compartment (see Table IV) Total des moments de chavirement, compartiments partiellement remplis (voir le Tableau IV)	18,085.96	x	● 1.12 ○ 1.00	=	+ 20,256.27
			Total Corrected Value of Upsetting Moments Total corrigé des moments de chavirement		25,520.19

TABLE VI MAXIMUM ALLOWABLE UPSETTING MOMENTS / TABLEAU VI MAXIMUM DE MOMENT DE CHAVIREMENT ADMISSIBLE

	Departure Départ	Intermediate Intermédiaire	Arrival Arrivée
Corrected KG (from Table III) / KG corrigé (voir Tableau III) =	9.08	9.04	9.06
Displacement (from Table II) / Déplacement (voir Tableau II) =	43,012.09	43,121.09	43,021.09
(A) Maximum allowable upsetting moment (from ship's stability book) Maximum de moment de chavirement admissible (voir le manuel de stabilité du navire) 27151	27,902.00	27593 27,633.42	27347 27,498.22
(B) Actual corrected value of upsetting moments (from Table V) Valeur corrigée réelle du moment de chavirement (voir Tableau V)	25,520.19	25,520.19	25,520.19

If (A) exceeds (B), vessel complies. / Si (A) est supérieur à (B), le navire est conforme aux exigences.

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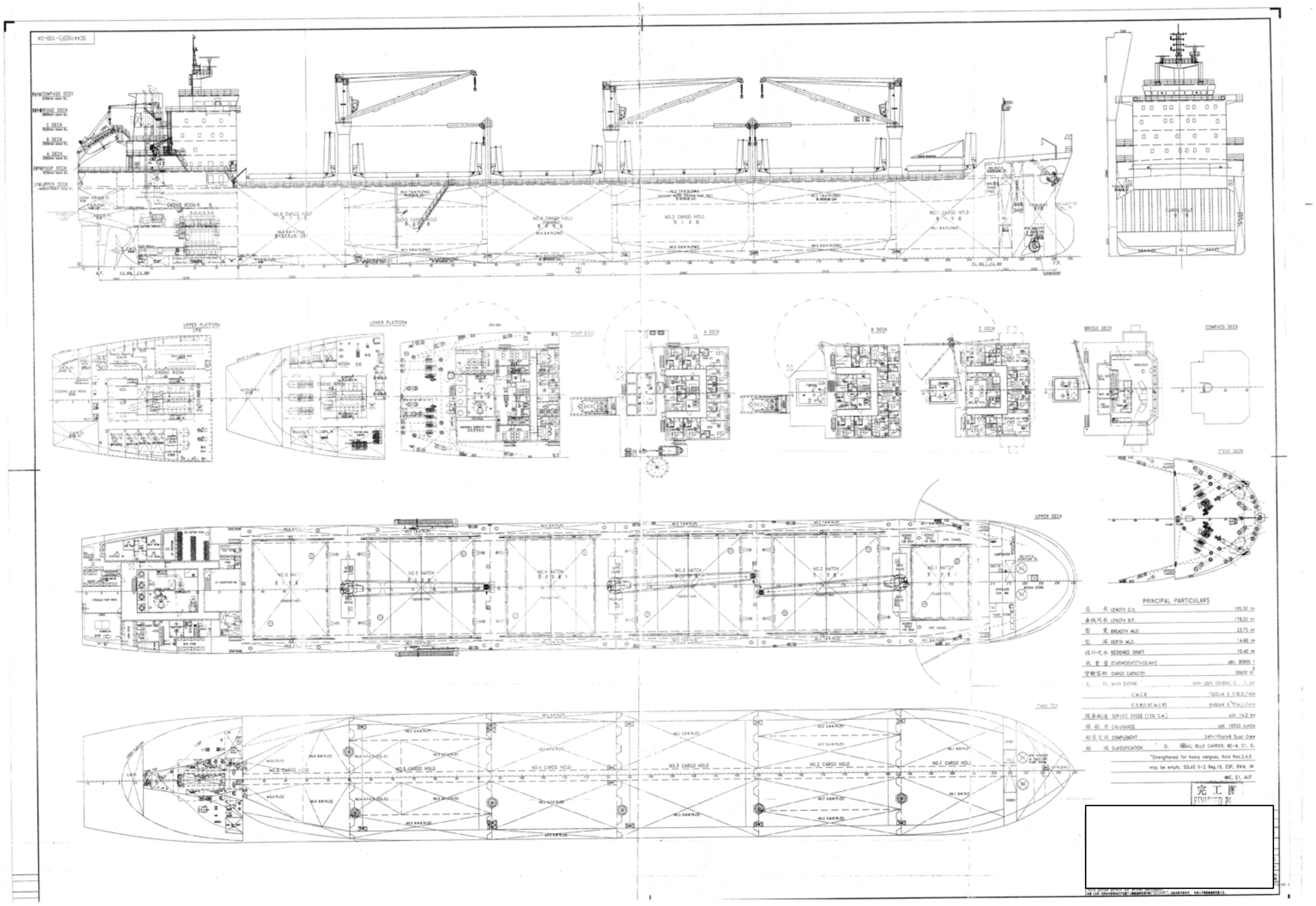
10.3- APPENDIX 3

CONSIDERATIONS ON THE COMPLIANCE OF RELEVANT REGULATIONS WHEN DEBALLASTING AT SEA

1. The international Grain Code, Part A Specific Requirements, 7 Stability requirements, 7.1 requires minimum intact stability requirements for any ship carrying bulk grain, to be met **throughout the voyage**.
2. The International Grain Code was adopted by Resolution MSC.23(59) to amend SOLAS 1974 including Chapter VI, Part C
3. The SOLAS 1974 in its Part A Applications, definitions, etc., Regulation 2, definitions, 2(d) International voyage means a voyage from a country to which the present convention applies to a **port outside such country**, or conversely.
4. Accordingly, once the ship arrives to the port limits, it has rendered its voyage according to SOLAS.

10.4 - APPENDIX 4

GENERAL ARRANGEMENT PLAN

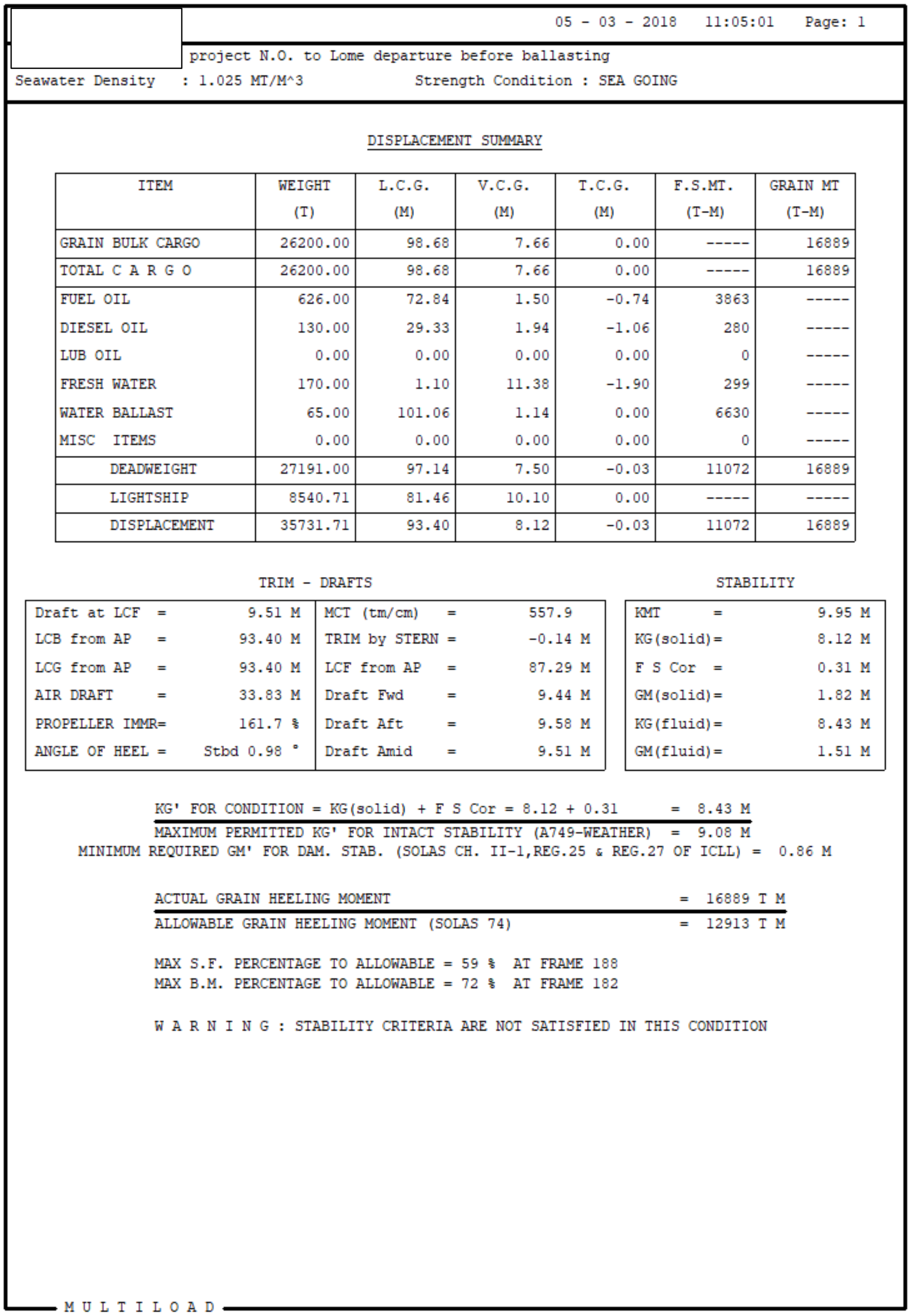


10.5- APPENDIX 5

LOADING CONDITIONS

10.5.1 - DEPARTURE CONDITION WITH FULL BUNKERS AND WITHOUT BALLAST

A- WEIGHT DISTRIBUTION, INTACT STABILITY PARAMETERS



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project N.O. to Lome departure before ballasting

Seawater Density : 1.025 MT/M^3   Strength Condition : SEA GOING

DISPLACEMENT SUMMARY

ITEM	WEIGHT (T)	L.C.G. (M)	V.C.G. (M)	T.C.G. (M)	F.S.MT. (T-M)	GRAIN MT (T-M)
GRAIN BULK CARGO	26200.00	98.68	7.66	0.00	-----	16889
TOTAL C A R G O	26200.00	98.68	7.66	0.00	-----	16889
FUEL OIL	626.00	72.84	1.50	-0.74	3863	-----
DIESEL OIL	130.00	29.33	1.94	-1.06	280	-----
LUB OIL	0.00	0.00	0.00	0.00	0	-----
FRESH WATER	170.00	1.10	11.38	-1.90	299	-----
WATER BALLAST	65.00	101.06	1.14	0.00	6630	-----
MISC ITEMS	0.00	0.00	0.00	0.00	0	-----
DEADWEIGHT	27191.00	97.14	7.50	-0.03	11072	16889
LIGHTSHIP	8540.71	81.46	10.10	0.00	-----	-----
DISPLACEMENT	35731.71	93.40	8.12	-0.03	11072	16889

TRIM - DRAFTS

Draft at LCF = 9.51 M
LCB from AP = 93.40 M
LCG from AP = 93.40 M
AIR DRAFT = 33.83 M
PROPELLER IMMR= 161.7 %
ANGLE OF HEEL = Stbd 0.98 °

MCT (tm/cm) = 557.9
TRIM by STERN = -0.14 M
LCF from AP = 87.29 M
Draft Fwd = 9.44 M
Draft Aft = 9.58 M
Draft Amid = 9.51 M

STABILITY

KMT = 9.95 M
KG(solid)= 8.12 M
F S Cor = 0.31 M
GM(solid)= 1.82 M
KG(fluid)= 8.43 M
GM(fluid)= 1.51 M

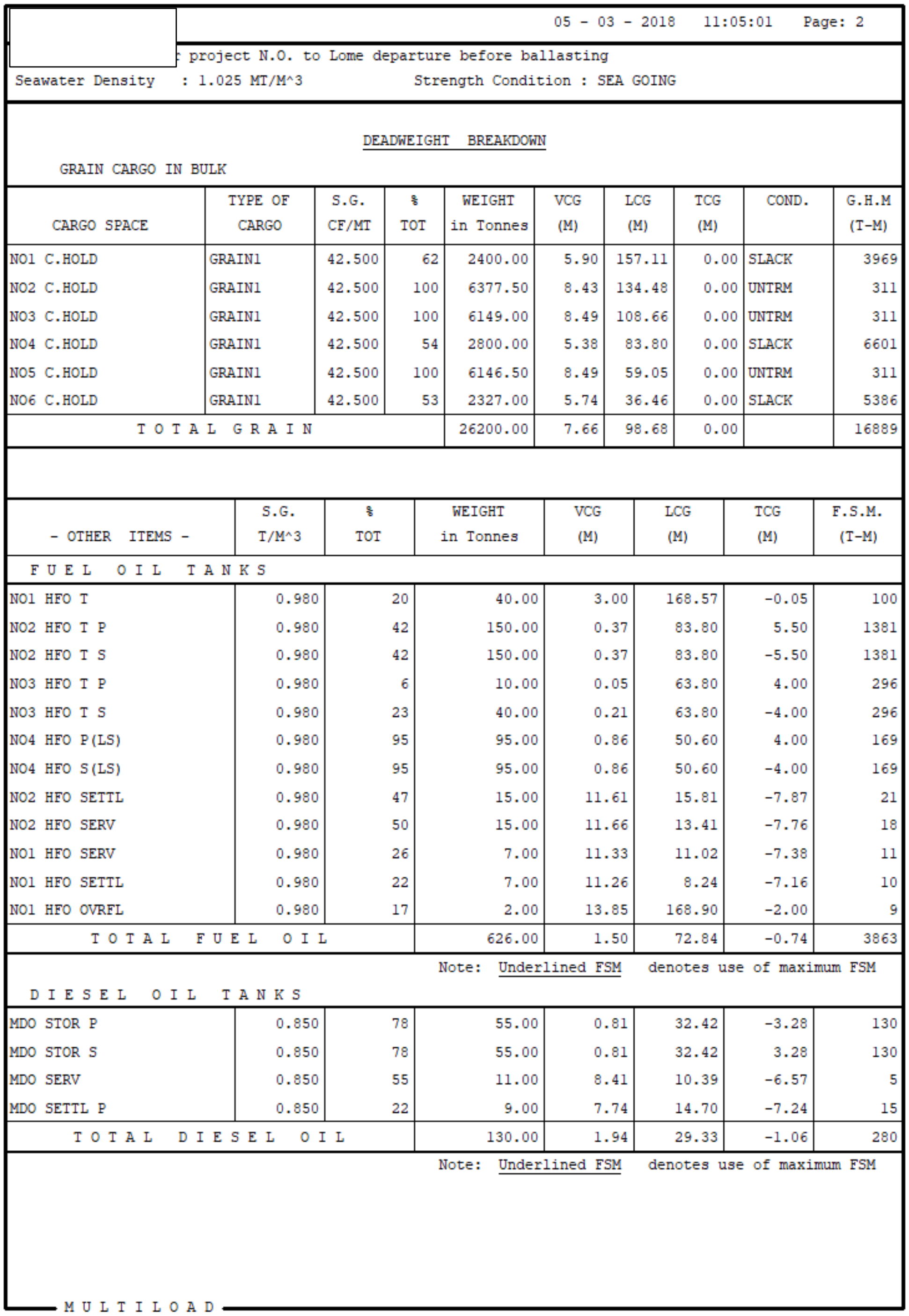
KG' FOR CONDITION = KG(solid) + F S Cor = 8.12 + 0.31 = 8.43 M
MAXIMUM PERMITTED KG' FOR INTACT STABILITY (A749-WEATHER) = 9.08 M
MINIMUM REQUIRED GM' FOR DAM. STAB. (SOLAS CH. II-1,REG.25 & REG.27 OF ICLL) = 0.86 M

ACTUAL GRAIN HEELING MOMENT = 16889 T M
ALLOWABLE GRAIN HEELING MOMENT (SOLAS 74) = 12913 T M

MAX S.F. PERCENTAGE TO ALLOWABLE = 59 % AT FRAME 188
MAX B.M. PERCENTAGE TO ALLOWABLE = 72 % AT FRAME 182

WARNING : STABILITY CRITERIA ARE NOT SATISFIED IN THIS CONDITION

MULTILOAD



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[redacted] project N.O. to Lome departure before ballasting

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

DEADWEIGHT BREAKDOWN

GRAIN CARGO IN BULK

CARGO SPACE	TYPE OF CARGO	S.G. CF/MT	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	COND.	G.H.M (T-M)
NO1 C.HOLD	GRAIN1	42.500	62	2400.00	5.90	157.11	0.00	SLACK	3969
NO2 C.HOLD	GRAIN1	42.500	100	6377.50	8.43	134.48	0.00	UNTRM	311
NO3 C.HOLD	GRAIN1	42.500	100	6149.00	8.49	108.66	0.00	UNTRM	311
NO4 C.HOLD	GRAIN1	42.500	54	2800.00	5.38	83.80	0.00	SLACK	6601
NO5 C.HOLD	GRAIN1	42.500	100	6146.50	8.49	59.05	0.00	UNTRM	311
NO6 C.HOLD	GRAIN1	42.500	53	2327.00	5.74	36.46	0.00	SLACK	5386
TOTAL GRAIN				26200.00	7.66	98.68	0.00		16889

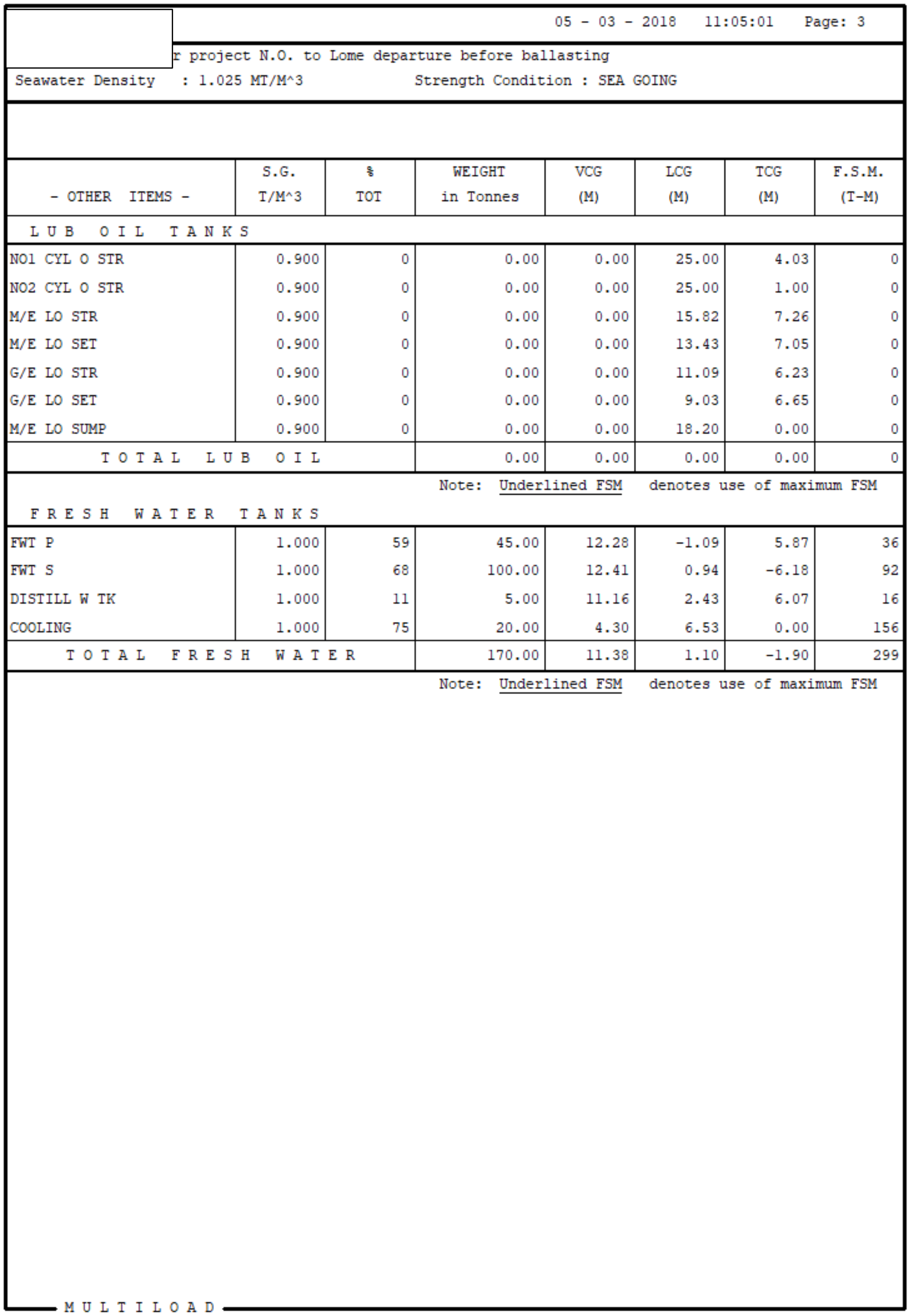
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
FUEL OIL TANKS							
NO1 HFO T	0.980	20	40.00	3.00	168.57	-0.05	100
NO2 HFO T P	0.980	42	150.00	0.37	83.80	5.50	1381
NO2 HFO T S	0.980	42	150.00	0.37	83.80	-5.50	1381
NO3 HFO T P	0.980	6	10.00	0.05	63.80	4.00	296
NO3 HFO T S	0.980	23	40.00	0.21	63.80	-4.00	296
NO4 HFO P(LS)	0.980	95	95.00	0.86	50.60	4.00	169
NO4 HFO S(LS)	0.980	95	95.00	0.86	50.60	-4.00	169
NO2 HFO SETTL	0.980	47	15.00	11.61	15.81	-7.87	21
NO2 HFO SERV	0.980	50	15.00	11.66	13.41	-7.76	18
NO1 HFO SERV	0.980	26	7.00	11.33	11.02	-7.38	11
NO1 HFO SETTL	0.980	22	7.00	11.26	8.24	-7.16	10
NO1 HFO OVRFL	0.980	17	2.00	13.85	168.90	-2.00	9
TOTAL FUEL OIL			626.00	1.50	72.84	-0.74	3863

Note: Underlined FSM denotes use of maximum FSM

DIESEL OIL TANKS							
MDO STOR P	0.850	78	55.00	0.81	32.42	-3.28	130
MDO STOR S	0.850	78	55.00	0.81	32.42	3.28	130
MDO SERV	0.850	55	11.00	8.41	10.39	-6.57	5
MDO SETTL P	0.850	22	9.00	7.74	14.70	-7.24	15
TOTAL DIESEL OIL			130.00	1.94	29.33	-1.06	280

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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r project N.O. to Lome departure before ballasting

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

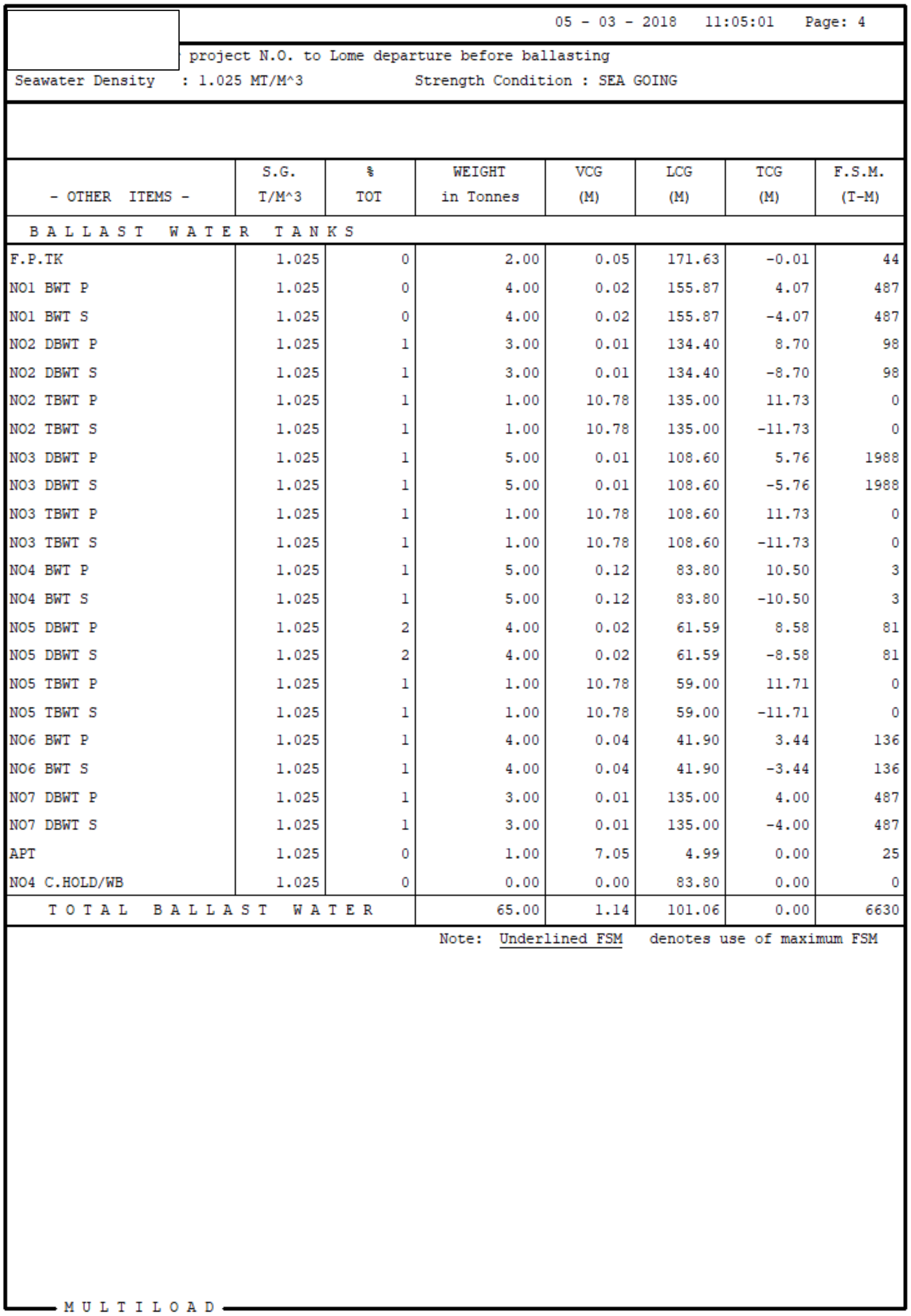
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
LUB OIL TANKS							
NO1 CYL O STR	0.900	0	0.00	0.00	25.00	4.03	0
NO2 CYL O STR	0.900	0	0.00	0.00	25.00	1.00	0
M/E LO STR	0.900	0	0.00	0.00	15.82	7.26	0
M/E LO SET	0.900	0	0.00	0.00	13.43	7.05	0
G/E LO STR	0.900	0	0.00	0.00	11.09	6.23	0
G/E LO SET	0.900	0	0.00	0.00	9.03	6.65	0
M/E LO SUMP	0.900	0	0.00	0.00	18.20	0.00	0
TOTAL LUB OIL			0.00	0.00	0.00	0.00	0

Note: Underlined FSM denotes use of maximum FSM

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
FRESH WATER TANKS							
FWT P	1.000	59	45.00	12.28	-1.09	5.87	36
FWT S	1.000	68	100.00	12.41	0.94	-6.18	92
DISTILL W TK	1.000	11	5.00	11.16	2.43	6.07	16
COOLING	1.000	75	20.00	4.30	6.53	0.00	156
TOTAL FRESH WATER			170.00	11.38	1.10	-1.90	299

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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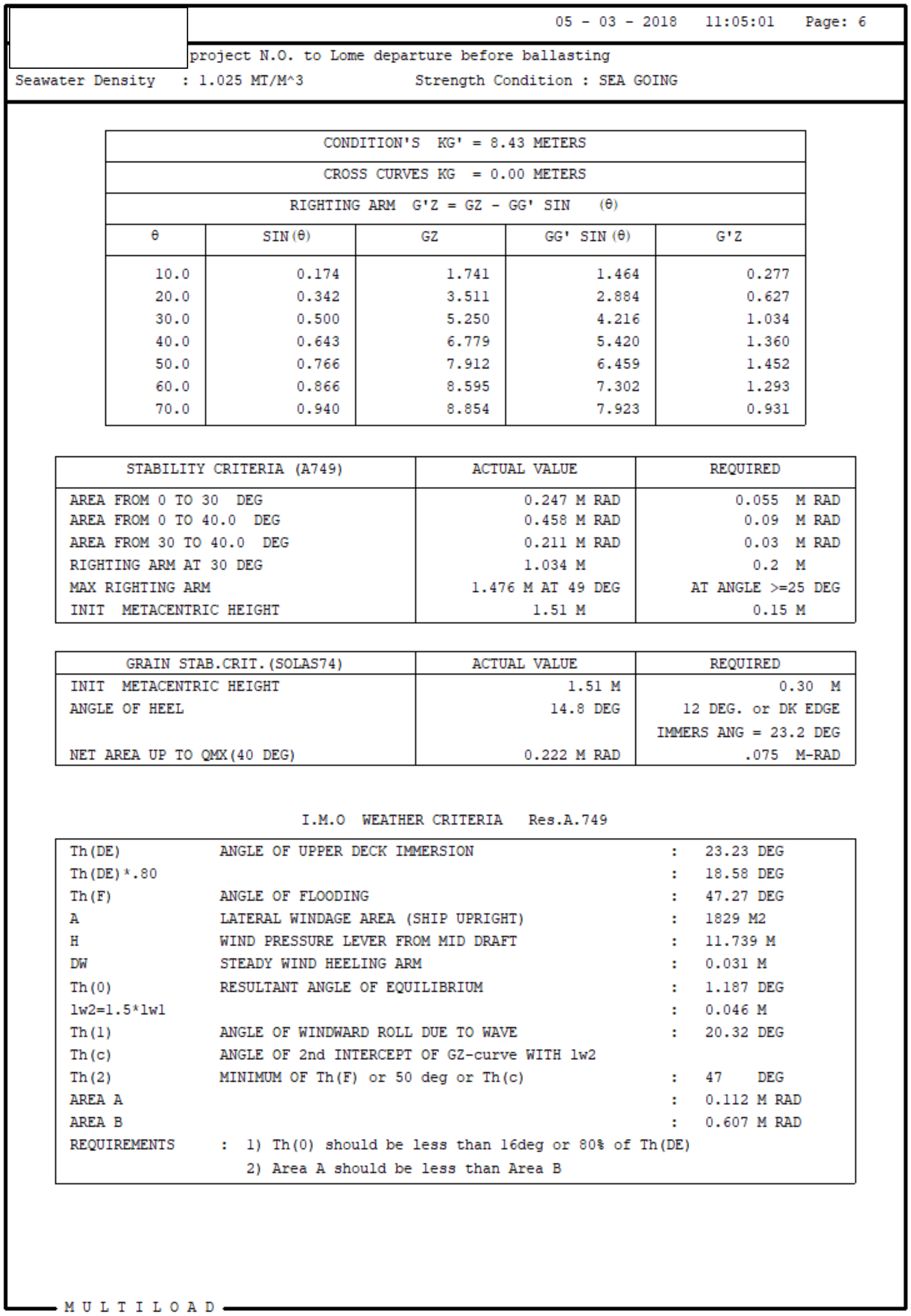
[redacted] project N.O. to Lome departure before ballasting

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
B A L L A S T W A T E R T A N K S							
F.P.TK	1.025	0	2.00	0.05	171.63	-0.01	44
NO1 BWT P	1.025	0	4.00	0.02	155.87	4.07	487
NO1 BWT S	1.025	0	4.00	0.02	155.87	-4.07	487
NO2 DBWT P	1.025	1	3.00	0.01	134.40	8.70	98
NO2 DBWT S	1.025	1	3.00	0.01	134.40	-8.70	98
NO2 TBWT P	1.025	1	1.00	10.78	135.00	11.73	0
NO2 TBWT S	1.025	1	1.00	10.78	135.00	-11.73	0
NO3 DBWT P	1.025	1	5.00	0.01	108.60	5.76	1988
NO3 DBWT S	1.025	1	5.00	0.01	108.60	-5.76	1988
NO3 TBWT P	1.025	1	1.00	10.78	108.60	11.73	0
NO3 TBWT S	1.025	1	1.00	10.78	108.60	-11.73	0
NO4 BWT P	1.025	1	5.00	0.12	83.80	10.50	3
NO4 BWT S	1.025	1	5.00	0.12	83.80	-10.50	3
NO5 DBWT P	1.025	2	4.00	0.02	61.59	8.58	81
NO5 DBWT S	1.025	2	4.00	0.02	61.59	-8.58	81
NO5 TBWT P	1.025	1	1.00	10.78	59.00	11.71	0
NO5 TBWT S	1.025	1	1.00	10.78	59.00	-11.71	0
NO6 BWT P	1.025	1	4.00	0.04	41.90	3.44	136
NO6 BWT S	1.025	1	4.00	0.04	41.90	-3.44	136
NO7 DBWT P	1.025	1	3.00	0.01	135.00	4.00	487
NO7 DBWT S	1.025	1	3.00	0.01	135.00	-4.00	487
APT	1.025	0	1.00	7.05	4.99	0.00	25
NO4 C.HOLD/WB	1.025	0	0.00	0.00	83.80	0.00	0
T O T A L B A L L A S T W A T E R			65.00	1.14	101.06	0.00	6630

Note: Underlined FSM denotes use of maximum FSM

M U L T I L O A D



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                    project N.O. to Lome departure before ballasting
Seawater Density   : 1.025 MT/M^3           Strength Condition : SEA GOING

                       CONDITION'S  KG' = 8.43 METERS
                       CROSS CURVES KG  = 0.00 METERS
                    RIGHTING ARM  G'Z = GZ - GG' SIN   (θ)
          θ        SIN(θ)         GZ         GG' SIN(θ)        G'Z

        10.0        0.174        1.741         1.464          0.277
        20.0        0.342        3.511         2.884          0.627
        30.0        0.500        5.250         4.216          1.034
        40.0        0.643        6.779         5.420          1.360
        50.0        0.766        7.912         6.459          1.452
        60.0        0.866        8.595         7.302          1.293
        70.0        0.940        8.854         7.923          0.931

       STABILITY CRITERIA (A749)          ACTUAL VALUE            REQUIRED
  AREA FROM 0 TO 30  DEG                    0.247 M RAD          0.055  M RAD
  AREA FROM 0 TO 40.0  DEG                  0.458 M RAD          0.09   M RAD
  AREA FROM 30 TO 40.0  DEG                 0.211 M RAD          0.03   M RAD
  RIGHTING ARM AT 30 DEG                    1.034 M              0.2    M
  MAX RIGHTING ARM                     1.476 M AT 49 DEG     AT ANGLE >=25 DEG
  INIT  METACENTRIC HEIGHT                  1.51 M               0.15 M

       GRAIN STAB.CRIT.(SOLAS74)          ACTUAL VALUE            REQUIRED
  INIT  METACENTRIC HEIGHT                     1.51 M               0.30  M
  ANGLE OF HEEL                               14.8 DEG       12 DEG. or DK EDGE
                                                            IMMERS ANG = 23.2 DEG
  NET AREA UP TO QMX(40 DEG)                0.222 M RAD           .075  M-RAD


                       I.M.O  WEATHER CRITERIA   Res.A.749
  Th(DE)          ANGLE OF UPPER DECK IMMERSION                 :   23.23 DEG
  Th(DE)*.80                                                    :   18.58 DEG
  Th(F)           ANGLE OF FLOODING                             :   47.27 DEG
  A               LATERAL WINDAGE AREA (SHIP UPRIGHT)           :   1829 M2
  H               WIND PRESSURE LEVER FROM MID DRAFT            :   11.739 M
  DW              STEADY WIND HEELING ARM                       :   0.031 M
  Th(0)           RESULTANT ANGLE OF EQUILIBRIUM                :   1.187 DEG
  lw2=1.5*lw1                                                   :   0.046 M
  Th(1)           ANGLE OF WINDWARD ROLL DUE TO WAVE            :   20.32 DEG
  Th(c)           ANGLE OF 2nd INTERCEPT OF GZ-curve WITH lw2
  Th(2)           MINIMUM OF Th(F) or 50 deg or Th(c)           :   47    DEG
  AREA A                                                        :   0.112 M RAD
  AREA B                                                        :   0.607 M RAD
  REQUIREMENTS    :  1) Th(0) should be less than 16deg or 80% of Th(DE)
                     2) Area A should be less than Area B



  M U L T I L O A D
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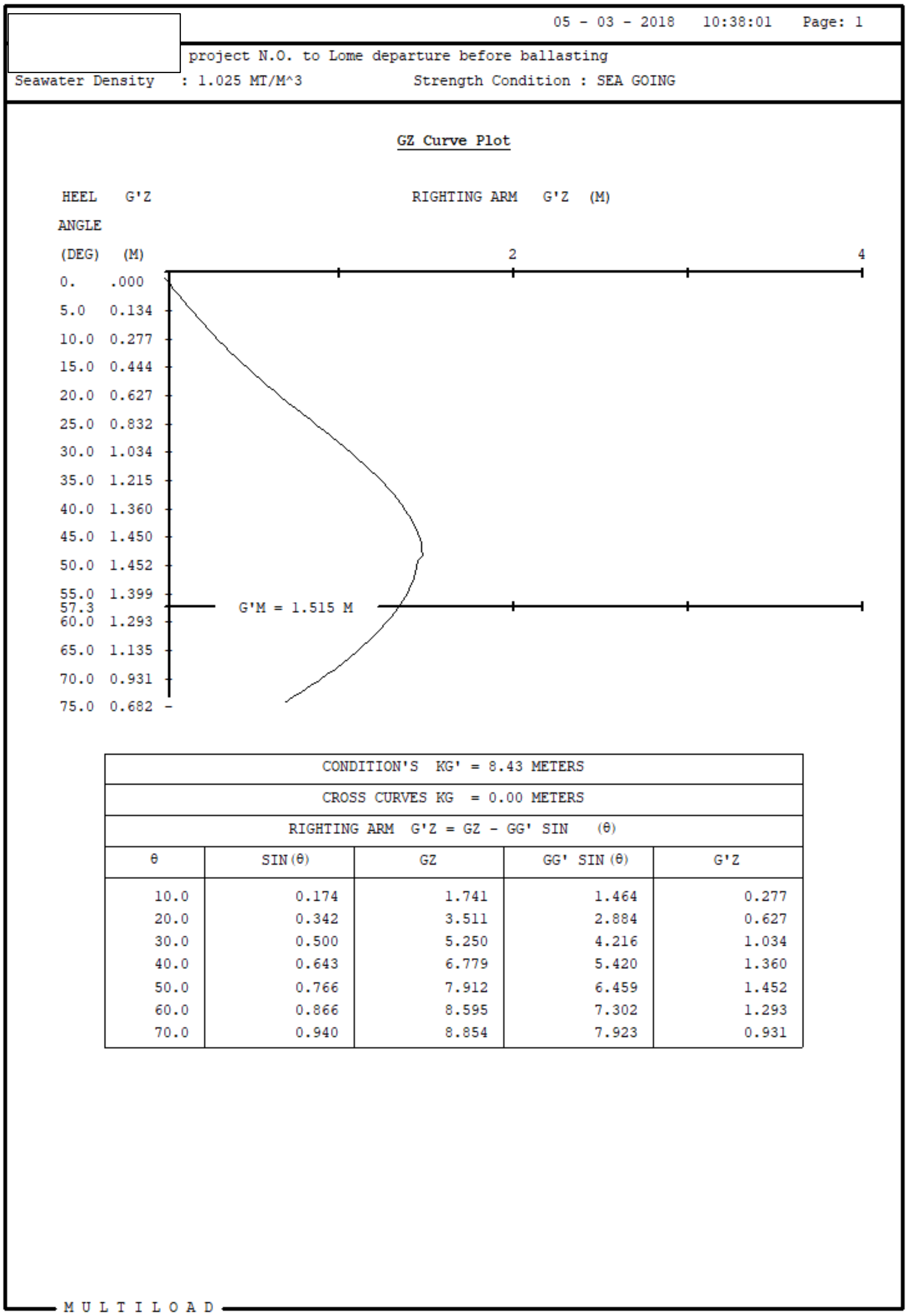
GZ CURVE



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project N.O. to Lome departure before ballasting

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

GZ Curve Plot

HEEL ANGLE (DEG)	G'Z (M)
0.	.000
5.0	0.134
10.0	0.277
15.0	0.444
20.0	0.627
25.0	0.832
30.0	1.034
35.0	1.215
40.0	1.360
45.0	1.450
50.0	1.452
55.0	1.399
57.3	
60.0	1.293
65.0	1.135
70.0	0.931
75.0	0.682

CONDITION'S KG' = 8.43 METERS

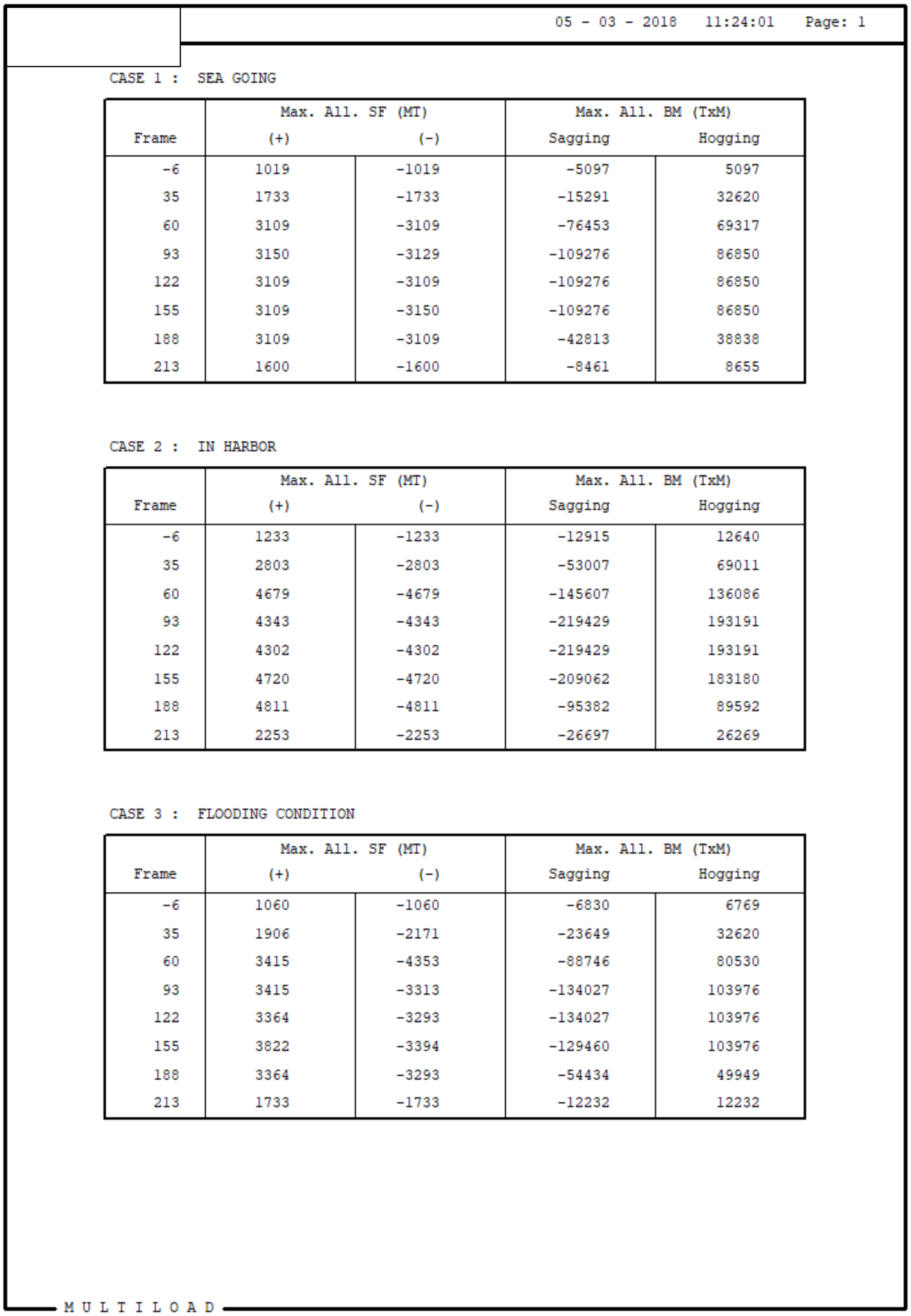
CROSS CURVES KG = 0.00 METERS

RIGHTING ARM G'Z = GZ - GG' SIN (θ)

θ	SIN(θ)	GZ	GG' SIN(θ)	G'Z
10.0	0.174	1.741	1.464	0.277
20.0	0.342	3.511	2.884	0.627
30.0	0.500	5.250	4.216	1.034
40.0	0.643	6.779	5.420	1.360
50.0	0.766	7.912	6.459	1.452
60.0	0.866	8.595	7.302	1.293
70.0	0.940	8.854	7.923	0.931

M U L T I L O A D

DEFLECTIONS (SF & BM)



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CASE 1 : SEA GOING

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1019	-1019	-5097	5097
35	1733	-1733	-15291	32620
60	3109	-3109	-76453	69317
93	3150	-3129	-109276	86850
122	3109	-3109	-109276	86850
155	3109	-3150	-109276	86850
188	3109	-3109	-42813	38838
213	1600	-1600	-8461	8655

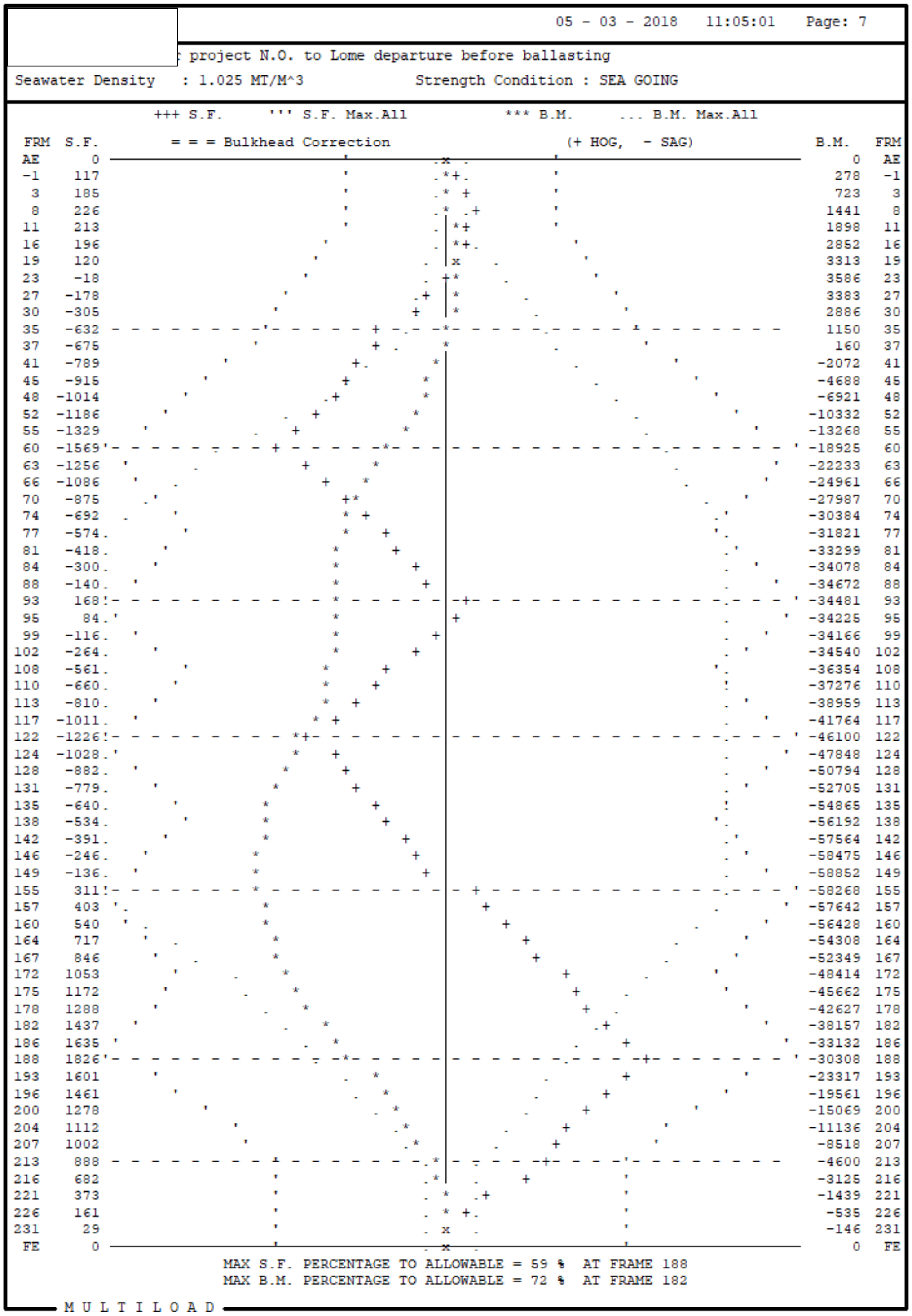
CASE 2 : IN HARBOR

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1233	-1233	-12915	12640
35	2803	-2803	-53007	69011
60	4679	-4679	-145607	136086
93	4343	-4343	-219429	193191
122	4302	-4302	-219429	193191
155	4720	-4720	-209062	183180
188	4811	-4811	-95382	89592
213	2253	-2253	-26697	26269

CASE 3 : FLOODING CONDITION

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1060	-1060	-6830	6769
35	1906	-2171	-23649	32620
60	3415	-4353	-88746	80530
93	3415	-3313	-134027	103976
122	3364	-3293	-134027	103976
155	3822	-3394	-129460	103976
188	3364	-3293	-54434	49949
213	1733	-1733	-12232	12232

MULTILOAD



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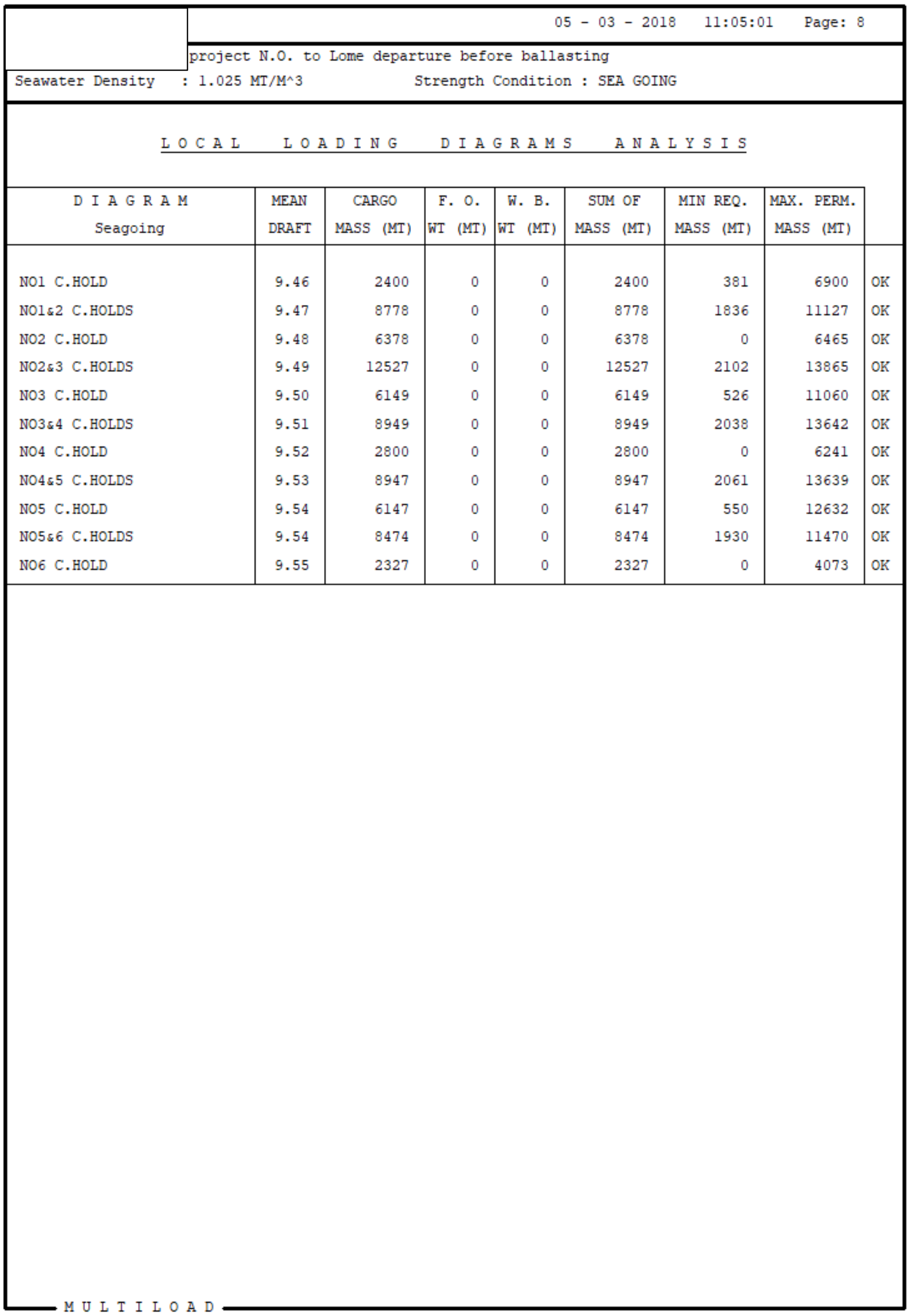
                                 05 - 03 - 2018   11:05:01   Page: 7
            project N.O. to Lome departure before ballasting
Seawater Density   : 1.025 MT/M^3         Strength Condition : SEA GOING

         +++ S.F.    ''' S.F. Max.All        *** B.M.    ... B.M. Max.All

 FRM  S.F.       = = = Bulkhead Correction        (+ HOG,  - SAG)        B.M.   FRM
 AE      0                                                                  0   AE
 -1    117                                                                278   -1
  3    185                                                                723    3
  8    226                                                               1441    8
 11    213                                                               1898   11
 16    196                                                               2852   16
 19    120                                                               3313   19
 23    -18                                                               3586   23
 27   -178                                                               3383   27
 30   -305                                                               2886   30
 35   -632                                                               1150   35
 37   -675                                                                160   37
 41   -789                                                              -2072   41
 45   -915                                                              -4688   45
 48  -1014                                                              -6921   48
 52  -1186                                                             -10332   52
 55  -1329                                                             -13268   55
 60  -1569                                                             -18925   60
 63  -1256                                                             -22233   63
 66  -1086                                                             -24961   66
 70   -875                                                             -27987   70
 74   -692                                                             -30384   74
 77   -574                                                             -31821   77
 81   -418                                                             -33299   81
 84   -300                                                             -34078   84
 88   -140                                                             -34672   88
 93    168                                                             -34481   93
 95     84                                                             -34225   95
 99   -116                                                             -34166   99
102   -264                                                             -34540  102
108   -561                                                             -36354  108
110   -660                                                             -37276  110
113   -810                                                             -38959  113
117  -1011                                                             -41764  117
122  -1226                                                             -46100  122
124  -1028                                                             -47848  124
128   -882                                                             -50794  128
131   -779                                                             -52705  131
135   -640                                                             -54865  135
138   -534                                                             -56192  138
142   -391                                                             -57564  142
146   -246                                                             -58475  146
149   -136                                                             -58852  149
155    311                                                             -58268  155
157    403                                                             -57642  157
160    540                                                             -56428  160
164    717                                                             -54308  164
167    846                                                             -52349  167
172   1053                                                             -48414  172
175   1172                                                             -45662  175
178   1288                                                             -42627  178
182   1437                                                             -38157  182
186   1635                                                             -33132  186
188   1826                                                             -30308  188
193   1601                                                             -23317  193
196   1461                                                             -19561  196
200   1278                                                             -15069  200
204   1112                                                             -11136  204
207   1002                                                              -8518  207
213    888                                                              -4600  213
216    682                                                              -3125  216
221    373                                                              -1439  221
226    161                                                               -535  226
231     29                                                               -146  231
 FE      0                                                                  0   FE
              MAX S.F. PERCENTAGE TO ALLOWABLE = 59 %  AT FRAME 188
              MAX B.M. PERCENTAGE TO ALLOWABLE = 72 %  AT FRAME 182
    M U L T I L O A D
```

HOLD MASS TABLES



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project N.O. to Lome departure before ballasting

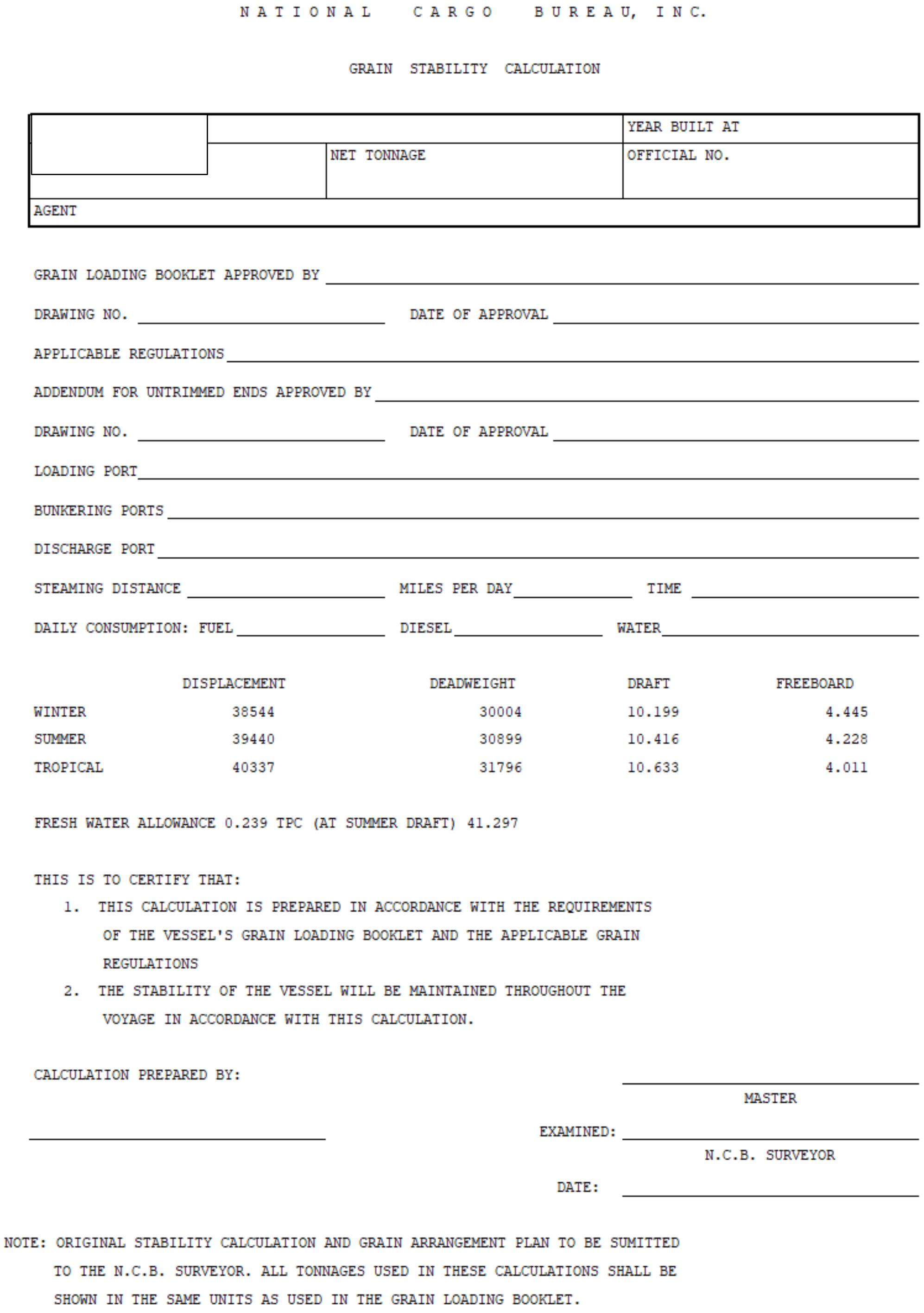
Seawater Density : 1.025 MT/M^3   Strength Condition : SEA GOING

LOCAL LOADING DIAGRAMS ANALYSIS

DIAGRAM Seagoing	MEAN DRAFT	CARGO MASS (MT)	F. O. WT (MT)	W. B. WT (MT)	SUM OF MASS (MT)	MIN REQ. MASS (MT)	MAX. PERM. MASS (MT)	
NO1 C.HOLD	9.46	2400	0	0	2400	381	6900	OK
NO1&2 C.HOLDS	9.47	8778	0	0	8778	1836	11127	OK
NO2 C.HOLD	9.48	6378	0	0	6378	0	6465	OK
NO2&3 C.HOLDS	9.49	12527	0	0	12527	2102	13865	OK
NO3 C.HOLD	9.50	6149	0	0	6149	526	11060	OK
NO3&4 C.HOLDS	9.51	8949	0	0	8949	2038	13642	OK
NO4 C.HOLD	9.52	2800	0	0	2800	0	6241	OK
NO4&5 C.HOLDS	9.53	8947	0	0	8947	2061	13639	OK
NO5 C.HOLD	9.54	6147	0	0	6147	550	12632	OK
NO5&6 C.HOLDS	9.54	8474	0	0	8474	1930	11470	OK
NO6 C.HOLD	9.55	2327	0	0	2327	0	4073	OK

MULTILOAD

B- GRAIN STABILITY CALCULATIONS, SEA GOING CRITERION



NATIONAL CARGO BUREAU, INC.

GRAIN STABILITY CALCULATION

		YEAR BUILT AT
	NET TONNAGE	OFFICIAL NO.
AGENT		

GRAIN LOADING BOOKLET APPROVED BY ____________

DRAWING NO. ____________ DATE OF APPROVAL ____________

APPLICABLE REGULATIONS ____________

ADDENDUM FOR UNTRIMMED ENDS APPROVED BY ____________

DRAWING NO. ____________ DATE OF APPROVAL ____________

LOADING PORT ____________

BUNKERING PORTS ____________

DISCHARGE PORT ____________

STEAMING DISTANCE ____________ MILES PER DAY ____________ TIME ____________

DAILY CONSUMPTION: FUEL ____________ DIESEL ____________ WATER ____________

	DISPLACEMENT	DEADWEIGHT	DRAFT	FREEBOARD
WINTER	38544	30004	10.199	4.445
SUMMER	39440	30899	10.416	4.228
TROPICAL	40337	31796	10.633	4.011

FRESH WATER ALLOWANCE 0.239 TPC (AT SUMMER DRAFT) 41.297

THIS IS TO CERTIFY THAT:

1. THIS CALCULATION IS PREPARED IN ACCORDANCE WITH THE REQUIREMENTS OF THE VESSEL'S GRAIN LOADING BOOKLET AND THE APPLICABLE GRAIN REGULATIONS
2. THE STABILITY OF THE VESSEL WILL BE MAINTAINED THROUGHOUT THE VOYAGE IN ACCORDANCE WITH THIS CALCULATION.

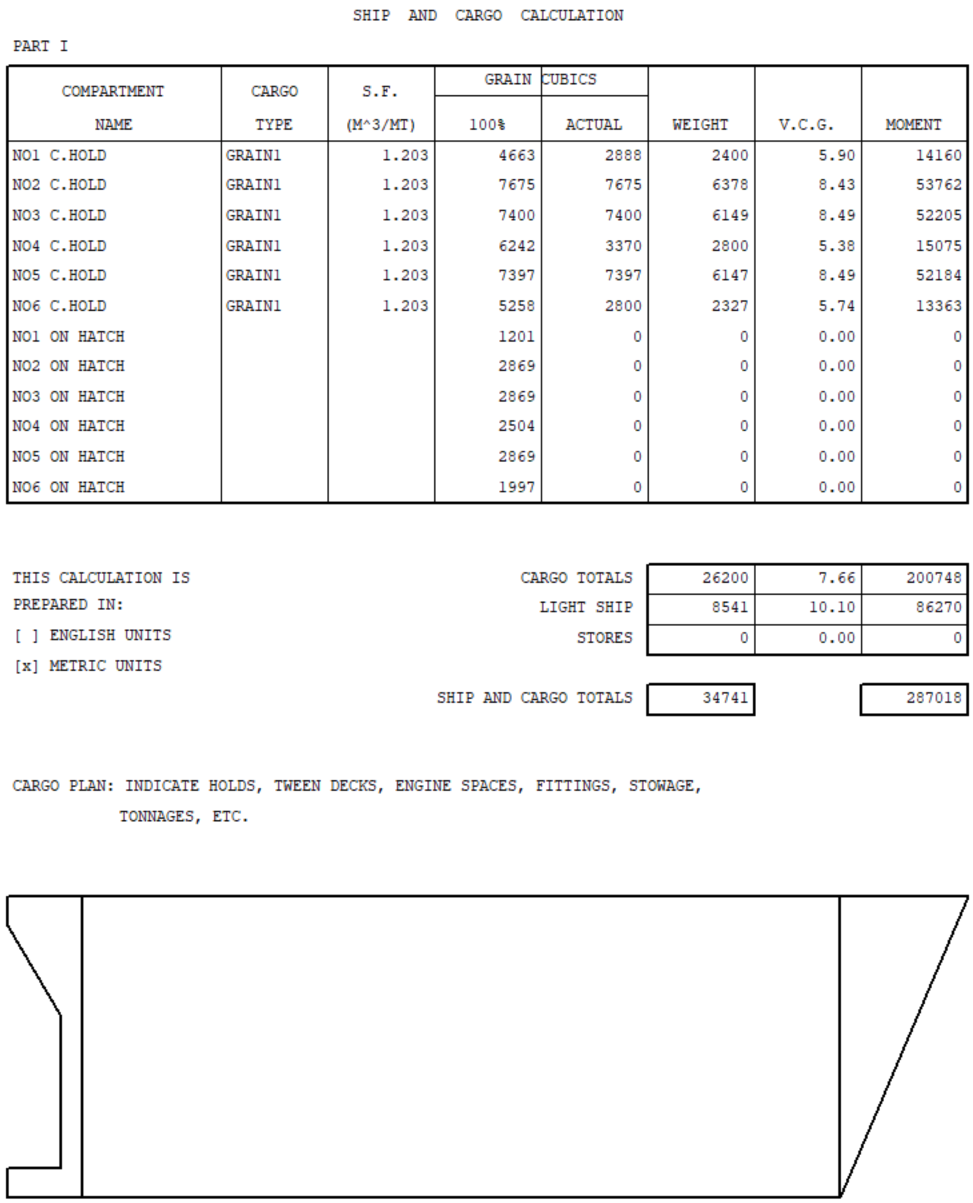
CALCULATION PREPARED BY:

____________ MASTER

____________ EXAMINED: ____________ N.C.B. SURVEYOR

DATE: ____________

NOTE: ORIGINAL STABILITY CALCULATION AND GRAIN ARRANGEMENT PLAN TO BE SUMITTED TO THE N.C.B. SURVEYOR. ALL TONNAGES USED IN THESE CALCULATIONS SHALL BE SHOWN IN THE SAME UNITS AS USED IN THE GRAIN LOADING BOOKLET.



SHIP AND CARGO CALCULATION

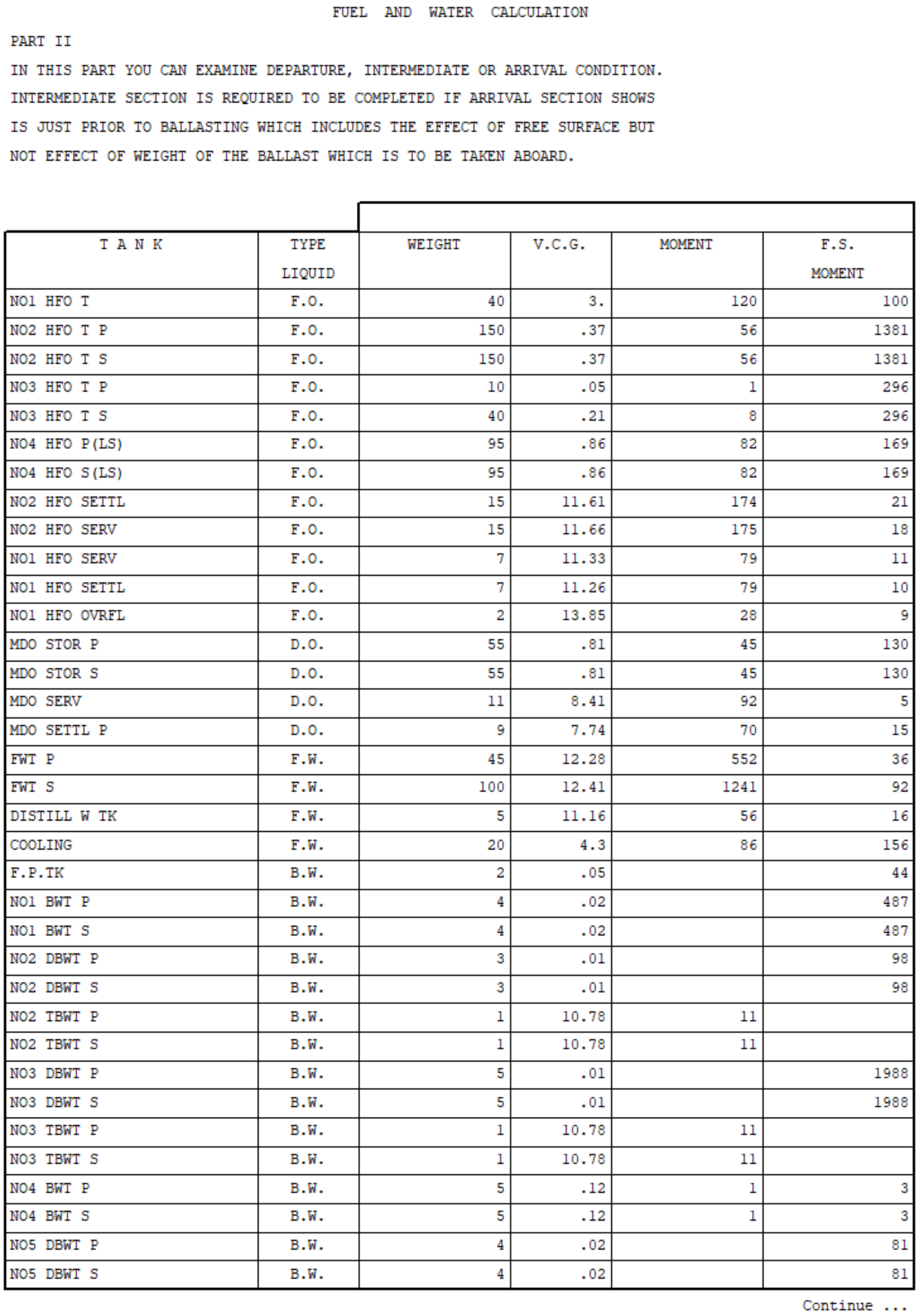
PART I

COMPARTMENT NAME	CARGO TYPE	S.F. (M^3/MT)	GRAIN CUBICS 100%	ACTUAL	WEIGHT	V.C.G.	MOMENT
NO1 C.HOLD	GRAIN1	1.203	4663	2888	2400	5.90	14160
NO2 C.HOLD	GRAIN1	1.203	7675	7675	6378	8.43	53762
NO3 C.HOLD	GRAIN1	1.203	7400	7400	6149	8.49	52205
NO4 C.HOLD	GRAIN1	1.203	6242	3370	2800	5.38	15075
NO5 C.HOLD	GRAIN1	1.203	7397	7397	6147	8.49	52184
NO6 C.HOLD	GRAIN1	1.203	5258	2800	2327	5.74	13363
NO1 ON HATCH			1201	0	0	0.00	0
NO2 ON HATCH			2869	0	0	0.00	0
NO3 ON HATCH			2869	0	0	0.00	0
NO4 ON HATCH			2504	0	0	0.00	0
NO5 ON HATCH			2869	0	0	0.00	0
NO6 ON HATCH			1997	0	0	0.00	0

THIS CALCULATION IS
PREPARED IN:
[ ] ENGLISH UNITS
[x] METRIC UNITS

CARGO TOTALS	26200	7.66	200748
LIGHT SHIP	8541	10.10	86270
STORES	0	0.00	0
SHIP AND CARGO TOTALS	34741		287018

CARGO PLAN: INDICATE HOLDS, TWEEN DECKS, ENGINE SPACES, FITTINGS, STOWAGE,
TONNAGES, ETC.



FUEL AND WATER CALCULATION

PART II

IN THIS PART YOU CAN EXAMINE DEPARTURE, INTERMEDIATE OR ARRIVAL CONDITION.

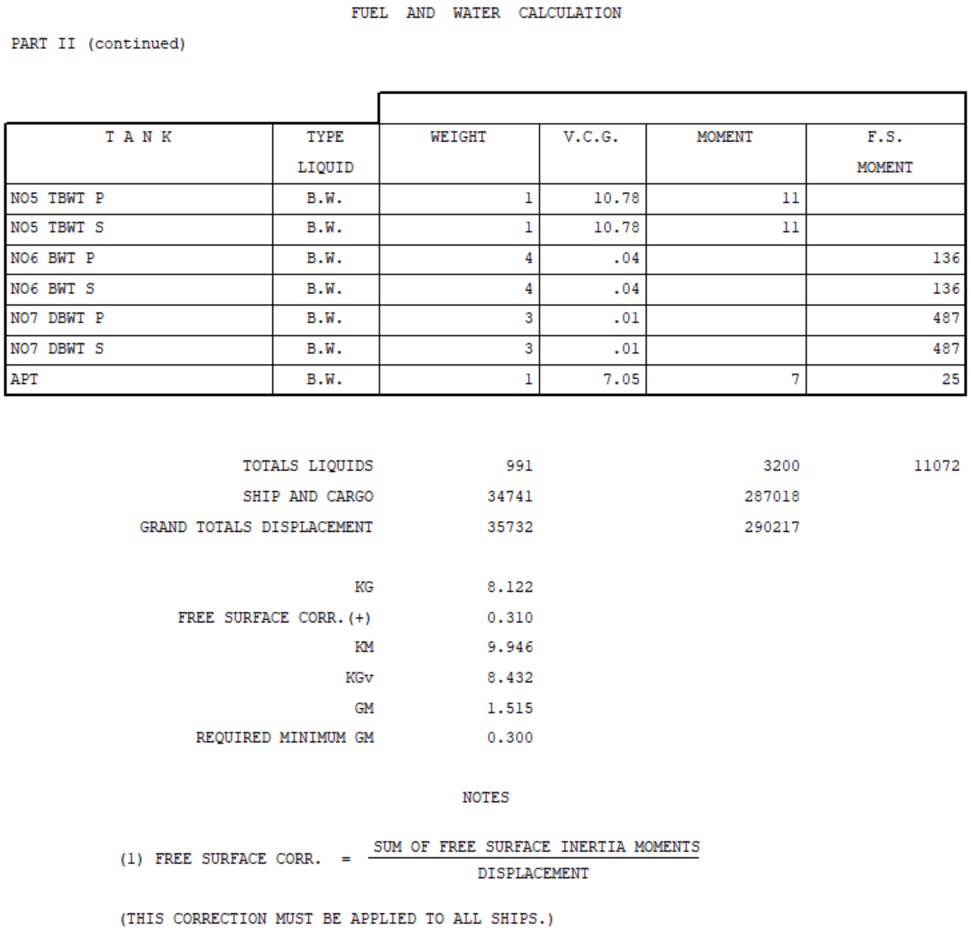
INTERMEDIATE SECTION IS REQUIRED TO BE COMPLETED IF ARRIVAL SECTION SHOWS

IS JUST PRIOR TO BALLASTING WHICH INCLUDES THE EFFECT OF FREE SURFACE BUT

NOT EFFECT OF WEIGHT OF THE BALLAST WHICH IS TO BE TAKEN ABOARD.

T A N K	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO1 HFO T	F.O.	40	3.	120	100
NO2 HFO T P	F.O.	150	.37	56	1381
NO2 HFO T S	F.O.	150	.37	56	1381
NO3 HFO T P	F.O.	10	.05	1	296
NO3 HFO T S	F.O.	40	.21	8	296
NO4 HFO P(LS)	F.O.	95	.86	82	169
NO4 HFO S(LS)	F.O.	95	.86	82	169
NO2 HFO SETTL	F.O.	15	11.61	174	21
NO2 HFO SERV	F.O.	15	11.66	175	18
NO1 HFO SERV	F.O.	7	11.33	79	11
NO1 HFO SETTL	F.O.	7	11.26	79	10
NO1 HFO OVRFL	F.O.	2	13.85	28	9
MDO STOR P	D.O.	55	.81	45	130
MDO STOR S	D.O.	55	.81	45	130
MDO SERV	D.O.	11	8.41	92	5
MDO SETTL P	D.O.	9	7.74	70	15
FWT P	F.W.	45	12.28	552	36
FWT S	F.W.	100	12.41	1241	92
DISTILL W TK	F.W.	5	11.16	56	16
COOLING	F.W.	20	4.3	86	156
F.P.TK	B.W.	2	.05		44
NO1 BWT P	B.W.	4	.02		487
NO1 BWT S	B.W.	4	.02		487
NO2 DBWT P	B.W.	3	.01		98
NO2 DBWT S	B.W.	3	.01		98
NO2 TBWT P	B.W.	1	10.78	11	
NO2 TBWT S	B.W.	1	10.78	11	
NO3 DBWT P	B.W.	5	.01		1988
NO3 DBWT S	B.W.	5	.01		1988
NO3 TBWT P	B.W.	1	10.78	11	
NO3 TBWT S	B.W.	1	10.78	11	
NO4 BWT P	B.W.	5	.12	1	3
NO4 BWT S	B.W.	5	.12	1	3
NO5 DBWT P	B.W.	4	.02		81
NO5 DBWT S	B.W.	4	.02		81

Continue ...



FUEL AND WATER CALCULATION

PART II (continued)

T A N K	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO5 TBWT P	B.W.	1	10.78	11	
NO5 TBWT S	B.W.	1	10.78	11	
NO6 BWT P	B.W.	4	.04		136
NO6 BWT S	B.W.	4	.04		136
NO7 DBWT P	B.W.	3	.01		487
NO7 DBWT S	B.W.	3	.01		487
APT	B.W.	1	7.05	7	25

```
            TOTALS LIQUIDS          991                3200      11072
             SHIP AND CARGO        34741              287018
  GRAND TOTALS DISPLACEMENT        35732              290217

                         KG        8.122
      FREE SURFACE CORR.(+)        0.310
                         KM        9.946
                        KGv        8.432
                         GM        1.515
        REQUIRED MINIMUM GM        0.300

                                NOTES

(1) FREE SURFACE CORR.  =  SUM OF FREE SURFACE INERTIA MOMENTS
                           -----------------------------------
                                     DISPLACEMENT

(THIS CORRECTION MUST BE APPLIED TO ALL SHIPS.)
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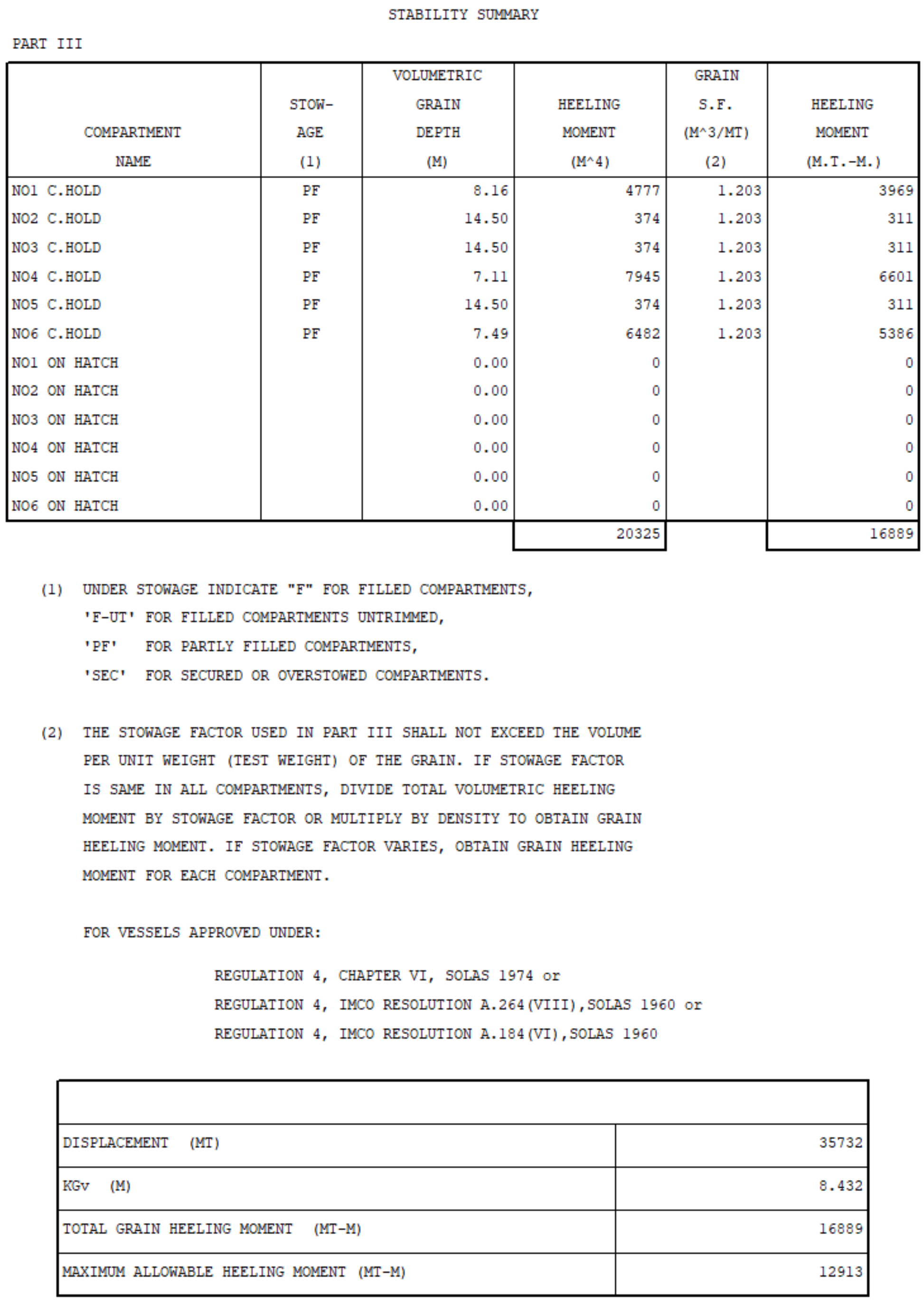


STABILITY SUMMARY

PART III

COMPARTMENT NAME	STOW-AGE (1)	VOLUMETRIC GRAIN DEPTH (M)	HEELING MOMENT (M^4)	GRAIN S.F. (M^3/MT) (2)	HEELING MOMENT (M.T.-M.)
NO1 C.HOLD	PF	8.16	4777	1.203	3969
NO2 C.HOLD	PF	14.50	374	1.203	311
NO3 C.HOLD	PF	14.50	374	1.203	311
NO4 C.HOLD	PF	7.11	7945	1.203	6601
NO5 C.HOLD	PF	14.50	374	1.203	311
NO6 C.HOLD	PF	7.49	6482	1.203	5386
NO1 ON HATCH		0.00	0		0
NO2 ON HATCH		0.00	0		0
NO3 ON HATCH		0.00	0		0
NO4 ON HATCH		0.00	0		0
NO5 ON HATCH		0.00	0		0
NO6 ON HATCH		0.00	0		0
			20325		16889

(1) UNDER STOWAGE INDICATE "F" FOR FILLED COMPARTMENTS,
'F-UT' FOR FILLED COMPARTMENTS UNTRIMMED,
'PF' FOR PARTLY FILLED COMPARTMENTS,
'SEC' FOR SECURED OR OVERSTOWED COMPARTMENTS.

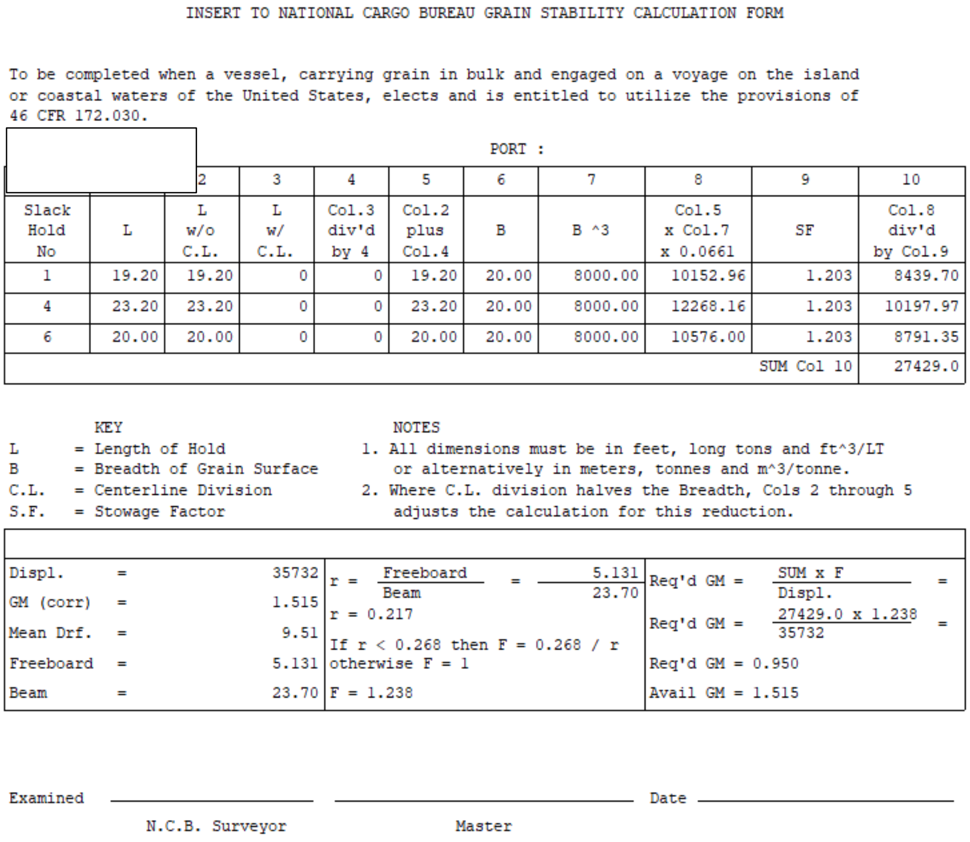
(2) THE STOWAGE FACTOR USED IN PART III SHALL NOT EXCEED THE VOLUME PER UNIT WEIGHT (TEST WEIGHT) OF THE GRAIN. IF STOWAGE FACTOR IS SAME IN ALL COMPARTMENTS, DIVIDE TOTAL VOLUMETRIC HEELING MOMENT BY STOWAGE FACTOR OR MULTIPLY BY DENSITY TO OBTAIN GRAIN HEELING MOMENT. IF STOWAGE FACTOR VARIES, OBTAIN GRAIN HEELING MOMENT FOR EACH COMPARTMENT.

FOR VESSELS APPROVED UNDER:

REGULATION 4, CHAPTER VI, SOLAS 1974 or
REGULATION 4, IMCO RESOLUTION A.264(VIII),SOLAS 1960 or
REGULATION 4, IMCO RESOLUTION A.184(VI),SOLAS 1960

DISPLACEMENT (MT)	35732
KGv (M)	8.432
TOTAL GRAIN HEELING MOMENT (MT-M)	16889
MAXIMUM ALLOWABLE HEELING MOMENT (MT-M)	12913

GRAIN STABILITY SHELTERED WATER CCRITERION



INSERT TO NATIONAL CARGO BUREAU GRAIN STABILITY CALCULATION FORM

To be completed when a vessel, carrying grain in bulk and engaged on a voyage on the island or coastal waters of the United States, elects and is entitled to utilize the provisions of 46 CFR 172.030.

PORT :

	2	3	4	5	6	7	8	9	10
Slack Hold No	L	L w/o C.L.	L w/ C.L.	Col.3 div'd by 4	Col.2 plus Col.4	B	B ^3	Col.5 x Col.7 x 0.0661	SF	Col.8 div'd by Col.9
1	19.20	19.20	0	0	19.20	20.00	8000.00	10152.96	1.203	8439.70
4	23.20	23.20	0	0	23.20	20.00	8000.00	12268.16	1.203	10197.97
6	20.00	20.00	0	0	20.00	20.00	8000.00	10576.00	1.203	8791.35
									SUM Col 10	27429.0

KEY

L = Length of Hold
B = Breadth of Grain Surface
C.L. = Centerline Division
S.F. = Stowage Factor

NOTES

1. All dimensions must be in feet, long tons and ft^3/LT or alternatively in meters, tonnes and m^3/tonne.
2. Where C.L. division halves the Breadth, Cols 2 through 5 adjusts the calculation for this reduction.

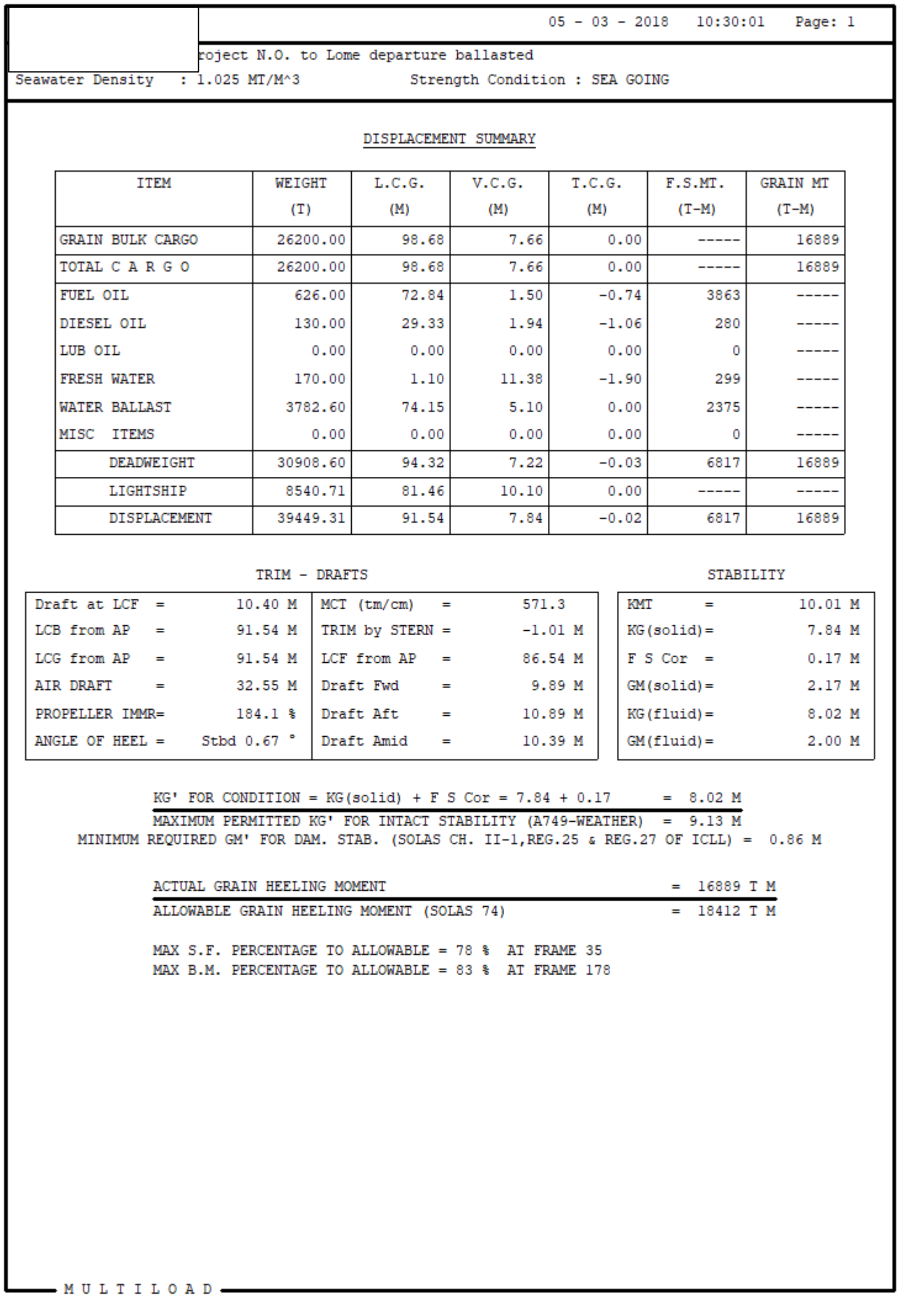
Displ. = 35732	$r = \frac{\text{Freeboard}}{\text{Beam}} = \frac{5.131}{23.70}$	Req'd GM = $\frac{\text{SUM x F}}{\text{Displ.}}$ =
GM (corr) = 1.515	r = 0.217	Req'd GM = $\frac{27429.0 \text{ x } 1.238}{35732}$ =
Mean Drf. = 9.51	If r < 0.268 then F = 0.268 / r	
Freeboard = 5.131	otherwise F = 1	Req'd GM = 0.950
Beam = 23.70	F = 1.238	Avail GM = 1.515

Examined ____________ ____________ Date ____________

N.C.B. Surveyor Master

10.5.2- DEPARTURE CONDITION WITH FULL BUNKERS AND BALLASTED

A- WEIGHT DISTRIBUTION, INTACT STABILITY PARAMETERS



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                    roject N.O. to Lome departure ballasted
Seawater Density   : 1.025 MT/M^3             Strength Condition : SEA GOING

                                  DISPLACEMENT SUMMARY

      ITEM              WEIGHT     L.C.G.     V.C.G.     T.C.G.     F.S.MT.    GRAIN MT
                          (T)        (M)        (M)        (M)       (T-M)      (T-M)
 GRAIN BULK CARGO       26200.00     98.68       7.66       0.00      -----      16889
 TOTAL C A R G O        26200.00     98.68       7.66       0.00      -----      16889
 FUEL OIL                 626.00     72.84       1.50      -0.74       3863      -----
 DIESEL OIL               130.00     29.33       1.94      -1.06        280      -----
 LUB OIL                    0.00      0.00       0.00       0.00          0      -----
 FRESH WATER              170.00      1.10      11.38      -1.90        299      -----
 WATER BALLAST           3782.60     74.15       5.10       0.00       2375      -----
 MISC  ITEMS                0.00      0.00       0.00       0.00          0      -----
      DEADWEIGHT        30908.60     94.32       7.22      -0.03       6817      16889
      LIGHTSHIP          8540.71     81.46      10.10       0.00      -----      -----
      DISPLACEMENT      39449.31     91.54       7.84      -0.02       6817      16889

                          TRIM - DRAFTS                                  STABILITY
 Draft at LCF   =       10.40 M | MCT  (tm/cm)    =       571.3    | KMT       =      10.01 M
 LCB from AP    =       91.54 M | TRIM by STERN   =      -1.01 M   | KG(solid)=        7.84 M
 LCG from AP    =       91.54 M | LCF from AP     =      86.54 M   | F S Cor   =        0.17 M
 AIR DRAFT      =       32.55 M | Draft Fwd       =       9.89 M   | GM(solid)=        2.17 M
 PROPELLER IMMR=        184.1 % | Draft Aft       =      10.89 M   | KG(fluid)=        8.02 M
 ANGLE OF HEEL =   Stbd 0.67 °  | Draft Amid      =      10.39 M   | GM(fluid)=        2.00 M

          KG' FOR CONDITION = KG(solid) + F S Cor = 7.84 + 0.17      =  8.02 M
          MAXIMUM PERMITTED KG' FOR INTACT STABILITY (A749-WEATHER)  =  9.13 M
   MINIMUM REQUIRED GM' FOR DAM. STAB. (SOLAS CH. II-1,REG.25 & REG.27 OF ICLL) =  0.86 M

          ACTUAL GRAIN HEELING MOMENT                                 =  16889 T M
          ALLOWABLE GRAIN HEELING MOMENT (SOLAS 74)                   =  18412 T M

          MAX S.F. PERCENTAGE TO ALLOWABLE = 78 %  AT FRAME 35
          MAX B.M. PERCENTAGE TO ALLOWABLE = 83 %  AT FRAME 178

    M U L T I L O A D
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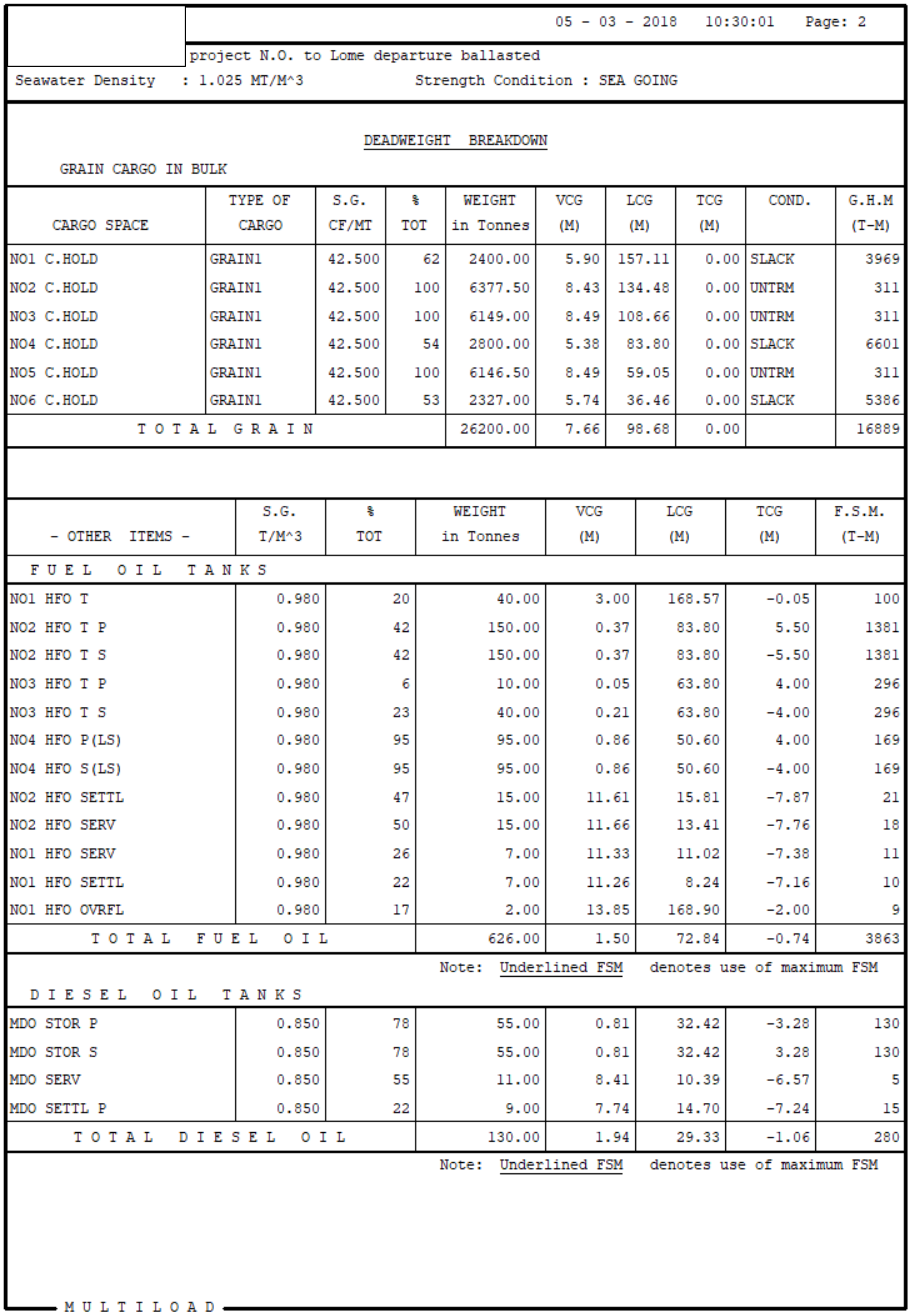

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project N.O. to Lome departure ballasted

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

DEADWEIGHT BREAKDOWN

GRAIN CARGO IN BULK

CARGO SPACE	TYPE OF CARGO	S.G. CF/MT	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	COND.	G.H.M (T-M)
NO1 C.HOLD	GRAIN1	42.500	62	2400.00	5.90	157.11	0.00	SLACK	3969
NO2 C.HOLD	GRAIN1	42.500	100	6377.50	8.43	134.48	0.00	UNTRM	311
NO3 C.HOLD	GRAIN1	42.500	100	6149.00	8.49	108.66	0.00	UNTRM	311
NO4 C.HOLD	GRAIN1	42.500	54	2800.00	5.38	83.80	0.00	SLACK	6601
NO5 C.HOLD	GRAIN1	42.500	100	6146.50	8.49	59.05	0.00	UNTRM	311
NO6 C.HOLD	GRAIN1	42.500	53	2327.00	5.74	36.46	0.00	SLACK	5386
TOTAL GRAIN				26200.00	7.66	98.68	0.00		16889

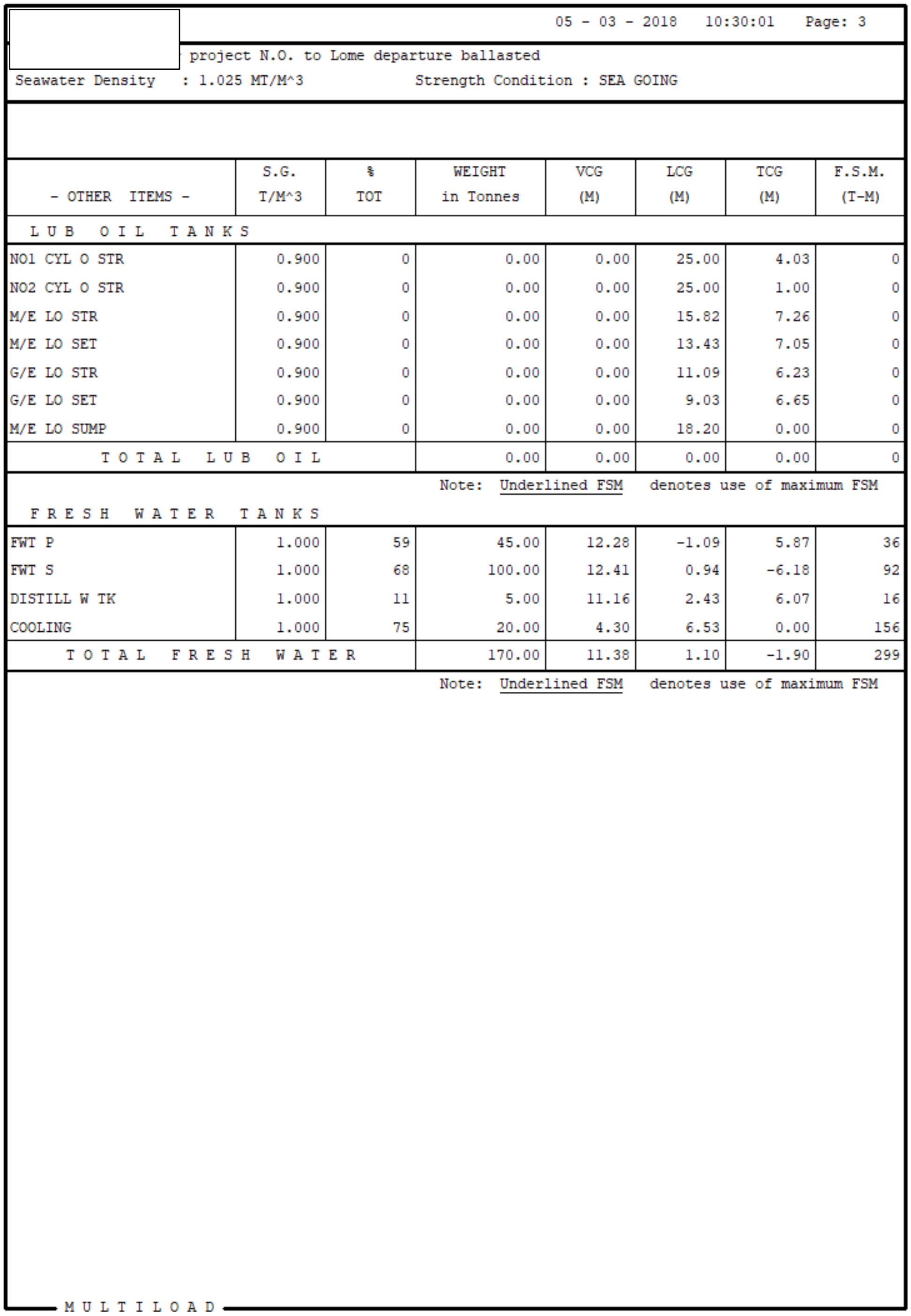
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
FUEL OIL TANKS							
NO1 HFO T	0.980	20	40.00	3.00	168.57	-0.05	100
NO2 HFO T P	0.980	42	150.00	0.37	83.80	5.50	1381
NO2 HFO T S	0.980	42	150.00	0.37	83.80	-5.50	1381
NO3 HFO T P	0.980	6	10.00	0.05	63.80	4.00	296
NO3 HFO T S	0.980	23	40.00	0.21	63.80	-4.00	296
NO4 HFO P(LS)	0.980	95	95.00	0.86	50.60	4.00	169
NO4 HFO S(LS)	0.980	95	95.00	0.86	50.60	-4.00	169
NO2 HFO SETTL	0.980	47	15.00	11.61	15.81	-7.87	21
NO2 HFO SERV	0.980	50	15.00	11.66	13.41	-7.76	18
NO1 HFO SERV	0.980	26	7.00	11.33	11.02	-7.38	11
NO1 HFO SETTL	0.980	22	7.00	11.26	8.24	-7.16	10
NO1 HFO OVRFL	0.980	17	2.00	13.85	168.90	-2.00	9
TOTAL FUEL OIL			626.00	1.50	72.84	-0.74	3863

Note: Underlined FSM denotes use of maximum FSM

DIESEL OIL TANKS							
MDO STOR P	0.850	78	55.00	0.81	32.42	-3.28	130
MDO STOR S	0.850	78	55.00	0.81	32.42	3.28	130
MDO SERV	0.850	55	11.00	8.41	10.39	-6.57	5
MDO SETTL P	0.850	22	9.00	7.74	14.70	-7.24	15
TOTAL DIESEL OIL			130.00	1.94	29.33	-1.06	280

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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project N.O. to Lome departure ballasted

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

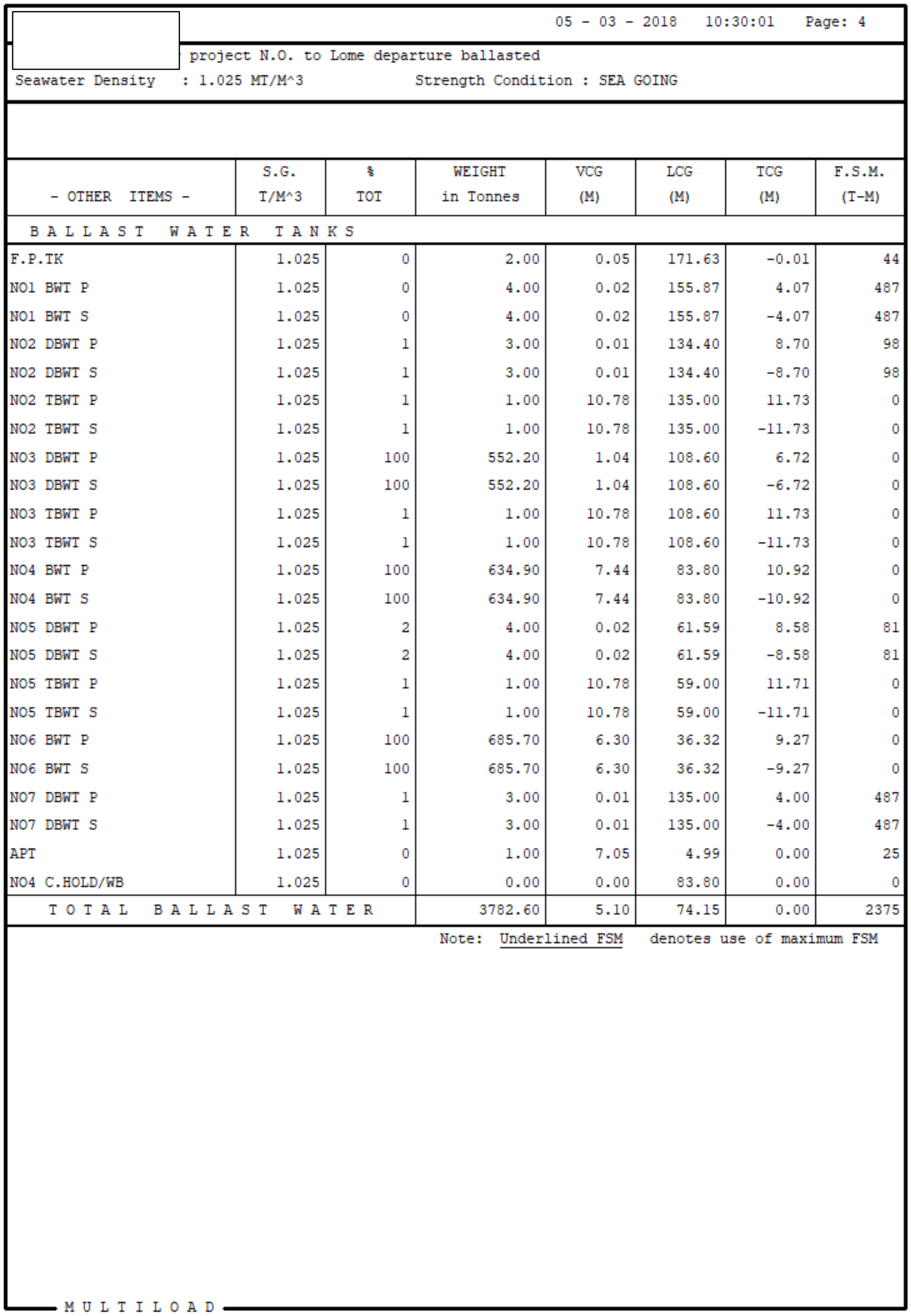
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
LUB OIL TANKS							
NO1 CYL O STR	0.900	0	0.00	0.00	25.00	4.03	0
NO2 CYL O STR	0.900	0	0.00	0.00	25.00	1.00	0
M/E LO STR	0.900	0	0.00	0.00	15.82	7.26	0
M/E LO SET	0.900	0	0.00	0.00	13.43	7.05	0
G/E LO STR	0.900	0	0.00	0.00	11.09	6.23	0
G/E LO SET	0.900	0	0.00	0.00	9.03	6.65	0
M/E LO SUMP	0.900	0	0.00	0.00	18.20	0.00	0
TOTAL LUB OIL			0.00	0.00	0.00	0.00	0

Note: Underlined FSM denotes use of maximum FSM

FRESH WATER TANKS							
FWT P	1.000	59	45.00	12.28	-1.09	5.87	36
FWT S	1.000	68	100.00	12.41	0.94	-6.18	92
DISTILL W TK	1.000	11	5.00	11.16	2.43	6.07	16
COOLING	1.000	75	20.00	4.30	6.53	0.00	156
TOTAL FRESH WATER			170.00	11.38	1.10	-1.90	299

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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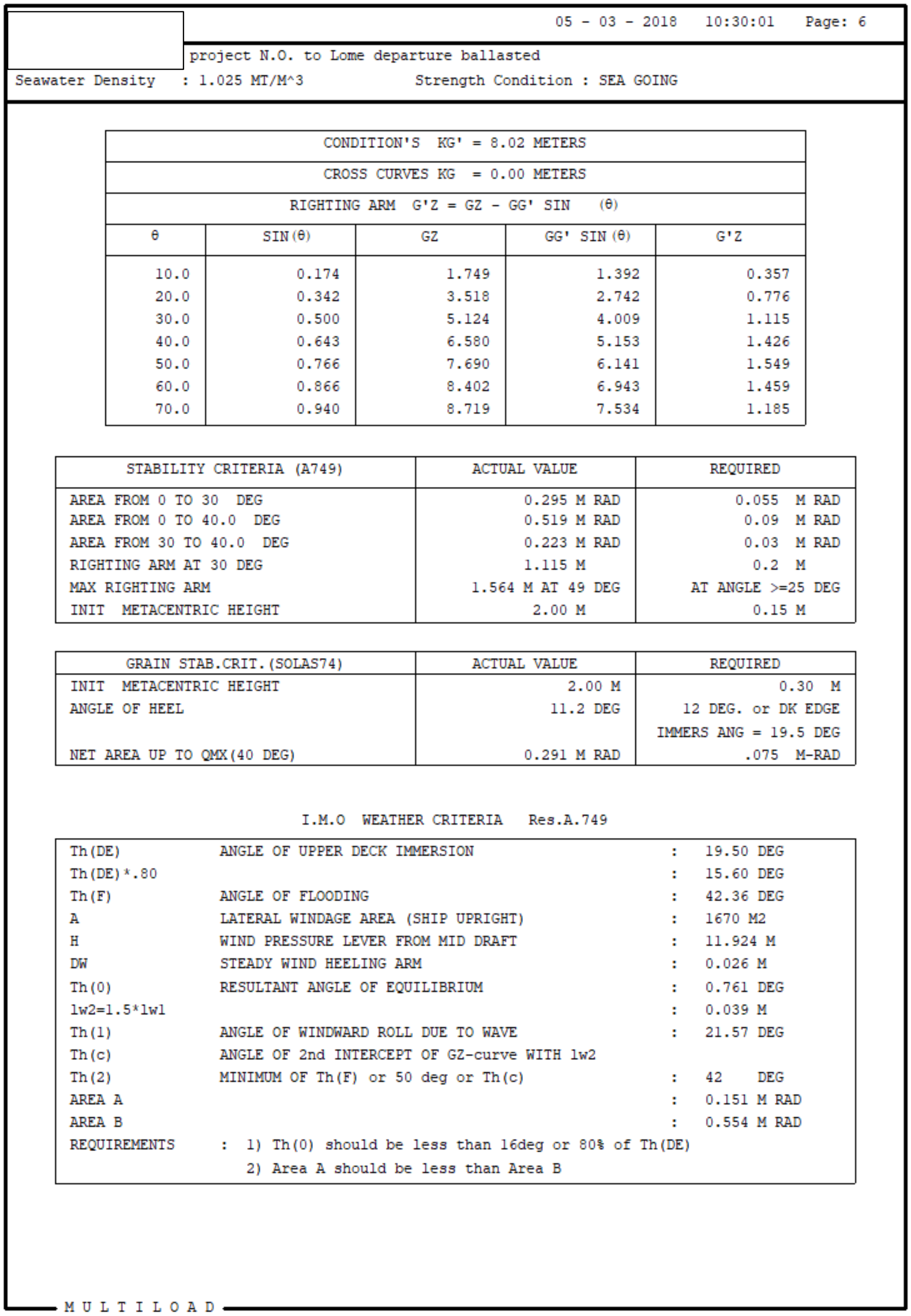
project N.O. to Lome departure ballasted

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
BALLAST WATER TANKS							
F.P.TK	1.025	0	2.00	0.05	171.63	-0.01	44
NO1 BWT P	1.025	0	4.00	0.02	155.87	4.07	487
NO1 BWT S	1.025	0	4.00	0.02	155.87	-4.07	487
NO2 DBWT P	1.025	1	3.00	0.01	134.40	8.70	98
NO2 DBWT S	1.025	1	3.00	0.01	134.40	-8.70	98
NO2 TBWT P	1.025	1	1.00	10.78	135.00	11.73	0
NO2 TBWT S	1.025	1	1.00	10.78	135.00	-11.73	0
NO3 DBWT P	1.025	100	552.20	1.04	108.60	6.72	0
NO3 DBWT S	1.025	100	552.20	1.04	108.60	-6.72	0
NO3 TBWT P	1.025	1	1.00	10.78	108.60	11.73	0
NO3 TBWT S	1.025	1	1.00	10.78	108.60	-11.73	0
NO4 BWT P	1.025	100	634.90	7.44	83.80	10.92	0
NO4 BWT S	1.025	100	634.90	7.44	83.80	-10.92	0
NO5 DBWT P	1.025	2	4.00	0.02	61.59	8.58	81
NO5 DBWT S	1.025	2	4.00	0.02	61.59	-8.58	81
NO5 TBWT P	1.025	1	1.00	10.78	59.00	11.71	0
NO5 TBWT S	1.025	1	1.00	10.78	59.00	-11.71	0
NO6 BWT P	1.025	100	685.70	6.30	36.32	9.27	0
NO6 BWT S	1.025	100	685.70	6.30	36.32	-9.27	0
NO7 DBWT P	1.025	1	3.00	0.01	135.00	4.00	487
NO7 DBWT S	1.025	1	3.00	0.01	135.00	-4.00	487
APT	1.025	0	1.00	7.05	4.99	0.00	25
NO4 C.HOLD/WB	1.025	0	0.00	0.00	83.80	0.00	0
TOTAL BALLAST WATER			3782.60	5.10	74.15	0.00	2375

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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                                                 05 - 03 - 2018    10:30:01    Page: 6
                    project N.O. to Lome departure ballasted
Seawater Density    : 1.025 MT/M^3            Strength Condition : SEA GOING

                         CONDITION'S  KG' = 8.02 METERS
                         CROSS CURVES KG  = 0.00 METERS
                     RIGHTING ARM  G'Z = GZ - GG' SIN   (θ)
          θ          SIN(θ)          GZ          GG' SIN(θ)         G'Z

         10.0         0.174         1.749         1.392         0.357
         20.0         0.342         3.518         2.742         0.776
         30.0         0.500         5.124         4.009         1.115
         40.0         0.643         6.580         5.153         1.426
         50.0         0.766         7.690         6.141         1.549
         60.0         0.866         8.402         6.943         1.459
         70.0         0.940         8.719         7.534         1.185

      STABILITY CRITERIA (A749)          ACTUAL VALUE            REQUIRED
  AREA FROM 0 TO 30  DEG                  0.295 M RAD           0.055  M RAD
  AREA FROM 0 TO 40.0  DEG                0.519 M RAD           0.09   M RAD
  AREA FROM 30 TO 40.0  DEG               0.223 M RAD           0.03   M RAD
  RIGHTING ARM AT 30 DEG                  1.115 M               0.2   M
  MAX RIGHTING ARM                   1.564 M AT 49 DEG     AT ANGLE >=25 DEG
  INIT  METACENTRIC HEIGHT                2.00 M                0.15 M

      GRAIN STAB.CRIT.(SOLAS74)          ACTUAL VALUE            REQUIRED
  INIT  METACENTRIC HEIGHT                     2.00 M               0.30  M
  ANGLE OF HEEL                               11.2 DEG       12 DEG. or DK EDGE
                                                           IMMERS ANG = 19.5 DEG
  NET AREA UP TO QMX(40 DEG)              0.291 M RAD          .075  M-RAD

                       I.M.O  WEATHER CRITERIA   Res.A.749
  Th(DE)           ANGLE OF UPPER DECK IMMERSION                 :  19.50 DEG
  Th(DE)*.80                                                     :  15.60 DEG
  Th(F)            ANGLE OF FLOODING                             :  42.36 DEG
  A                LATERAL WINDAGE AREA (SHIP UPRIGHT)           :  1670 M2
  H                WIND PRESSURE LEVER FROM MID DRAFT            :  11.924 M
  DW               STEADY WIND HEELING ARM                       :  0.026 M
  Th(0)            RESULTANT ANGLE OF EQUILIBRIUM                :  0.761 DEG
  lw2=1.5*lw1                                                    :  0.039 M
  Th(1)            ANGLE OF WINDWARD ROLL DUE TO WAVE            :  21.57 DEG
  Th(c)            ANGLE OF 2nd INTERCEPT OF GZ-curve WITH lw2
  Th(2)            MINIMUM OF Th(F) or 50 deg or Th(c)           :  42    DEG
  AREA A                                                         :  0.151 M RAD
  AREA B                                                         :  0.554 M RAD
  REQUIREMENTS     :  1) Th(0) should be less than 16deg or 80% of Th(DE)
                      2) Area A should be less than Area B

    M U L T I L O A D
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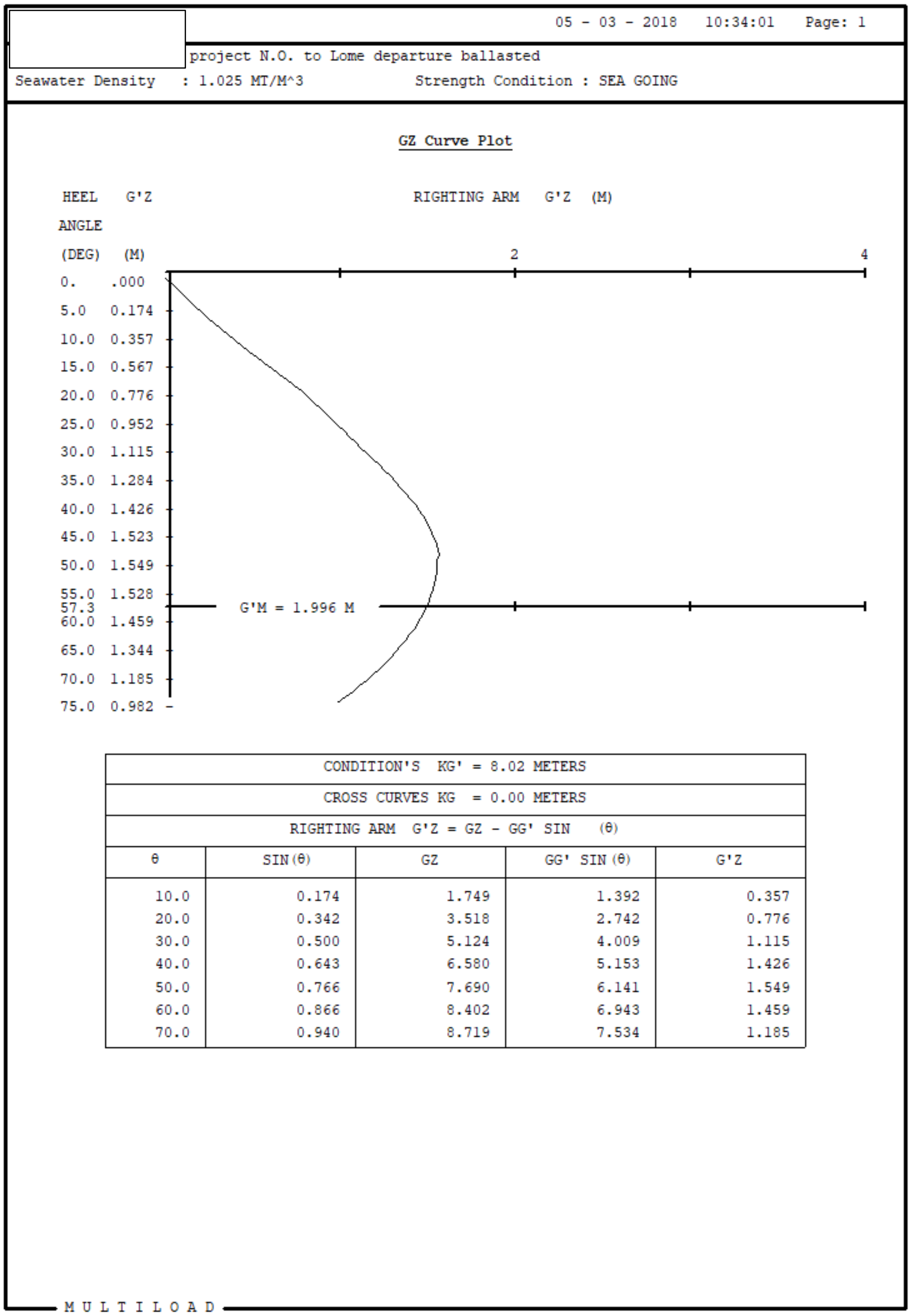
GZ CURVES



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project N.O. to Lome departure ballasted

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

GZ Curve Plot

HEEL ANGLE (DEG)	G'Z (M)
0.	.000
5.0	0.174
10.0	0.357
15.0	0.567
20.0	0.776
25.0	0.952
30.0	1.115
35.0	1.284
40.0	1.426
45.0	1.523
50.0	1.549
55.0	1.528
57.3	
60.0	1.459
65.0	1.344
70.0	1.185
75.0	0.982

CONDITION'S KG' = 8.02 METERS

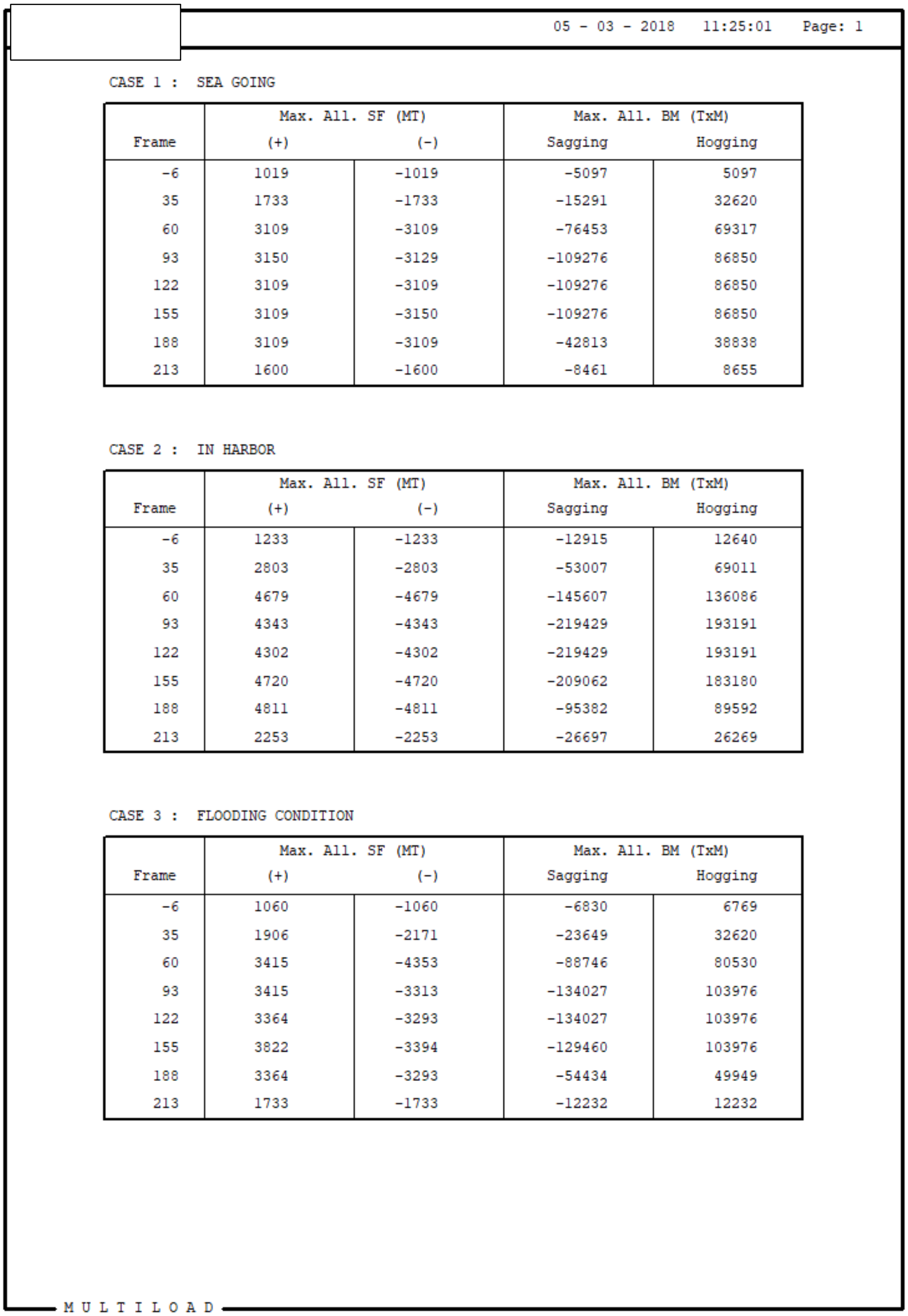
CROSS CURVES KG = 0.00 METERS

RIGHTING ARM G'Z = GZ - GG' SIN (θ)

θ	SIN(θ)	GZ	GG' SIN (θ)	G'Z
10.0	0.174	1.749	1.392	0.357
20.0	0.342	3.518	2.742	0.776
30.0	0.500	5.124	4.009	1.115
40.0	0.643	6.580	5.153	1.426
50.0	0.766	7.690	6.141	1.549
60.0	0.866	8.402	6.943	1.459
70.0	0.940	8.719	7.534	1.185

MULTILOAD

DEFLECTIONS (SF & BM)



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CASE 1 : SEA GOING

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1019	-1019	-5097	5097
35	1733	-1733	-15291	32620
60	3109	-3109	-76453	69317
93	3150	-3129	-109276	86850
122	3109	-3109	-109276	86850
155	3109	-3150	-109276	86850
188	3109	-3109	-42813	38838
213	1600	-1600	-8461	8655

CASE 2 : IN HARBOR

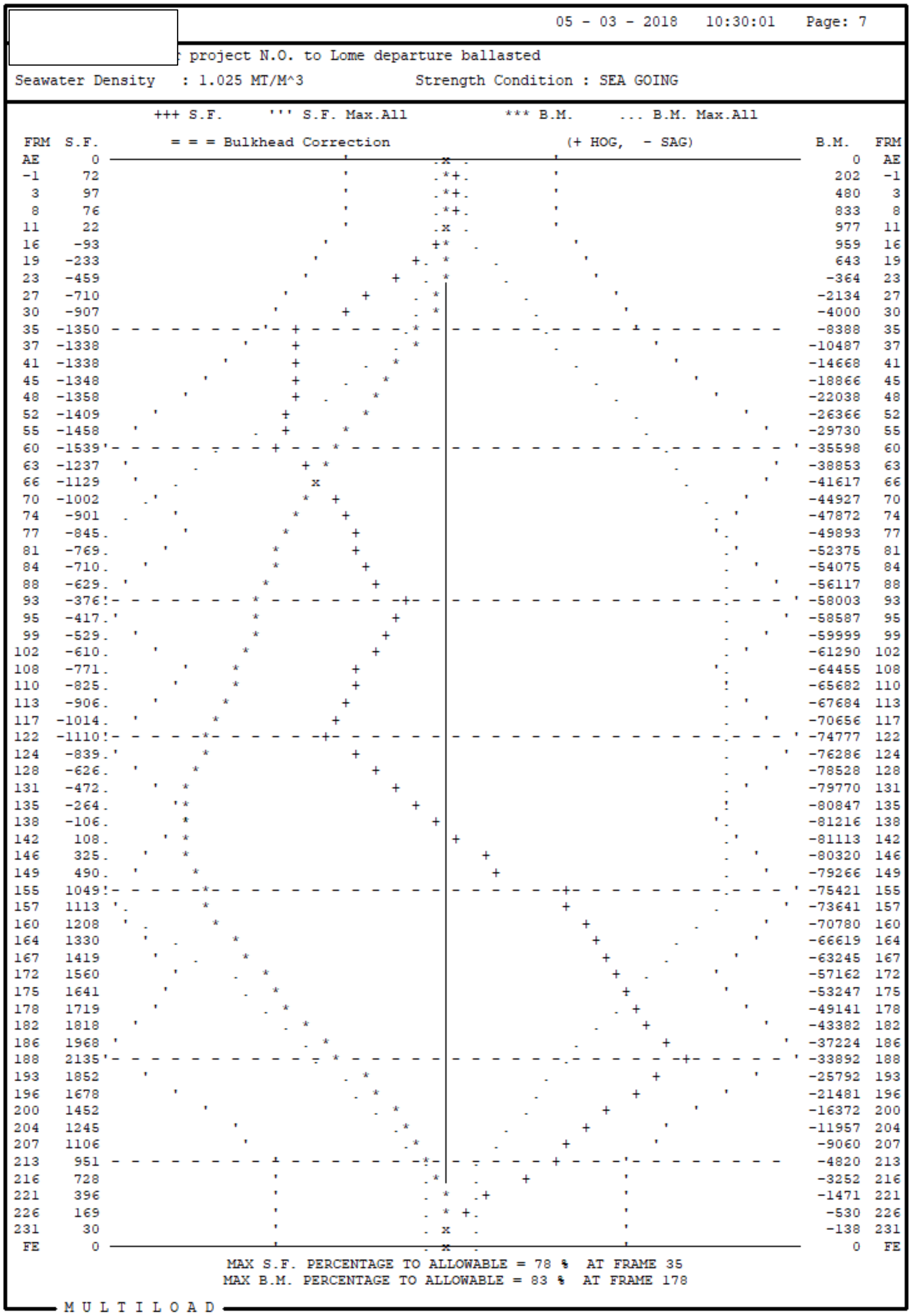
Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1233	-1233	-12915	12640
35	2803	-2803	-53007	69011
60	4679	-4679	-145607	136086
93	4343	-4343	-219429	193191
122	4302	-4302	-219429	193191
155	4720	-4720	-209062	183180
188	4811	-4811	-95382	89592
213	2253	-2253	-26697	26269

CASE 3 : FLOODING CONDITION

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1060	-1060	-6830	6769
35	1906	-2171	-23649	32620
60	3415	-4353	-88746	80530
93	3415	-3313	-134027	103976
122	3364	-3293	-134027	103976
155	3822	-3394	-129460	103976
188	3364	-3293	-54434	49949
213	1733	-1733	-12232	12232

MULTILOAD

V



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[redacted]                                   05 - 03 - 2018    10:30:01    Page: 7
[redacted] project N.O. to Lome departure ballasted
Seawater Density   : 1.025 MT/M^3          Strength Condition : SEA GOING

          +++ S.F.     ''' S.F. Max.All           *** B.M.     ... B.M. Max.All

 FRM  S.F.        = = = Bulkhead Correction                (+ HOG,  - SAG)        B.M.   FRM
 AE      0                                                                            0   AE
 -1     72                                                                          202   -1
  3     97                                                                          480    3
  8     76                                                                          833    8
 11     22                                                                          977   11
 16    -93                                                                          959   16
 19   -233                                                                          643   19
 23   -459                                                                         -364   23
 27   -710                                                                        -2134   27
 30   -907                                                                        -4000   30
 35  -1350                                                                        -8388   35
 37  -1338                                                                       -10487   37
 41  -1338                                                                       -14668   41
 45  -1348                                                                       -18866   45
 48  -1358                                                                       -22038   48
 52  -1409                                                                       -26366   52
 55  -1458                                                                       -29730   55
 60  -1539                                                                       -35598   60
 63  -1237                                                                       -38853   63
 66  -1129                                                                       -41617   66
 70  -1002                                                                       -44927   70
 74   -901                                                                       -47872   74
 77   -845                                                                       -49893   77
 81   -769                                                                       -52375   81
 84   -710                                                                       -54075   84
 88   -629                                                                       -56117   88
 93   -376                                                                       -58003   93
 95   -417                                                                       -58587   95
 99   -529                                                                       -59999   99
102   -610                                                                       -61290  102
108   -771                                                                       -64455  108
110   -825                                                                       -65682  110
113   -906                                                                       -67684  113
117  -1014                                                                       -70656  117
122  -1110                                                                       -74777  122
124   -839                                                                       -76286  124
128   -626                                                                       -78528  128
131   -472                                                                       -79770  131
135   -264                                                                       -80847  135
138   -106                                                                       -81216  138
142    108                                                                       -81113  142
146    325                                                                       -80320  146
149    490                                                                       -79266  149
155   1049                                                                       -75421  155
157   1113                                                                       -73641  157
160   1208                                                                       -70780  160
164   1330                                                                       -66619  164
167   1419                                                                       -63245  167
172   1560                                                                       -57162  172
175   1641                                                                       -53247  175
178   1719                                                                       -49141  178
182   1818                                                                       -43382  182
186   1968                                                                       -37224  186
188   2135                                                                       -33892  188
193   1852                                                                       -25792  193
196   1678                                                                       -21481  196
200   1452                                                                       -16372  200
204   1245                                                                       -11957  204
207   1106                                                                        -9060  207
213    951                                                                        -4820  213
216    728                                                                        -3252  216
221    396                                                                        -1471  221
226    169                                                                         -530  226
231     30                                                                         -138  231
 FE      0                                                                            0   FE
                  MAX S.F. PERCENTAGE TO ALLOWABLE = 78 %  AT FRAME 35
                  MAX B.M. PERCENTAGE TO ALLOWABLE = 83 %  AT FRAME 178
   M U L T I L O A D
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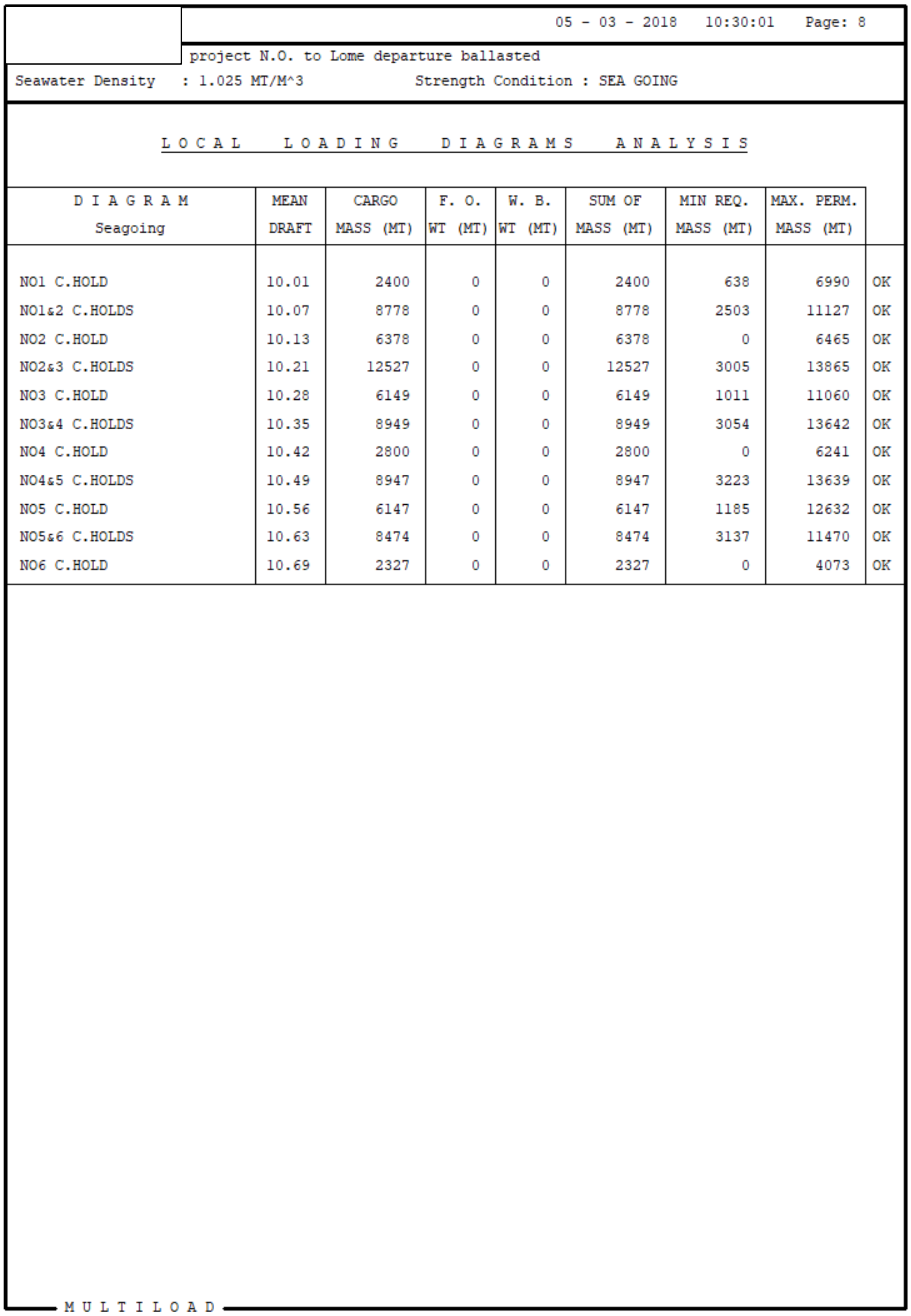
HOLD MASS TABLE



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                                              05 - 03 - 2018    10:30:01    Page: 8
                   project N.O. to Lome departure ballasted
Seawater Density   : 1.025 MT/M^3            Strength Condition : SEA GOING

                 LOCAL   LOADING   DIAGRAMS   ANALYSIS

      DIAGRAM           MEAN    CARGO     F. O.    W. B.    SUM OF    MIN REQ.  MAX. PERM.
      Seagoing          DRAFT   MASS (MT) WT (MT)  WT (MT)  MASS (MT) MASS (MT) MASS (MT)

 NO1 C.HOLD             10.01      2400       0        0      2400       638      6990   OK
 NO1&2 C.HOLDS          10.07      8778       0        0      8778      2503     11127   OK
 NO2 C.HOLD             10.13      6378       0        0      6378         0      6465   OK
 NO2&3 C.HOLDS          10.21     12527       0        0     12527      3005     13865   OK
 NO3 C.HOLD             10.28      6149       0        0      6149      1011     11060   OK
 NO3&4 C.HOLDS          10.35      8949       0        0      8949      3054     13642   OK
 NO4 C.HOLD             10.42      2800       0        0      2800         0      6241   OK
 NO4&5 C.HOLDS          10.49      8947       0        0      8947      3223     13639   OK
 NO5 C.HOLD             10.56      6147       0        0      6147      1185     12632   OK
 NO5&6 C.HOLDS          10.63      8474       0        0      8474      3137     11470   OK
 NO6 C.HOLD             10.69      2327       0        0      2327         0      4073   OK

 MULTILOAD
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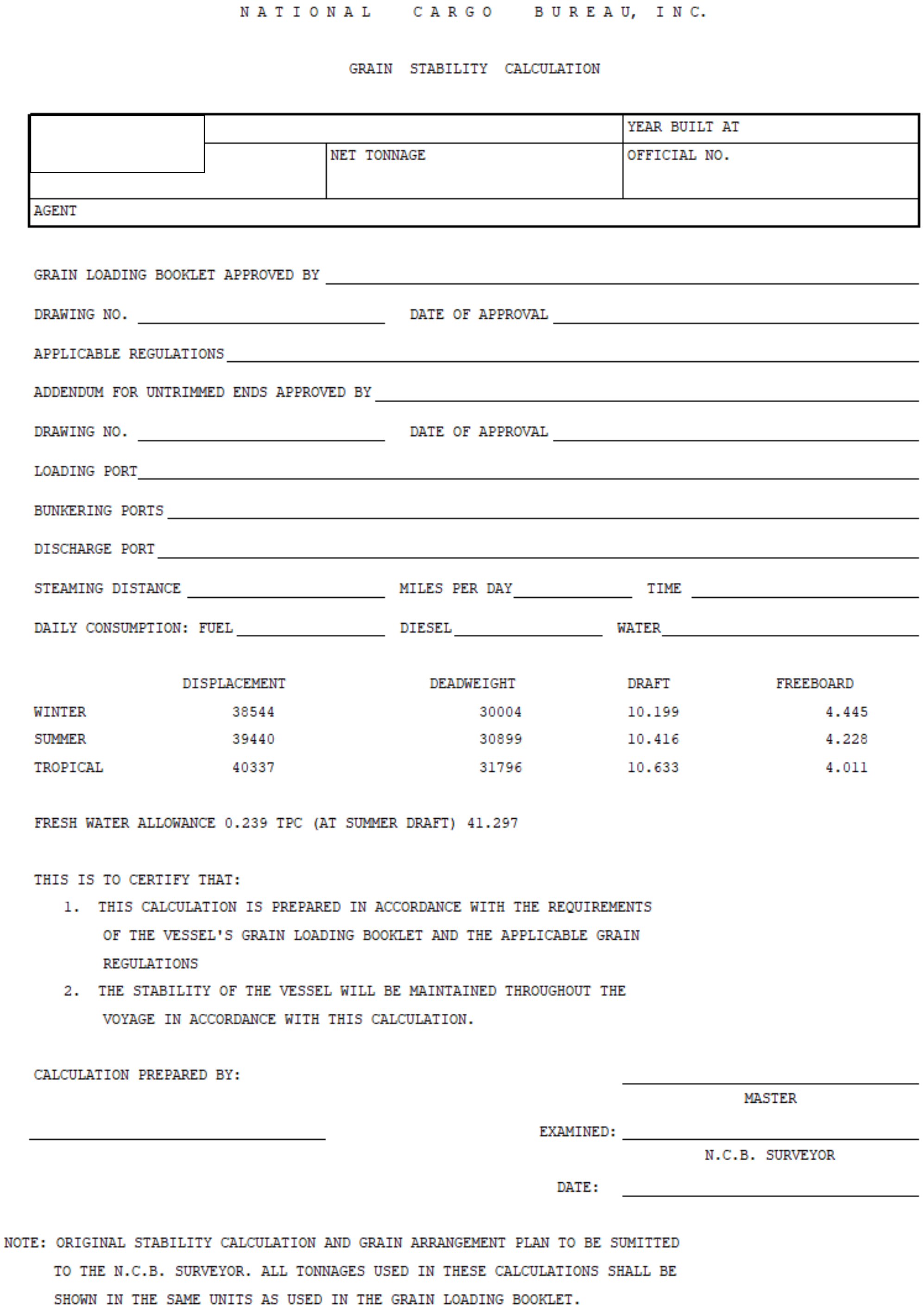
GRAIN STABILITY, SEA GOING CRITERION



NATIONAL CARGO BUREAU, INC.

GRAIN STABILITY CALCULATION

		YEAR BUILT AT
	NET TONNAGE	OFFICIAL NO.
AGENT		

GRAIN LOADING BOOKLET APPROVED BY ______

DRAWING NO. ______ DATE OF APPROVAL ______

APPLICABLE REGULATIONS ______

ADDENDUM FOR UNTRIMMED ENDS APPROVED BY ______

DRAWING NO. ______ DATE OF APPROVAL ______

LOADING PORT ______

BUNKERING PORTS ______

DISCHARGE PORT ______

STEAMING DISTANCE ______ MILES PER DAY ______ TIME ______

DAILY CONSUMPTION: FUEL ______ DIESEL ______ WATER ______

	DISPLACEMENT	DEADWEIGHT	DRAFT	FREEBOARD
WINTER	38544	30004	10.199	4.445
SUMMER	39440	30899	10.416	4.228
TROPICAL	40337	31796	10.633	4.011

FRESH WATER ALLOWANCE 0.239 TPC (AT SUMMER DRAFT) 41.297

THIS IS TO CERTIFY THAT:

1. THIS CALCULATION IS PREPARED IN ACCORDANCE WITH THE REQUIREMENTS OF THE VESSEL'S GRAIN LOADING BOOKLET AND THE APPLICABLE GRAIN REGULATIONS
2. THE STABILITY OF THE VESSEL WILL BE MAINTAINED THROUGHOUT THE VOYAGE IN ACCORDANCE WITH THIS CALCULATION.

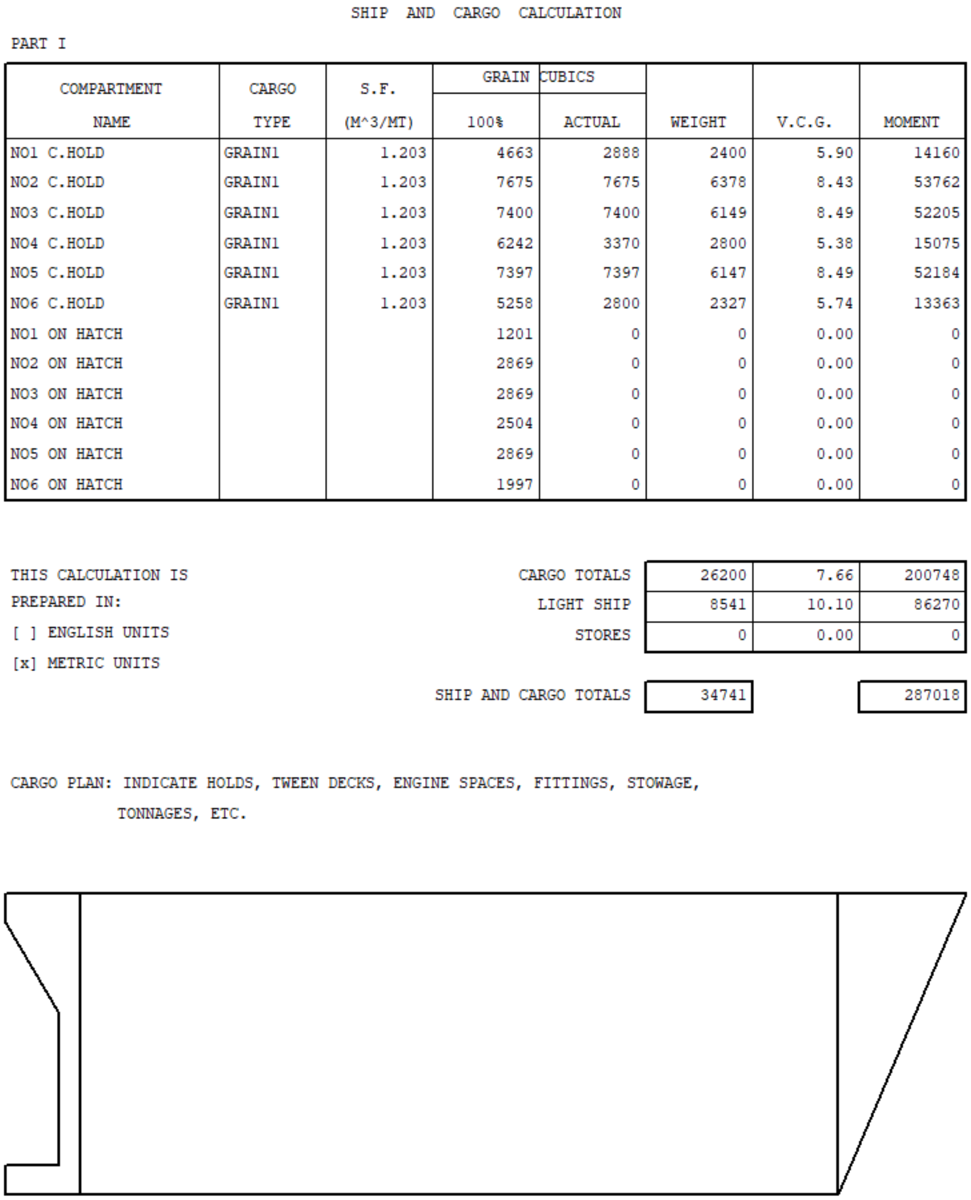
CALCULATION PREPARED BY:

______
MASTER

______ EXAMINED: ______
N.C.B. SURVEYOR

DATE: ______

NOTE: ORIGINAL STABILITY CALCULATION AND GRAIN ARRANGEMENT PLAN TO BE SUMITTED TO THE N.C.B. SURVEYOR. ALL TONNAGES USED IN THESE CALCULATIONS SHALL BE SHOWN IN THE SAME UNITS AS USED IN THE GRAIN LOADING BOOKLET.



SHIP AND CARGO CALCULATION

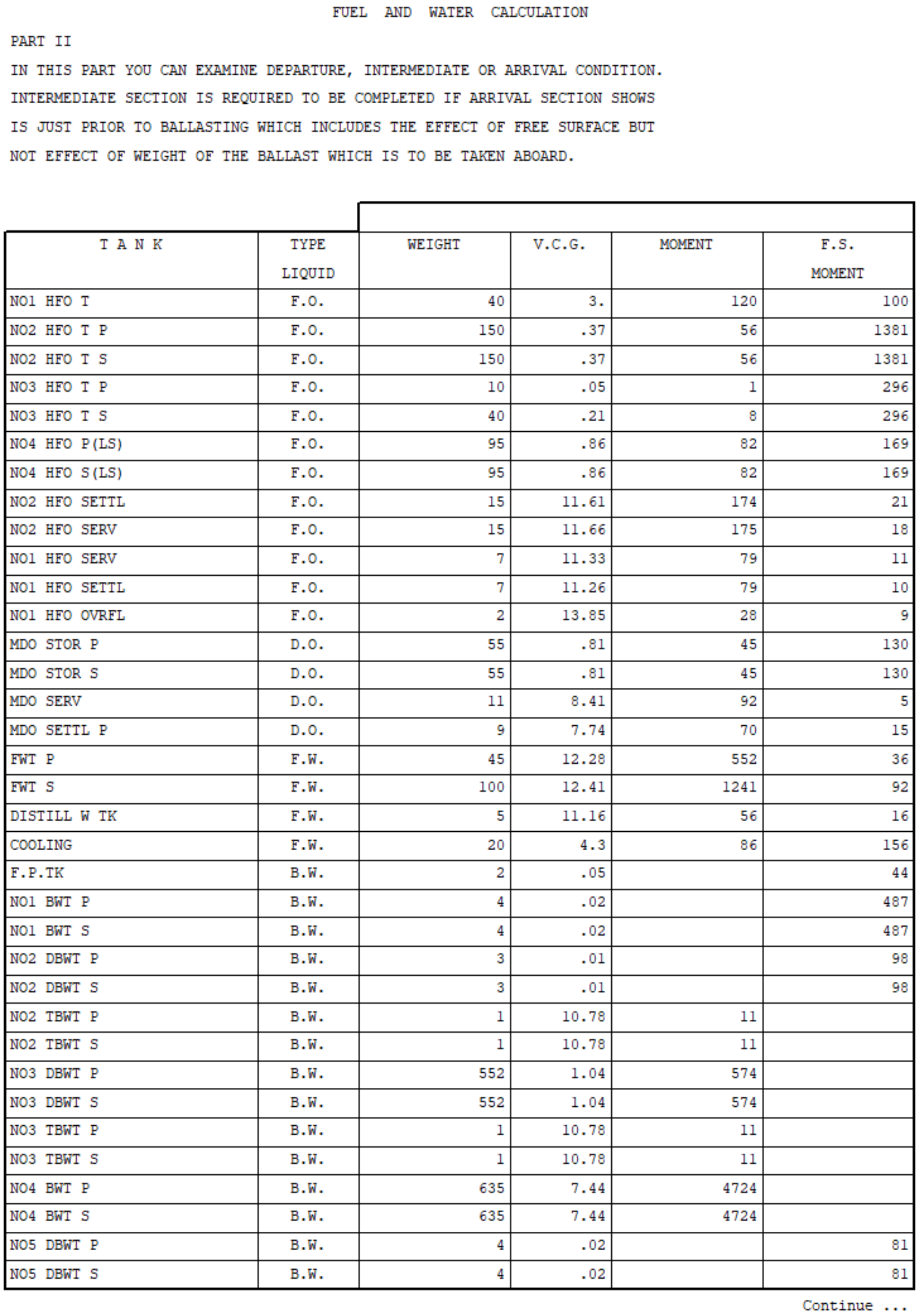
PART I

COMPARTMENT NAME	CARGO TYPE	S.F. (M^3/MT)	GRAIN CUBICS 100%	ACTUAL	WEIGHT	V.C.G.	MOMENT
NO1 C.HOLD	GRAIN1	1.203	4663	2888	2400	5.90	14160
NO2 C.HOLD	GRAIN1	1.203	7675	7675	6378	8.43	53762
NO3 C.HOLD	GRAIN1	1.203	7400	7400	6149	8.49	52205
NO4 C.HOLD	GRAIN1	1.203	6242	3370	2800	5.38	15075
NO5 C.HOLD	GRAIN1	1.203	7397	7397	6147	8.49	52184
NO6 C.HOLD	GRAIN1	1.203	5258	2800	2327	5.74	13363
NO1 ON HATCH			1201	0	0	0.00	0
NO2 ON HATCH			2869	0	0	0.00	0
NO3 ON HATCH			2869	0	0	0.00	0
NO4 ON HATCH			2504	0	0	0.00	0
NO5 ON HATCH			2869	0	0	0.00	0
NO6 ON HATCH			1997	0	0	0.00	0

THIS CALCULATION IS
PREPARED IN:
[ ] ENGLISH UNITS
[x] METRIC UNITS

CARGO TOTALS	26200	7.66	200748
LIGHT SHIP	8541	10.10	86270
STORES	0	0.00	0
SHIP AND CARGO TOTALS	34741		287018

CARGO PLAN: INDICATE HOLDS, TWEEN DECKS, ENGINE SPACES, FITTINGS, STOWAGE,
TONNAGES, ETC.



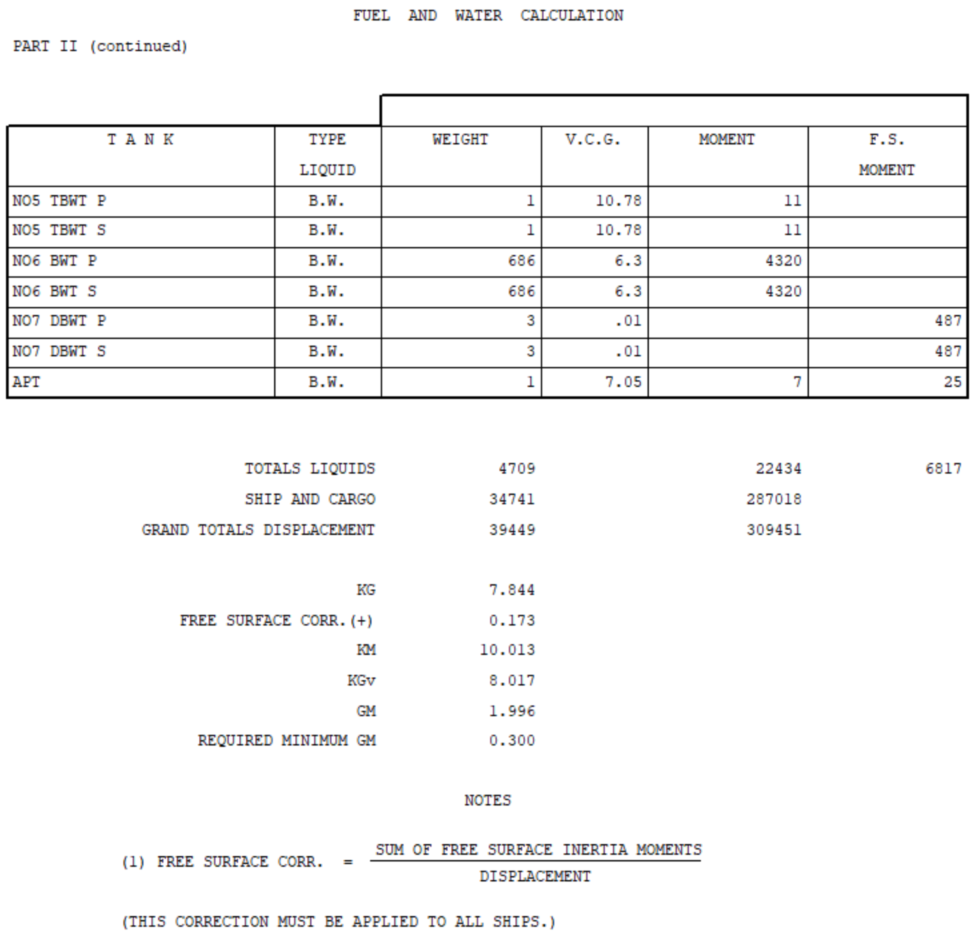
FUEL AND WATER CALCULATION

PART II

IN THIS PART YOU CAN EXAMINE DEPARTURE, INTERMEDIATE OR ARRIVAL CONDITION.
INTERMEDIATE SECTION IS REQUIRED TO BE COMPLETED IF ARRIVAL SECTION SHOWS
IS JUST PRIOR TO BALLASTING WHICH INCLUDES THE EFFECT OF FREE SURFACE BUT
NOT EFFECT OF WEIGHT OF THE BALLAST WHICH IS TO BE TAKEN ABOARD.

TANK	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO1 HFO T	F.O.	40	3.	120	100
NO2 HFO T P	F.O.	150	.37	56	1381
NO2 HFO T S	F.O.	150	.37	56	1381
NO3 HFO T P	F.O.	10	.05	1	296
NO3 HFO T S	F.O.	40	.21	8	296
NO4 HFO P(LS)	F.O.	95	.86	82	169
NO4 HFO S(LS)	F.O.	95	.86	82	169
NO2 HFO SETTL	F.O.	15	11.61	174	21
NO2 HFO SERV	F.O.	15	11.66	175	18
NO1 HFO SERV	F.O.	7	11.33	79	11
NO1 HFO SETTL	F.O.	7	11.26	79	10
NO1 HFO OVRFL	F.O.	2	13.85	28	9
MDO STOR P	D.O.	55	.81	45	130
MDO STOR S	D.O.	55	.81	45	130
MDO SERV	D.O.	11	8.41	92	5
MDO SETTL P	D.O.	9	7.74	70	15
FWT P	F.W.	45	12.28	552	36
FWT S	F.W.	100	12.41	1241	92
DISTILL W TK	F.W.	5	11.16	56	16
COOLING	F.W.	20	4.3	86	156
F.P.TK	B.W.	2	.05		44
NO1 BWT P	B.W.	4	.02		487
NO1 BWT S	B.W.	4	.02		487
NO2 DBWT P	B.W.	3	.01		98
NO2 DBWT S	B.W.	3	.01		98
NO2 TBWT P	B.W.	1	10.78	11	
NO2 TBWT S	B.W.	1	10.78	11	
NO3 DBWT P	B.W.	552	1.04	574	
NO3 DBWT S	B.W.	552	1.04	574	
NO3 TBWT P	B.W.	1	10.78	11	
NO3 TBWT S	B.W.	1	10.78	11	
NO4 BWT P	B.W.	635	7.44	4724	
NO4 BWT S	B.W.	635	7.44	4724	
NO5 DBWT P	B.W.	4	.02		81
NO5 DBWT S	B.W.	4	.02		81

Continue ...



FUEL AND WATER CALCULATION

PART II (continued)

T A N K	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO5 TBWT P	B.W.	1	10.78	11	
NO5 TBWT S	B.W.	1	10.78	11	
NO6 BWT P	B.W.	686	6.3	4320	
NO6 BWT S	B.W.	686	6.3	4320	
NO7 DBWT P	B.W.	3	.01		487
NO7 DBWT S	B.W.	3	.01		487
APT	B.W.	1	7.05	7	25

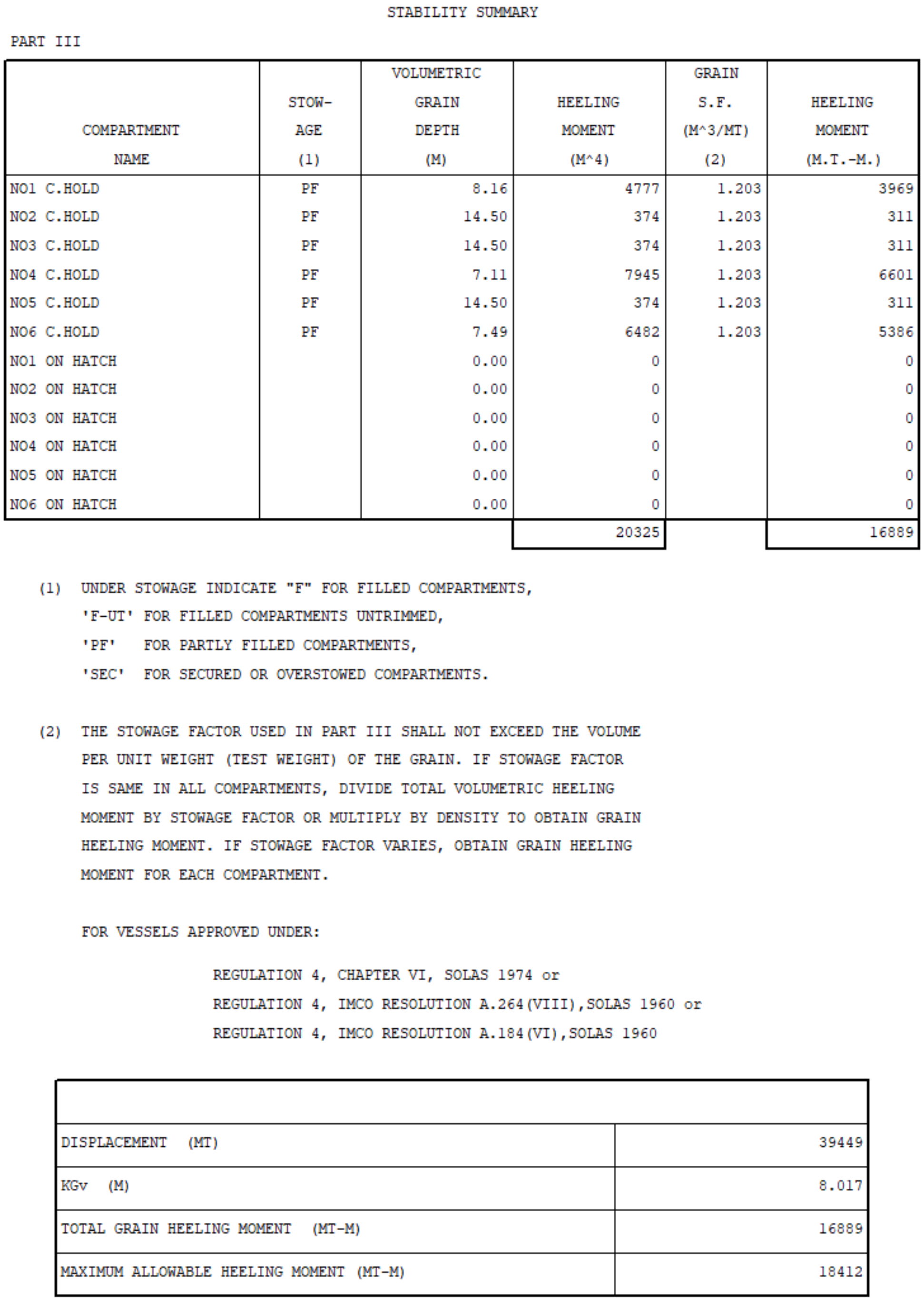
```
               TOTALS LIQUIDS        4709                 22434         6817
               SHIP AND CARGO       34741                287018
   GRAND TOTALS DISPLACEMENT        39449                309451

                           KG       7.844
        FREE SURFACE CORR.(+)       0.173
                           KM      10.013
                          KGv       8.017
                           GM       1.996
          REQUIRED MINIMUM GM       0.300
```

NOTES

$$(1)\ \text{FREE SURFACE CORR.} = \frac{\text{SUM OF FREE SURFACE INERTIA MOMENTS}}{\text{DISPLACEMENT}}$$

(THIS CORRECTION MUST BE APPLIED TO ALL SHIPS.)



STABILITY SUMMARY

PART III

COMPARTMENT NAME	STOW- AGE (1)	VOLUMETRIC GRAIN DEPTH (M)	HEELING MOMENT (M^4)	GRAIN S.F. (M^3/MT) (2)	HEELING MOMENT (M.T.-M.)
NO1 C.HOLD	PF	8.16	4777	1.203	3969
NO2 C.HOLD	PF	14.50	374	1.203	311
NO3 C.HOLD	PF	14.50	374	1.203	311
NO4 C.HOLD	PF	7.11	7945	1.203	6601
NO5 C.HOLD	PF	14.50	374	1.203	311
NO6 C.HOLD	PF	7.49	6482	1.203	5386
NO1 ON HATCH		0.00	0		0
NO2 ON HATCH		0.00	0		0
NO3 ON HATCH		0.00	0		0
NO4 ON HATCH		0.00	0		0
NO5 ON HATCH		0.00	0		0
NO6 ON HATCH		0.00	0		0
			20325		16889

(1) UNDER STOWAGE INDICATE "F" FOR FILLED COMPARTMENTS,
'F-UT' FOR FILLED COMPARTMENTS UNTRIMMED,
'PF' FOR PARTLY FILLED COMPARTMENTS,
'SEC' FOR SECURED OR OVERSTOWED COMPARTMENTS.

(2) THE STOWAGE FACTOR USED IN PART III SHALL NOT EXCEED THE VOLUME PER UNIT WEIGHT (TEST WEIGHT) OF THE GRAIN. IF STOWAGE FACTOR IS SAME IN ALL COMPARTMENTS, DIVIDE TOTAL VOLUMETRIC HEELING MOMENT BY STOWAGE FACTOR OR MULTIPLY BY DENSITY TO OBTAIN GRAIN HEELING MOMENT. IF STOWAGE FACTOR VARIES, OBTAIN GRAIN HEELING MOMENT FOR EACH COMPARTMENT.

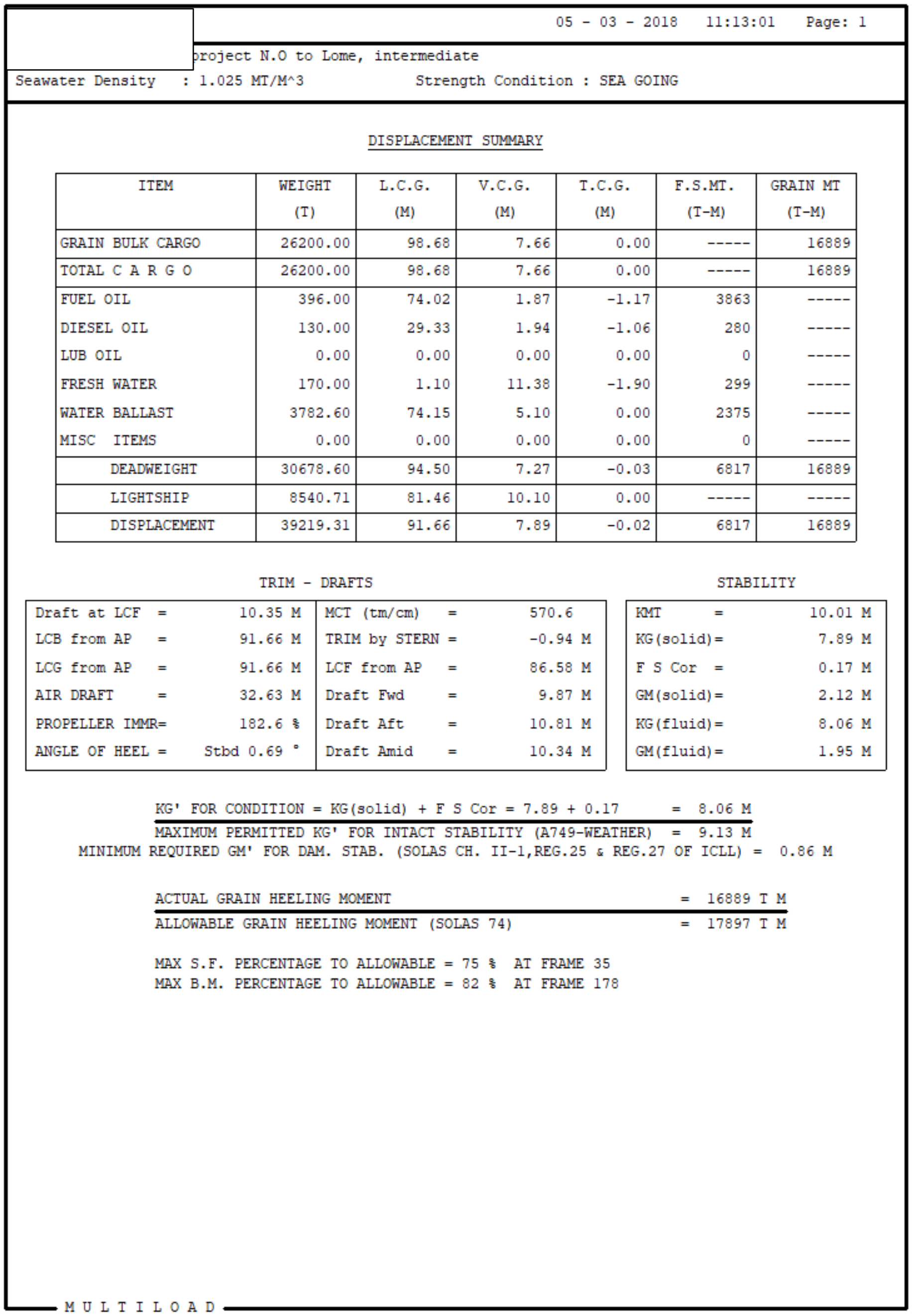
FOR VESSELS APPROVED UNDER:

REGULATION 4, CHAPTER VI, SOLAS 1974 or
REGULATION 4, IMCO RESOLUTION A.264(VIII),SOLAS 1960 or
REGULATION 4, IMCO RESOLUTION A.184(VI),SOLAS 1960

DISPLACEMENT (MT)	39449
KGv (M)	8.017
TOTAL GRAIN HEELING MOMENT (MT-M)	16889
MAXIMUM ALLOWABLE HEELING MOMENT (MT-M)	18412

10.5.3- INTERMEDIATE CONDITION WITH INTERMEDIATE BUNKERS AND BALLASTED

A- WEIGHT DISTRIBUTION, INTACT STABILITY PARAMETERS



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                     project N.O to Lome, intermediate
Seawater Density   : 1.025 MT/M^3            Strength Condition : SEA GOING

                              DISPLACEMENT SUMMARY

      ITEM               WEIGHT    L.C.G.    V.C.G.    T.C.G.   F.S.MT.   GRAIN MT
                          (T)       (M)       (M)       (M)     (T-M)     (T-M)
 GRAIN BULK CARGO      26200.00     98.68      7.66      0.00     -----     16889
 TOTAL C A R G O       26200.00     98.68      7.66      0.00     -----     16889
 FUEL OIL                396.00     74.02      1.87     -1.17      3863     -----
 DIESEL OIL              130.00     29.33      1.94     -1.06       280     -----
 LUB OIL                   0.00      0.00      0.00      0.00         0     -----
 FRESH WATER             170.00      1.10     11.38     -1.90       299     -----
 WATER BALLAST          3782.60     74.15      5.10      0.00      2375     -----
 MISC  ITEMS               0.00      0.00      0.00      0.00         0     -----
       DEADWEIGHT      30678.60     94.50      7.27     -0.03      6817     16889
       LIGHTSHIP        8540.71     81.46     10.10      0.00     -----     -----
       DISPLACEMENT    39219.31     91.66      7.89     -0.02      6817     16889

                       TRIM - DRAFTS                            STABILITY
 Draft at LCF  =        10.35 M | MCT  (tm/cm)   =      570.6 | KMT      =      10.01 M
 LCB from AP   =        91.66 M | TRIM by STERN =      -0.94 M | KG(solid)=       7.89 M
 LCG from AP   =        91.66 M | LCF from AP   =      86.58 M | F S Cor  =       0.17 M
 AIR DRAFT     =        32.63 M | Draft Fwd     =       9.87 M | GM(solid)=       2.12 M
 PROPELLER IMMR=        182.6 % | Draft Aft     =      10.81 M | KG(fluid)=       8.06 M
 ANGLE OF HEEL =     Stbd 0.69 ° | Draft Amid    =      10.34 M | GM(fluid)=       1.95 M

            KG' FOR CONDITION = KG(solid) + F S Cor = 7.89 + 0.17       =  8.06 M
            MAXIMUM PERMITTED KG' FOR INTACT STABILITY (A749-WEATHER)   =  9.13 M
    MINIMUM REQUIRED GM' FOR DAM. STAB. (SOLAS CH. II-1,REG.25 & REG.27 OF ICLL) =  0.86 M

            ACTUAL GRAIN HEELING MOMENT                                  =  16889 T M
            ALLOWABLE GRAIN HEELING MOMENT (SOLAS 74)                    =  17897 T M

            MAX S.F. PERCENTAGE TO ALLOWABLE = 75 %  AT FRAME 35
            MAX B.M. PERCENTAGE TO ALLOWABLE = 82 %  AT FRAME 178

       MULTILOAD
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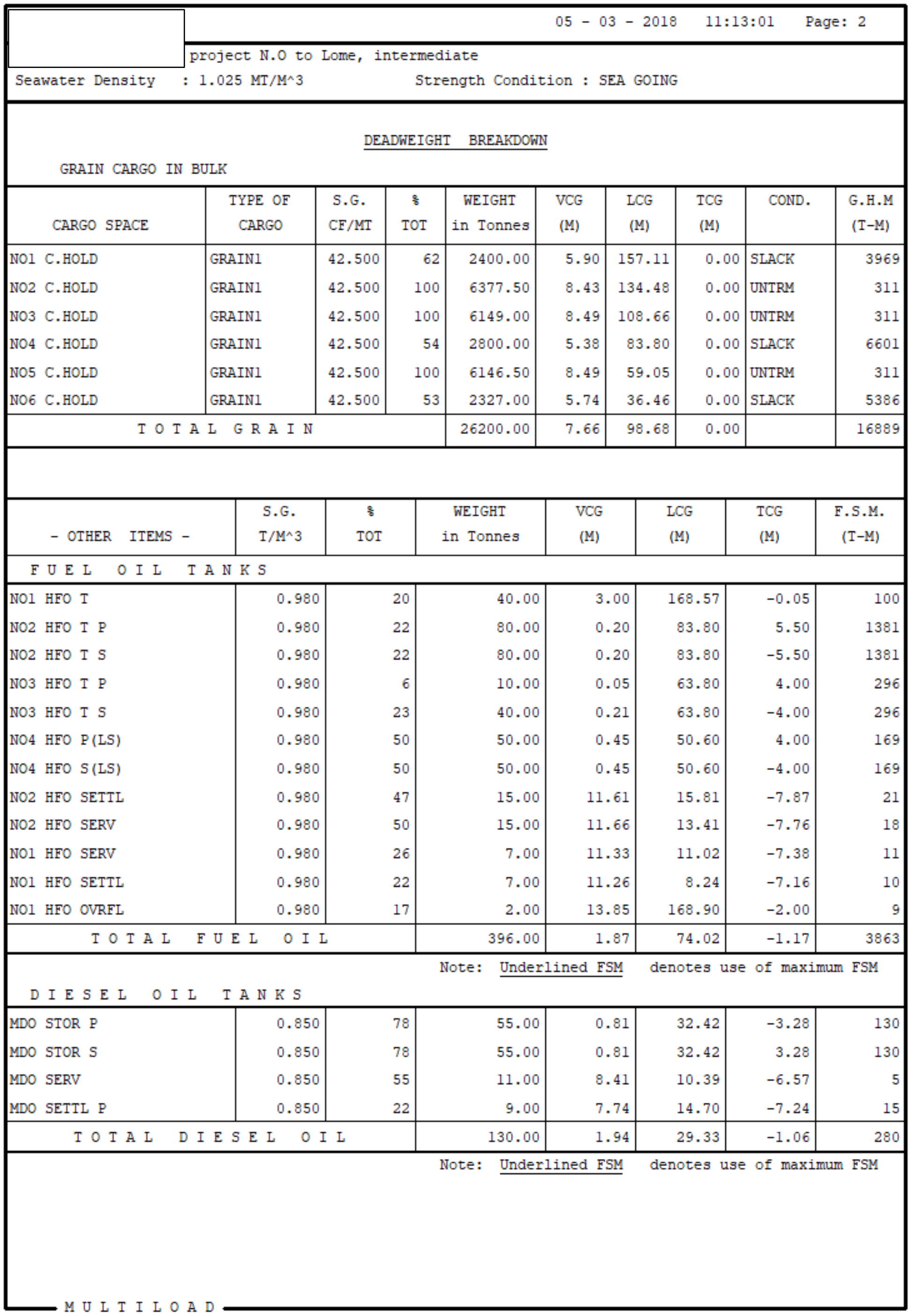

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                         project N.O to Lome, intermediate
Seawater Density    : 1.025 MT/M^3           Strength Condition : SEA GOING

                                    DEADWEIGHT  BREAKDOWN
      GRAIN CARGO IN BULK

                      TYPE OF     S.G.     %     WEIGHT      VCG     LCG     TCG     COND.     G.H.M
   CARGO SPACE         CARGO     CF/MT    TOT   in Tonnes    (M)     (M)     (M)               (T-M)
NO1 C.HOLD          GRAIN1      42.500     62    2400.00    5.90  157.11    0.00  SLACK         3969
NO2 C.HOLD          GRAIN1      42.500    100    6377.50    8.43  134.48    0.00  UNTRM          311
NO3 C.HOLD          GRAIN1      42.500    100    6149.00    8.49  108.66    0.00  UNTRM          311
NO4 C.HOLD          GRAIN1      42.500     54    2800.00    5.38   83.80    0.00  SLACK         6601
NO5 C.HOLD          GRAIN1      42.500    100    6146.50    8.49   59.05    0.00  UNTRM          311
NO6 C.HOLD          GRAIN1      42.500     53    2327.00    5.74   36.46    0.00  SLACK         5386
            T O T A L  G R A I N            26200.00    7.66   98.68    0.00               16889


                         S.G.        %         WEIGHT        VCG        LCG        TCG      F.S.M.
  - OTHER  ITEMS -      T/M^3       TOT       in Tonnes      (M)        (M)        (M)      (T-M)
  F U E L   O I L   T A N K S
NO1 HFO T               0.980        20         40.00       3.00     168.57      -0.05        100
NO2 HFO T P             0.980        22         80.00       0.20      83.80       5.50       1381
NO2 HFO T S             0.980        22         80.00       0.20      83.80      -5.50       1381
NO3 HFO T P             0.980         6         10.00       0.05      63.80       4.00        296
NO3 HFO T S             0.980        23         40.00       0.21      63.80      -4.00        296
NO4 HFO P(LS)           0.980        50         50.00       0.45      50.60       4.00        169
NO4 HFO S(LS)           0.980        50         50.00       0.45      50.60      -4.00        169
NO2 HFO SETTL           0.980        47         15.00      11.61      15.81      -7.87         21
NO2 HFO SERV            0.980        50         15.00      11.66      13.41      -7.76         18
NO1 HFO SERV            0.980        26          7.00      11.33      11.02      -7.38         11
NO1 HFO SETTL           0.980        22          7.00      11.26       8.24      -7.16         10
NO1 HFO OVRFL           0.980        17          2.00      13.85     168.90      -2.00          9
         T O T A L   F U E L   O I L           396.00       1.87      74.02      -1.17       3863
                                   Note:  Underlined FSM   denotes use of maximum FSM
  D I E S E L   O I L   T A N K S
MDO STOR P              0.850        78         55.00       0.81      32.42      -3.28        130
MDO STOR S              0.850        78         55.00       0.81      32.42       3.28        130
MDO SERV                0.850        55         11.00       8.41      10.39      -6.57          5
MDO SETTL P             0.850        22          9.00       7.74      14.70      -7.24         15
       T O T A L   D I E S E L   O I L         130.00       1.94      29.33      -1.06        280
                                   Note:  Underlined FSM   denotes use of maximum FSM




      M U L T I L O A D
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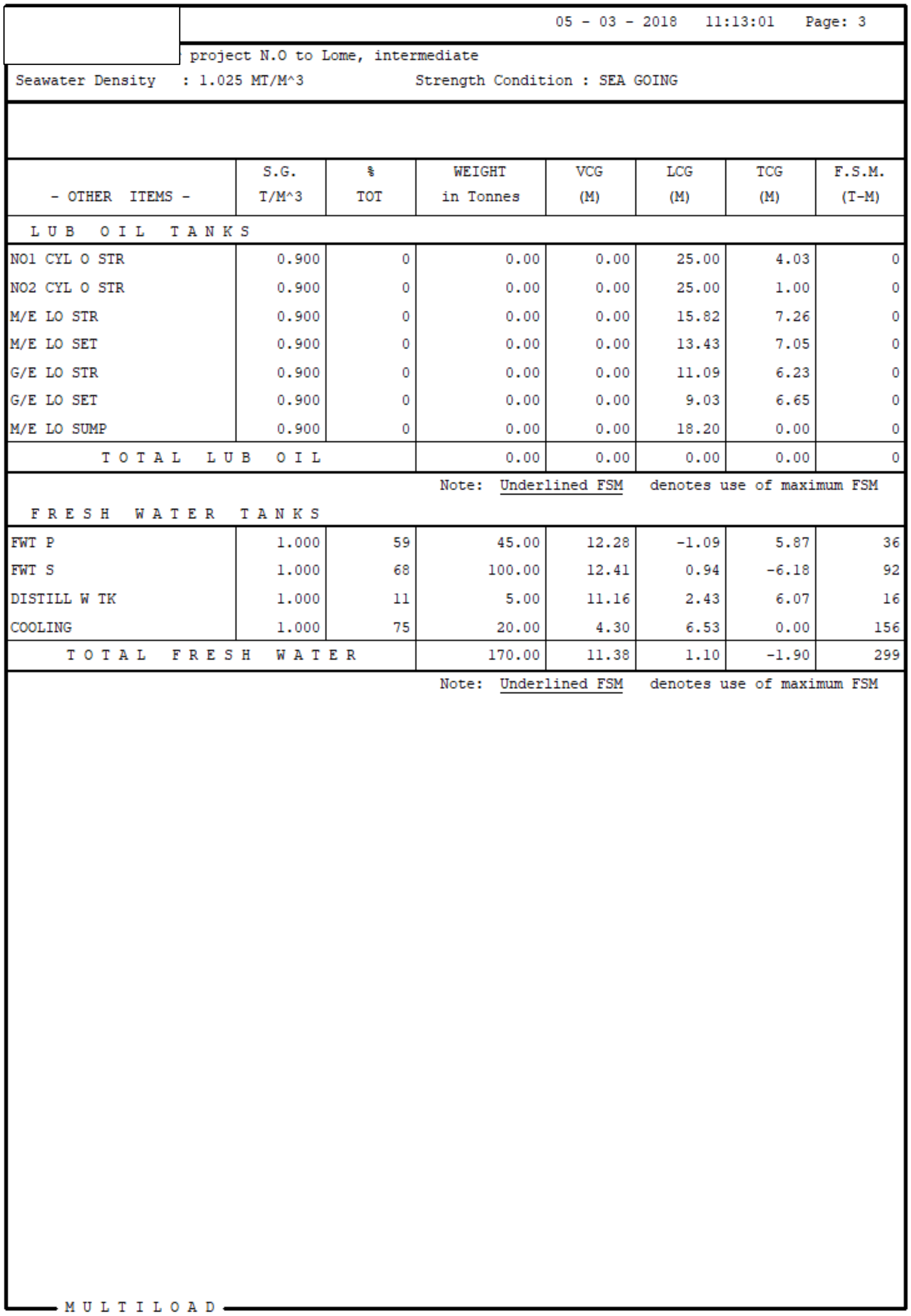

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project N.O to Lome, intermediate

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

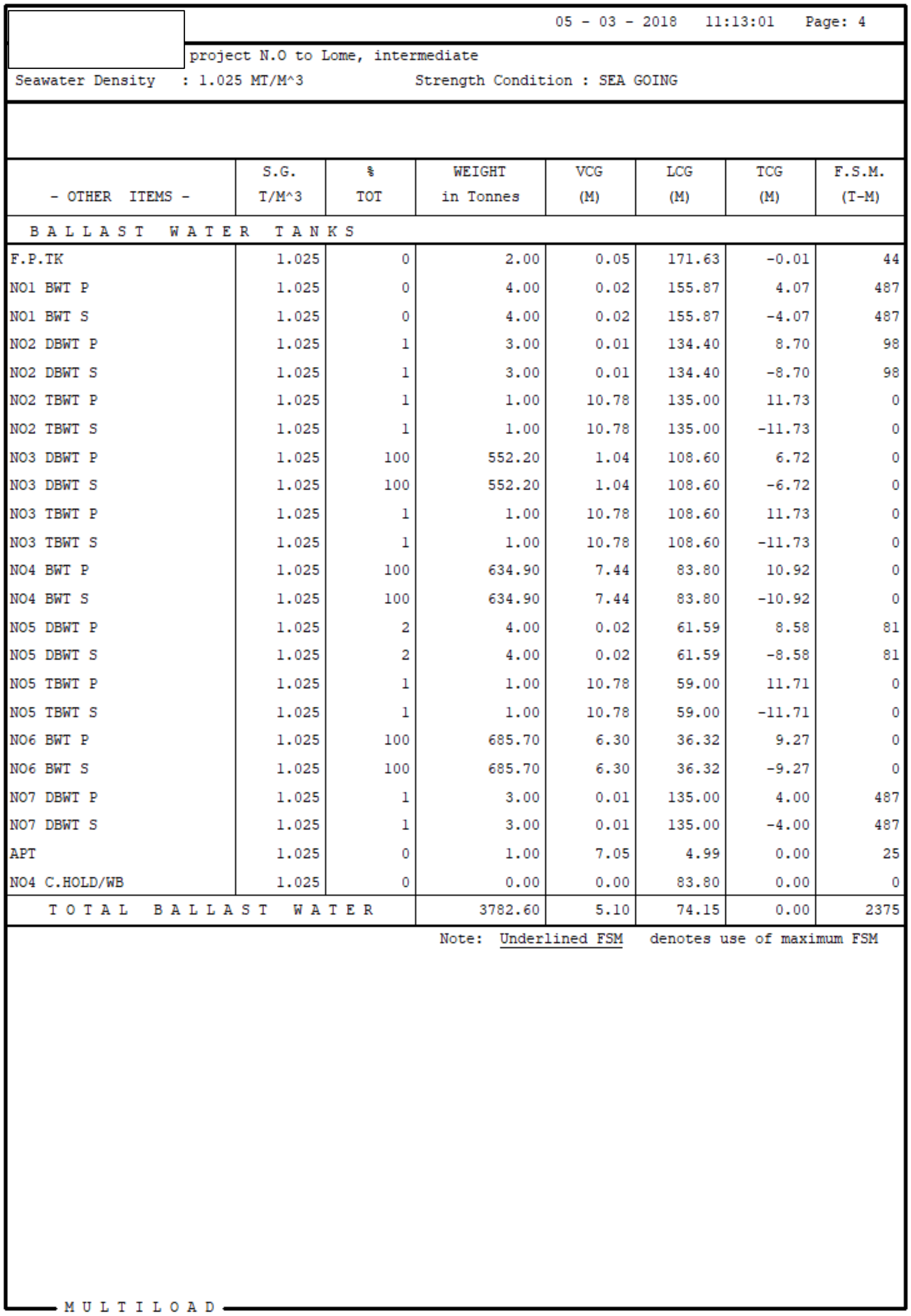
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
LUB OIL TANKS							
NO1 CYL O STR	0.900	0	0.00	0.00	25.00	4.03	0
NO2 CYL O STR	0.900	0	0.00	0.00	25.00	1.00	0
M/E LO STR	0.900	0	0.00	0.00	15.82	7.26	0
M/E LO SET	0.900	0	0.00	0.00	13.43	7.05	0
G/E LO STR	0.900	0	0.00	0.00	11.09	6.23	0
G/E LO SET	0.900	0	0.00	0.00	9.03	6.65	0
M/E LO SUMP	0.900	0	0.00	0.00	18.20	0.00	0
TOTAL LUB OIL			0.00	0.00	0.00	0.00	0

Note: Underlined FSM denotes use of maximum FSM

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
FRESH WATER TANKS							
FWT P	1.000	59	45.00	12.28	-1.09	5.87	36
FWT S	1.000	68	100.00	12.41	0.94	-6.18	92
DISTILL W TK	1.000	11	5.00	11.16	2.43	6.07	16
COOLING	1.000	75	20.00	4.30	6.53	0.00	156
TOTAL FRESH WATER			170.00	11.38	1.10	-1.90	299

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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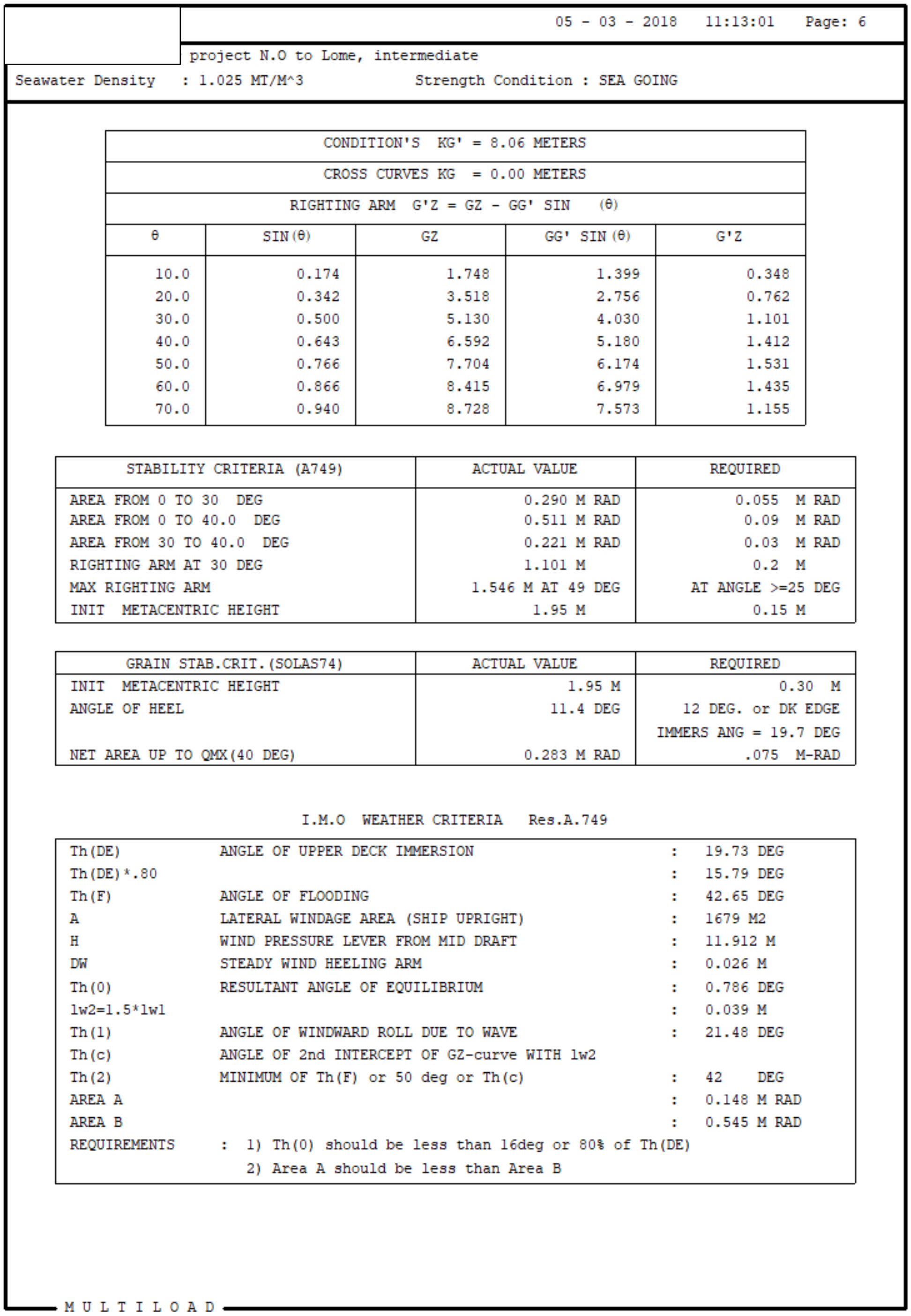
project N.O to Lome, intermediate

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
BALLAST WATER TANKS							
F.P.TK	1.025	0	2.00	0.05	171.63	-0.01	44
NO1 BWT P	1.025	0	4.00	0.02	155.87	4.07	487
NO1 BWT S	1.025	0	4.00	0.02	155.87	-4.07	487
NO2 DBWT P	1.025	1	3.00	0.01	134.40	8.70	98
NO2 DBWT S	1.025	1	3.00	0.01	134.40	-8.70	98
NO2 TBWT P	1.025	1	1.00	10.78	135.00	11.73	0
NO2 TBWT S	1.025	1	1.00	10.78	135.00	-11.73	0
NO3 DBWT P	1.025	100	552.20	1.04	108.60	6.72	0
NO3 DBWT S	1.025	100	552.20	1.04	108.60	-6.72	0
NO3 TBWT P	1.025	1	1.00	10.78	108.60	11.73	0
NO3 TBWT S	1.025	1	1.00	10.78	108.60	-11.73	0
NO4 BWT P	1.025	100	634.90	7.44	83.80	10.92	0
NO4 BWT S	1.025	100	634.90	7.44	83.80	-10.92	0
NO5 DBWT P	1.025	2	4.00	0.02	61.59	8.58	81
NO5 DBWT S	1.025	2	4.00	0.02	61.59	-8.58	81
NO5 TBWT P	1.025	1	1.00	10.78	59.00	11.71	0
NO5 TBWT S	1.025	1	1.00	10.78	59.00	-11.71	0
NO6 BWT P	1.025	100	685.70	6.30	36.32	9.27	0
NO6 BWT S	1.025	100	685.70	6.30	36.32	-9.27	0
NO7 DBWT P	1.025	1	3.00	0.01	135.00	4.00	487
NO7 DBWT S	1.025	1	3.00	0.01	135.00	-4.00	487
APT	1.025	0	1.00	7.05	4.99	0.00	25
NO4 C.HOLD/WB	1.025	0	0.00	0.00	83.80	0.00	0
TOTAL BALLAST WATER			3782.60	5.10	74.15	0.00	2375

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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                                        05 - 03 - 2018    11:13:01    Page: 6
                    project N.O to Lome, intermediate
Seawater Density    : 1.025 MT/M^3            Strength Condition : SEA GOING

                       CONDITION'S  KG' = 8.06 METERS
                       CROSS CURVES KG  = 0.00 METERS
                    RIGHTING ARM  G'Z = GZ - GG' SIN   (θ)
         θ          SIN(θ)         GZ          GG' SIN(θ)       G'Z

        10.0         0.174        1.748          1.399         0.348
        20.0         0.342        3.518          2.756         0.762
        30.0         0.500        5.130          4.030         1.101
        40.0         0.643        6.592          5.180         1.412
        50.0         0.766        7.704          6.174         1.531
        60.0         0.866        8.415          6.979         1.435
        70.0         0.940        8.728          7.573         1.155

     STABILITY CRITERIA (A749)          ACTUAL VALUE         REQUIRED
  AREA FROM 0 TO 30  DEG                0.290 M RAD       0.055  M RAD
  AREA FROM 0 TO 40.0  DEG              0.511 M RAD       0.09   M RAD
  AREA FROM 30 TO 40.0  DEG             0.221 M RAD       0.03   M RAD
  RIGHTING ARM AT 30 DEG                1.101 M           0.2   M
  MAX RIGHTING ARM                1.546 M AT 49 DEG       AT ANGLE >=25 DEG
  INIT  METACENTRIC HEIGHT              1.95 M            0.15 M

     GRAIN STAB.CRIT.(SOLAS74)          ACTUAL VALUE         REQUIRED
  INIT  METACENTRIC HEIGHT                   1.95 M            0.30  M
  ANGLE OF HEEL                              11.4 DEG    12 DEG. or DK EDGE
                                                         IMMERS ANG = 19.7 DEG
  NET AREA UP TO QMX(40 DEG)            0.283 M RAD           .075  M-RAD

                  I.M.O  WEATHER CRITERIA   Res.A.749

  Th(DE)        ANGLE OF UPPER DECK IMMERSION               :  19.73 DEG
  Th(DE)*.80                                                :  15.79 DEG
  Th(F)         ANGLE OF FLOODING                           :  42.65 DEG
  A             LATERAL WINDAGE AREA (SHIP UPRIGHT)         :  1679 M2
  H             WIND PRESSURE LEVER FROM MID DRAFT          :  11.912 M
  DW            STEADY WIND HEELING ARM                     :  0.026 M
  Th(0)         RESULTANT ANGLE OF EQUILIBRIUM              :  0.786 DEG
  lw2=1.5*lw1                                               :  0.039 M
  Th(1)         ANGLE OF WINDWARD ROLL DUE TO WAVE          :  21.48 DEG
  Th(c)         ANGLE OF 2nd INTERCEPT OF GZ-curve WITH lw2
  Th(2)         MINIMUM OF Th(F) or 50 deg or Th(c)         :  42    DEG
  AREA A                                                    :  0.148 M RAD
  AREA B                                                    :  0.545 M RAD
  REQUIREMENTS    :  1) Th(0) should be less than 16deg or 80% of Th(DE)
                     2) Area A should be less than Area B

      M U L T I L O A D
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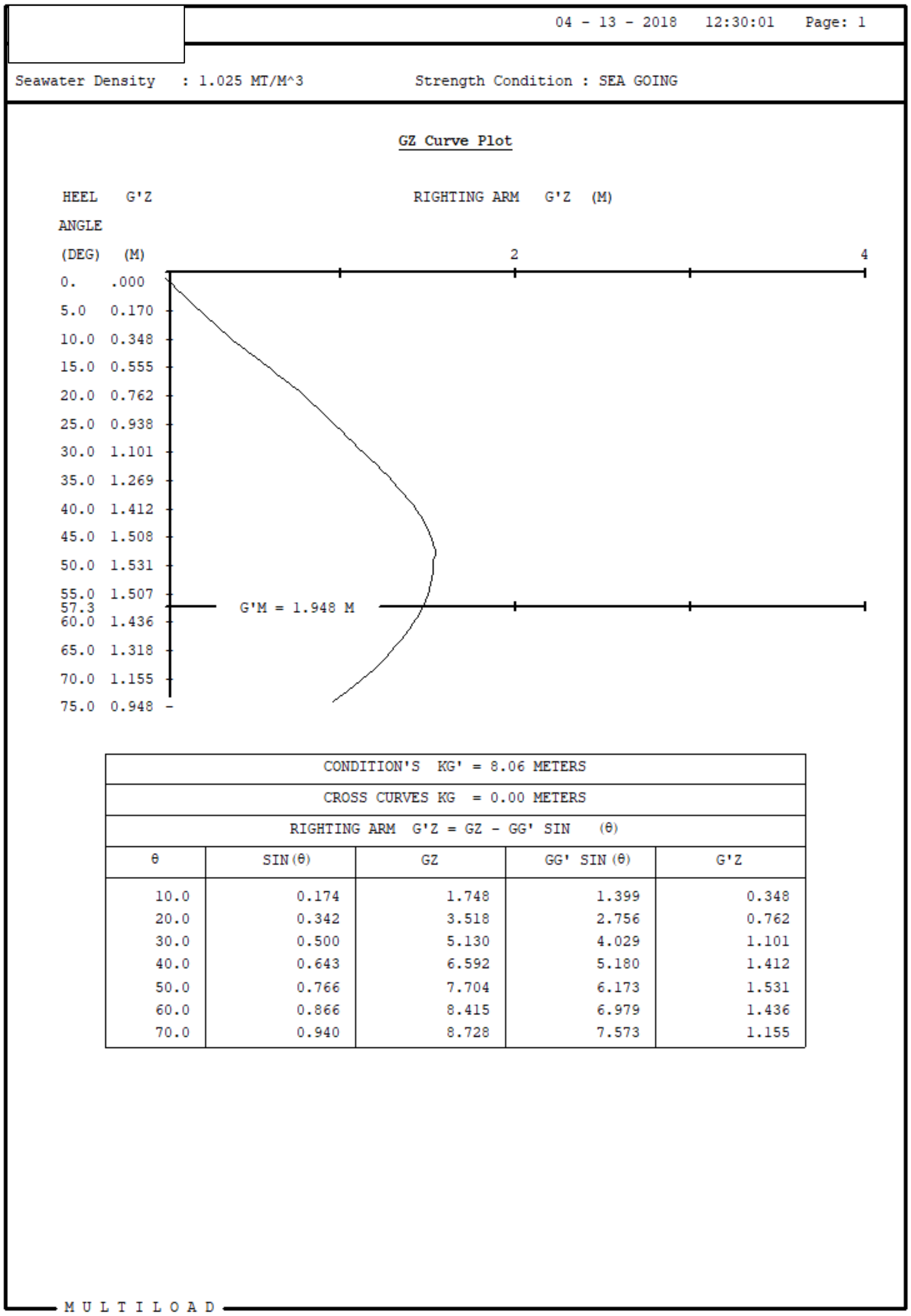
GZ CURVE



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Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

GZ Curve Plot

HEEL ANGLE (DEG)	G'Z (M)
0.	.000
5.0	0.170
10.0	0.348
15.0	0.555
20.0	0.762
25.0	0.938
30.0	1.101
35.0	1.269
40.0	1.412
45.0	1.508
50.0	1.531
55.0	1.507
57.3	
60.0	1.436
65.0	1.318
70.0	1.155
75.0	0.948

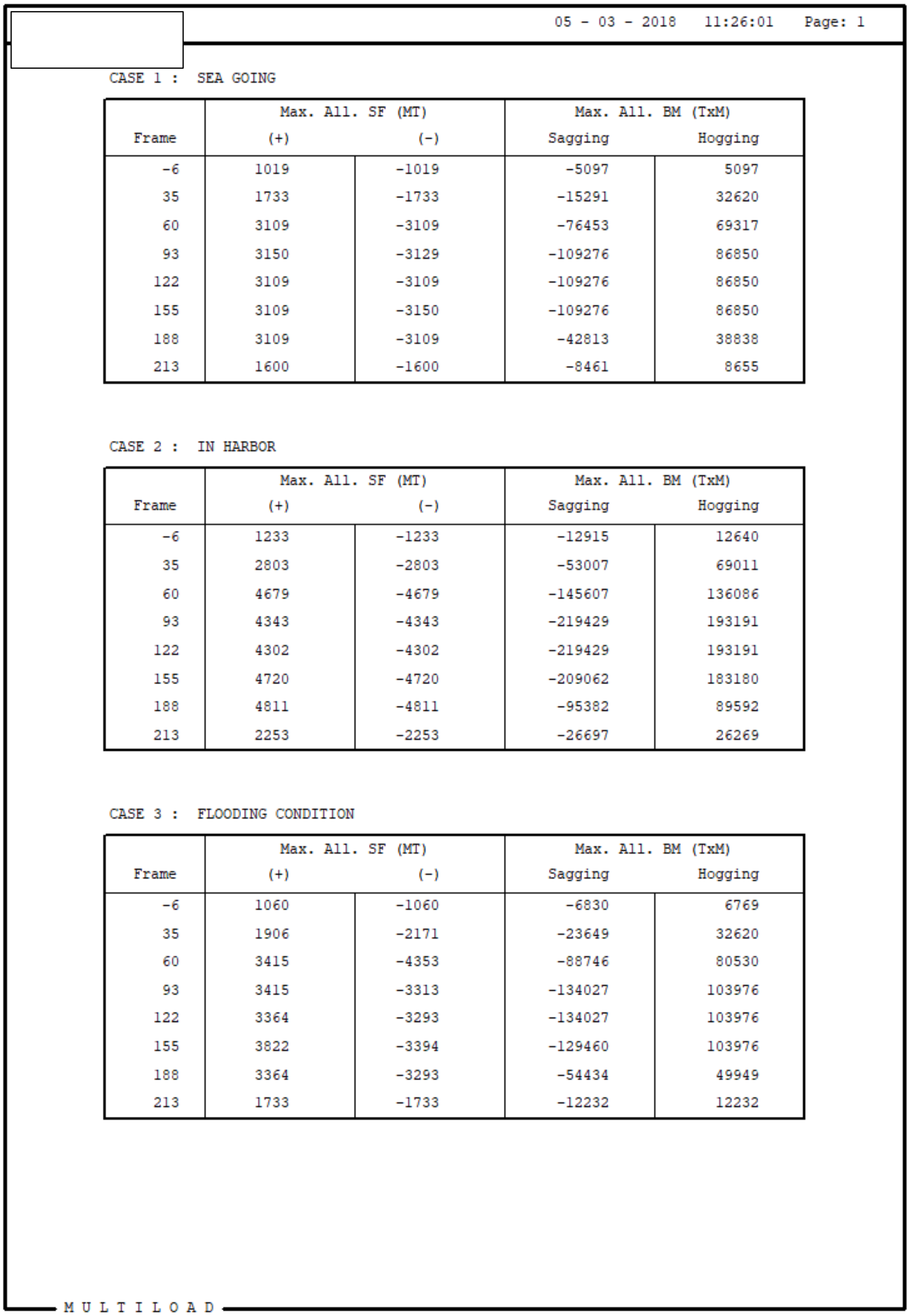
CONDITION'S KG' = 8.06 METERS

CROSS CURVES KG = 0.00 METERS

RIGHTING ARM G'Z = GZ - GG' SIN (θ)

θ	SIN(θ)	GZ	GG' SIN(θ)	G'Z
10.0	0.174	1.748	1.399	0.348
20.0	0.342	3.518	2.756	0.762
30.0	0.500	5.130	4.029	1.101
40.0	0.643	6.592	5.180	1.412
50.0	0.766	7.704	6.173	1.531
60.0	0.866	8.415	6.979	1.436
70.0	0.940	8.728	7.573	1.155

DEFLECTIONS (SF & BM)



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CASE 1 : SEA GOING

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1019	-1019	-5097	5097
35	1733	-1733	-15291	32620
60	3109	-3109	-76453	69317
93	3150	-3129	-109276	86850
122	3109	-3109	-109276	86850
155	3109	-3150	-109276	86850
188	3109	-3109	-42813	38838
213	1600	-1600	-8461	8655

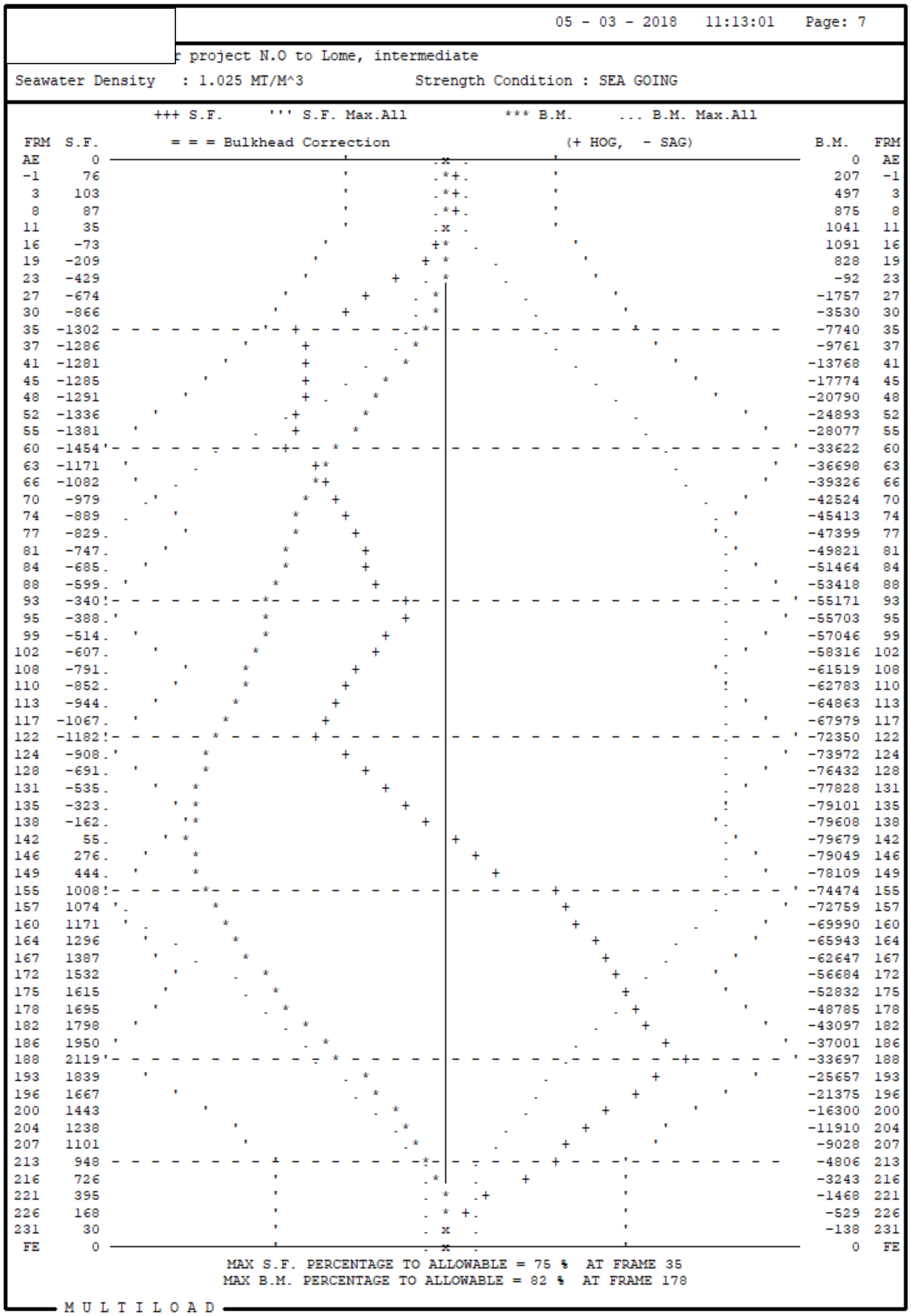
CASE 2 : IN HARBOR

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1233	-1233	-12915	12640
35	2803	-2803	-53007	69011
60	4679	-4679	-145607	136086
93	4343	-4343	-219429	193191
122	4302	-4302	-219429	193191
155	4720	-4720	-209062	183180
188	4811	-4811	-95382	89592
213	2253	-2253	-26697	26269

CASE 3 : FLOODING CONDITION

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1060	-1060	-6830	6769
35	1906	-2171	-23649	32620
60	3415	-4353	-88746	80530
93	3415	-3313	-134027	103976
122	3364	-3293	-134027	103976
155	3822	-3394	-129460	103976
188	3364	-3293	-54434	49949
213	1733	-1733	-12232	12232

MULTILOAD



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                         05 - 03 - 2018    11:13:01    Page: 7
 project N.O to Lome, intermediate
Seawater Density   : 1.025 MT/M^3          Strength Condition : SEA GOING

        +++ S.F.    ''' S.F. Max.All          *** B.M.     ... B.M. Max.All

FRM  S.F.      = = = Bulkhead Correction          (+ HOG,  - SAG)      B.M.   FRM
AE      0                                                                 0    AE
-1     76                                                               207    -1
 3    103                                                               497     3
 8     87                                                               875     8
11     35                                                              1041    11
16    -73                                                              1091    16
19   -209                                                               828    19
23   -429                                                               -92    23
27   -674                                                             -1757    27
30   -866                                                             -3530    30
35  -1302                                                             -7740    35
37  -1286                                                             -9761    37
41  -1281                                                            -13768    41
45  -1285                                                            -17774    45
48  -1291                                                            -20790    48
52  -1336                                                            -24893    52
55  -1381                                                            -28077    55
60  -1454                                                            -33622    60
63  -1171                                                            -36698    63
66  -1082                                                            -39326    66
70   -979                                                            -42524    70
74   -889                                                            -45413    74
77   -829                                                            -47399    77
81   -747                                                            -49821    81
84   -685                                                            -51464    84
88   -599                                                            -53418    88
93   -340                                                            -55171    93
95   -388                                                            -55703    95
99   -514                                                            -57046    99
102  -607                                                            -58316   102
108  -791                                                            -61519   108
110  -852                                                            -62783   110
113  -944                                                            -64863   113
117 -1067                                                            -67979   117
122 -1182                                                            -72350   122
124  -908                                                            -73972   124
128  -691                                                            -76432   128
131  -535                                                            -77828   131
135  -323                                                            -79101   135
138  -162                                                            -79608   138
142    55                                                            -79679   142
146   276                                                            -79049   146
149   444                                                            -78109   149
155  1008                                                            -74474   155
157  1074                                                            -72759   157
160  1171                                                            -69990   160
164  1296                                                            -65943   164
167  1387                                                            -62647   167
172  1532                                                            -56684   172
175  1615                                                            -52832   175
178  1695                                                            -48785   178
182  1798                                                            -43097   182
186  1950                                                            -37001   186
188  2119                                                            -33697   188
193  1839                                                            -25657   193
196  1667                                                            -21375   196
200  1443                                                            -16300   200
204  1238                                                            -11910   204
207  1101                                                             -9028   207
213   948                                                             -4806   213
216   726                                                             -3243   216
221   395                                                             -1468   221
226   168                                                              -529   226
231    30                                                              -138   231
FE      0                                                                 0    FE
              MAX S.F. PERCENTAGE TO ALLOWABLE = 75 %  AT FRAME 35
              MAX B.M. PERCENTAGE TO ALLOWABLE = 82 %  AT FRAME 178

    M U L T I L O A D
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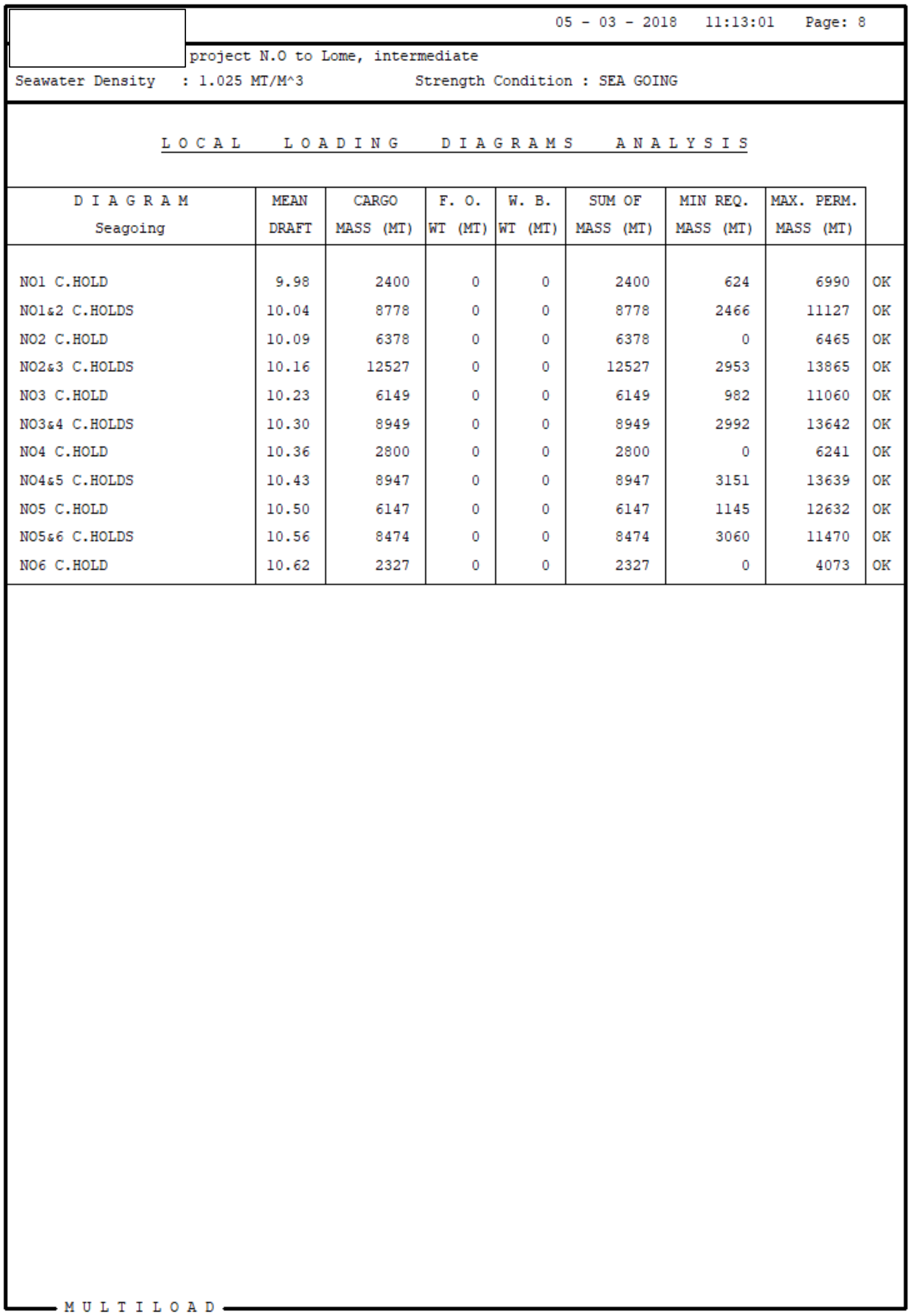
HOLD MASS TABLES



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                                                 05 - 03 - 2018   11:13:01   Page: 8
                         project N.O to Lome, intermediate
Seawater Density   : 1.025 MT/M^3          Strength Condition : SEA GOING

                L O C A L   L O A D I N G   D I A G R A M S   A N A L Y S I S

      D I A G R A M        | MEAN | CARGO    | F. O.   | W. B.   | SUM OF   | MIN REQ. | MAX. PERM.|
        Seagoing           | DRAFT| MASS (MT)| WT (MT) | WT (MT) | MASS (MT)| MASS (MT)| MASS (MT) |

 NO1 C.HOLD                  9.98     2400        0         0       2400        624       6990   OK
 NO1&2 C.HOLDS              10.04     8778        0         0       8778       2466      11127   OK
 NO2 C.HOLD                 10.09     6378        0         0       6378          0       6465   OK
 NO2&3 C.HOLDS              10.16    12527        0         0      12527       2953      13865   OK
 NO3 C.HOLD                 10.23     6149        0         0       6149        982      11060   OK
 NO3&4 C.HOLDS              10.30     8949        0         0       8949       2992      13642   OK
 NO4 C.HOLD                 10.36     2800        0         0       2800          0       6241   OK
 NO4&5 C.HOLDS              10.43     8947        0         0       8947       3151      13639   OK
 NO5 C.HOLD                 10.50     6147        0         0       6147       1145      12632   OK
 NO5&6 C.HOLDS              10.56     8474        0         0       8474       3060      11470   OK
 NO6 C.HOLD                 10.62     2327        0         0       2327          0       4073   OK

 M U L T I L O A D
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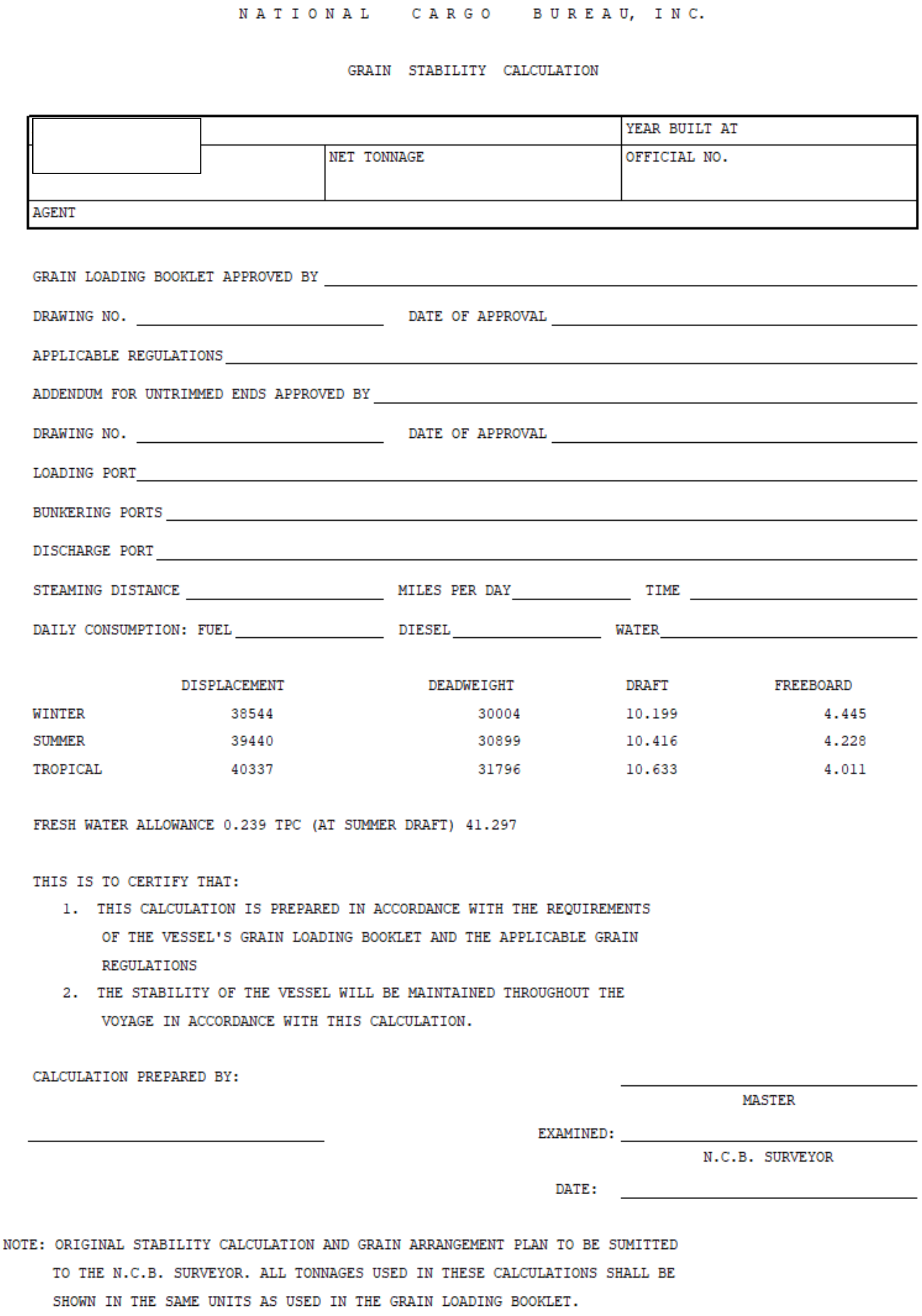
GRAIN STABILITY, SEA GOING CRITERION



NATIONAL CARGO BUREAU, INC.

GRAIN STABILITY CALCULATION

		YEAR BUILT AT
	NET TONNAGE	OFFICIAL NO.
AGENT		

GRAIN LOADING BOOKLET APPROVED BY __________

DRAWING NO. __________ DATE OF APPROVAL __________

APPLICABLE REGULATIONS __________

ADDENDUM FOR UNTRIMMED ENDS APPROVED BY __________

DRAWING NO. __________ DATE OF APPROVAL __________

LOADING PORT __________

BUNKERING PORTS __________

DISCHARGE PORT __________

STEAMING DISTANCE __________ MILES PER DAY __________ TIME __________

DAILY CONSUMPTION: FUEL __________ DIESEL __________ WATER __________

	DISPLACEMENT	DEADWEIGHT	DRAFT	FREEBOARD
WINTER	38544	30004	10.199	4.445
SUMMER	39440	30899	10.416	4.228
TROPICAL	40337	31796	10.633	4.011

FRESH WATER ALLOWANCE 0.239 TPC (AT SUMMER DRAFT) 41.297

THIS IS TO CERTIFY THAT:

1. THIS CALCULATION IS PREPARED IN ACCORDANCE WITH THE REQUIREMENTS OF THE VESSEL'S GRAIN LOADING BOOKLET AND THE APPLICABLE GRAIN REGULATIONS
2. THE STABILITY OF THE VESSEL WILL BE MAINTAINED THROUGHOUT THE VOYAGE IN ACCORDANCE WITH THIS CALCULATION.

CALCULATION PREPARED BY:

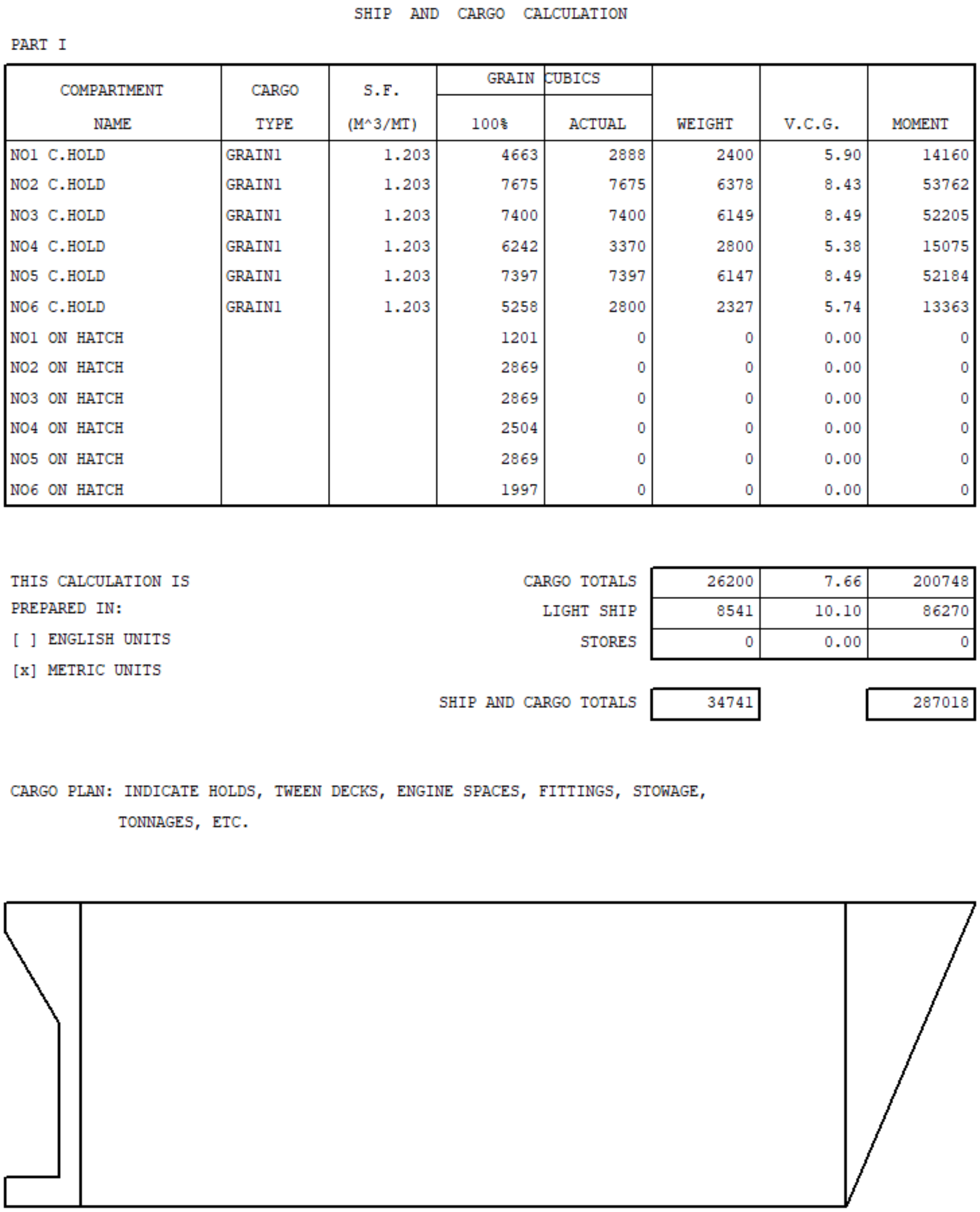
____
MASTER

____

EXAMINED: __________
N.C.B. SURVEYOR

DATE: __________

NOTE: ORIGINAL STABILITY CALCULATION AND GRAIN ARRANGEMENT PLAN TO BE SUMITTED TO THE N.C.B. SURVEYOR. ALL TONNAGES USED IN THESE CALCULATIONS SHALL BE SHOWN IN THE SAME UNITS AS USED IN THE GRAIN LOADING BOOKLET.



SHIP AND CARGO CALCULATION

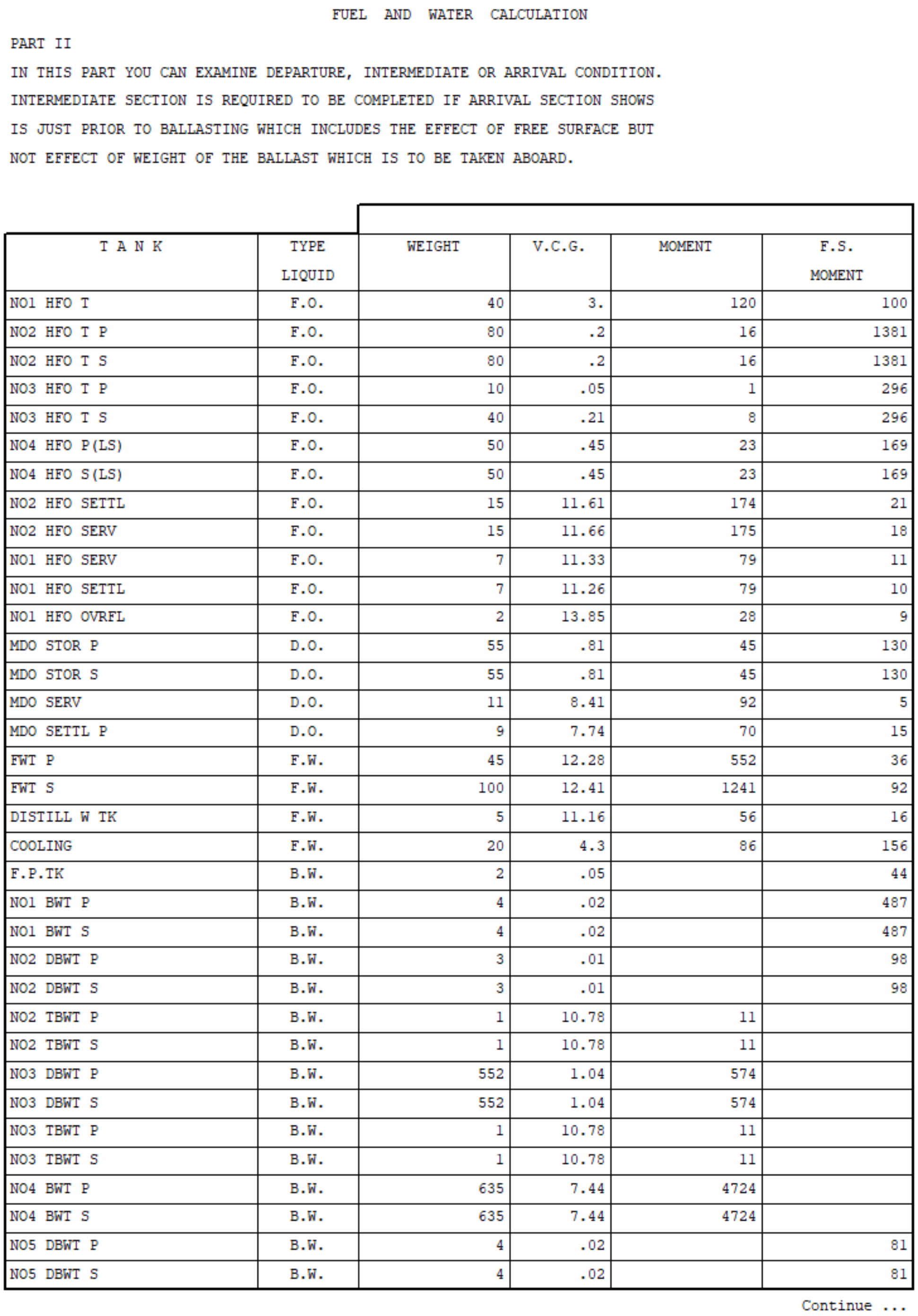
PART I

COMPARTMENT NAME	CARGO TYPE	S.F. (M^3/MT)	GRAIN CUBICS 100%	ACTUAL	WEIGHT	V.C.G.	MOMENT
NO1 C.HOLD	GRAIN1	1.203	4663	2888	2400	5.90	14160
NO2 C.HOLD	GRAIN1	1.203	7675	7675	6378	8.43	53762
NO3 C.HOLD	GRAIN1	1.203	7400	7400	6149	8.49	52205
NO4 C.HOLD	GRAIN1	1.203	6242	3370	2800	5.38	15075
NO5 C.HOLD	GRAIN1	1.203	7397	7397	6147	8.49	52184
NO6 C.HOLD	GRAIN1	1.203	5258	2800	2327	5.74	13363
NO1 ON HATCH			1201	0	0	0.00	0
NO2 ON HATCH			2869	0	0	0.00	0
NO3 ON HATCH			2869	0	0	0.00	0
NO4 ON HATCH			2504	0	0	0.00	0
NO5 ON HATCH			2869	0	0	0.00	0
NO6 ON HATCH			1997	0	0	0.00	0

THIS CALCULATION IS
PREPARED IN:
[ ] ENGLISH UNITS
[x] METRIC UNITS

CARGO TOTALS	26200	7.66	200748
LIGHT SHIP	8541	10.10	86270
STORES	0	0.00	0
SHIP AND CARGO TOTALS	34741		287018

CARGO PLAN: INDICATE HOLDS, TWEEN DECKS, ENGINE SPACES, FITTINGS, STOWAGE, TONNAGES, ETC.



FUEL AND WATER CALCULATION

PART II

IN THIS PART YOU CAN EXAMINE DEPARTURE, INTERMEDIATE OR ARRIVAL CONDITION.

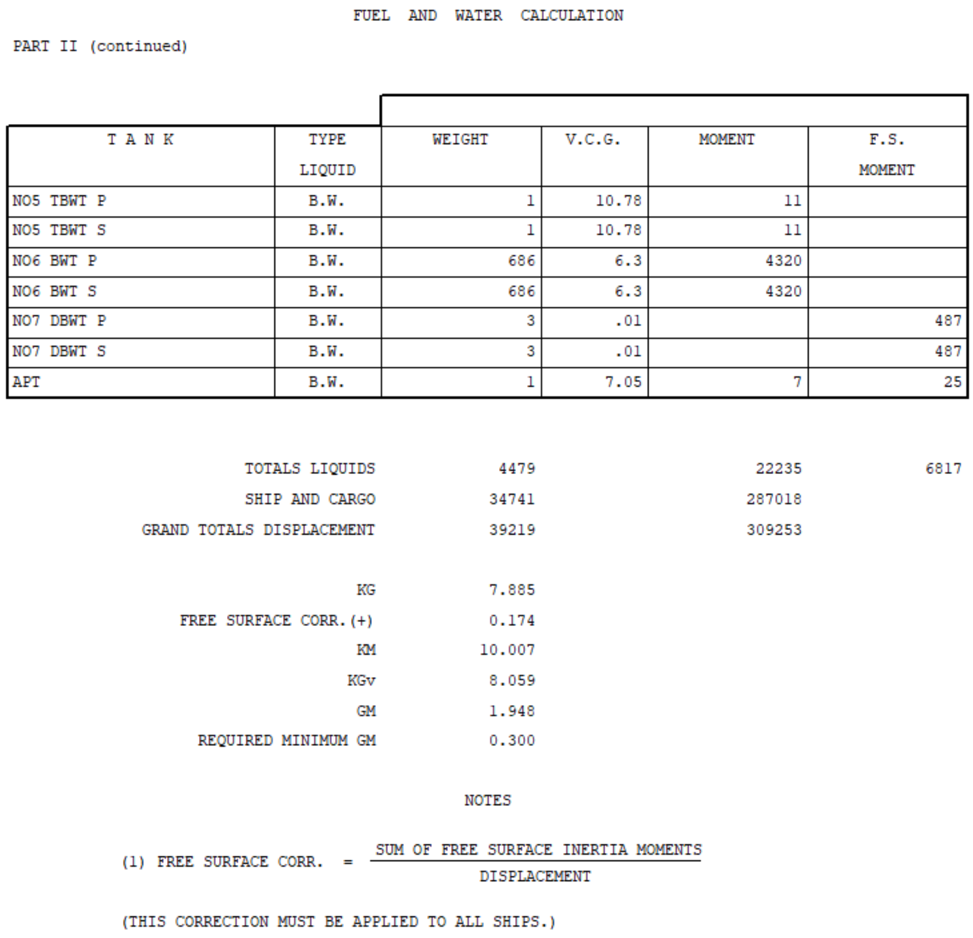
INTERMEDIATE SECTION IS REQUIRED TO BE COMPLETED IF ARRIVAL SECTION SHOWS

IS JUST PRIOR TO BALLASTING WHICH INCLUDES THE EFFECT OF FREE SURFACE BUT

NOT EFFECT OF WEIGHT OF THE BALLAST WHICH IS TO BE TAKEN ABOARD.

T A N K	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO1 HFO T	F.O.	40	3.	120	100
NO2 HFO T P	F.O.	80	.2	16	1381
NO2 HFO T S	F.O.	80	.2	16	1381
NO3 HFO T P	F.O.	10	.05	1	296
NO3 HFO T S	F.O.	40	.21	8	296
NO4 HFO P(LS)	F.O.	50	.45	23	169
NO4 HFO S(LS)	F.O.	50	.45	23	169
NO2 HFO SETTL	F.O.	15	11.61	174	21
NO2 HFO SERV	F.O.	15	11.66	175	18
NO1 HFO SERV	F.O.	7	11.33	79	11
NO1 HFO SETTL	F.O.	7	11.26	79	10
NO1 HFO OVRFL	F.O.	2	13.85	28	9
MDO STOR P	D.O.	55	.81	45	130
MDO STOR S	D.O.	55	.81	45	130
MDO SERV	D.O.	11	8.41	92	5
MDO SETTL P	D.O.	9	7.74	70	15
FWT P	F.W.	45	12.28	552	36
FWT S	F.W.	100	12.41	1241	92
DISTILL W TK	F.W.	5	11.16	56	16
COOLING	F.W.	20	4.3	86	156
F.P.TK	B.W.	2	.05		44
NO1 BWT P	B.W.	4	.02		487
NO1 BWT S	B.W.	4	.02		487
NO2 DBWT P	B.W.	3	.01		98
NO2 DBWT S	B.W.	3	.01		98
NO2 TBWT P	B.W.	1	10.78	11	
NO2 TBWT S	B.W.	1	10.78	11	
NO3 DBWT P	B.W.	552	1.04	574	
NO3 DBWT S	B.W.	552	1.04	574	
NO3 TBWT P	B.W.	1	10.78	11	
NO3 TBWT S	B.W.	1	10.78	11	
NO4 BWT P	B.W.	635	7.44	4724	
NO4 BWT S	B.W.	635	7.44	4724	
NO5 DBWT P	B.W.	4	.02		81
NO5 DBWT S	B.W.	4	.02		81

Continue ...



FUEL AND WATER CALCULATION

PART II (continued)

TANK	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO5 TBWT P	B.W.	1	10.78	11	
NO5 TBWT S	B.W.	1	10.78	11	
NO6 BWT P	B.W.	686	6.3	4320	
NO6 BWT S	B.W.	686	6.3	4320	
NO7 DBWT P	B.W.	3	.01		487
NO7 DBWT S	B.W.	3	.01		487
APT	B.W.	1	7.05	7	25

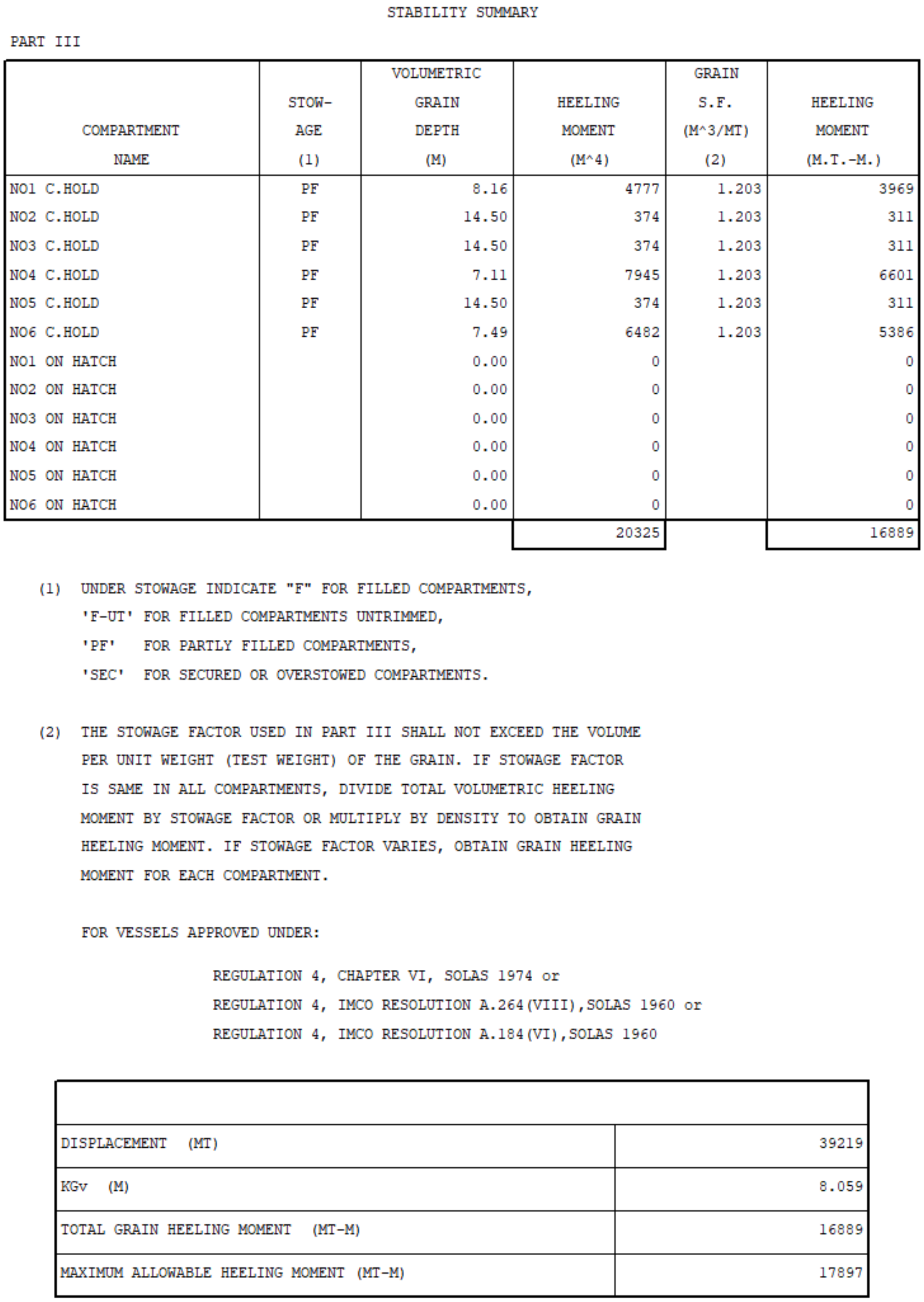
TOTALS LIQUIDS	4479	22235	6817
SHIP AND CARGO	34741	287018	
GRAND TOTALS DISPLACEMENT	39219	309253	

KG	7.885
FREE SURFACE CORR.(+)	0.174
KM	10.007
KGv	8.059
GM	1.948
REQUIRED MINIMUM GM	0.300

NOTES

(1) FREE SURFACE CORR. $= \frac{\text{SUM OF FREE SURFACE INERTIA MOMENTS}}{\text{DISPLACEMENT}}$

(THIS CORRECTION MUST BE APPLIED TO ALL SHIPS.)



STABILITY SUMMARY

PART III

COMPARTMENT NAME	STOW- AGE (1)	VOLUMETRIC GRAIN DEPTH (M)	HEELING MOMENT (M^4)	GRAIN S.F. (M^3/MT) (2)	HEELING MOMENT (M.T.-M.)
NO1 C.HOLD	PF	8.16	4777	1.203	3969
NO2 C.HOLD	PF	14.50	374	1.203	311
NO3 C.HOLD	PF	14.50	374	1.203	311
NO4 C.HOLD	PF	7.11	7945	1.203	6601
NO5 C.HOLD	PF	14.50	374	1.203	311
NO6 C.HOLD	PF	7.49	6482	1.203	5386
NO1 ON HATCH		0.00	0		0
NO2 ON HATCH		0.00	0		0
NO3 ON HATCH		0.00	0		0
NO4 ON HATCH		0.00	0		0
NO5 ON HATCH		0.00	0		0
NO6 ON HATCH		0.00	0		0
			20325		16889

(1) UNDER STOWAGE INDICATE "F" FOR FILLED COMPARTMENTS,
'F-UT' FOR FILLED COMPARTMENTS UNTRIMMED,
'PF' FOR PARTLY FILLED COMPARTMENTS,
'SEC' FOR SECURED OR OVERSTOWED COMPARTMENTS.

(2) THE STOWAGE FACTOR USED IN PART III SHALL NOT EXCEED THE VOLUME PER UNIT WEIGHT (TEST WEIGHT) OF THE GRAIN. IF STOWAGE FACTOR IS SAME IN ALL COMPARTMENTS, DIVIDE TOTAL VOLUMETRIC HEELING MOMENT BY STOWAGE FACTOR OR MULTIPLY BY DENSITY TO OBTAIN GRAIN HEELING MOMENT. IF STOWAGE FACTOR VARIES, OBTAIN GRAIN HEELING MOMENT FOR EACH COMPARTMENT.

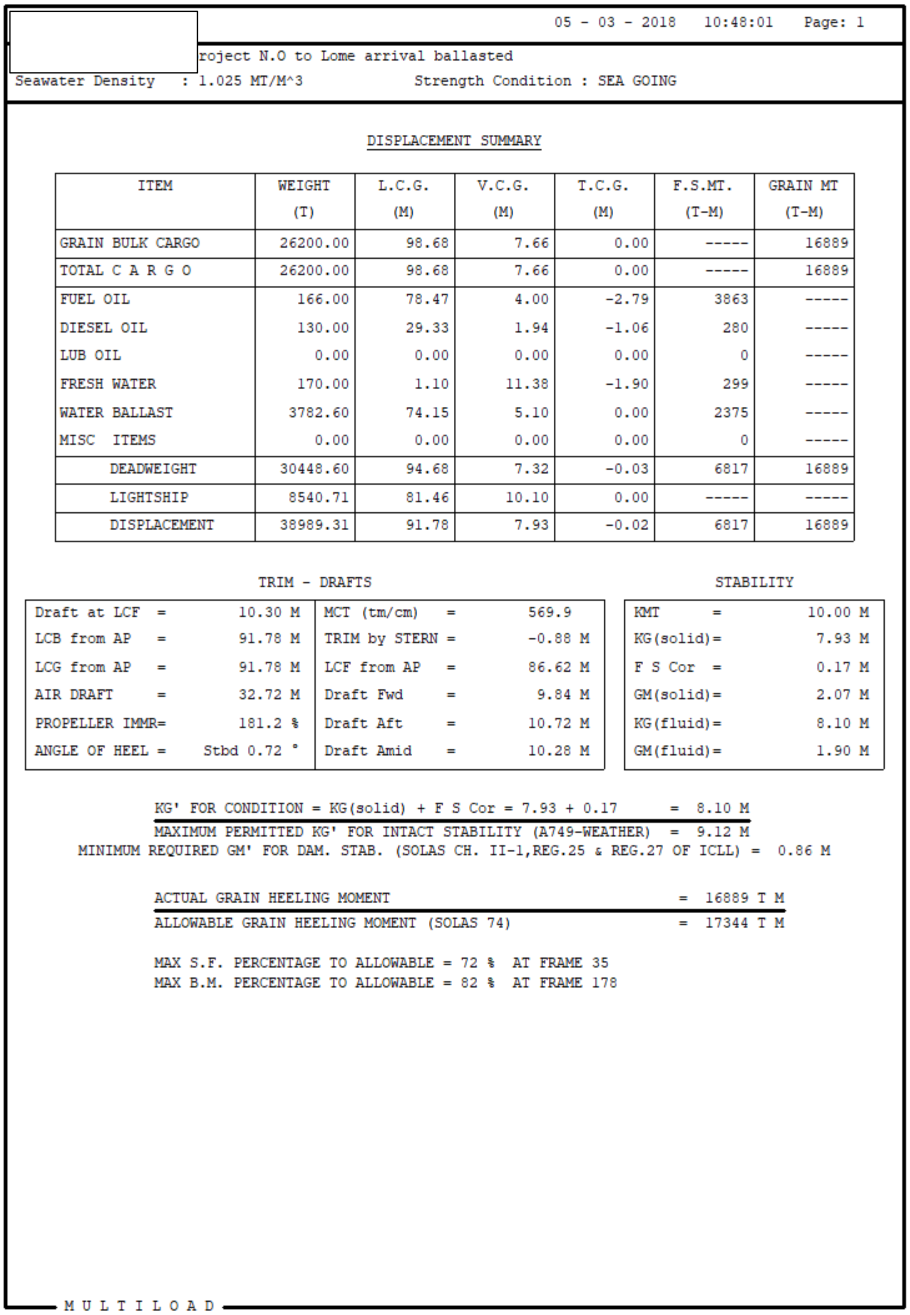
FOR VESSELS APPROVED UNDER:

REGULATION 4, CHAPTER VI, SOLAS 1974 or
REGULATION 4, IMCO RESOLUTION A.264(VIII),SOLAS 1960 or
REGULATION 4, IMCO RESOLUTION A.184(VI),SOLAS 1960

DISPLACEMENT (MT)	39219
KGv (M)	8.059
TOTAL GRAIN HEELING MOMENT (MT-M)	16889
MAXIMUM ALLOWABLE HEELING MOMENT (MT-M)	17897

10.5.4- ARRIVAL CONDITION WITH MINIMUM BUNKERS AND BALLASTED

A- WEIGHT DISTRIBUTION, INTACT STABILITY PARAMETERS



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                                          05 - 03 - 2018    10:48:01    Page: 1
[redacted]roject N.O to Lome arrival ballasted
Seawater Density   : 1.025 MT/M^3             Strength Condition : SEA GOING

                            DISPLACEMENT SUMMARY

 ITEM                  WEIGHT    L.C.G.    V.C.G.    T.C.G.    F.S.MT.   GRAIN MT
                         (T)       (M)       (M)       (M)      (T-M)     (T-M)
 GRAIN BULK CARGO     26200.00    98.68      7.66      0.00     -----     16889
 TOTAL C A R G O      26200.00    98.68      7.66      0.00     -----     16889
 FUEL OIL               166.00    78.47      4.00     -2.79      3863     -----
 DIESEL OIL             130.00    29.33      1.94     -1.06       280     -----
 LUB OIL                  0.00     0.00      0.00      0.00         0     -----
 FRESH WATER            170.00     1.10     11.38     -1.90       299     -----
 WATER BALLAST         3782.60    74.15      5.10      0.00      2375     -----
 MISC  ITEMS              0.00     0.00      0.00      0.00         0     -----
       DEADWEIGHT     30448.60    94.68      7.32     -0.03      6817     16889
       LIGHTSHIP       8540.71    81.46     10.10      0.00     -----     -----
       DISPLACEMENT   38989.31    91.78      7.93     -0.02      6817     16889

                     TRIM - DRAFTS                                  STABILITY
 Draft at LCF   =      10.30 M | MCT (tm/cm)   =     569.9 | KMT       =      10.00 M
 LCB from AP    =      91.78 M | TRIM by STERN =     -0.88 M | KG(solid)=       7.93 M
 LCG from AP    =      91.78 M | LCF from AP   =     86.62 M | F S Cor  =       0.17 M
 AIR DRAFT      =      32.72 M | Draft Fwd     =      9.84 M | GM(solid)=       2.07 M
 PROPELLER IMMR=       181.2 % | Draft Aft     =     10.72 M | KG(fluid)=       8.10 M
 ANGLE OF HEEL =    Stbd 0.72 ° | Draft Amid    =     10.28 M | GM(fluid)=       1.90 M

           KG' FOR CONDITION = KG(solid) + F S Cor = 7.93 + 0.17      =  8.10 M
           MAXIMUM PERMITTED KG' FOR INTACT STABILITY (A749-WEATHER)  =  9.12 M
      MINIMUM REQUIRED GM' FOR DAM. STAB. (SOLAS CH. II-1,REG.25 & REG.27 OF ICLL) =  0.86 M

           ACTUAL GRAIN HEELING MOMENT                                  =  16889 T M
           ALLOWABLE GRAIN HEELING MOMENT (SOLAS 74)                    =  17344 T M

           MAX S.F. PERCENTAGE TO ALLOWABLE = 72 %  AT FRAME 35
           MAX B.M. PERCENTAGE TO ALLOWABLE = 82 %  AT FRAME 178

   M U L T I L O A D
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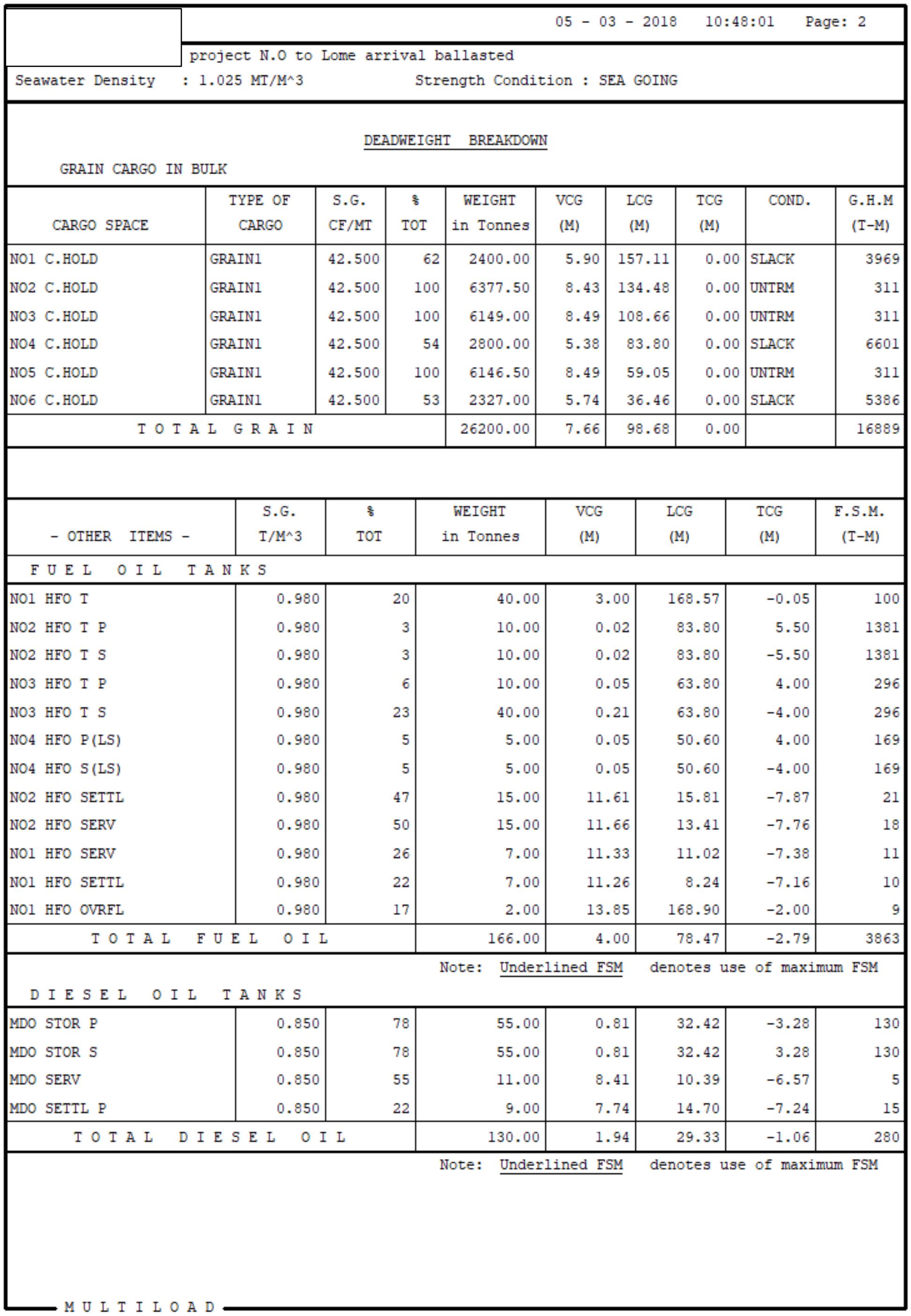

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project N.0 to Lome arrival ballasted

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

DEADWEIGHT BREAKDOWN

GRAIN CARGO IN BULK

CARGO SPACE	TYPE OF CARGO	S.G. CF/MT	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	COND.	G.H.M (T-M)
NO1 C.HOLD	GRAIN1	42.500	62	2400.00	5.90	157.11	0.00	SLACK	3969
NO2 C.HOLD	GRAIN1	42.500	100	6377.50	8.43	134.48	0.00	UNTRM	311
NO3 C.HOLD	GRAIN1	42.500	100	6149.00	8.49	108.66	0.00	UNTRM	311
NO4 C.HOLD	GRAIN1	42.500	54	2800.00	5.38	83.80	0.00	SLACK	6601
NO5 C.HOLD	GRAIN1	42.500	100	6146.50	8.49	59.05	0.00	UNTRM	311
NO6 C.HOLD	GRAIN1	42.500	53	2327.00	5.74	36.46	0.00	SLACK	5386
TOTAL GRAIN				26200.00	7.66	98.68	0.00		16889

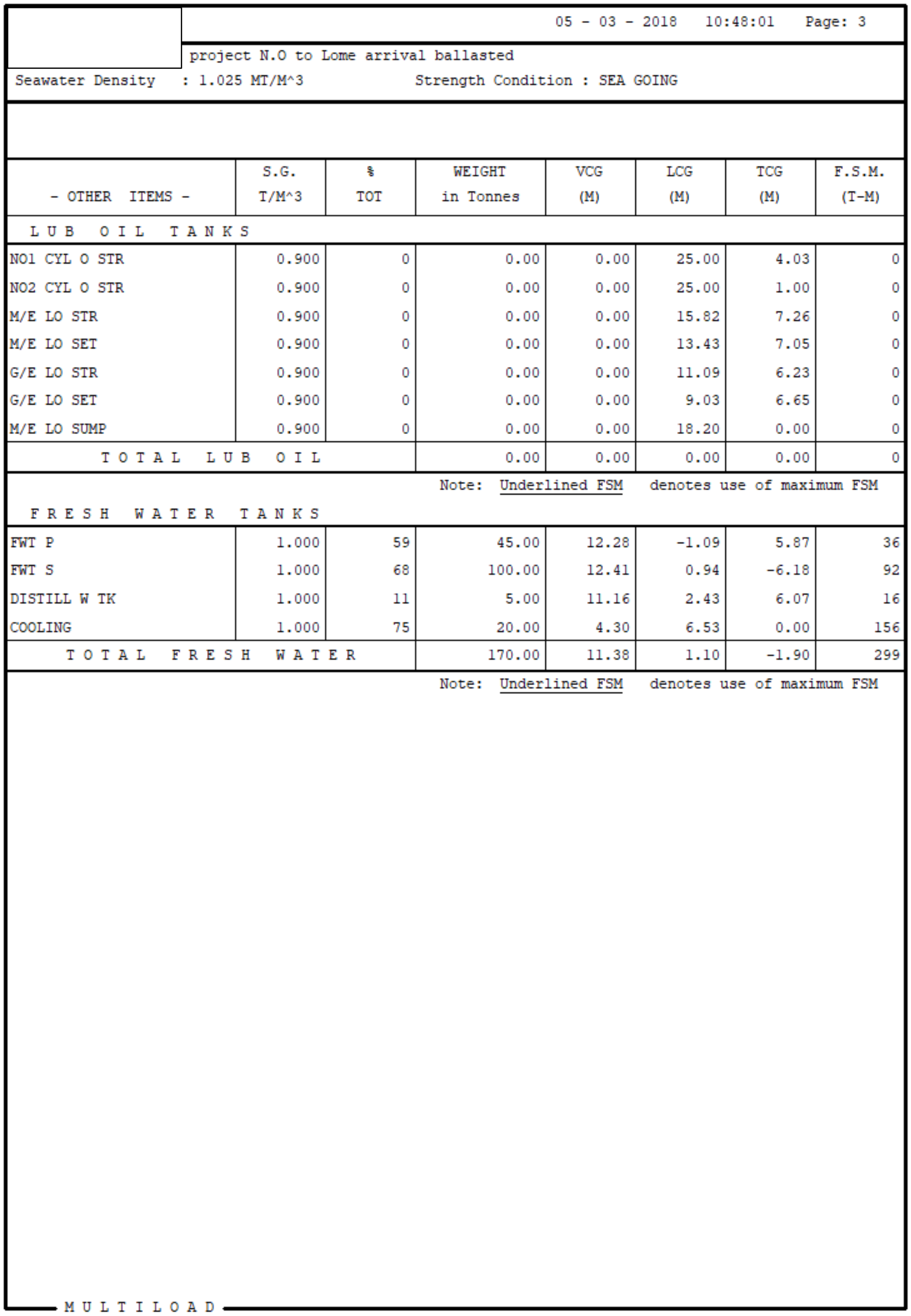
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
FUEL OIL TANKS							
NO1 HFO T	0.980	20	40.00	3.00	168.57	-0.05	100
NO2 HFO T P	0.980	3	10.00	0.02	83.80	5.50	1381
NO2 HFO T S	0.980	3	10.00	0.02	83.80	-5.50	1381
NO3 HFO T P	0.980	6	10.00	0.05	63.80	4.00	296
NO3 HFO T S	0.980	23	40.00	0.21	63.80	-4.00	296
NO4 HFO P(LS)	0.980	5	5.00	0.05	50.60	4.00	169
NO4 HFO S(LS)	0.980	5	5.00	0.05	50.60	-4.00	169
NO2 HFO SETTL	0.980	47	15.00	11.61	15.81	-7.87	21
NO2 HFO SERV	0.980	50	15.00	11.66	13.41	-7.76	18
NO1 HFO SERV	0.980	26	7.00	11.33	11.02	-7.38	11
NO1 HFO SETTL	0.980	22	7.00	11.26	8.24	-7.16	10
NO1 HFO OVRFL	0.980	17	2.00	13.85	168.90	-2.00	9
TOTAL FUEL OIL			166.00	4.00	78.47	-2.79	3863

Note: Underlined FSM denotes use of maximum FSM

DIESEL OIL TANKS							
MDO STOR P	0.850	78	55.00	0.81	32.42	-3.28	130
MDO STOR S	0.850	78	55.00	0.81	32.42	3.28	130
MDO SERV	0.850	55	11.00	8.41	10.39	-6.57	5
MDO SETTL P	0.850	22	9.00	7.74	14.70	-7.24	15
TOTAL DIESEL OIL			130.00	1.94	29.33	-1.06	280

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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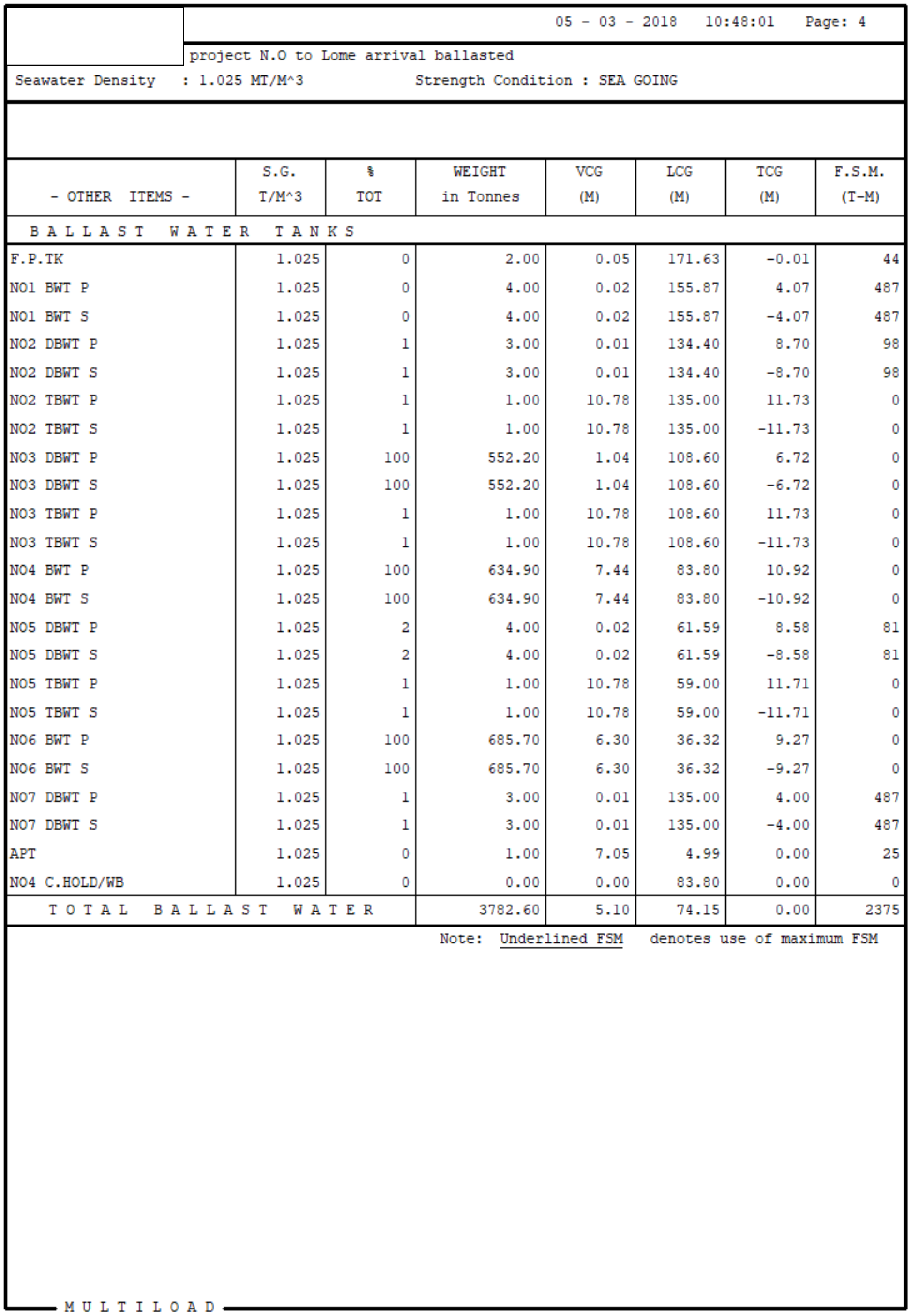
project N.O to Lome arrival ballasted

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
LUB OIL TANKS							
NO1 CYL O STR	0.900	0	0.00	0.00	25.00	4.03	0
NO2 CYL O STR	0.900	0	0.00	0.00	25.00	1.00	0
M/E LO STR	0.900	0	0.00	0.00	15.82	7.26	0
M/E LO SET	0.900	0	0.00	0.00	13.43	7.05	0
G/E LO STR	0.900	0	0.00	0.00	11.09	6.23	0
G/E LO SET	0.900	0	0.00	0.00	9.03	6.65	0
M/E LO SUMP	0.900	0	0.00	0.00	18.20	0.00	0
TOTAL LUB OIL			0.00	0.00	0.00	0.00	0
Note: Underlined FSM denotes use of maximum FSM							
FRESH WATER TANKS							
FWT P	1.000	59	45.00	12.28	-1.09	5.87	36
FWT S	1.000	68	100.00	12.41	0.94	-6.18	92
DISTILL W TK	1.000	11	5.00	11.16	2.43	6.07	16
COOLING	1.000	75	20.00	4.30	6.53	0.00	156
TOTAL FRESH WATER			170.00	11.38	1.10	-1.90	299

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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                                          05 - 03 - 2018    10:48:01    Page: 4
                       project N.O to Lome arrival ballasted
Seawater Density   : 1.025 MT/M^3           Strength Condition : SEA GOING

                          S.G.      %       WEIGHT      VCG      LCG      TCG     F.S.M.
   - OTHER  ITEMS -      T/M^3     TOT    in Tonnes     (M)      (M)      (M)     (T-M)
  B A L L A S T   W A T E R   T A N K S
F.P.TK                   1.025       0         2.00     0.05   171.63    -0.01       44
NO1 BWT P                1.025       0         4.00     0.02   155.87     4.07      487
NO1 BWT S                1.025       0         4.00     0.02   155.87    -4.07      487
NO2 DBWT P               1.025       1         3.00     0.01   134.40     8.70       98
NO2 DBWT S               1.025       1         3.00     0.01   134.40    -8.70       98
NO2 TBWT P               1.025       1         1.00    10.78   135.00    11.73        0
NO2 TBWT S               1.025       1         1.00    10.78   135.00   -11.73        0
NO3 DBWT P               1.025     100       552.20     1.04   108.60     6.72        0
NO3 DBWT S               1.025     100       552.20     1.04   108.60    -6.72        0
NO3 TBWT P               1.025       1         1.00    10.78   108.60    11.73        0
NO3 TBWT S               1.025       1         1.00    10.78   108.60   -11.73        0
NO4 BWT P                1.025     100       634.90     7.44    83.80    10.92        0
NO4 BWT S                1.025     100       634.90     7.44    83.80   -10.92        0
NO5 DBWT P               1.025       2         4.00     0.02    61.59     8.58       81
NO5 DBWT S               1.025       2         4.00     0.02    61.59    -8.58       81
NO5 TBWT P               1.025       1         1.00    10.78    59.00    11.71        0
NO5 TBWT S               1.025       1         1.00    10.78    59.00   -11.71        0
NO6 BWT P                1.025     100       685.70     6.30    36.32     9.27        0
NO6 BWT S                1.025     100       685.70     6.30    36.32    -9.27        0
NO7 DBWT P               1.025       1         3.00     0.01   135.00     4.00      487
NO7 DBWT S               1.025       1         3.00     0.01   135.00    -4.00      487
APT                      1.025       0         1.00     7.05     4.99     0.00       25
NO4 C.HOLD/WB            1.025       0         0.00     0.00    83.80     0.00        0
    T O T A L   B A L L A S T   W A T E R   3782.60     5.10    74.15     0.00     2375
                                     Note:  Underlined FSM   denotes use of maximum FSM

      M U L T I L O A D
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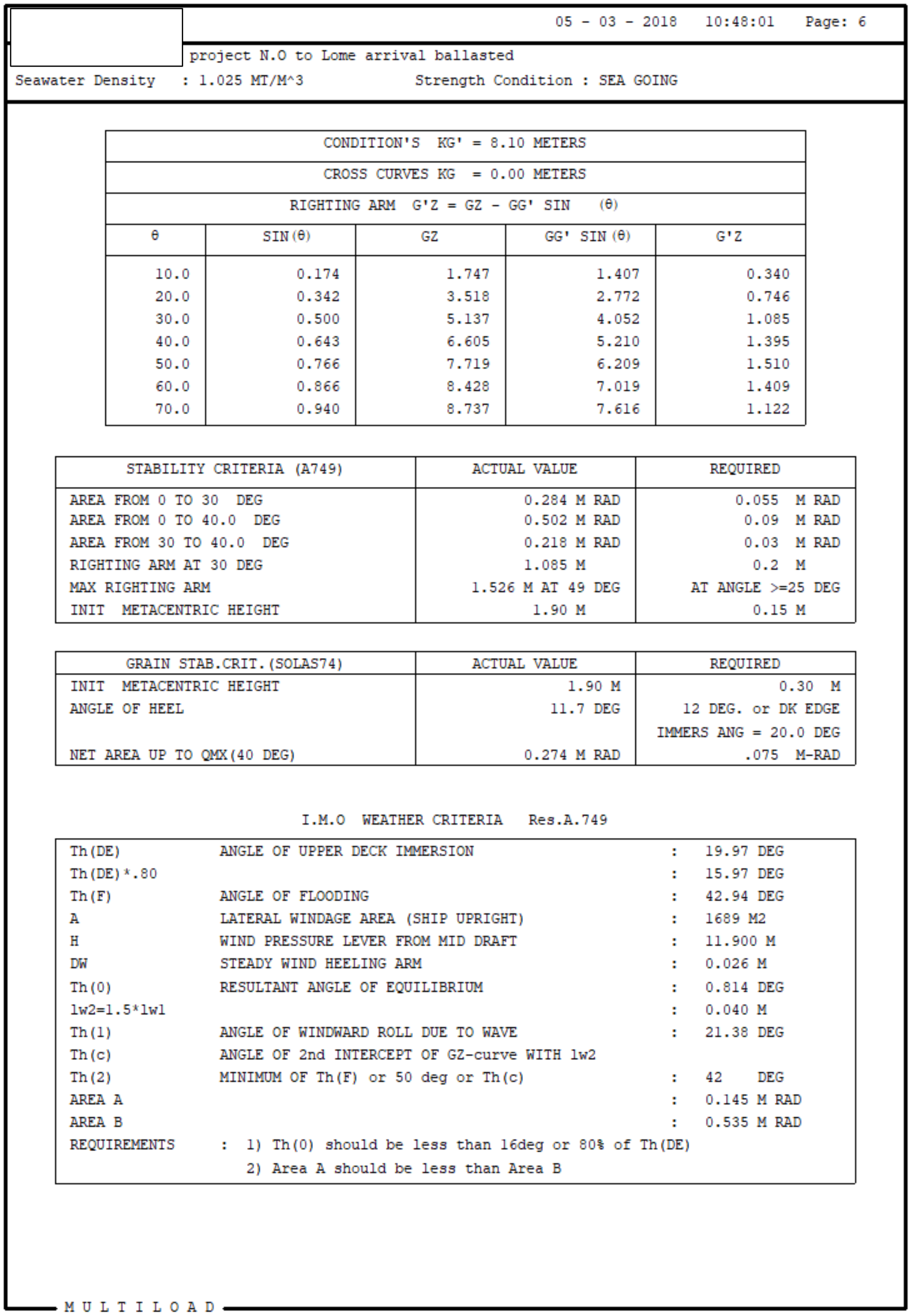

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                                        05 - 03 - 2018    10:48:01    Page: 6
                    project N.O to Lome arrival ballasted
Seawater Density   : 1.025 MT/M^3            Strength Condition : SEA GOING

                      CONDITION'S  KG' = 8.10 METERS
                      CROSS CURVES KG  = 0.00 METERS
                  RIGHTING ARM  G'Z = GZ - GG' SIN   (θ)
          θ         SIN(θ)          GZ          GG' SIN(θ)        G'Z

         10.0        0.174         1.747         1.407          0.340
         20.0        0.342         3.518         2.772          0.746
         30.0        0.500         5.137         4.052          1.085
         40.0        0.643         6.605         5.210          1.395
         50.0        0.766         7.719         6.209          1.510
         60.0        0.866         8.428         7.019          1.409
         70.0        0.940         8.737         7.616          1.122

      STABILITY CRITERIA (A749)          ACTUAL VALUE            REQUIRED
   AREA FROM 0 TO 30  DEG                 0.284 M RAD         0.055  M RAD
   AREA FROM 0 TO 40.0  DEG               0.502 M RAD          0.09  M RAD
   AREA FROM 30 TO 40.0  DEG              0.218 M RAD          0.03  M RAD
   RIGHTING ARM AT 30 DEG                 1.085 M               0.2  M
   MAX RIGHTING ARM                 1.526 M AT 49 DEG    AT ANGLE >=25 DEG
   INIT  METACENTRIC HEIGHT               1.90 M                0.15 M

      GRAIN STAB.CRIT.(SOLAS74)          ACTUAL VALUE            REQUIRED
   INIT  METACENTRIC HEIGHT                   1.90 M               0.30  M
   ANGLE OF HEEL                              11.7 DEG     12 DEG. or DK EDGE
                                                         IMMERS ANG = 20.0 DEG
   NET AREA UP TO QMX(40 DEG)             0.274 M RAD           .075  M-RAD

                     I.M.O  WEATHER CRITERIA   Res.A.749
   Th(DE)          ANGLE OF UPPER DECK IMMERSION              :   19.97 DEG
   Th(DE)*.80                                                 :   15.97 DEG
   Th(F)           ANGLE OF FLOODING                          :   42.94 DEG
   A               LATERAL WINDAGE AREA (SHIP UPRIGHT)        :   1689 M2
   H               WIND PRESSURE LEVER FROM MID DRAFT         :   11.900 M
   DW              STEADY WIND HEELING ARM                    :   0.026 M
   Th(0)           RESULTANT ANGLE OF EQUILIBRIUM             :   0.814 DEG
   lw2=1.5*lw1                                                :   0.040 M
   Th(1)           ANGLE OF WINDWARD ROLL DUE TO WAVE         :   21.38 DEG
   Th(c)           ANGLE OF 2nd INTERCEPT OF GZ-curve WITH lw2
   Th(2)           MINIMUM OF Th(F) or 50 deg or Th(c)        :   42    DEG
   AREA A                                                     :   0.145 M RAD
   AREA B                                                     :   0.535 M RAD
   REQUIREMENTS    :  1) Th(0) should be less than 16deg or 80% of Th(DE)
                      2) Area A should be less than Area B

 M U L T I L O A D
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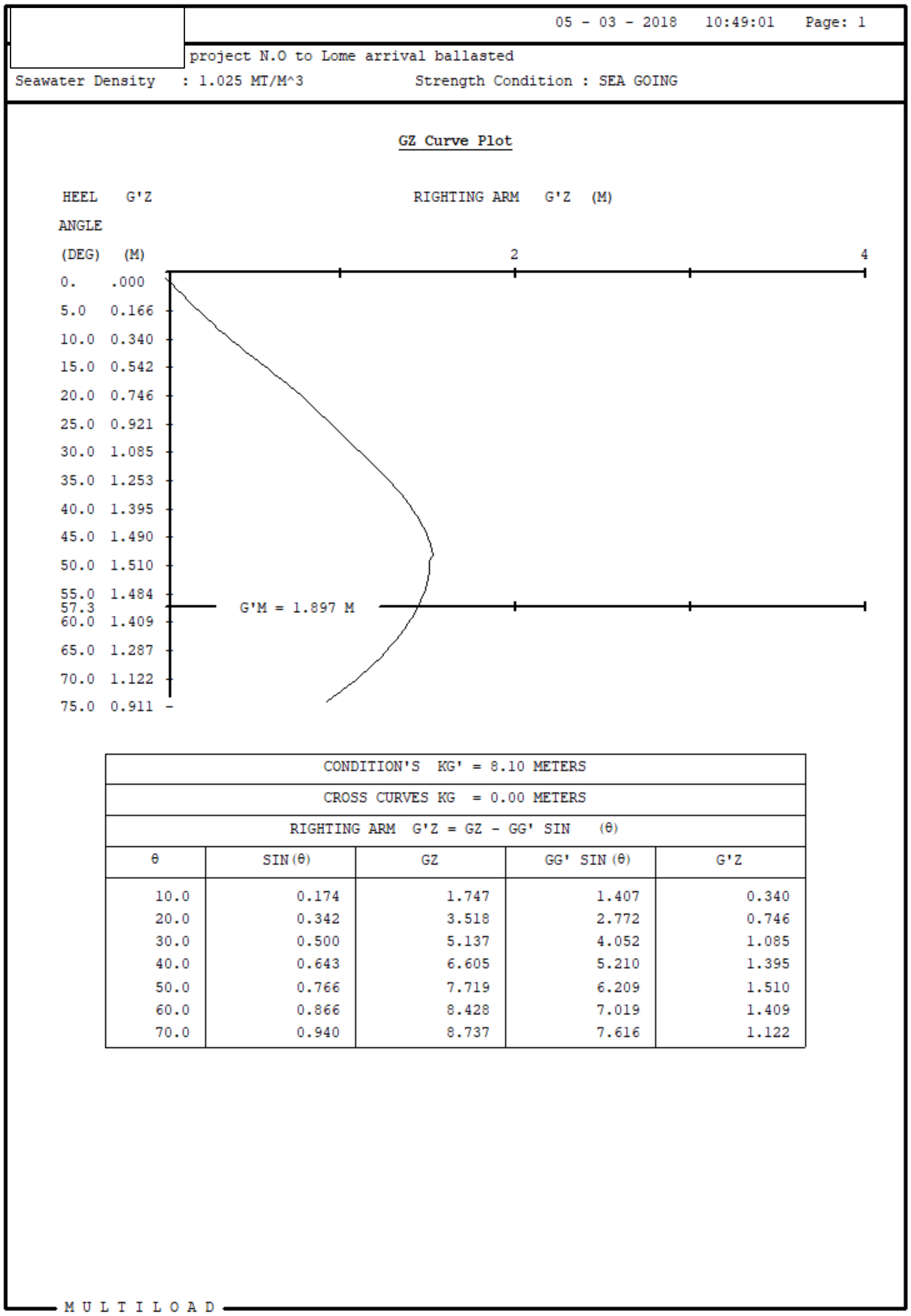
GZ CURVE



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project N.O to Lome arrival ballasted

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

GZ Curve Plot

RIGHTING ARM G'Z (M)

HEEL ANGLE (DEG)	G'Z (M)
0.	.000
5.0	0.166
10.0	0.340
15.0	0.542
20.0	0.746
25.0	0.921
30.0	1.085
35.0	1.253
40.0	1.395
45.0	1.490
50.0	1.510
55.0	1.484
57.3	
60.0	1.409
65.0	1.287
70.0	1.122
75.0	0.911

CONDITION'S KG' = 8.10 METERS

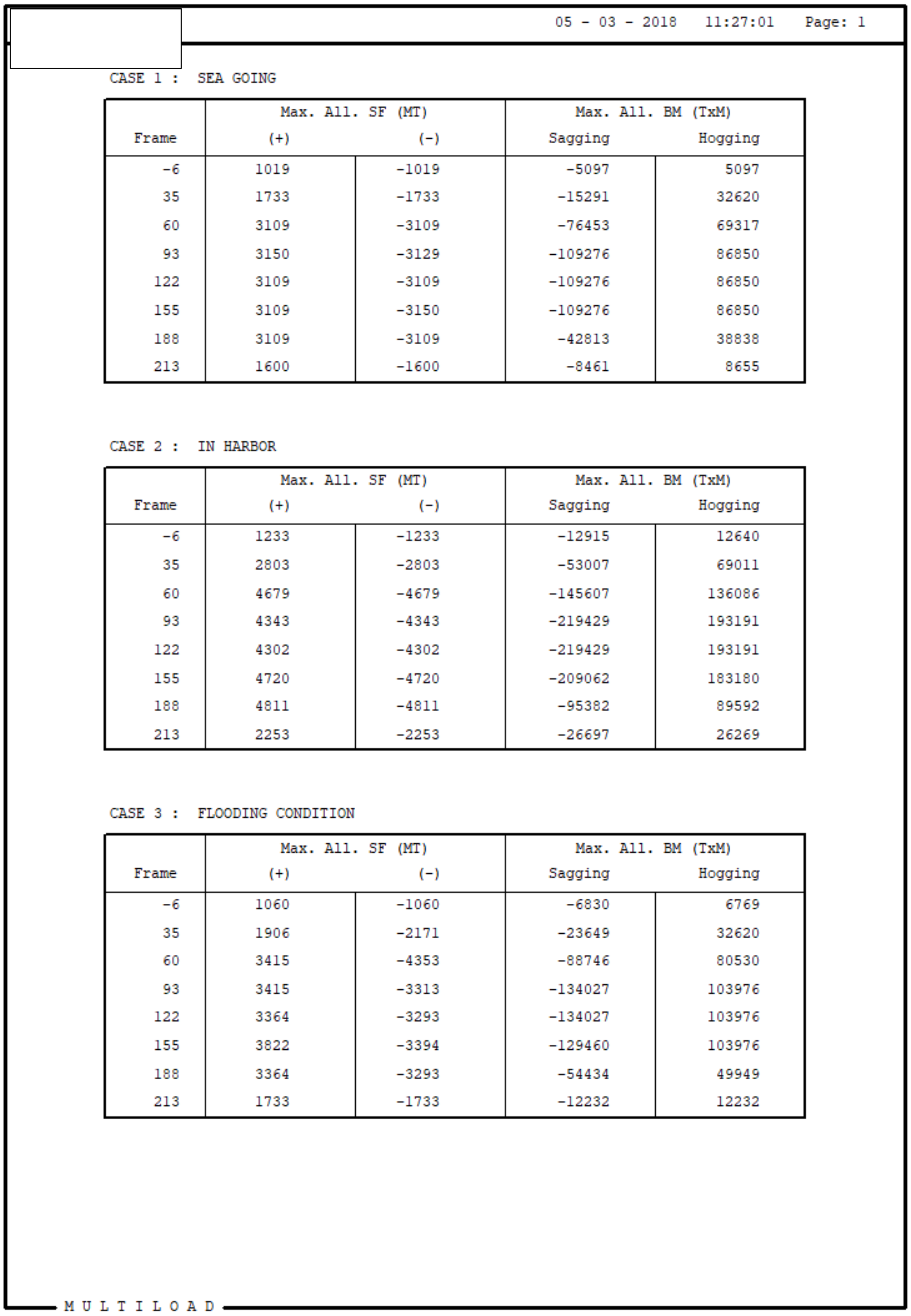
CROSS CURVES KG = 0.00 METERS

RIGHTING ARM G'Z = GZ - GG' SIN (θ)

θ	SIN(θ)	GZ	GG' SIN(θ)	G'Z
10.0	0.174	1.747	1.407	0.340
20.0	0.342	3.518	2.772	0.746
30.0	0.500	5.137	4.052	1.085
40.0	0.643	6.605	5.210	1.395
50.0	0.766	7.719	6.209	1.510
60.0	0.866	8.428	7.019	1.409
70.0	0.940	8.737	7.616	1.122

MULTILOAD

DEFLECTIONS (SF & BM)



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CASE 1 : SEA GOING

	Max. All. SF (MT)		Max. All. BM (TxM)	
Frame	(+)	(-)	Sagging	Hogging
-6	1019	-1019	-5097	5097
35	1733	-1733	-15291	32620
60	3109	-3109	-76453	69317
93	3150	-3129	-109276	86850
122	3109	-3109	-109276	86850
155	3109	-3150	-109276	86850
188	3109	-3109	-42813	38838
213	1600	-1600	-8461	8655

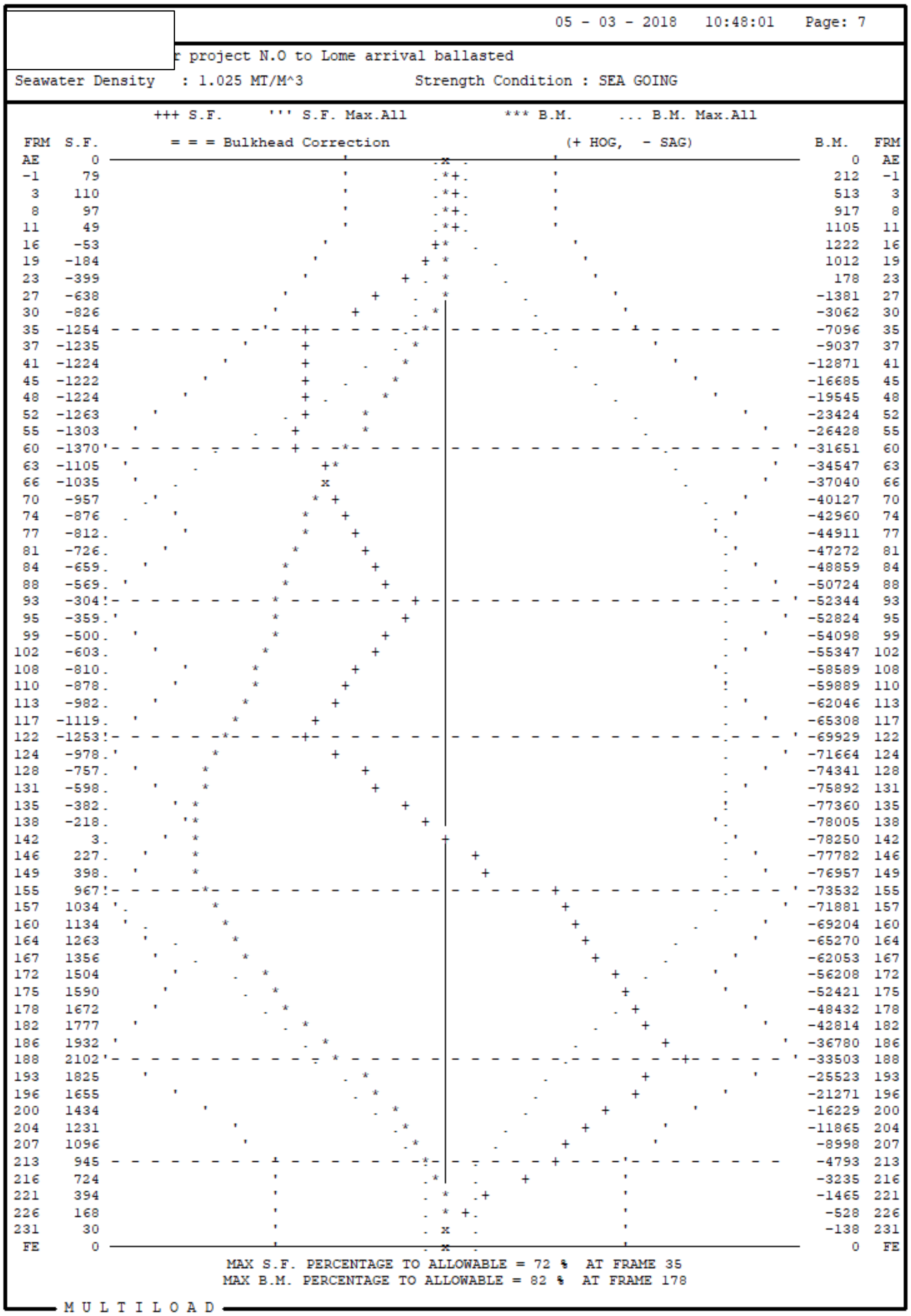
CASE 2 : IN HARBOR

	Max. All. SF (MT)		Max. All. BM (TxM)	
Frame	(+)	(-)	Sagging	Hogging
-6	1233	-1233	-12915	12640
35	2803	-2803	-53007	69011
60	4679	-4679	-145607	136086
93	4343	-4343	-219429	193191
122	4302	-4302	-219429	193191
155	4720	-4720	-209062	183180
188	4811	-4811	-95382	89592
213	2253	-2253	-26697	26269

CASE 3 : FLOODING CONDITION

	Max. All. SF (MT)		Max. All. BM (TxM)	
Frame	(+)	(-)	Sagging	Hogging
-6	1060	-1060	-6830	6769
35	1906	-2171	-23649	32620
60	3415	-4353	-88746	80530
93	3415	-3313	-134027	103976
122	3364	-3293	-134027	103976
155	3822	-3394	-129460	103976
188	3364	-3293	-54434	49949
213	1733	-1733	-12232	12232

MULTILOAD



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                                                  05 - 03 - 2018   10:48:01   Page: 7
[redacted]r project N.O to Lome arrival ballasted
Seawater Density   : 1.025 MT/M^3           Strength Condition : SEA GOING

             +++ S.F.    ''' S.F. Max.All          *** B.M.     ... B.M. Max.All

 FRM  S.F.     = = = Bulkhead Correction               (+ HOG,  - SAG)         B.M.  FRM
 AE      0                                                                        0   AE
 -1     79                                                                      212   -1
  3    110                                                                      513    3
  8     97                                                                      917    8
 11     49                                                                     1105   11
 16    -53                                                                     1222   16
 19   -184                                                                     1012   19
 23   -399                                                                      178   23
 27   -638                                                                    -1381   27
 30   -826                                                                    -3062   30
 35  -1254                                                                    -7096   35
 37  -1235                                                                    -9037   37
 41  -1224                                                                   -12871   41
 45  -1222                                                                   -16685   45
 48  -1224                                                                   -19545   48
 52  -1263                                                                   -23424   52
 55  -1303                                                                   -26428   55
 60  -1370                                                                   -31651   60
 63  -1105                                                                   -34547   63
 66  -1035                                                                   -37040   66
 70   -957                                                                   -40127   70
 74   -876                                                                   -42960   74
 77   -812                                                                   -44911   77
 81   -726                                                                   -47272   81
 84   -659                                                                   -48859   84
 88   -569                                                                   -50724   88
 93   -304                                                                   -52344   93
 95   -359                                                                   -52824   95
 99   -500                                                                   -54098   99
102   -603                                                                   -55347  102
108   -810                                                                   -58589  108
110   -878                                                                   -59889  110
113   -982                                                                   -62046  113
117  -1119                                                                   -65308  117
122  -1253                                                                   -69929  122
124   -978                                                                   -71664  124
128   -757                                                                   -74341  128
131   -598                                                                   -75892  131
135   -382                                                                   -77360  135
138   -218                                                                   -78005  138
142      3                                                                   -78250  142
146    227                                                                   -77782  146
149    398                                                                   -76957  149
155    967                                                                   -73532  155
157   1034                                                                   -71881  157
160   1134                                                                   -69204  160
164   1263                                                                   -65270  164
167   1356                                                                   -62053  167
172   1504                                                                   -56208  172
175   1590                                                                   -52421  175
178   1672                                                                   -48432  178
182   1777                                                                   -42814  182
186   1932                                                                   -36780  186
188   2102                                                                   -33503  188
193   1825                                                                   -25523  193
196   1655                                                                   -21271  196
200   1434                                                                   -16229  200
204   1231                                                                   -11865  204
207   1096                                                                    -8998  207
213    945                                                                    -4793  213
216    724                                                                    -3235  216
221    394                                                                    -1465  221
226    168                                                                     -528  226
231     30                                                                     -138  231
 FE      0                                                                        0   FE
                    MAX S.F. PERCENTAGE TO ALLOWABLE = 72 %  AT FRAME 35
                    MAX B.M. PERCENTAGE TO ALLOWABLE = 82 %  AT FRAME 178
     M U L T I L O A D
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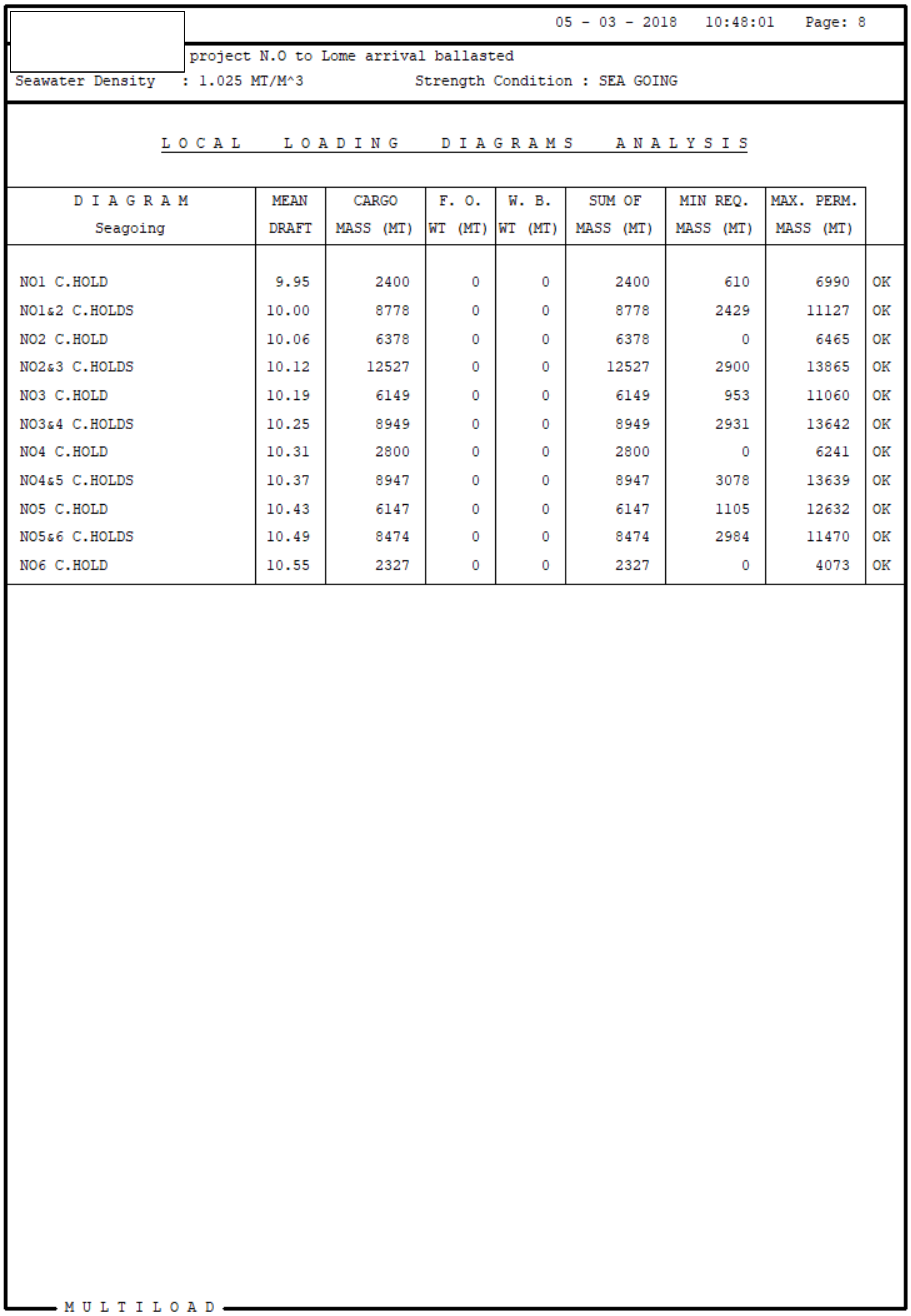
HOLD MASS TABLES



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project N.O to Lome arrival ballasted

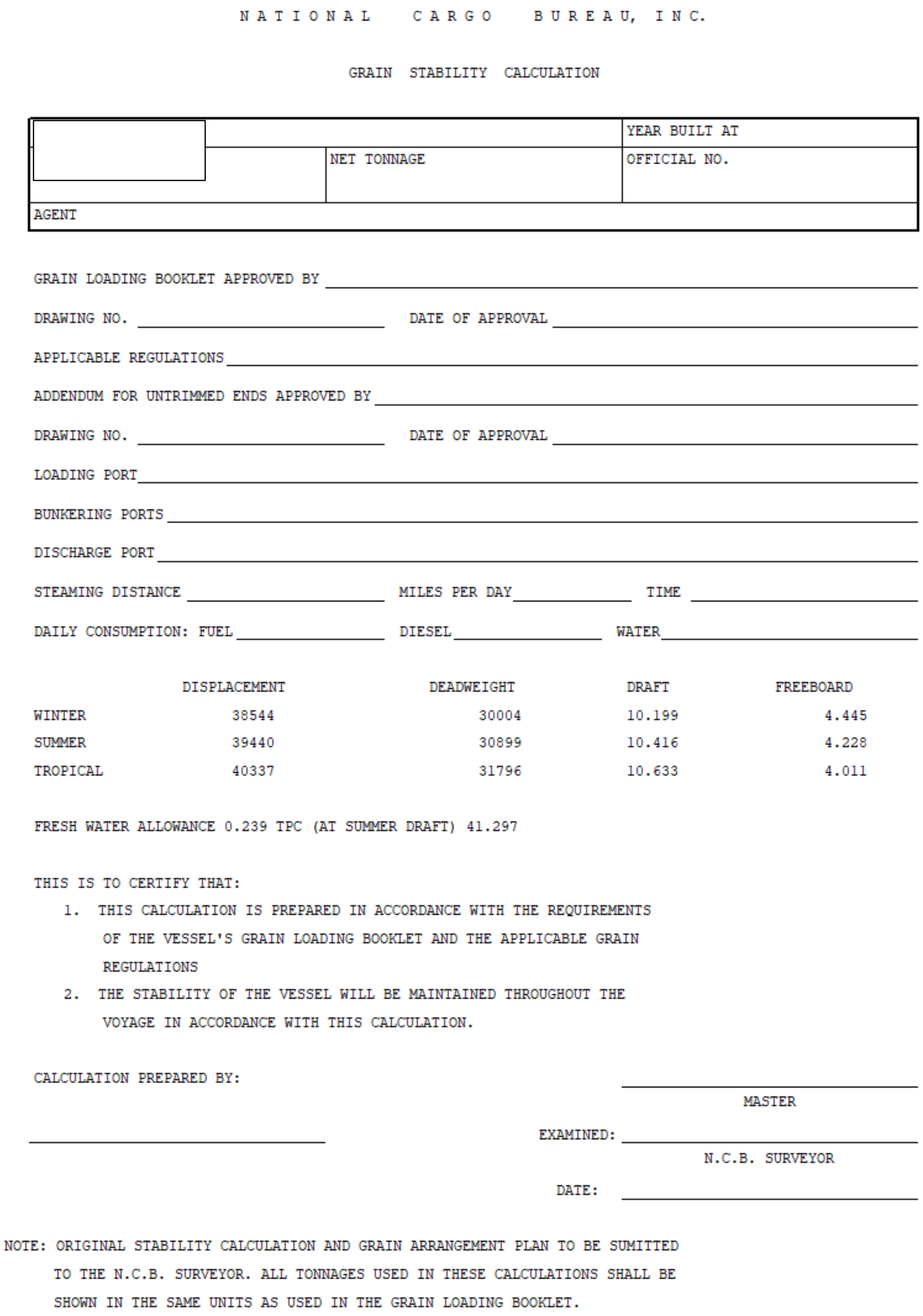
Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

LOCAL LOADING DIAGRAMS ANALYSIS

DIAGRAM	MEAN	CARGO	F. O.	W. B.	SUM OF	MIN REQ.	MAX. PERM.	
Seagoing	DRAFT	MASS (MT)	WT (MT)	WT (MT)	MASS (MT)	MASS (MT)	MASS (MT)	
NO1 C.HOLD	9.95	2400	0	0	2400	610	6990	OK
NO1&2 C.HOLDS	10.00	8778	0	0	8778	2429	11127	OK
NO2 C.HOLD	10.06	6378	0	0	6378	0	6465	OK
NO2&3 C.HOLDS	10.12	12527	0	0	12527	2900	13865	OK
NO3 C.HOLD	10.19	6149	0	0	6149	953	11060	OK
NO3&4 C.HOLDS	10.25	8949	0	0	8949	2931	13642	OK
NO4 C.HOLD	10.31	2800	0	0	2800	0	6241	OK
NO4&5 C.HOLDS	10.37	8947	0	0	8947	3078	13639	OK
NO5 C.HOLD	10.43	6147	0	0	6147	1105	12632	OK
NO5&6 C.HOLDS	10.49	8474	0	0	8474	2984	11470	OK
NO6 C.HOLD	10.55	2327	0	0	2327	0	4073	OK

MULTILOAD

GRAIN STABILITY, SEA GOING CRITERION



NATIONAL CARGO BUREAU, INC.

GRAIN STABILITY CALCULATION

		YEAR BUILT AT
	NET TONNAGE	OFFICIAL NO.
AGENT		

GRAIN LOADING BOOKLET APPROVED BY

DRAWING NO. DATE OF APPROVAL

APPLICABLE REGULATIONS

ADDENDUM FOR UNTRIMMED ENDS APPROVED BY

DRAWING NO. DATE OF APPROVAL

LOADING PORT

BUNKERING PORTS

DISCHARGE PORT

STEAMING DISTANCE MILES PER DAY TIME

DAILY CONSUMPTION: FUEL DIESEL WATER

	DISPLACEMENT	DEADWEIGHT	DRAFT	FREEBOARD
WINTER	38544	30004	10.199	4.445
SUMMER	39440	30899	10.416	4.228
TROPICAL	40337	31796	10.633	4.011

FRESH WATER ALLOWANCE 0.239 TPC (AT SUMMER DRAFT) 41.297

THIS IS TO CERTIFY THAT:

1. THIS CALCULATION IS PREPARED IN ACCORDANCE WITH THE REQUIREMENTS OF THE VESSEL'S GRAIN LOADING BOOKLET AND THE APPLICABLE GRAIN REGULATIONS
2. THE STABILITY OF THE VESSEL WILL BE MAINTAINED THROUGHOUT THE VOYAGE IN ACCORDANCE WITH THIS CALCULATION.

CALCULATION PREPARED BY:

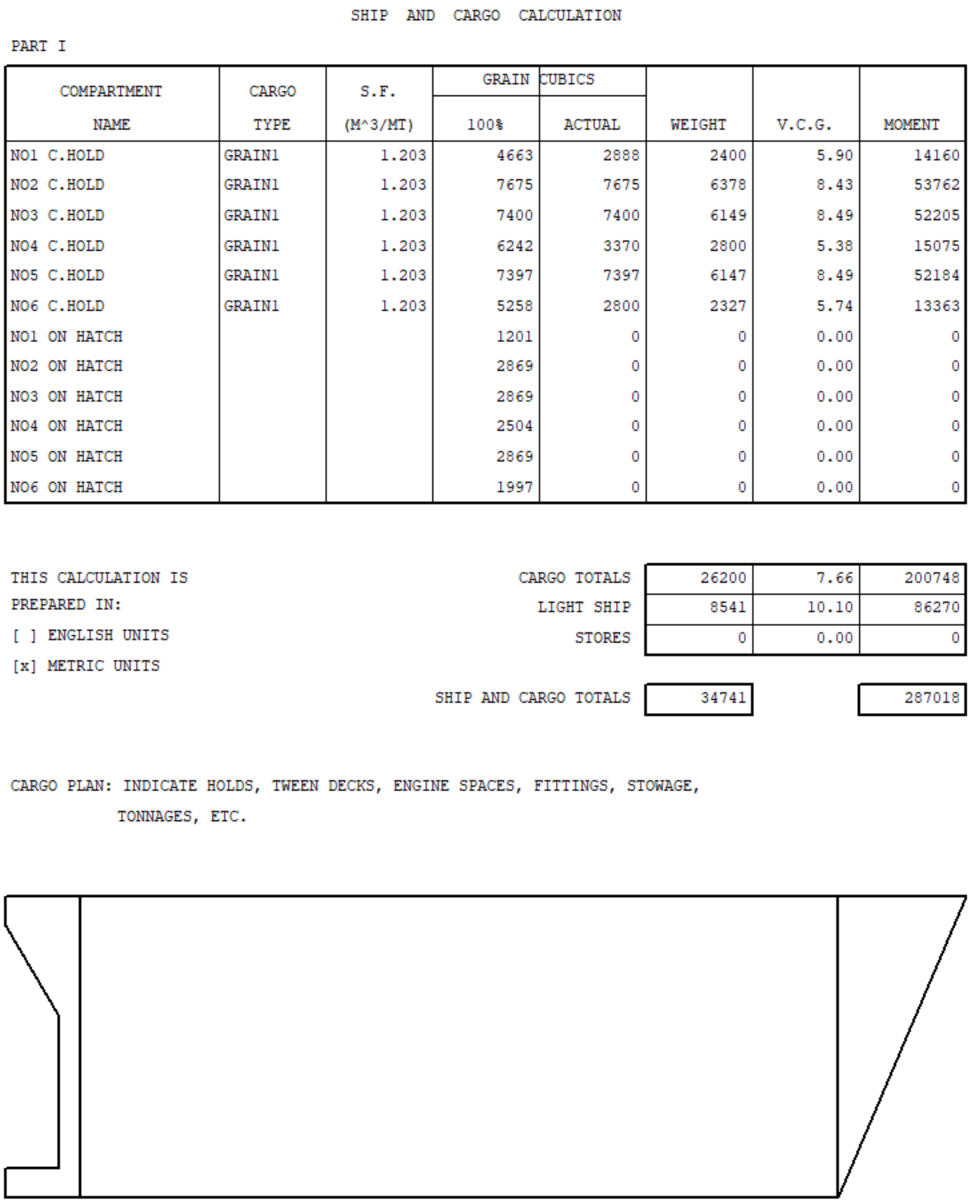
MASTER

EXAMINED:

N.C.B. SURVEYOR

DATE:

NOTE: ORIGINAL STABILITY CALCULATION AND GRAIN ARRANGEMENT PLAN TO BE SUMITTED TO THE N.C.B. SURVEYOR. ALL TONNAGES USED IN THESE CALCULATIONS SHALL BE SHOWN IN THE SAME UNITS AS USED IN THE GRAIN LOADING BOOKLET.



SHIP AND CARGO CALCULATION

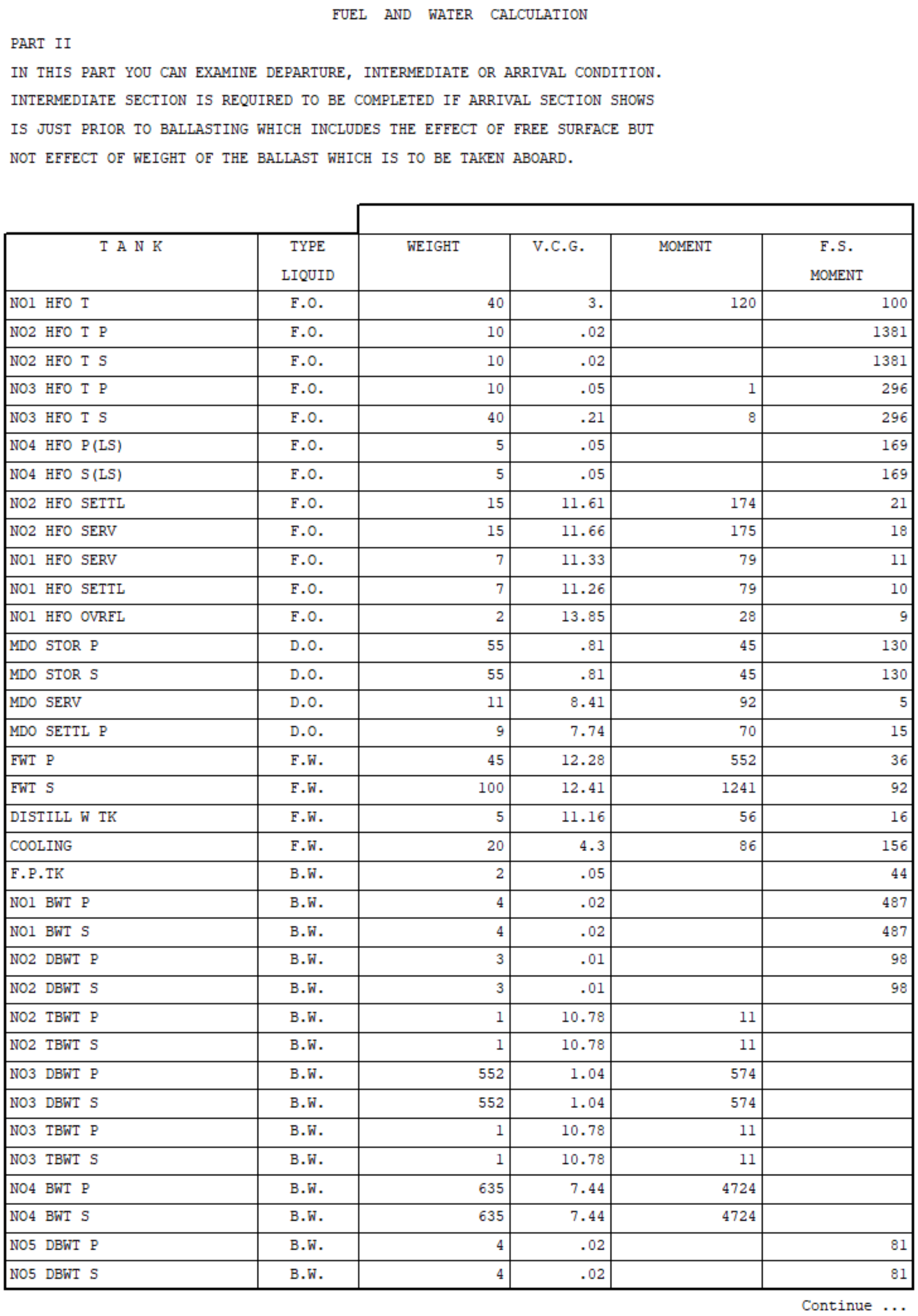
PART I

COMPARTMENT NAME	CARGO TYPE	S.F. (M^3/MT)	GRAIN CUBICS 100%	ACTUAL	WEIGHT	V.C.G.	MOMENT
NO1 C.HOLD	GRAIN1	1.203	4663	2888	2400	5.90	14160
NO2 C.HOLD	GRAIN1	1.203	7675	7675	6378	8.43	53762
NO3 C.HOLD	GRAIN1	1.203	7400	7400	6149	8.49	52205
NO4 C.HOLD	GRAIN1	1.203	6242	3370	2800	5.38	15075
NO5 C.HOLD	GRAIN1	1.203	7397	7397	6147	8.49	52184
NO6 C.HOLD	GRAIN1	1.203	5258	2800	2327	5.74	13363
NO1 ON HATCH			1201	0	0	0.00	0
NO2 ON HATCH			2869	0	0	0.00	0
NO3 ON HATCH			2869	0	0	0.00	0
NO4 ON HATCH			2504	0	0	0.00	0
NO5 ON HATCH			2869	0	0	0.00	0
NO6 ON HATCH			1997	0	0	0.00	0

THIS CALCULATION IS
PREPARED IN:
[ ] ENGLISH UNITS
[x] METRIC UNITS

CARGO TOTALS	26200	7.66	200748
LIGHT SHIP	8541	10.10	86270
STORES	0	0.00	0
SHIP AND CARGO TOTALS	34741		287018

CARGO PLAN: INDICATE HOLDS, TWEEN DECKS, ENGINE SPACES, FITTINGS, STOWAGE,
TONNAGES, ETC.



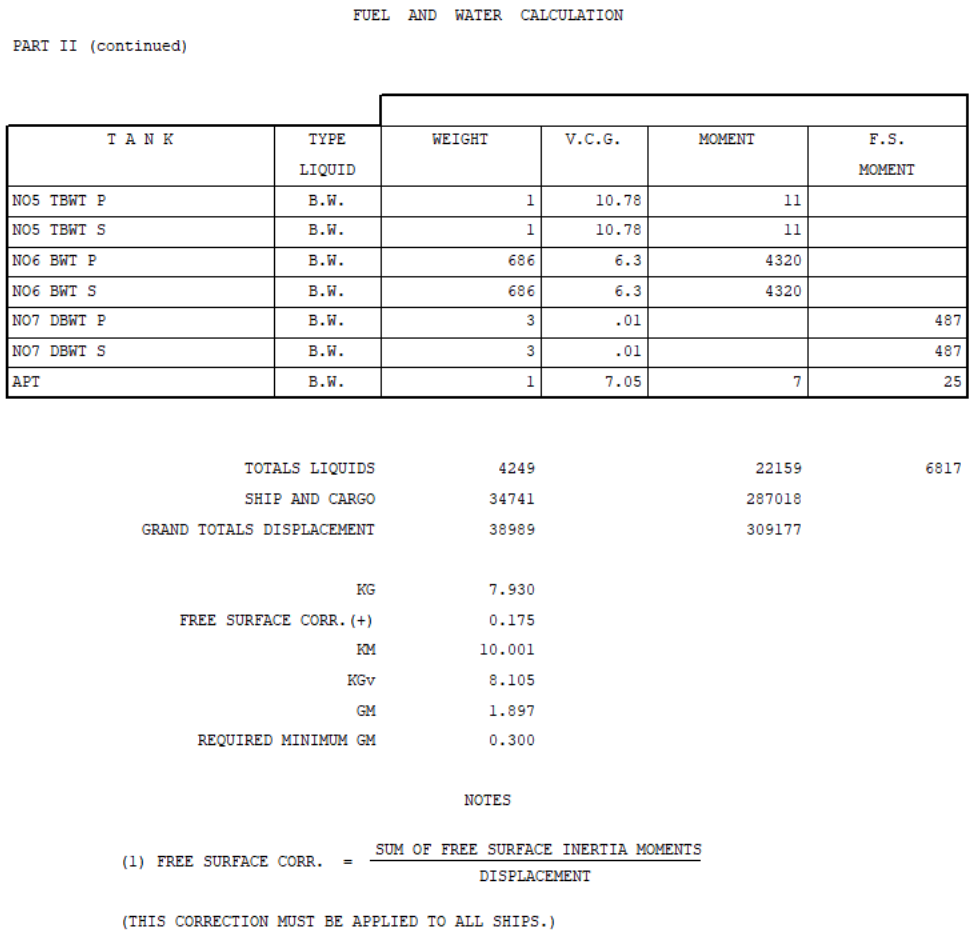
FUEL AND WATER CALCULATION

PART II

IN THIS PART YOU CAN EXAMINE DEPARTURE, INTERMEDIATE OR ARRIVAL CONDITION.
INTERMEDIATE SECTION IS REQUIRED TO BE COMPLETED IF ARRIVAL SECTION SHOWS
IS JUST PRIOR TO BALLASTING WHICH INCLUDES THE EFFECT OF FREE SURFACE BUT
NOT EFFECT OF WEIGHT OF THE BALLAST WHICH IS TO BE TAKEN ABOARD.

TANK	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO1 HFO T	F.O.	40	3.	120	100
NO2 HFO T P	F.O.	10	.02		1381
NO2 HFO T S	F.O.	10	.02		1381
NO3 HFO T P	F.O.	10	.05	1	296
NO3 HFO T S	F.O.	40	.21	8	296
NO4 HFO P(LS)	F.O.	5	.05		169
NO4 HFO S(LS)	F.O.	5	.05		169
NO2 HFO SETTL	F.O.	15	11.61	174	21
NO2 HFO SERV	F.O.	15	11.66	175	18
NO1 HFO SERV	F.O.	7	11.33	79	11
NO1 HFO SETTL	F.O.	7	11.26	79	10
NO1 HFO OVRFL	F.O.	2	13.85	28	9
MDO STOR P	D.O.	55	.81	45	130
MDO STOR S	D.O.	55	.81	45	130
MDO SERV	D.O.	11	8.41	92	5
MDO SETTL P	D.O.	9	7.74	70	15
FWT P	F.W.	45	12.28	552	36
FWT S	F.W.	100	12.41	1241	92
DISTILL W TK	F.W.	5	11.16	56	16
COOLING	F.W.	20	4.3	86	156
F.P.TK	B.W.	2	.05		44
NO1 BWT P	B.W.	4	.02		487
NO1 BWT S	B.W.	4	.02		487
NO2 DBWT P	B.W.	3	.01		98
NO2 DBWT S	B.W.	3	.01		98
NO2 TBWT P	B.W.	1	10.78	11	
NO2 TBWT S	B.W.	1	10.78	11	
NO3 DBWT P	B.W.	552	1.04	574	
NO3 DBWT S	B.W.	552	1.04	574	
NO3 TBWT P	B.W.	1	10.78	11	
NO3 TBWT S	B.W.	1	10.78	11	
NO4 BWT P	B.W.	635	7.44	4724	
NO4 BWT S	B.W.	635	7.44	4724	
NO5 DBWT P	B.W.	4	.02		81
NO5 DBWT S	B.W.	4	.02		81

Continue ...



FUEL AND WATER CALCULATION

PART II (continued)

T A N K	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO5 TBWT P	B.W.	1	10.78	11	
NO5 TBWT S	B.W.	1	10.78	11	
NO6 BWT P	B.W.	686	6.3	4320	
NO6 BWT S	B.W.	686	6.3	4320	
NO7 DBWT P	B.W.	3	.01		487
NO7 DBWT S	B.W.	3	.01		487
APT	B.W.	1	7.05	7	25

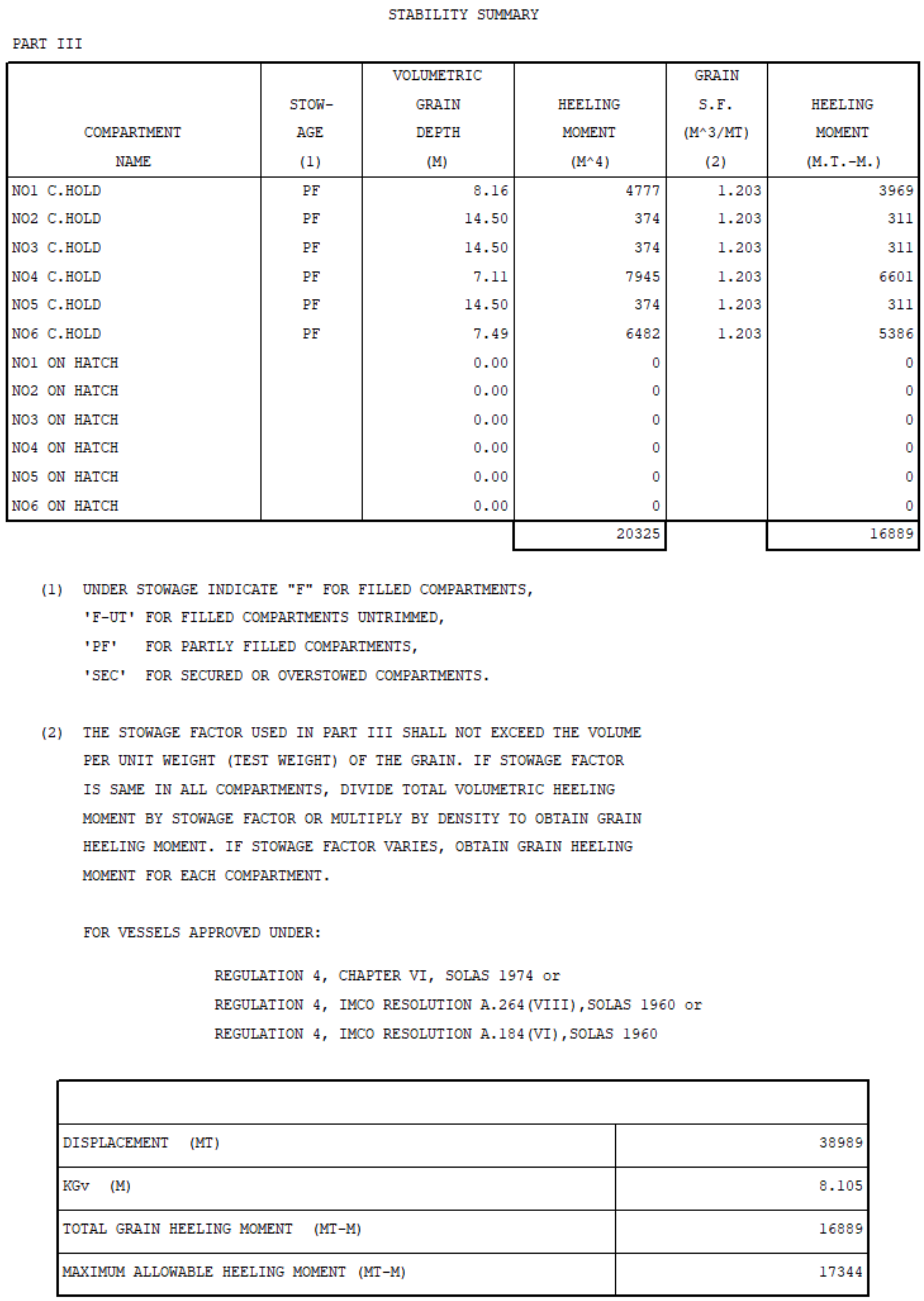
```
                TOTALS LIQUIDS       4249                 22159        6817
                 SHIP AND CARGO     34741                287018
     GRAND TOTALS DISPLACEMENT      38989                309177

                            KG      7.930
         FREE SURFACE CORR.(+)      0.175
                            KM     10.001
                           KGv      8.105
                            GM      1.897
            REQUIRED MINIMUM GM     0.300
```

NOTES

$$(1)\ \text{FREE SURFACE CORR.} = \frac{\text{SUM OF FREE SURFACE INERTIA MOMENTS}}{\text{DISPLACEMENT}}$$

(THIS CORRECTION MUST BE APPLIED TO ALL SHIPS.)



STABILITY SUMMARY

PART III

COMPARTMENT NAME	STOW- AGE (1)	VOLUMETRIC GRAIN DEPTH (M)	HEELING MOMENT (M^4)	GRAIN S.F. (M^3/MT) (2)	HEELING MOMENT (M.T.-M.)
NO1 C.HOLD	PF	8.16	4777	1.203	3969
NO2 C.HOLD	PF	14.50	374	1.203	311
NO3 C.HOLD	PF	14.50	374	1.203	311
NO4 C.HOLD	PF	7.11	7945	1.203	6601
NO5 C.HOLD	PF	14.50	374	1.203	311
NO6 C.HOLD	PF	7.49	6482	1.203	5386
NO1 ON HATCH		0.00	0		0
NO2 ON HATCH		0.00	0		0
NO3 ON HATCH		0.00	0		0
NO4 ON HATCH		0.00	0		0
NO5 ON HATCH		0.00	0		0
NO6 ON HATCH		0.00	0		0
			20325		16889

(1) UNDER STOWAGE INDICATE "F" FOR FILLED COMPARTMENTS,
'F-UT' FOR FILLED COMPARTMENTS UNTRIMMED,
'PF' FOR PARTLY FILLED COMPARTMENTS,
'SEC' FOR SECURED OR OVERSTOWED COMPARTMENTS.

(2) THE STOWAGE FACTOR USED IN PART III SHALL NOT EXCEED THE VOLUME PER UNIT WEIGHT (TEST WEIGHT) OF THE GRAIN. IF STOWAGE FACTOR IS SAME IN ALL COMPARTMENTS, DIVIDE TOTAL VOLUMETRIC HEELING MOMENT BY STOWAGE FACTOR OR MULTIPLY BY DENSITY TO OBTAIN GRAIN HEELING MOMENT. IF STOWAGE FACTOR VARIES, OBTAIN GRAIN HEELING MOMENT FOR EACH COMPARTMENT.

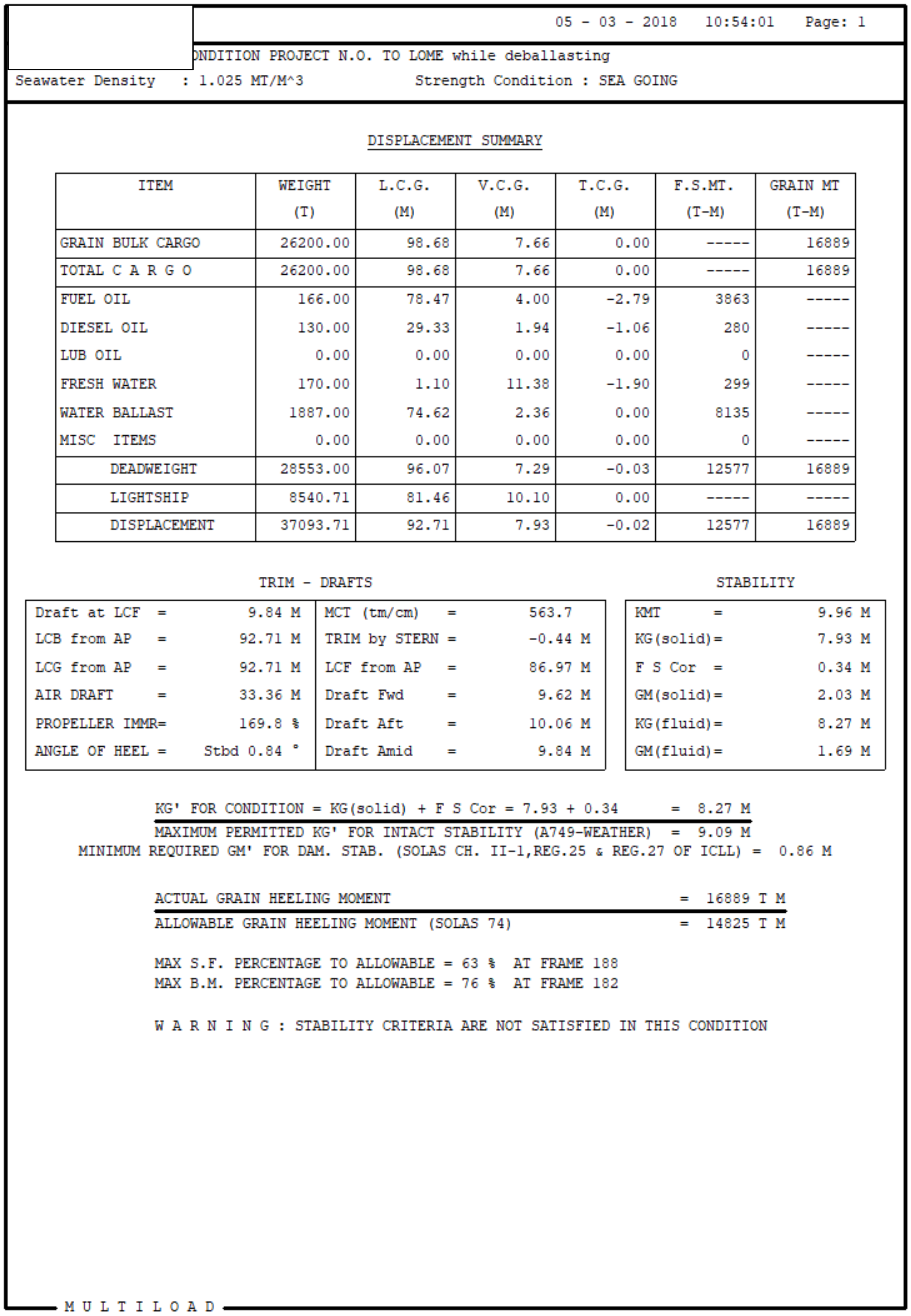
FOR VESSELS APPROVED UNDER:

REGULATION 4, CHAPTER VI, SOLAS 1974 or
REGULATION 4, IMCO RESOLUTION A.264(VIII),SOLAS 1960 or
REGULATION 4, IMCO RESOLUTION A.184(VI),SOLAS 1960

DISPLACEMENT (MT)	38989
KGv (M)	8.105
TOTAL GRAIN HEELING MOMENT (MT-M)	16889
MAXIMUM ALLOWABLE HEELING MOMENT (MT-M)	17344

10.5.5- ARRIVAL CONDITION WITH MINIMUM BUNKERS WHILE DEBALLASTING

A- WEIGHT DISTRIBUTION, INTACT STABILITY PARAMETERS



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           ONDITION PROJECT N.O. TO LOME while deballasting
Seawater Density   : 1.025 MT/M^3            Strength Condition : SEA GOING

                              DISPLACEMENT SUMMARY

 ITEM                 WEIGHT    L.C.G.    V.C.G.    T.C.G.    F.S.MT.   GRAIN MT
                        (T)       (M)       (M)       (M)      (T-M)     (T-M)
 GRAIN BULK CARGO    26200.00     98.68      7.66      0.00     -----     16889
 TOTAL C A R G O     26200.00     98.68      7.66      0.00     -----     16889
 FUEL OIL              166.00     78.47      4.00     -2.79      3863     -----
 DIESEL OIL            130.00     29.33      1.94     -1.06       280     -----
 LUB OIL                 0.00      0.00      0.00      0.00         0     -----
 FRESH WATER           170.00      1.10     11.38     -1.90       299     -----
 WATER BALLAST        1887.00     74.62      2.36      0.00      8135     -----
 MISC  ITEMS             0.00      0.00      0.00      0.00         0     -----
      DEADWEIGHT     28553.00     96.07      7.29     -0.03     12577     16889
      LIGHTSHIP       8540.71     81.46     10.10      0.00     -----     -----
      DISPLACEMENT   37093.71     92.71      7.93     -0.02     12577     16889

                     TRIM - DRAFTS                                STABILITY
 Draft at LCF  =          9.84 M | MCT  (tm/cm)   =        563.7 | KMT       =       9.96 M
 LCB from AP   =         92.71 M | TRIM by STERN  =       -0.44 M | KG(solid)=        7.93 M
 LCG from AP   =         92.71 M | LCF from AP    =       86.97 M | F S Cor  =        0.34 M
 AIR DRAFT     =         33.36 M | Draft Fwd      =        9.62 M | GM(solid)=        2.03 M
 PROPELLER IMMR=         169.8 % | Draft Aft      =       10.06 M | KG(fluid)=        8.27 M
 ANGLE OF HEEL =     Stbd 0.84 ° | Draft Amid     =        9.84 M | GM(fluid)=        1.69 M

          KG' FOR CONDITION = KG(solid) + F S Cor = 7.93 + 0.34      =  8.27 M
          MAXIMUM PERMITTED KG' FOR INTACT STABILITY (A749-WEATHER)  =  9.09 M
  MINIMUM REQUIRED GM' FOR DAM. STAB. (SOLAS CH. II-1,REG.25 & REG.27 OF ICLL) =  0.86 M

          ACTUAL GRAIN HEELING MOMENT                               =  16889 T M
          ALLOWABLE GRAIN HEELING MOMENT (SOLAS 74)                 =  14825 T M

          MAX S.F. PERCENTAGE TO ALLOWABLE = 63 %  AT FRAME 188
          MAX B.M. PERCENTAGE TO ALLOWABLE = 76 %  AT FRAME 182

          W A R N I N G : STABILITY CRITERIA ARE NOT SATISFIED IN THIS CONDITION

    M U L T I L O A D
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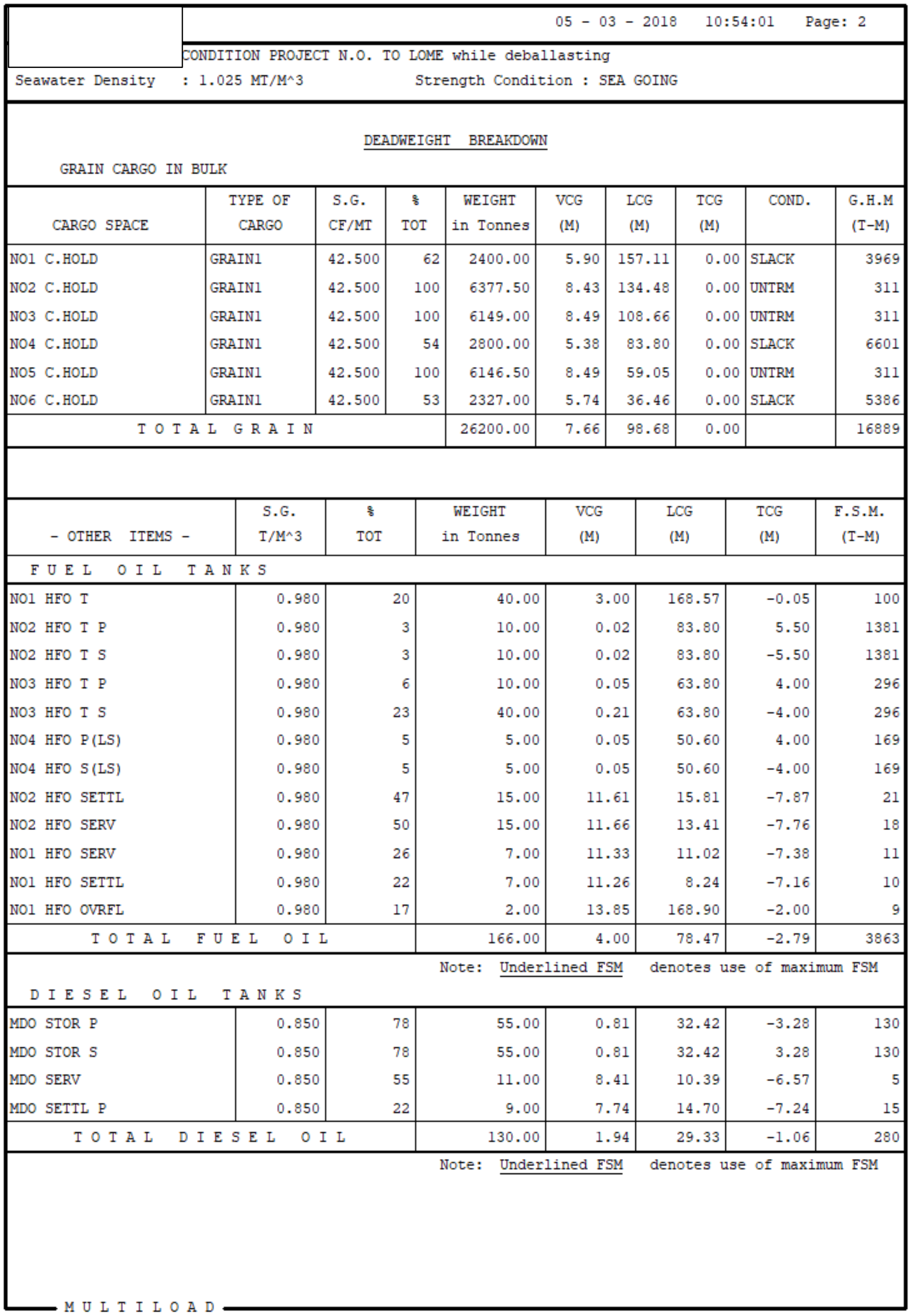

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                                          05 - 03 - 2018   10:54:01   Page: 2
                    CONDITION PROJECT N.O. TO LOME while deballasting
Seawater Density   : 1.025 MT/M^3          Strength Condition : SEA GOING

                              DEADWEIGHT  BREAKDOWN
     GRAIN CARGO IN BULK

                   TYPE OF   S.G.    %     WEIGHT    VCG    LCG    TCG    COND.   G.H.M
   CARGO SPACE      CARGO    CF/MT  TOT  in Tonnes   (M)    (M)    (M)            (T-M)
NO1 C.HOLD       GRAIN1     42.500   62   2400.00   5.90  157.11   0.00  SLACK    3969
NO2 C.HOLD       GRAIN1     42.500  100   6377.50   8.43  134.48   0.00  UNTRM     311
NO3 C.HOLD       GRAIN1     42.500  100   6149.00   8.49  108.66   0.00  UNTRM     311
NO4 C.HOLD       GRAIN1     42.500   54   2800.00   5.38   83.80   0.00  SLACK    6601
NO5 C.HOLD       GRAIN1     42.500  100   6146.50   8.49   59.05   0.00  UNTRM     311
NO6 C.HOLD       GRAIN1     42.500   53   2327.00   5.74   36.46   0.00  SLACK    5386
            T O T A L  G R A I N         26200.00   7.66   98.68   0.00           16889


                        S.G.       %        WEIGHT      VCG      LCG      TCG     F.S.M.
   - OTHER  ITEMS -    T/M^3      TOT     in Tonnes     (M)      (M)      (M)     (T-M)
  F U E L   O I L   T A N K S
NO1 HFO T              0.980       20        40.00     3.00   168.57    -0.05      100
NO2 HFO T P            0.980        3        10.00     0.02    83.80     5.50     1381
NO2 HFO T S            0.980        3        10.00     0.02    83.80    -5.50     1381
NO3 HFO T P            0.980        6        10.00     0.05    63.80     4.00      296
NO3 HFO T S            0.980       23        40.00     0.21    63.80    -4.00      296
NO4 HFO P(LS)          0.980        5         5.00     0.05    50.60     4.00      169
NO4 HFO S(LS)          0.980        5         5.00     0.05    50.60    -4.00      169
NO2 HFO SETTL          0.980       47        15.00    11.61    15.81    -7.87       21
NO2 HFO SERV           0.980       50        15.00    11.66    13.41    -7.76       18
NO1 HFO SERV           0.980       26         7.00    11.33    11.02    -7.38       11
NO1 HFO SETTL          0.980       22         7.00    11.26     8.24    -7.16       10
NO1 HFO OVRFL          0.980       17         2.00    13.85   168.90    -2.00        9
        T O T A L   F U E L   O I L         166.00     4.00    78.47    -2.79     3863
                                    Note:  Underlined FSM   denotes use of maximum FSM
  D I E S E L   O I L   T A N K S
MDO STOR P             0.850       78        55.00     0.81    32.42    -3.28      130
MDO STOR S             0.850       78        55.00     0.81    32.42     3.28      130
MDO SERV               0.850       55        11.00     8.41    10.39    -6.57        5
MDO SETTL P            0.850       22         9.00     7.74    14.70    -7.24       15
      T O T A L   D I E S E L   O I L       130.00     1.94    29.33    -1.06      280
                                    Note:  Underlined FSM   denotes use of maximum FSM



     M U L T I L O A D
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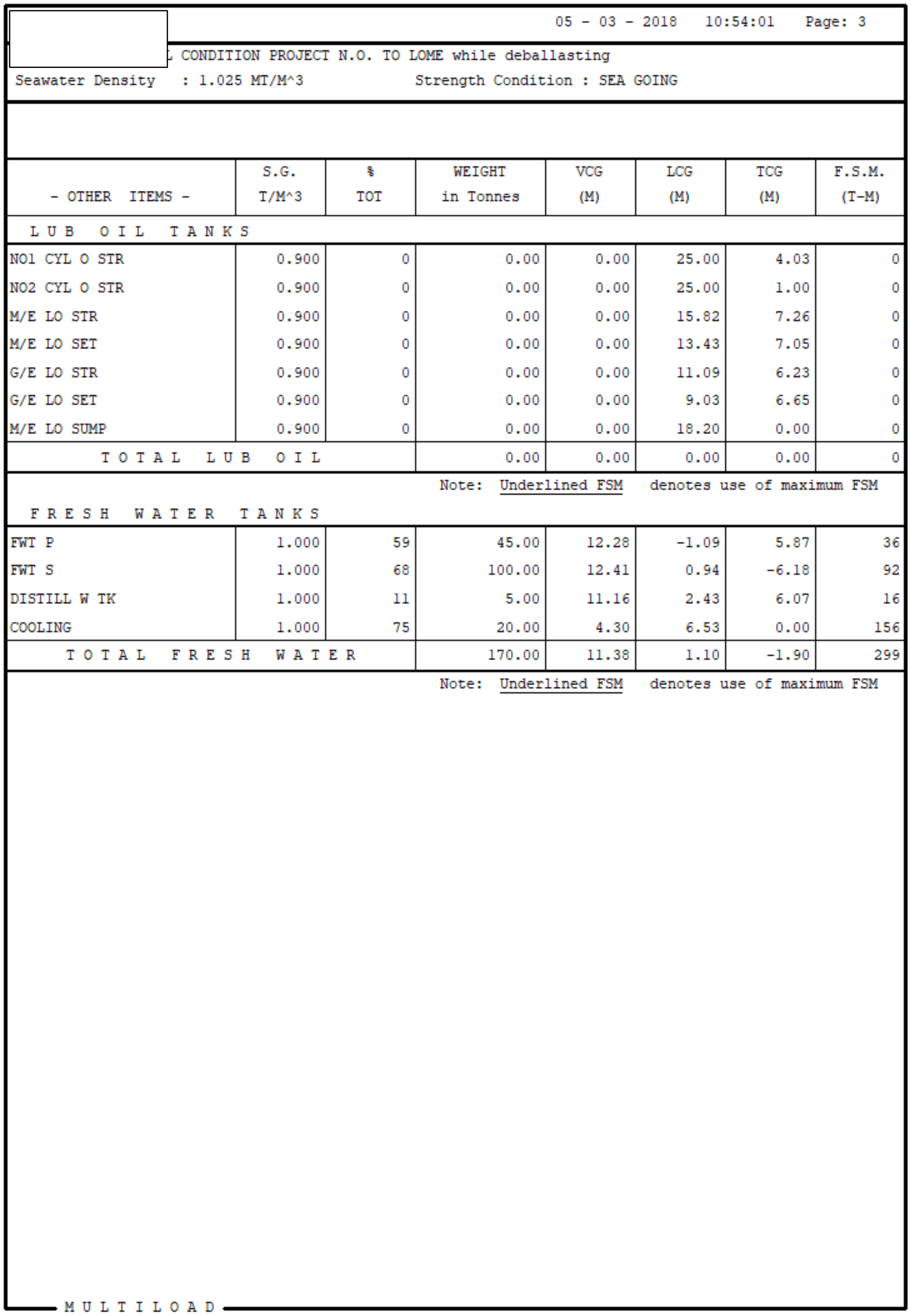

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[redacted] CONDITION PROJECT N.O. TO LOME while deballasting

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

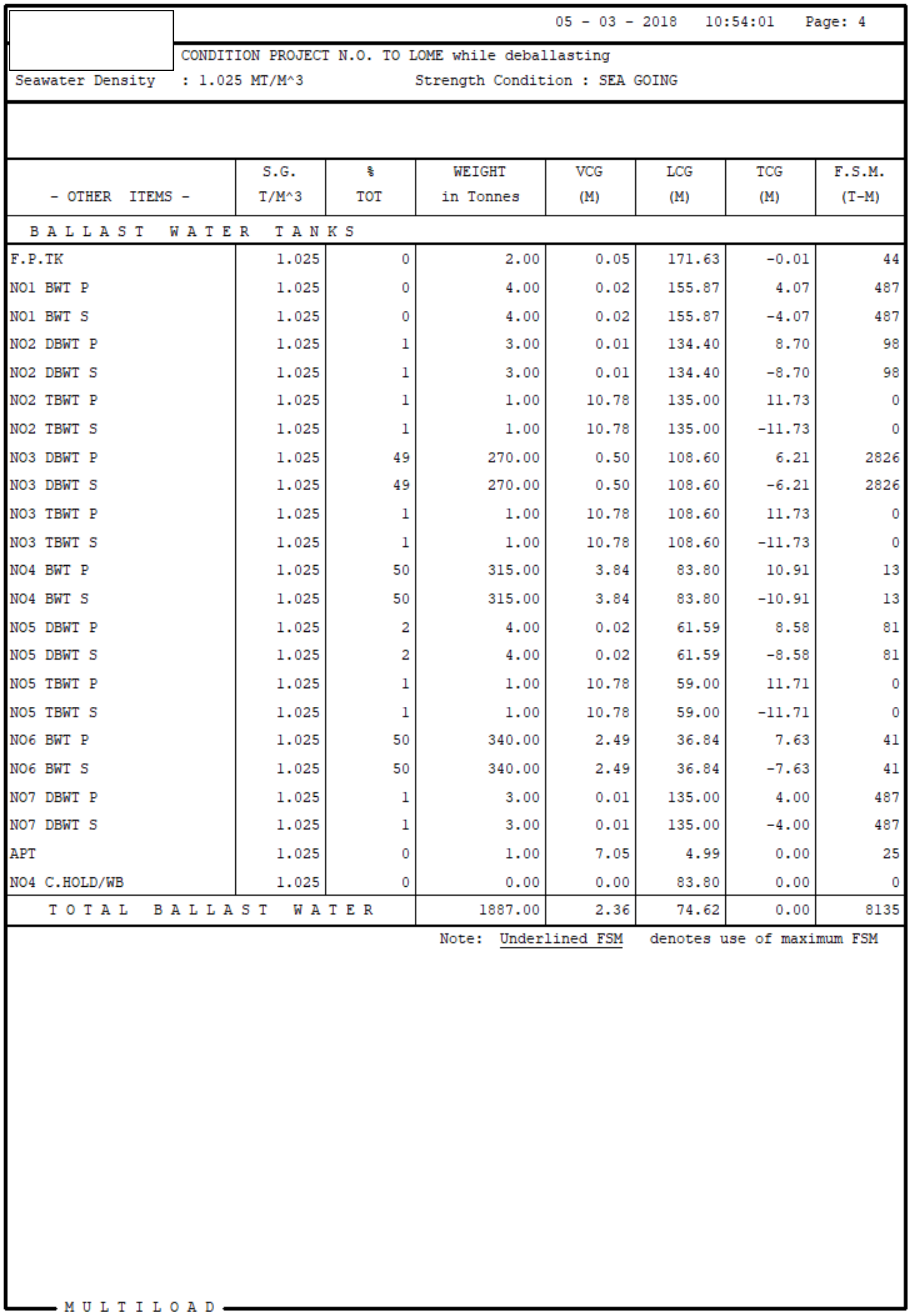
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
LUB OIL TANKS							
NO1 CYL O STR	0.900	0	0.00	0.00	25.00	4.03	0
NO2 CYL O STR	0.900	0	0.00	0.00	25.00	1.00	0
M/E LO STR	0.900	0	0.00	0.00	15.82	7.26	0
M/E LO SET	0.900	0	0.00	0.00	13.43	7.05	0
G/E LO STR	0.900	0	0.00	0.00	11.09	6.23	0
G/E LO SET	0.900	0	0.00	0.00	9.03	6.65	0
M/E LO SUMP	0.900	0	0.00	0.00	18.20	0.00	0
TOTAL LUB OIL			0.00	0.00	0.00	0.00	0

Note: Underlined FSM denotes use of maximum FSM

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
FRESH WATER TANKS							
FWT P	1.000	59	45.00	12.28	-1.09	5.87	36
FWT S	1.000	68	100.00	12.41	0.94	-6.18	92
DISTILL W TK	1.000	11	5.00	11.16	2.43	6.07	16
COOLING	1.000	75	20.00	4.30	6.53	0.00	156
TOTAL FRESH WATER			170.00	11.38	1.10	-1.90	299

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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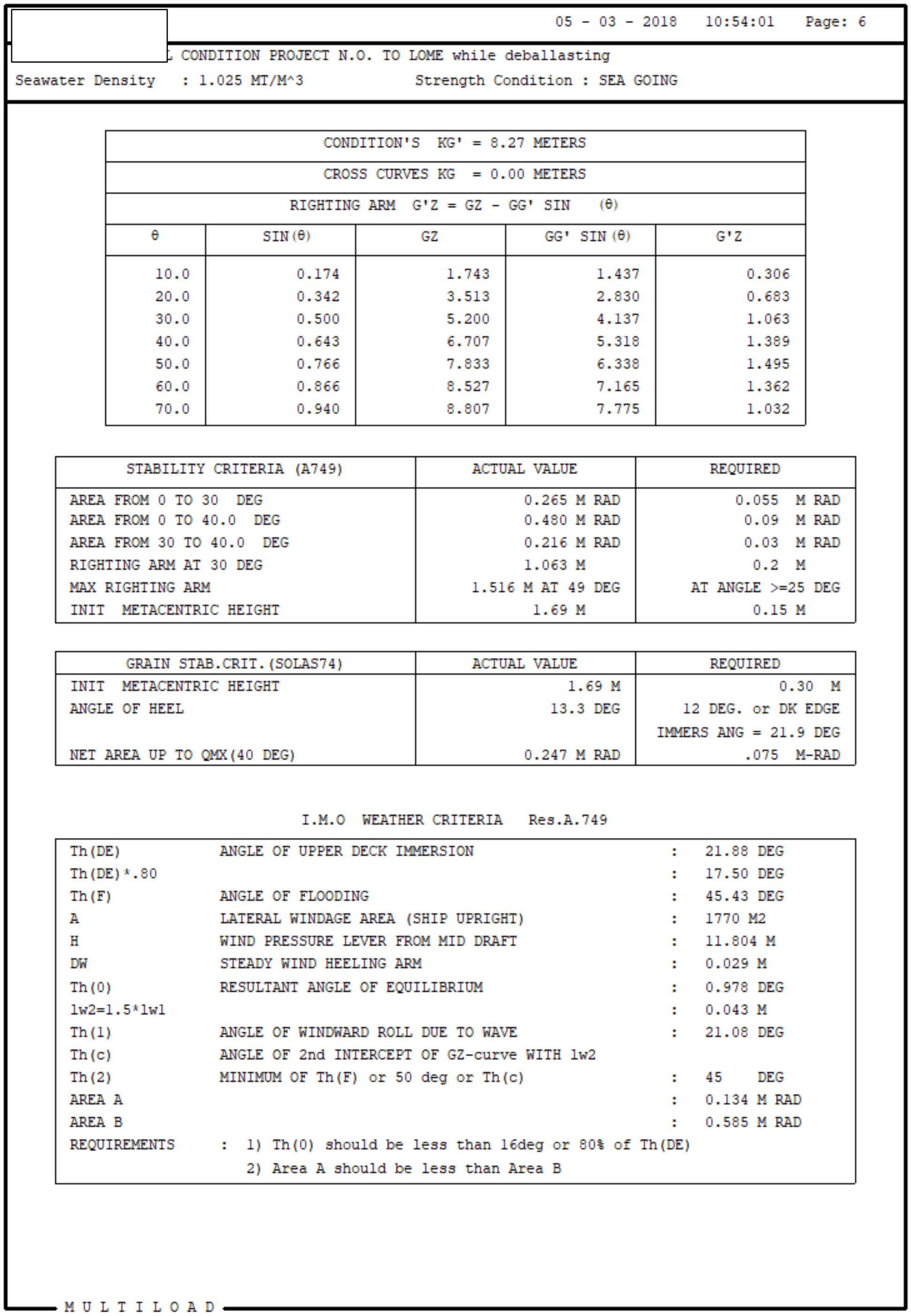
CONDITION PROJECT N.O. TO LOME while deballasting

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
BALLAST WATER TANKS							
F.P.TK	1.025	0	2.00	0.05	171.63	-0.01	44
NO1 BWT P	1.025	0	4.00	0.02	155.87	4.07	487
NO1 BWT S	1.025	0	4.00	0.02	155.87	-4.07	487
NO2 DBWT P	1.025	1	3.00	0.01	134.40	8.70	98
NO2 DBWT S	1.025	1	3.00	0.01	134.40	-8.70	98
NO2 TBWT P	1.025	1	1.00	10.78	135.00	11.73	0
NO2 TBWT S	1.025	1	1.00	10.78	135.00	-11.73	0
NO3 DBWT P	1.025	49	270.00	0.50	108.60	6.21	2826
NO3 DBWT S	1.025	49	270.00	0.50	108.60	-6.21	2826
NO3 TBWT P	1.025	1	1.00	10.78	108.60	11.73	0
NO3 TBWT S	1.025	1	1.00	10.78	108.60	-11.73	0
NO4 BWT P	1.025	50	315.00	3.84	83.80	10.91	13
NO4 BWT S	1.025	50	315.00	3.84	83.80	-10.91	13
NO5 DBWT P	1.025	2	4.00	0.02	61.59	8.58	81
NO5 DBWT S	1.025	2	4.00	0.02	61.59	-8.58	81
NO5 TBWT P	1.025	1	1.00	10.78	59.00	11.71	0
NO5 TBWT S	1.025	1	1.00	10.78	59.00	-11.71	0
NO6 BWT P	1.025	50	340.00	2.49	36.84	7.63	41
NO6 BWT S	1.025	50	340.00	2.49	36.84	-7.63	41
NO7 DBWT P	1.025	1	3.00	0.01	135.00	4.00	487
NO7 DBWT S	1.025	1	3.00	0.01	135.00	-4.00	487
APT	1.025	0	1.00	7.05	4.99	0.00	25
NO4 C.HOLD/WB	1.025	0	0.00	0.00	83.80	0.00	0
TOTAL BALLAST WATER			1887.00	2.36	74.62	0.00	8135

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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[redacted]                                        05 - 03 - 2018    10:54:01    Page: 6
[redacted] CONDITION PROJECT N.O. TO LOME while deballasting
Seawater Density   : 1.025 MT/M^3            Strength Condition : SEA GOING

                          CONDITION'S  KG' = 8.27 METERS
                          CROSS CURVES KG  = 0.00 METERS
                      RIGHTING ARM  G'Z = GZ - GG' SIN   (θ)
           θ          SIN(θ)           GZ          GG' SIN(θ)          G'Z

          10.0          0.174          1.743          1.437          0.306
          20.0          0.342          3.513          2.830          0.683
          30.0          0.500          5.200          4.137          1.063
          40.0          0.643          6.707          5.318          1.389
          50.0          0.766          7.833          6.338          1.495
          60.0          0.866          8.527          7.165          1.362
          70.0          0.940          8.807          7.775          1.032

        STABILITY CRITERIA (A749)              ACTUAL VALUE             REQUIRED
  AREA FROM 0 TO 30  DEG                          0.265 M RAD           0.055  M RAD
  AREA FROM 0 TO 40.0  DEG                        0.480 M RAD           0.09   M RAD
  AREA FROM 30 TO 40.0  DEG                       0.216 M RAD           0.03   M RAD
  RIGHTING ARM AT 30 DEG                          1.063 M               0.2    M
  MAX RIGHTING ARM                        1.516 M AT 49 DEG      AT ANGLE >=25 DEG
  INIT  METACENTRIC HEIGHT                         1.69 M                0.15 M

        GRAIN STAB.CRIT.(SOLAS74)              ACTUAL VALUE             REQUIRED
  INIT  METACENTRIC HEIGHT                          1.69 M                0.30  M
  ANGLE OF HEEL                                     13.3 DEG      12 DEG. or DK EDGE
                                                                IMMERS ANG = 21.9 DEG
  NET AREA UP TO QMX(40 DEG)                      0.247 M RAD           .075  M-RAD


                      I.M.O  WEATHER CRITERIA   Res.A.749

  Th(DE)           ANGLE OF UPPER DECK IMMERSION                :   21.88 DEG
  Th(DE)*.80                                                    :   17.50 DEG
  Th(F)            ANGLE OF FLOODING                            :   45.43 DEG
  A                LATERAL WINDAGE AREA (SHIP UPRIGHT)          :   1770 M2
  H                WIND PRESSURE LEVER FROM MID DRAFT           :   11.804 M
  DW               STEADY WIND HEELING ARM                      :   0.029 M
  Th(0)            RESULTANT ANGLE OF EQUILIBRIUM               :   0.978 DEG
  lw2=1.5*lw1                                                   :   0.043 M
  Th(1)            ANGLE OF WINDWARD ROLL DUE TO WAVE           :   21.08 DEG
  Th(c)            ANGLE OF 2nd INTERCEPT OF GZ-curve WITH lw2
  Th(2)            MINIMUM OF Th(F) or 50 deg or Th(c)          :   45    DEG
  AREA A                                                        :   0.134 M RAD
  AREA B                                                        :   0.585 M RAD
  REQUIREMENTS     :  1) Th(0) should be less than 16deg or 80% of Th(DE)
                      2) Area A should be less than Area B



  M U L T I L O A D
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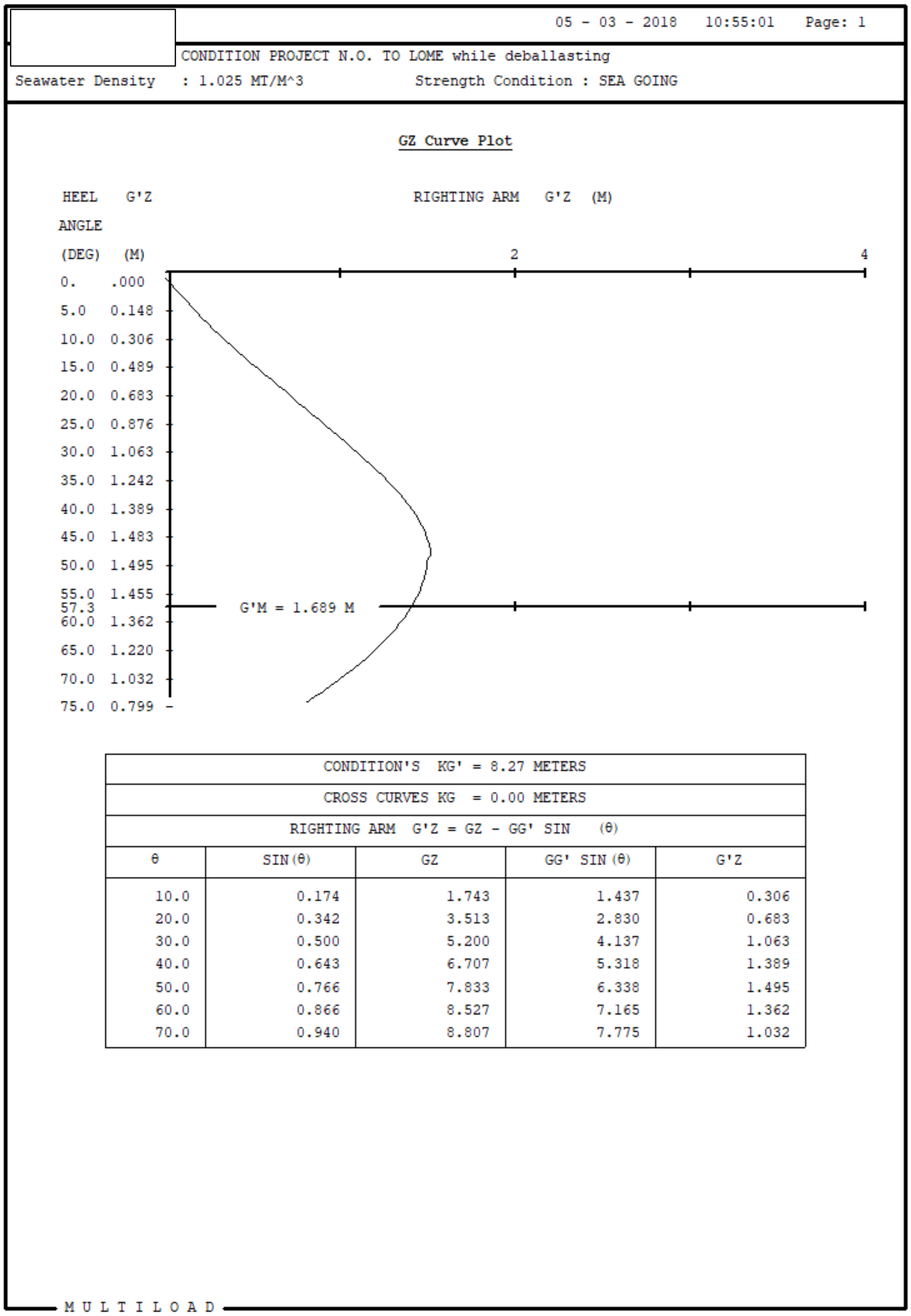
GZ CURVE



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CONDITION PROJECT N.O. TO LOME while deballasting

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

GZ Curve Plot

HEEL ANGLE (DEG)	G'Z (M)
0.	.000
5.0	0.148
10.0	0.306
15.0	0.489
20.0	0.683
25.0	0.876
30.0	1.063
35.0	1.242
40.0	1.389
45.0	1.483
50.0	1.495
55.0	1.455
57.3	
60.0	1.362
65.0	1.220
70.0	1.032
75.0	0.799

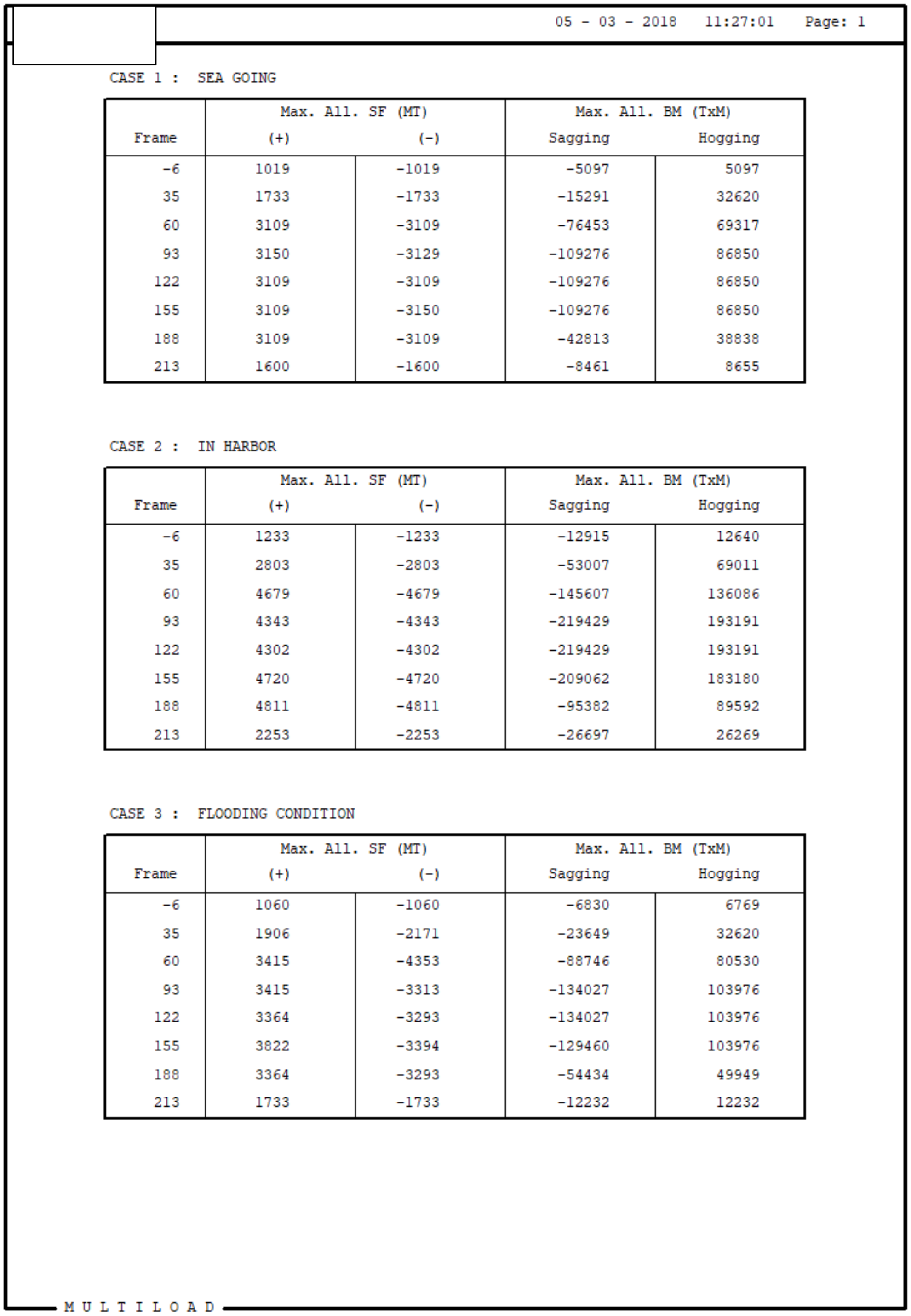
CONDITION'S KG' = 8.27 METERS

CROSS CURVES KG = 0.00 METERS

RIGHTING ARM G'Z = GZ - GG' SIN (θ)

θ	SIN(θ)	GZ	GG' SIN(θ)	G'Z
10.0	0.174	1.743	1.437	0.306
20.0	0.342	3.513	2.830	0.683
30.0	0.500	5.200	4.137	1.063
40.0	0.643	6.707	5.318	1.389
50.0	0.766	7.833	6.338	1.495
60.0	0.866	8.527	7.165	1.362
70.0	0.940	8.807	7.775	1.032

DEFLECTIONS (SF & BM)



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CASE 1 : SEA GOING

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1019	-1019	-5097	5097
35	1733	-1733	-15291	32620
60	3109	-3109	-76453	69317
93	3150	-3129	-109276	86850
122	3109	-3109	-109276	86850
155	3109	-3150	-109276	86850
188	3109	-3109	-42813	38838
213	1600	-1600	-8461	8655

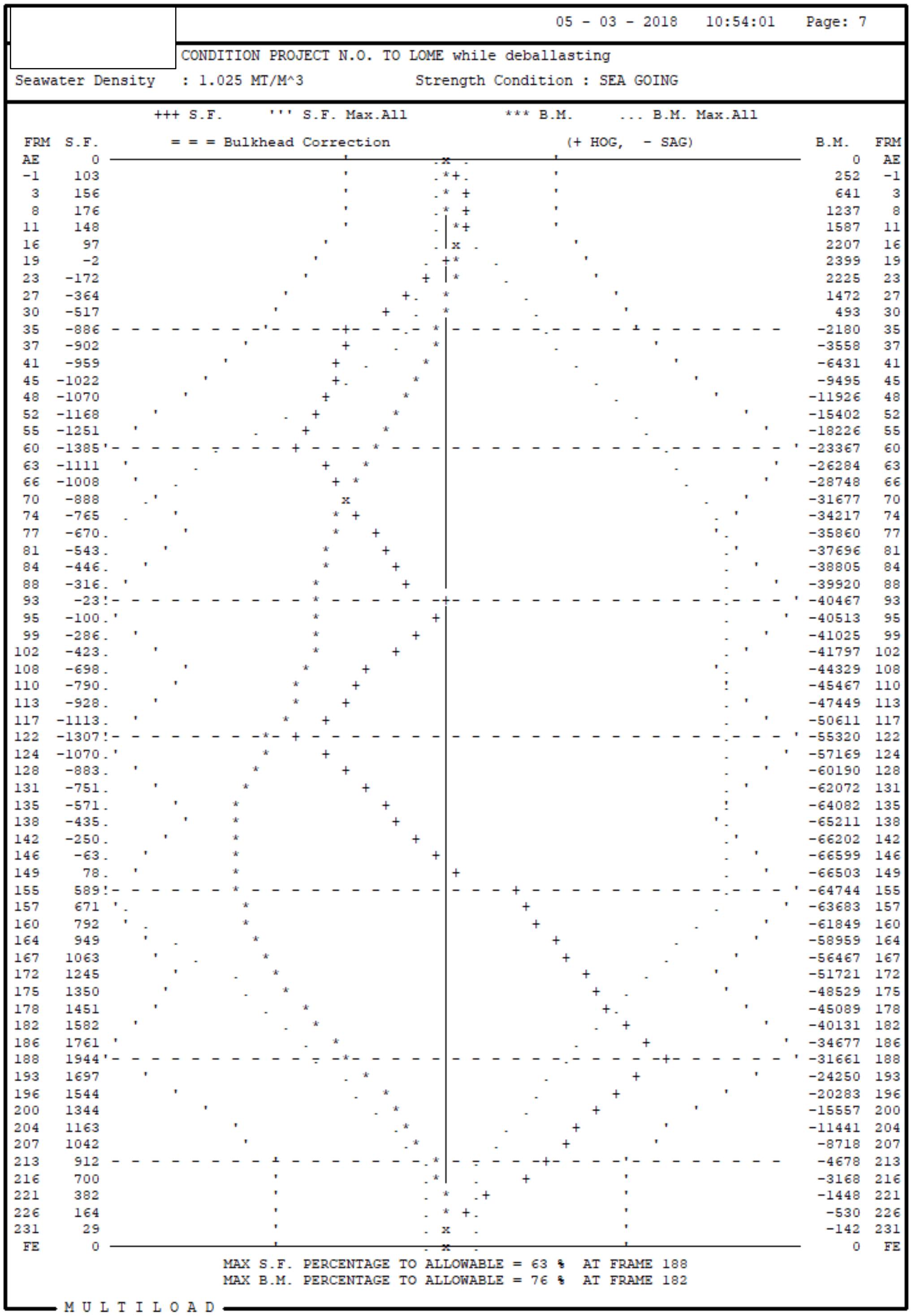
CASE 2 : IN HARBOR

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1233	-1233	-12915	12640
35	2803	-2803	-53007	69011
60	4679	-4679	-145607	136086
93	4343	-4343	-219429	193191
122	4302	-4302	-219429	193191
155	4720	-4720	-209062	183180
188	4811	-4811	-95382	89592
213	2253	-2253	-26697	26269

CASE 3 : FLOODING CONDITION

Frame	Max. All. SF (MT)		Max. All. BM (TxM)	
	(+)	(-)	Sagging	Hogging
-6	1060	-1060	-6830	6769
35	1906	-2171	-23649	32620
60	3415	-4353	-88746	80530
93	3415	-3313	-134027	103976
122	3364	-3293	-134027	103976
155	3822	-3394	-129460	103976
188	3364	-3293	-54434	49949
213	1733	-1733	-12232	12232

MULTILOAD



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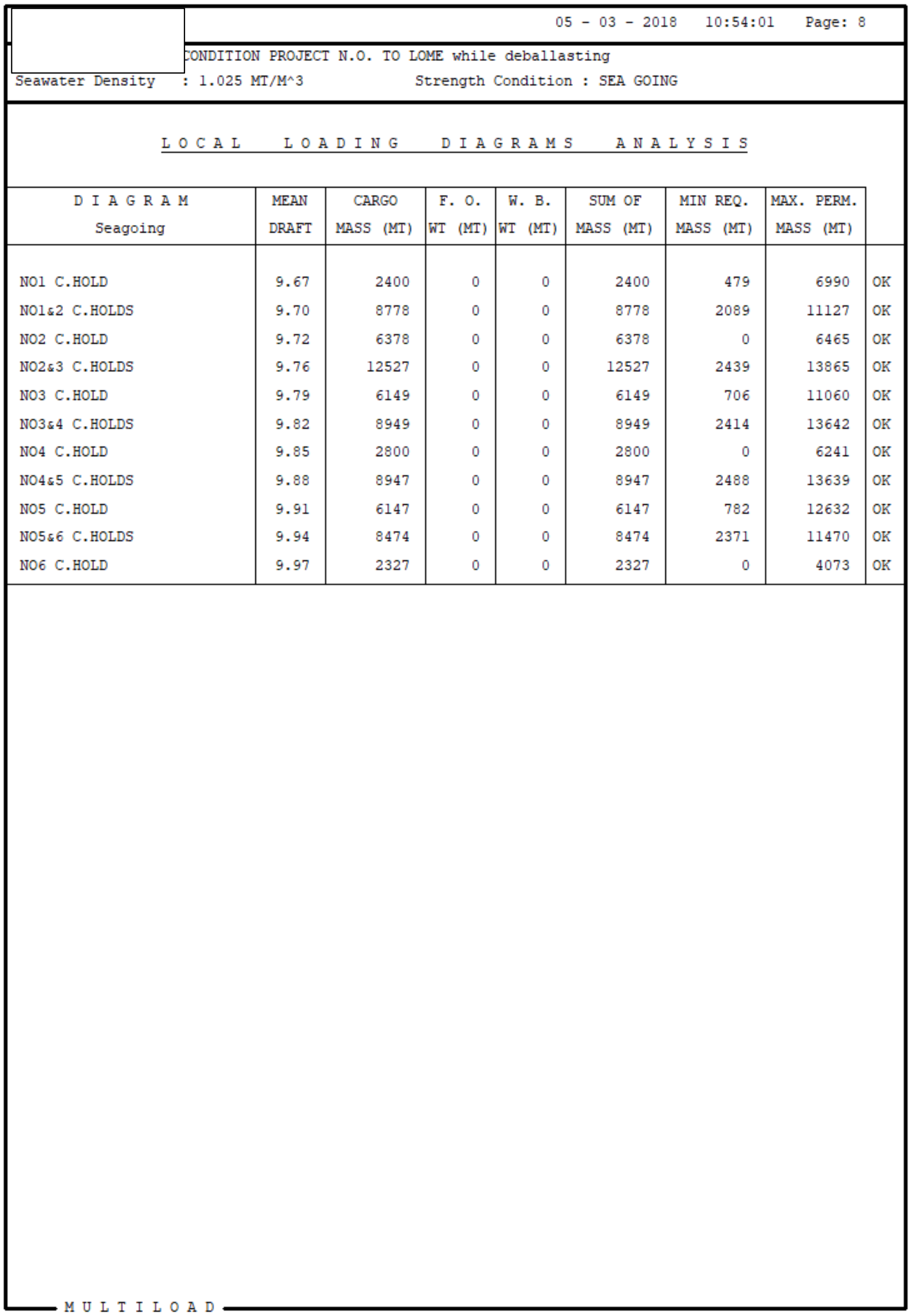
                                             05 - 03 - 2018    10:54:01    Page: 7
                    CONDITION PROJECT N.O. TO LOME while deballasting
Seawater Density   : 1.025 MT/M^3              Strength Condition : SEA GOING

              +++ S.F.     ''' S.F. Max.All          *** B.M.     ... B.M. Max.All

 FRM  S.F.      = = = Bulkhead Correction                  (+ HOG,  - SAG)          B.M.   FRM
 AE       0                                                                            0   AE
 -1     103                                                                          252   -1
  3     156                                                                          641    3
  8     176                                                                         1237    8
 11     148                                                                         1587   11
 16      97                                                                         2207   16
 19      -2                                                                         2399   19
 23    -172                                                                         2225   23
 27    -364                                                                         1472   27
 30    -517                                                                          493   30
 35    -886                                                                        -2180   35
 37    -902                                                                        -3558   37
 41    -959                                                                        -6431   41
 45   -1022                                                                        -9495   45
 48   -1070                                                                       -11926   48
 52   -1168                                                                       -15402   52
 55   -1251                                                                       -18226   55
 60   -1385                                                                       -23367   60
 63   -1111                                                                       -26284   63
 66   -1008                                                                       -28748   66
 70    -888                                                                       -31677   70
 74    -765                                                                       -34217   74
 77    -670                                                                       -35860   77
 81    -543                                                                       -37696   81
 84    -446                                                                       -38805   84
 88    -316                                                                       -39920   88
 93     -23                                                                       -40467   93
 95    -100                                                                       -40513   95
 99    -286                                                                       -41025   99
102    -423                                                                       -41797  102
108    -698                                                                       -44329  108
110    -790                                                                       -45467  110
113    -928                                                                       -47449  113
117   -1113                                                                       -50611  117
122   -1307                                                                       -55320  122
124   -1070                                                                       -57169  124
128    -883                                                                       -60190  128
131    -751                                                                       -62072  131
135    -571                                                                       -64082  135
138    -435                                                                       -65211  138
142    -250                                                                       -66202  142
146     -63                                                                       -66599  146
149      78                                                                       -66503  149
155     589                                                                       -64744  155
157     671                                                                       -63683  157
160     792                                                                       -61849  160
164     949                                                                       -58959  164
167    1063                                                                       -56467  167
172    1245                                                                       -51721  172
175    1350                                                                       -48529  175
178    1451                                                                       -45089  178
182    1582                                                                       -40131  182
186    1761                                                                       -34677  186
188    1944                                                                       -31661  188
193    1697                                                                       -24250  193
196    1544                                                                       -20283  196
200    1344                                                                       -15557  200
204    1163                                                                       -11441  204
207    1042                                                                        -8718  207
213     912                                                                        -4678  213
216     700                                                                        -3168  216
221     382                                                                        -1448  221
226     164                                                                         -530  226
231      29                                                                         -142  231
 FE       0                                                                            0   FE
                 MAX S.F. PERCENTAGE TO ALLOWABLE = 63 %   AT FRAME 188
                 MAX B.M. PERCENTAGE TO ALLOWABLE = 76 %   AT FRAME 182
    M U L T I L O A D
```

HOLD MASS TABLES



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[redacted] CONDITION PROJECT N.O. TO LOME while deballasting

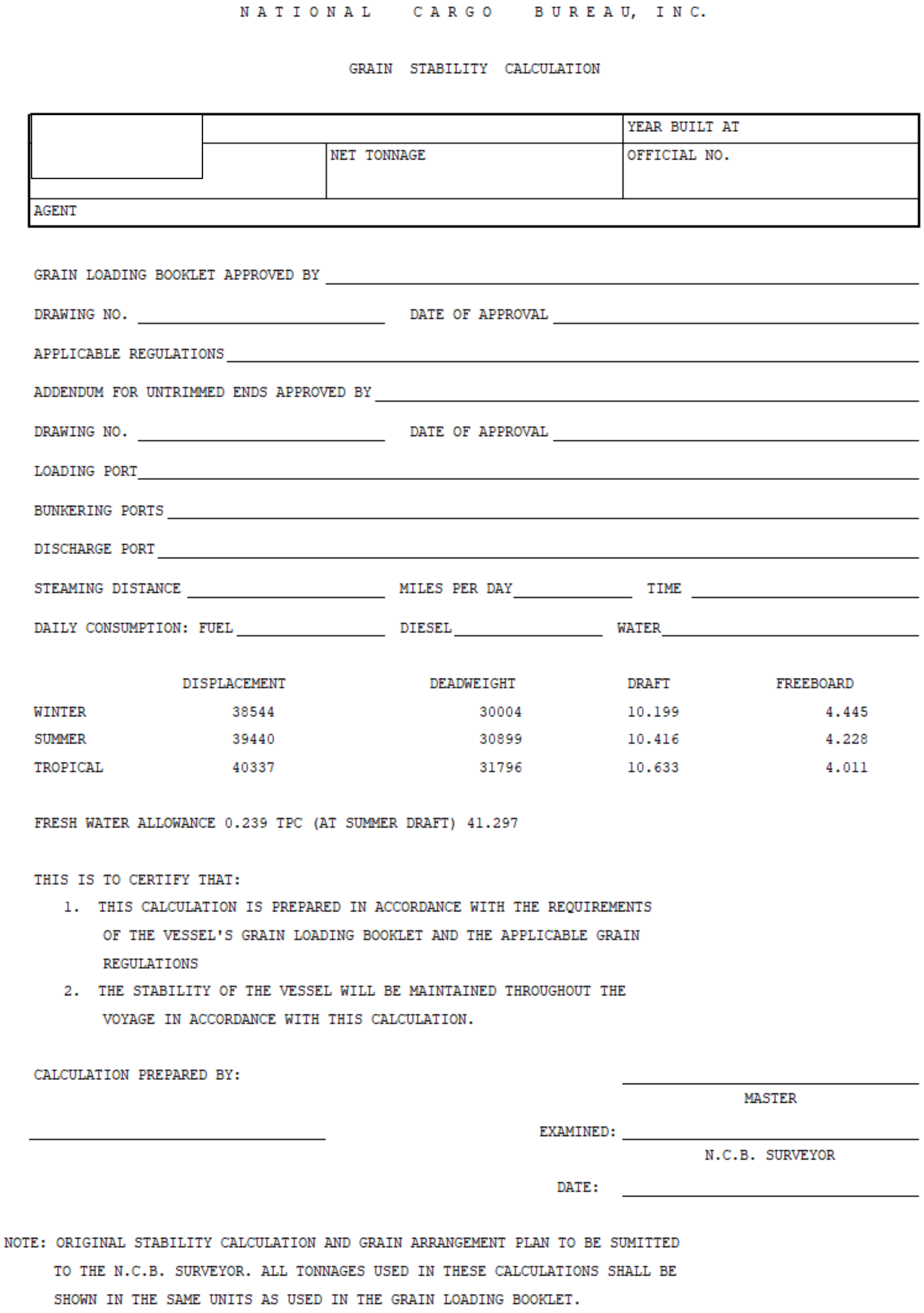
Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

LOCAL LOADING DIAGRAMS ANALYSIS

DIAGRAM Seagoing	MEAN DRAFT	CARGO MASS (MT)	F. O. WT (MT)	W. B. WT (MT)	SUM OF MASS (MT)	MIN REQ. MASS (MT)	MAX. PERM. MASS (MT)	
NO1 C.HOLD	9.67	2400	0	0	2400	479	6990	OK
NO1&2 C.HOLDS	9.70	8778	0	0	8778	2089	11127	OK
NO2 C.HOLD	9.72	6378	0	0	6378	0	6465	OK
NO2&3 C.HOLDS	9.76	12527	0	0	12527	2439	13865	OK
NO3 C.HOLD	9.79	6149	0	0	6149	706	11060	OK
NO3&4 C.HOLDS	9.82	8949	0	0	8949	2414	13642	OK
NO4 C.HOLD	9.85	2800	0	0	2800	0	6241	OK
NO4&5 C.HOLDS	9.88	8947	0	0	8947	2488	13639	OK
NO5 C.HOLD	9.91	6147	0	0	6147	782	12632	OK
NO5&6 C.HOLDS	9.94	8474	0	0	8474	2371	11470	OK
NO6 C.HOLD	9.97	2327	0	0	2327	0	4073	OK

MULTILOAD

GRAIN STABILITY, SEA GOING CRITERION



NATIONAL CARGO BUREAU, INC.

GRAIN STABILITY CALCULATION

			YEAR BUILT AT
		NET TONNAGE	OFFICIAL NO.
AGENT			

GRAIN LOADING BOOKLET APPROVED BY

DRAWING NO. DATE OF APPROVAL

APPLICABLE REGULATIONS

ADDENDUM FOR UNTRIMMED ENDS APPROVED BY

DRAWING NO. DATE OF APPROVAL

LOADING PORT

BUNKERING PORTS

DISCHARGE PORT

STEAMING DISTANCE MILES PER DAY TIME

DAILY CONSUMPTION: FUEL DIESEL WATER

	DISPLACEMENT	DEADWEIGHT	DRAFT	FREEBOARD
WINTER	38544	30004	10.199	4.445
SUMMER	39440	30899	10.416	4.228
TROPICAL	40337	31796	10.633	4.011

FRESH WATER ALLOWANCE 0.239 TPC (AT SUMMER DRAFT) 41.297

THIS IS TO CERTIFY THAT:

1. THIS CALCULATION IS PREPARED IN ACCORDANCE WITH THE REQUIREMENTS OF THE VESSEL'S GRAIN LOADING BOOKLET AND THE APPLICABLE GRAIN REGULATIONS
2. THE STABILITY OF THE VESSEL WILL BE MAINTAINED THROUGHOUT THE VOYAGE IN ACCORDANCE WITH THIS CALCULATION.

CALCULATION PREPARED BY:

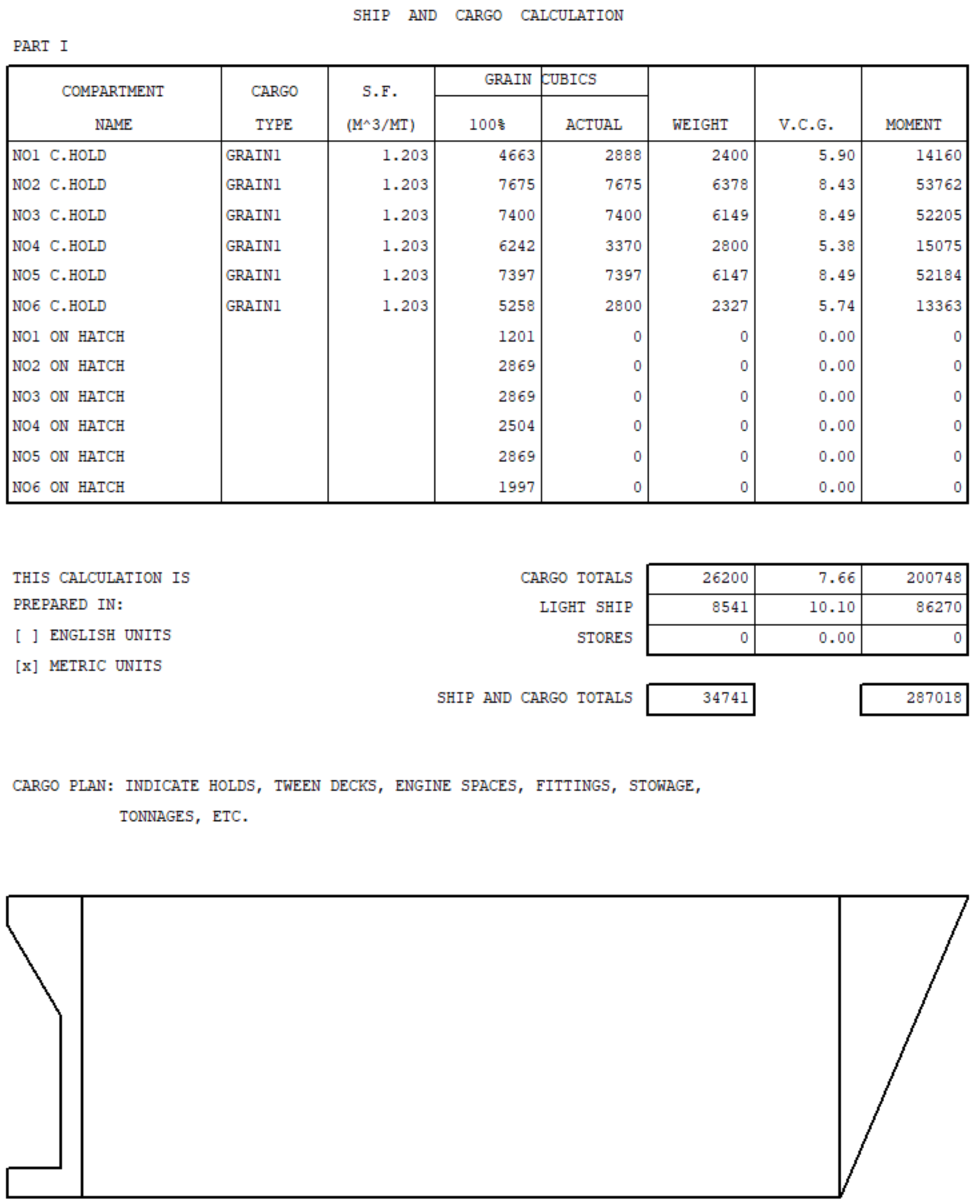
MASTER

EXAMINED:

N.C.B. SURVEYOR

DATE:

NOTE: ORIGINAL STABILITY CALCULATION AND GRAIN ARRANGEMENT PLAN TO BE SUMITTED TO THE N.C.B. SURVEYOR. ALL TONNAGES USED IN THESE CALCULATIONS SHALL BE SHOWN IN THE SAME UNITS AS USED IN THE GRAIN LOADING BOOKLET.



SHIP AND CARGO CALCULATION

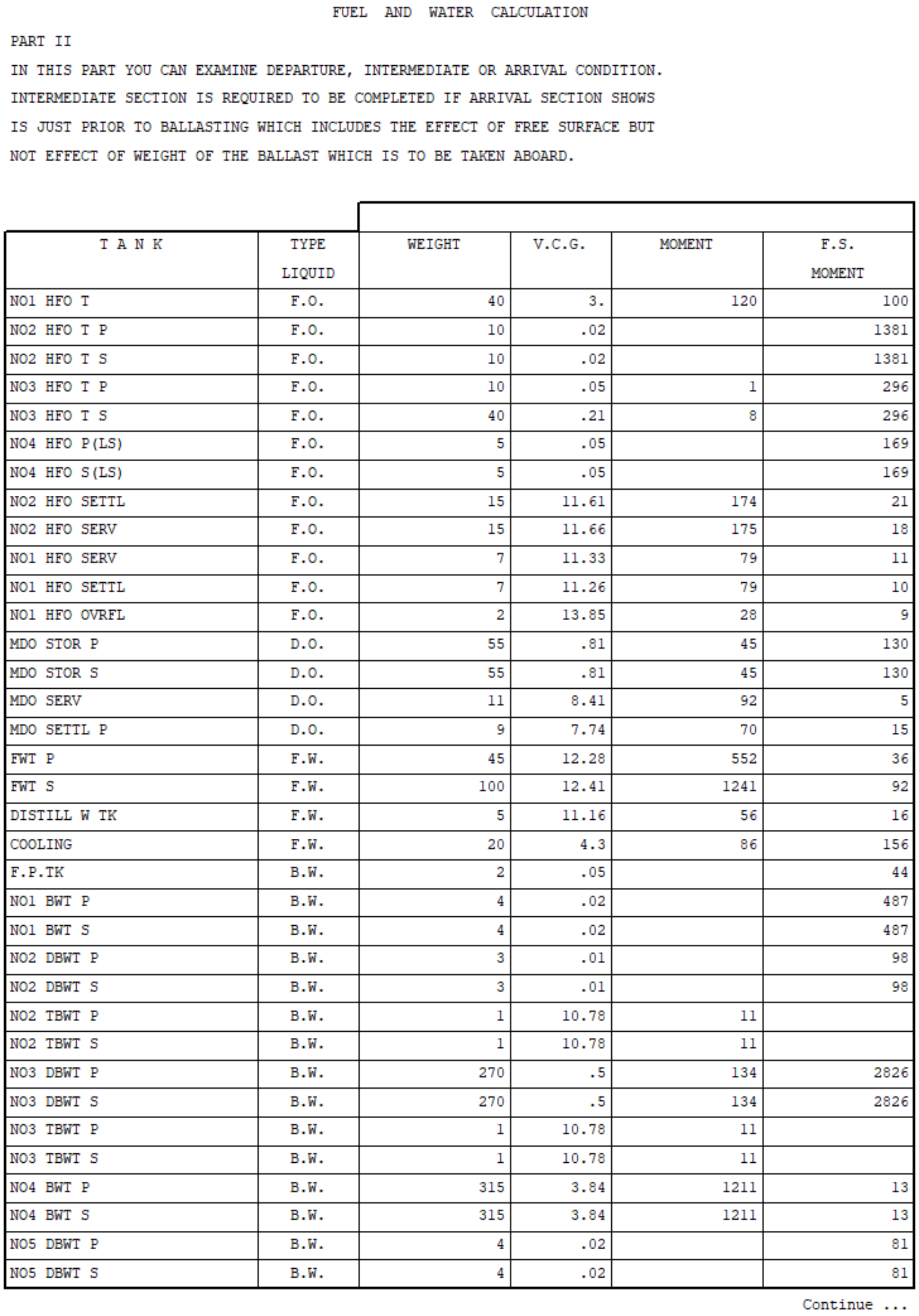
PART I

COMPARTMENT NAME	CARGO TYPE	S.F. (M^3/MT)	GRAIN CUBICS		WEIGHT	V.C.G.	MOMENT
			100%	ACTUAL			
NO1 C.HOLD	GRAIN1	1.203	4663	2888	2400	5.90	14160
NO2 C.HOLD	GRAIN1	1.203	7675	7675	6378	8.43	53762
NO3 C.HOLD	GRAIN1	1.203	7400	7400	6149	8.49	52205
NO4 C.HOLD	GRAIN1	1.203	6242	3370	2800	5.38	15075
NO5 C.HOLD	GRAIN1	1.203	7397	7397	6147	8.49	52184
NO6 C.HOLD	GRAIN1	1.203	5258	2800	2327	5.74	13363
NO1 ON HATCH			1201	0	0	0.00	0
NO2 ON HATCH			2869	0	0	0.00	0
NO3 ON HATCH			2869	0	0	0.00	0
NO4 ON HATCH			2504	0	0	0.00	0
NO5 ON HATCH			2869	0	0	0.00	0
NO6 ON HATCH			1997	0	0	0.00	0

THIS CALCULATION IS
PREPARED IN:
[ ] ENGLISH UNITS
[x] METRIC UNITS

CARGO TOTALS	26200	7.66	200748
LIGHT SHIP	8541	10.10	86270
STORES	0	0.00	0
SHIP AND CARGO TOTALS	34741		287018

CARGO PLAN: INDICATE HOLDS, TWEEN DECKS, ENGINE SPACES, FITTINGS, STOWAGE,
TONNAGES, ETC.



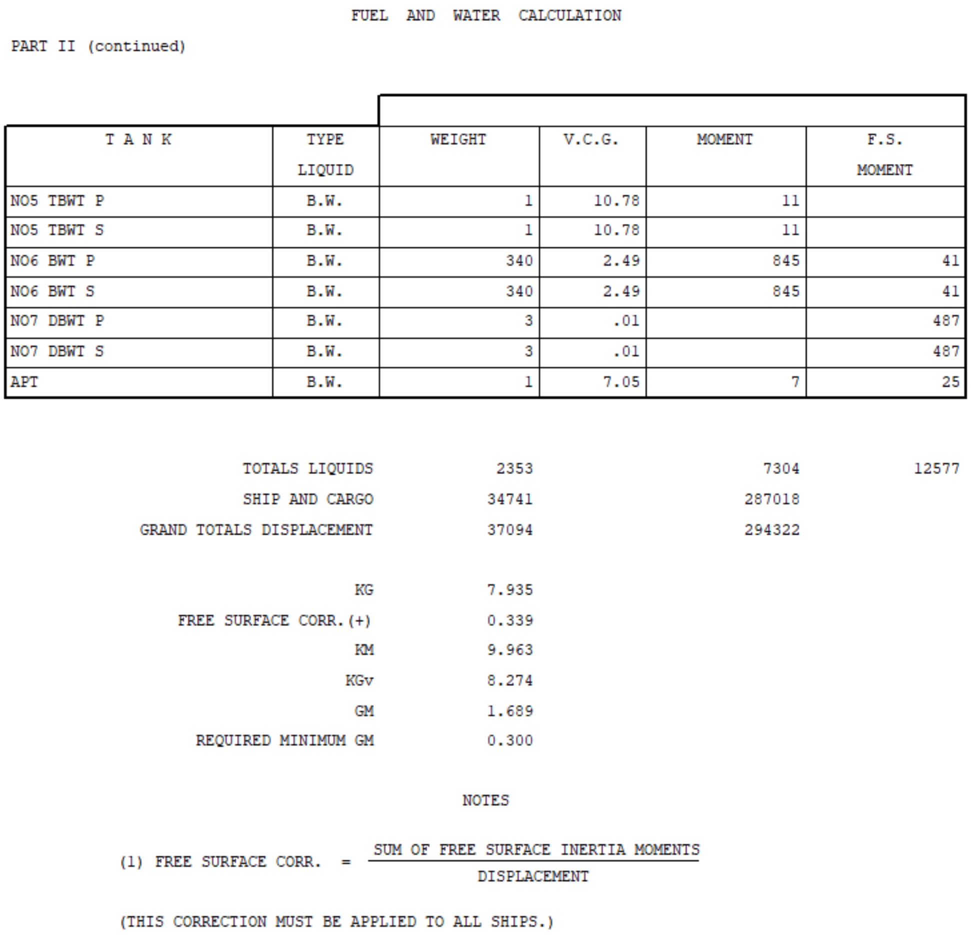
FUEL AND WATER CALCULATION

PART II

IN THIS PART YOU CAN EXAMINE DEPARTURE, INTERMEDIATE OR ARRIVAL CONDITION.
INTERMEDIATE SECTION IS REQUIRED TO BE COMPLETED IF ARRIVAL SECTION SHOWS
IS JUST PRIOR TO BALLASTING WHICH INCLUDES THE EFFECT OF FREE SURFACE BUT
NOT EFFECT OF WEIGHT OF THE BALLAST WHICH IS TO BE TAKEN ABOARD.

TANK	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO1 HFO T	F.O.	40	3.	120	100
NO2 HFO T P	F.O.	10	.02		1381
NO2 HFO T S	F.O.	10	.02		1381
NO3 HFO T P	F.O.	10	.05	1	296
NO3 HFO T S	F.O.	40	.21	8	296
NO4 HFO P(LS)	F.O.	5	.05		169
NO4 HFO S(LS)	F.O.	5	.05		169
NO2 HFO SETTL	F.O.	15	11.61	174	21
NO2 HFO SERV	F.O.	15	11.66	175	18
NO1 HFO SERV	F.O.	7	11.33	79	11
NO1 HFO SETTL	F.O.	7	11.26	79	10
NO1 HFO OVRFL	F.O.	2	13.85	28	9
MDO STOR P	D.O.	55	.81	45	130
MDO STOR S	D.O.	55	.81	45	130
MDO SERV	D.O.	11	8.41	92	5
MDO SETTL P	D.O.	9	7.74	70	15
FWT P	F.W.	45	12.28	552	36
FWT S	F.W.	100	12.41	1241	92
DISTILL W TK	F.W.	5	11.16	56	16
COOLING	F.W.	20	4.3	86	156
F.P.TK	B.W.	2	.05		44
NO1 BWT P	B.W.	4	.02		487
NO1 BWT S	B.W.	4	.02		487
NO2 DBWT P	B.W.	3	.01		98
NO2 DBWT S	B.W.	3	.01		98
NO2 TBWT P	B.W.	1	10.78	11	
NO2 TBWT S	B.W.	1	10.78	11	
NO3 DBWT P	B.W.	270	.5	134	2826
NO3 DBWT S	B.W.	270	.5	134	2826
NO3 TBWT P	B.W.	1	10.78	11	
NO3 TBWT S	B.W.	1	10.78	11	
NO4 BWT P	B.W.	315	3.84	1211	13
NO4 BWT S	B.W.	315	3.84	1211	13
NO5 DBWT P	B.W.	4	.02		81
NO5 DBWT S	B.W.	4	.02		81

Continue ...



FUEL AND WATER CALCULATION

PART II (continued)

TANK	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO5 TBWT P	B.W.	1	10.78	11	
NO5 TBWT S	B.W.	1	10.78	11	
NO6 BWT P	B.W.	340	2.49	845	41
NO6 BWT S	B.W.	340	2.49	845	41
NO7 DBWT P	B.W.	3	.01		487
NO7 DBWT S	B.W.	3	.01		487
APT	B.W.	1	7.05	7	25

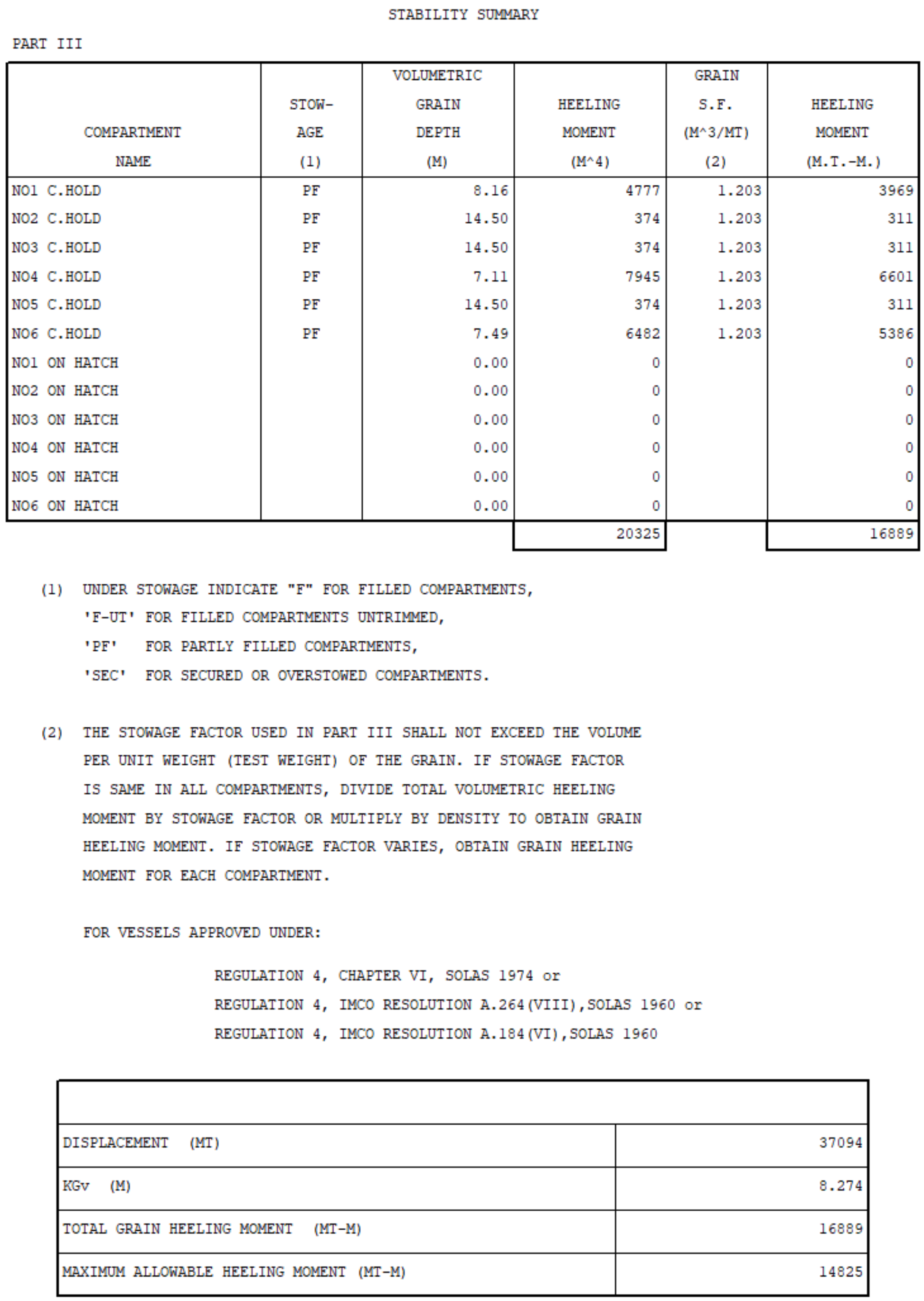
TOTALS LIQUIDS	2353	7304	12577
SHIP AND CARGO	34741	287018	
GRAND TOTALS DISPLACEMENT	37094	294322	

KG	7.935
FREE SURFACE CORR.(+)	0.339
KM	9.963
KGv	8.274
GM	1.689
REQUIRED MINIMUM GM	0.300

NOTES

(1) FREE SURFACE CORR. $= \frac{\text{SUM OF FREE SURFACE INERTIA MOMENTS}}{\text{DISPLACEMENT}}$

(THIS CORRECTION MUST BE APPLIED TO ALL SHIPS.)



STABILITY SUMMARY

PART III

COMPARTMENT NAME	STOW-AGE (1)	VOLUMETRIC GRAIN DEPTH (M)	HEELING MOMENT (M^4)	GRAIN S.F. (M^3/MT) (2)	HEELING MOMENT (M.T.-M.)
NO1 C.HOLD	PF	8.16	4777	1.203	3969
NO2 C.HOLD	PF	14.50	374	1.203	311
NO3 C.HOLD	PF	14.50	374	1.203	311
NO4 C.HOLD	PF	7.11	7945	1.203	6601
NO5 C.HOLD	PF	14.50	374	1.203	311
NO6 C.HOLD	PF	7.49	6482	1.203	5386
NO1 ON HATCH		0.00	0		0
NO2 ON HATCH		0.00	0		0
NO3 ON HATCH		0.00	0		0
NO4 ON HATCH		0.00	0		0
NO5 ON HATCH		0.00	0		0
NO6 ON HATCH		0.00	0		0
			20325		16889

(1) UNDER STOWAGE INDICATE "F" FOR FILLED COMPARTMENTS,
'F-UT' FOR FILLED COMPARTMENTS UNTRIMMED,
'PF' FOR PARTLY FILLED COMPARTMENTS,
'SEC' FOR SECURED OR OVERSTOWED COMPARTMENTS.

(2) THE STOWAGE FACTOR USED IN PART III SHALL NOT EXCEED THE VOLUME PER UNIT WEIGHT (TEST WEIGHT) OF THE GRAIN. IF STOWAGE FACTOR IS SAME IN ALL COMPARTMENTS, DIVIDE TOTAL VOLUMETRIC HEELING MOMENT BY STOWAGE FACTOR OR MULTIPLY BY DENSITY TO OBTAIN GRAIN HEELING MOMENT. IF STOWAGE FACTOR VARIES, OBTAIN GRAIN HEELING MOMENT FOR EACH COMPARTMENT.

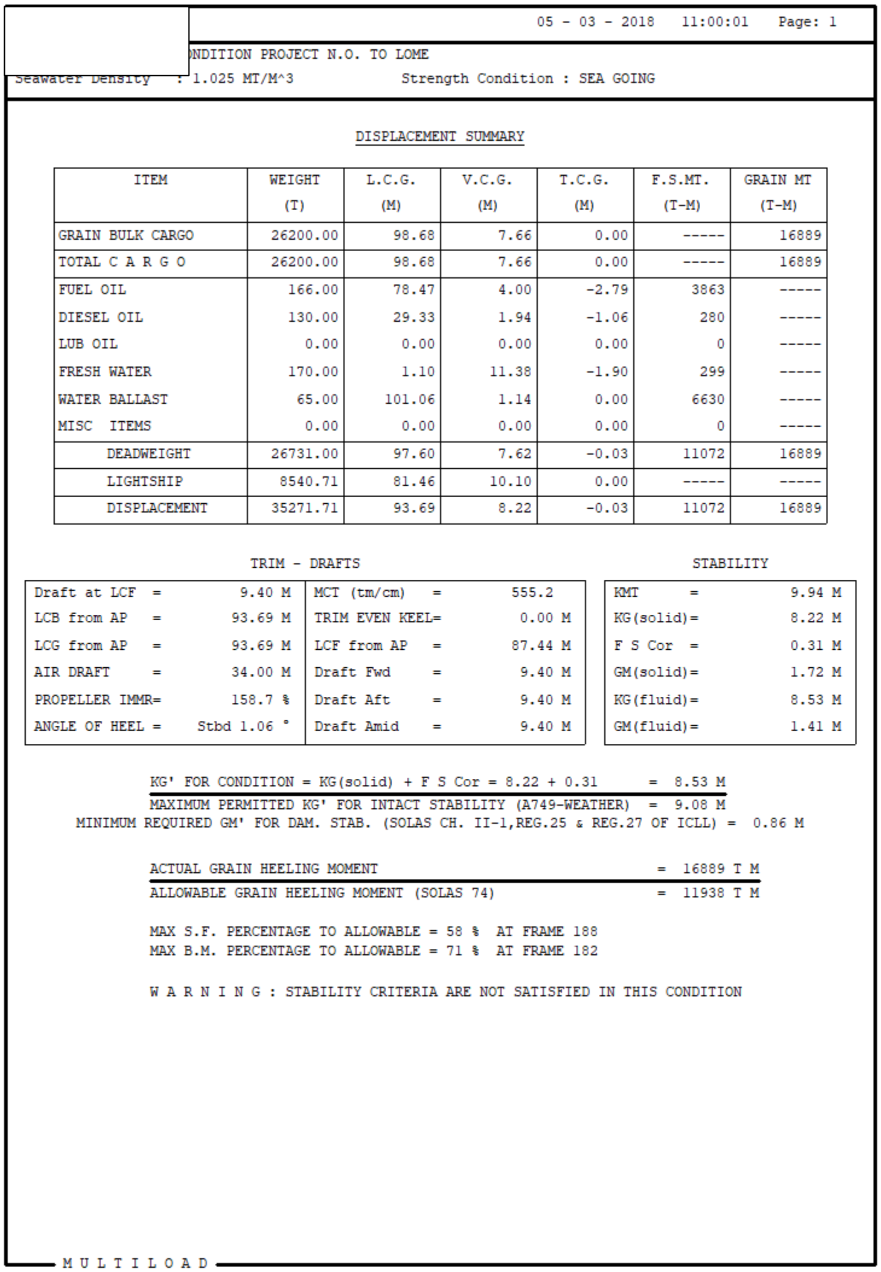
FOR VESSELS APPROVED UNDER:

REGULATION 4, CHAPTER VI, SOLAS 1974 or
REGULATION 4, IMCO RESOLUTION A.264(VIII),SOLAS 1960 or
REGULATION 4, IMCO RESOLUTION A.184(VI),SOLAS 1960

DISPLACEMENT (MT)	37094
KGv (M)	8.274
TOTAL GRAIN HEELING MOMENT (MT-M)	16889
MAXIMUM ALLOWABLE HEELING MOMENT (MT-M)	14825

10.5.6- ARRIVAL CONDITION WITH MINIMUM BUNKERS WITHOUT BALLAST

A- WEIGHT DISTRIBUTION, INTACT STABILITY PARAMETERS



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[redacted]NDITION PROJECT N.O. TO LOME
: 1.025 MT/M^3 Strength Condition : SEA GOING

DISPLACEMENT SUMMARY

ITEM	WEIGHT (T)	L.C.G. (M)	V.C.G. (M)	T.C.G. (M)	F.S.MT. (T-M)	GRAIN MT (T-M)
GRAIN BULK CARGO	26200.00	98.68	7.66	0.00	-----	16889
TOTAL C A R G O	26200.00	98.68	7.66	0.00	-----	16889
FUEL OIL	166.00	78.47	4.00	-2.79	3863	-----
DIESEL OIL	130.00	29.33	1.94	-1.06	280	-----
LUB OIL	0.00	0.00	0.00	0.00	0	-----
FRESH WATER	170.00	1.10	11.38	-1.90	299	-----
WATER BALLAST	65.00	101.06	1.14	0.00	6630	-----
MISC ITEMS	0.00	0.00	0.00	0.00	0	-----
DEADWEIGHT	26731.00	97.60	7.62	-0.03	11072	16889
LIGHTSHIP	8540.71	81.46	10.10	0.00	-----	-----
DISPLACEMENT	35271.71	93.69	8.22	-0.03	11072	16889

TRIM - DRAFTS

Draft at LCF =	9.40 M	MCT (tm/cm) =	555.2
LCB from AP =	93.69 M	TRIM EVEN KEEL=	0.00 M
LCG from AP =	93.69 M	LCF from AP =	87.44 M
AIR DRAFT =	34.00 M	Draft Fwd =	9.40 M
PROPELLER IMMR=	158.7 %	Draft Aft =	9.40 M
ANGLE OF HEEL =	Stbd 1.06 °	Draft Amid =	9.40 M

STABILITY

KMT =	9.94 M
KG(solid)=	8.22 M
F S Cor =	0.31 M
GM(solid)=	1.72 M
KG(fluid)=	8.53 M
GM(fluid)=	1.41 M

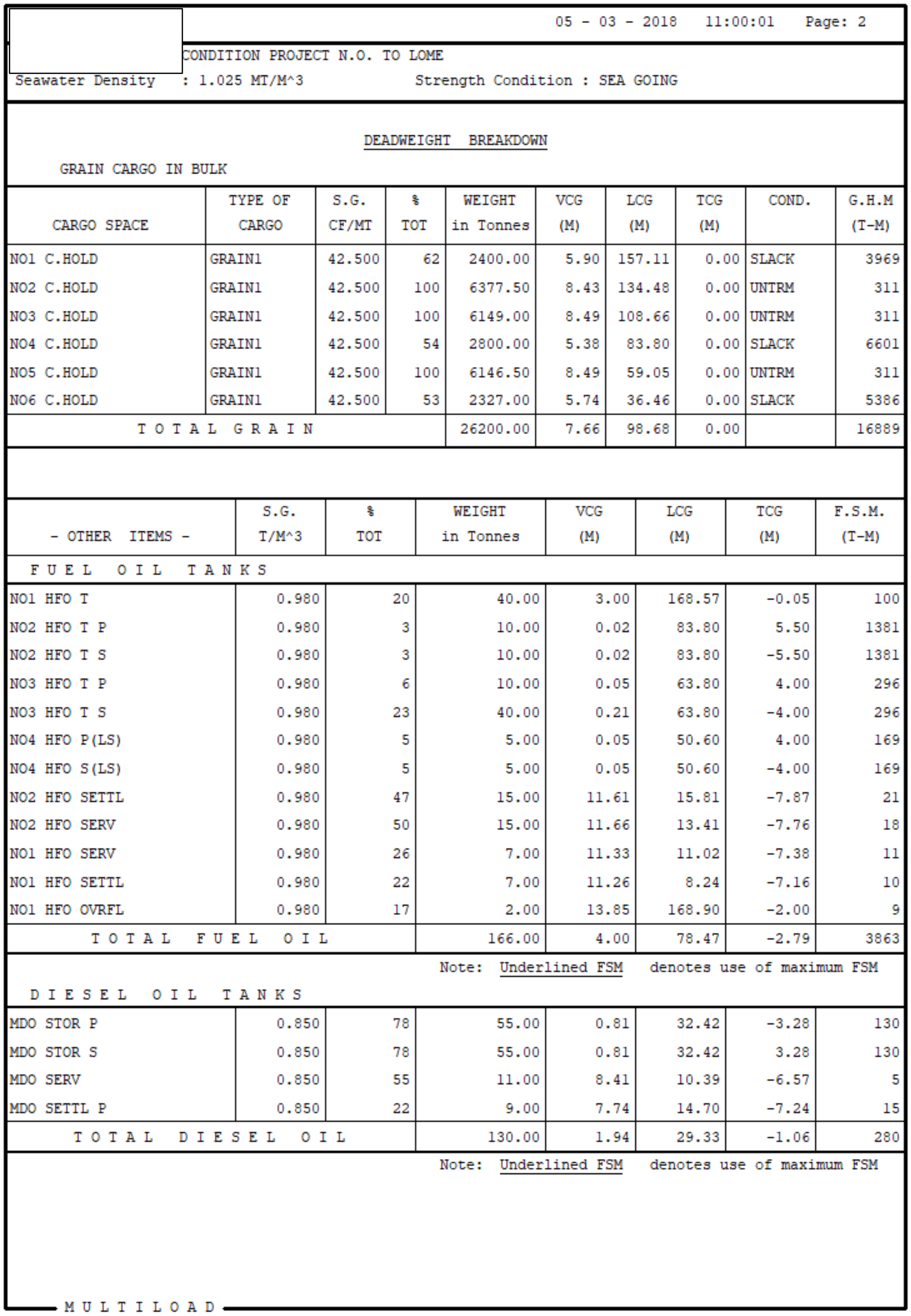
KG' FOR CONDITION = KG(solid) + F S Cor = 8.22 + 0.31 = 8.53 M
MAXIMUM PERMITTED KG' FOR INTACT STABILITY (A749-WEATHER) = 9.08 M
MINIMUM REQUIRED GM' FOR DAM. STAB. (SOLAS CH. II-1,REG.25 & REG.27 OF ICLL) = 0.86 M

ACTUAL GRAIN HEELING MOMENT = 16889 T M
ALLOWABLE GRAIN HEELING MOMENT (SOLAS 74) = 11938 T M

MAX S.F. PERCENTAGE TO ALLOWABLE = 58 % AT FRAME 188
MAX B.M. PERCENTAGE TO ALLOWABLE = 71 % AT FRAME 182

WARNING : STABILITY CRITERIA ARE NOT SATISFIED IN THIS CONDITION

MULTILOAD



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CONDITION PROJECT N.O. TO LOME

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

DEADWEIGHT BREAKDOWN

GRAIN CARGO IN BULK

CARGO SPACE	TYPE OF CARGO	S.G. CF/MT	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	COND.	G.H.M (T-M)
NO1 C.HOLD	GRAIN1	42.500	62	2400.00	5.90	157.11	0.00	SLACK	3969
NO2 C.HOLD	GRAIN1	42.500	100	6377.50	8.43	134.48	0.00	UNTRM	311
NO3 C.HOLD	GRAIN1	42.500	100	6149.00	8.49	108.66	0.00	UNTRM	311
NO4 C.HOLD	GRAIN1	42.500	54	2800.00	5.38	83.80	0.00	SLACK	6601
NO5 C.HOLD	GRAIN1	42.500	100	6146.50	8.49	59.05	0.00	UNTRM	311
NO6 C.HOLD	GRAIN1	42.500	53	2327.00	5.74	36.46	0.00	SLACK	5386
TOTAL GRAIN				26200.00	7.66	98.68	0.00		16889

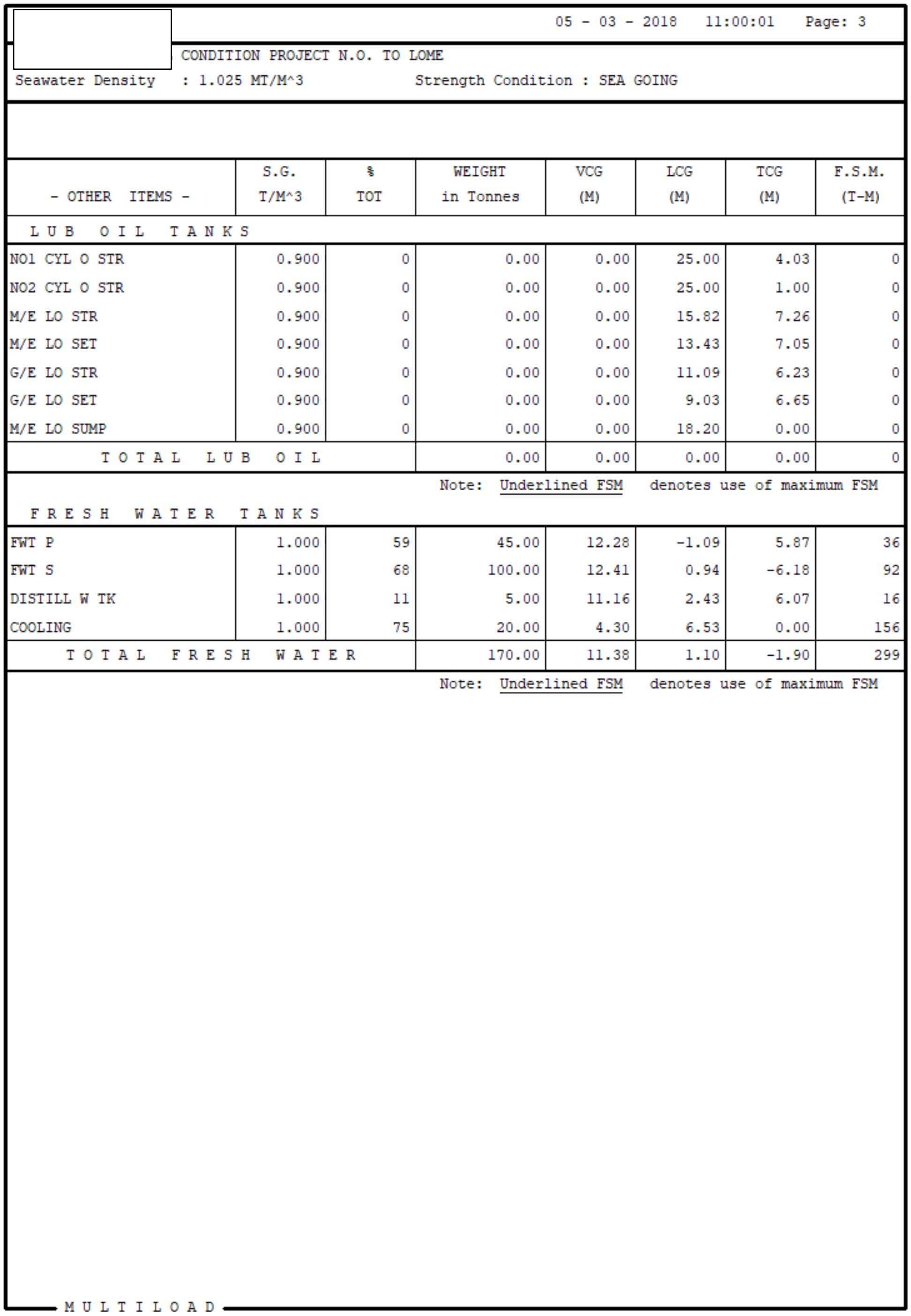
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
FUEL OIL TANKS							
NO1 HFO T	0.980	20	40.00	3.00	168.57	-0.05	100
NO2 HFO T P	0.980	3	10.00	0.02	83.80	5.50	1381
NO2 HFO T S	0.980	3	10.00	0.02	83.80	-5.50	1381
NO3 HFO T P	0.980	6	10.00	0.05	63.80	4.00	296
NO3 HFO T S	0.980	23	40.00	0.21	63.80	-4.00	296
NO4 HFO P(LS)	0.980	5	5.00	0.05	50.60	4.00	169
NO4 HFO S(LS)	0.980	5	5.00	0.05	50.60	-4.00	169
NO2 HFO SETTL	0.980	47	15.00	11.61	15.81	-7.87	21
NO2 HFO SERV	0.980	50	15.00	11.66	13.41	-7.76	18
NO1 HFO SERV	0.980	26	7.00	11.33	11.02	-7.38	11
NO1 HFO SETTL	0.980	22	7.00	11.26	8.24	-7.16	10
NO1 HFO OVRFL	0.980	17	2.00	13.85	168.90	-2.00	9
TOTAL FUEL OIL			166.00	4.00	78.47	-2.79	3863

Note: Underlined FSM denotes use of maximum FSM

DIESEL OIL TANKS							
MDO STOR P	0.850	78	55.00	0.81	32.42	-3.28	130
MDO STOR S	0.850	78	55.00	0.81	32.42	3.28	130
MDO SERV	0.850	55	11.00	8.41	10.39	-6.57	5
MDO SETTL P	0.850	22	9.00	7.74	14.70	-7.24	15
TOTAL DIESEL OIL			130.00	1.94	29.33	-1.06	280

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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CONDITION PROJECT N.O. TO LOME

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

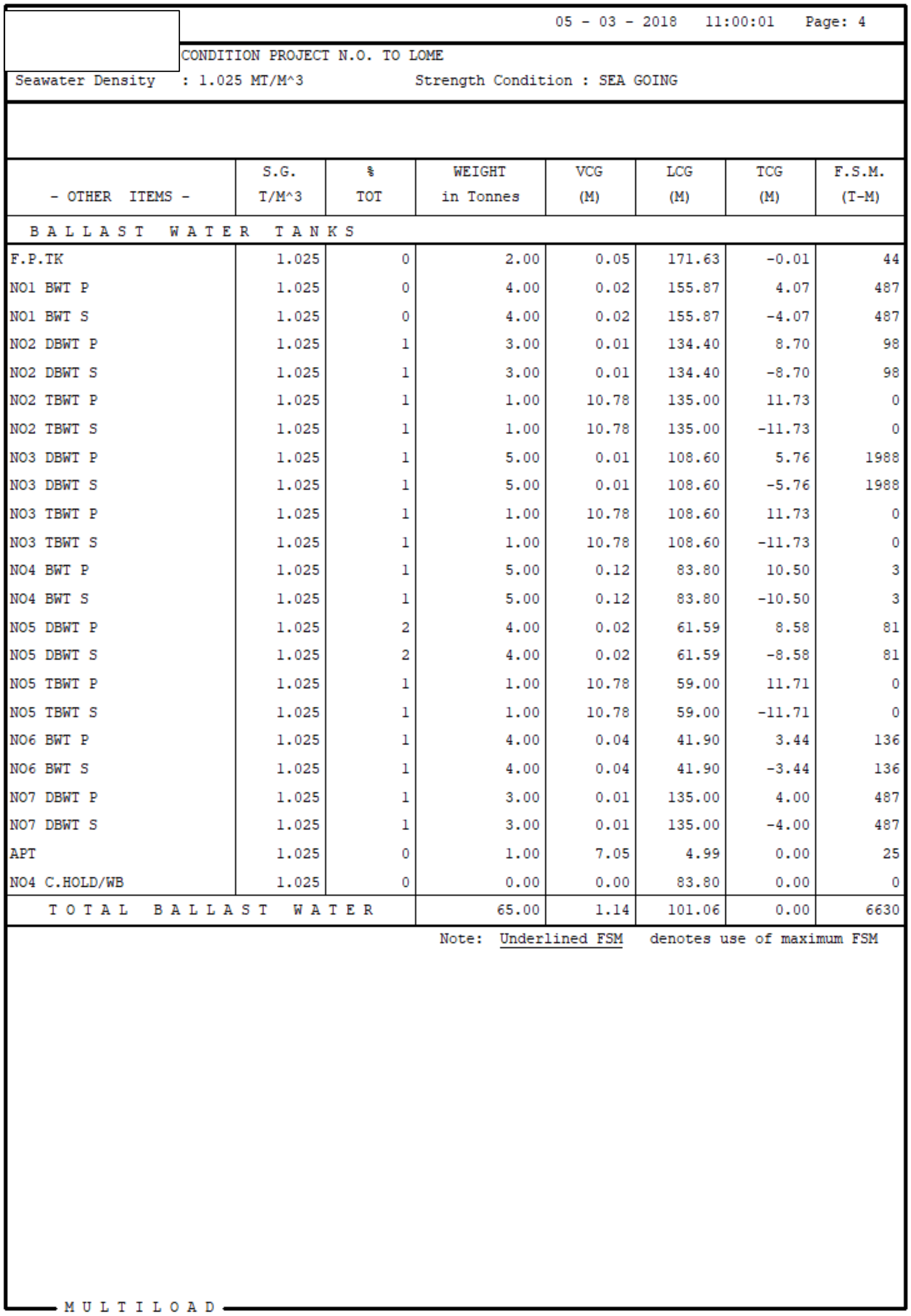
- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
LUB OIL TANKS							
NO1 CYL O STR	0.900	0	0.00	0.00	25.00	4.03	0
NO2 CYL O STR	0.900	0	0.00	0.00	25.00	1.00	0
M/E LO STR	0.900	0	0.00	0.00	15.82	7.26	0
M/E LO SET	0.900	0	0.00	0.00	13.43	7.05	0
G/E LO STR	0.900	0	0.00	0.00	11.09	6.23	0
G/E LO SET	0.900	0	0.00	0.00	9.03	6.65	0
M/E LO SUMP	0.900	0	0.00	0.00	18.20	0.00	0
TOTAL LUB OIL			0.00	0.00	0.00	0.00	0

Note: Underlined FSM denotes use of maximum FSM

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
FRESH WATER TANKS							
FWT P	1.000	59	45.00	12.28	-1.09	5.87	36
FWT S	1.000	68	100.00	12.41	0.94	-6.18	92
DISTILL W TK	1.000	11	5.00	11.16	2.43	6.07	16
COOLING	1.000	75	20.00	4.30	6.53	0.00	156
TOTAL FRESH WATER			170.00	11.38	1.10	-1.90	299

Note: Underlined FSM denotes use of maximum FSM

MULTILOAD



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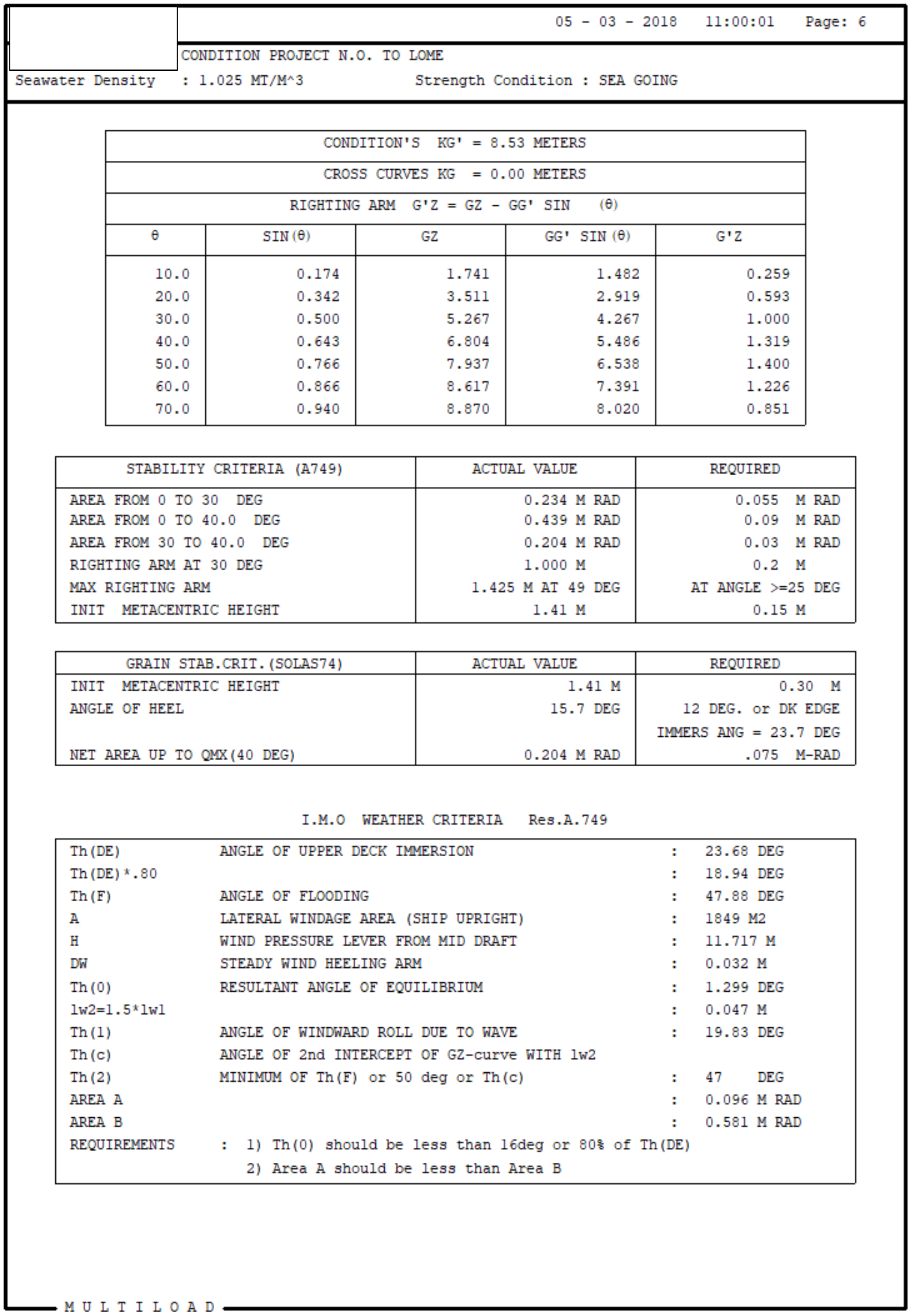
CONDITION PROJECT N.O. TO LOME

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

- OTHER ITEMS -	S.G. T/M^3	% TOT	WEIGHT in Tonnes	VCG (M)	LCG (M)	TCG (M)	F.S.M. (T-M)
BALLAST WATER TANKS							
F.P.TK	1.025	0	2.00	0.05	171.63	-0.01	44
NO1 BWT P	1.025	0	4.00	0.02	155.87	4.07	487
NO1 BWT S	1.025	0	4.00	0.02	155.87	-4.07	487
NO2 DBWT P	1.025	1	3.00	0.01	134.40	8.70	98
NO2 DBWT S	1.025	1	3.00	0.01	134.40	-8.70	98
NO2 TBWT P	1.025	1	1.00	10.78	135.00	11.73	0
NO2 TBWT S	1.025	1	1.00	10.78	135.00	-11.73	0
NO3 DBWT P	1.025	1	5.00	0.01	108.60	5.76	1988
NO3 DBWT S	1.025	1	5.00	0.01	108.60	-5.76	1988
NO3 TBWT P	1.025	1	1.00	10.78	108.60	11.73	0
NO3 TBWT S	1.025	1	1.00	10.78	108.60	-11.73	0
NO4 BWT P	1.025	1	5.00	0.12	83.80	10.50	3
NO4 BWT S	1.025	1	5.00	0.12	83.80	-10.50	3
NO5 DBWT P	1.025	2	4.00	0.02	61.59	8.58	81
NO5 DBWT S	1.025	2	4.00	0.02	61.59	-8.58	81
NO5 TBWT P	1.025	1	1.00	10.78	59.00	11.71	0
NO5 TBWT S	1.025	1	1.00	10.78	59.00	-11.71	0
NO6 BWT P	1.025	1	4.00	0.04	41.90	3.44	136
NO6 BWT S	1.025	1	4.00	0.04	41.90	-3.44	136
NO7 DBWT P	1.025	1	3.00	0.01	135.00	4.00	487
NO7 DBWT S	1.025	1	3.00	0.01	135.00	-4.00	487
APT	1.025	0	1.00	7.05	4.99	0.00	25
NO4 C.HOLD/WB	1.025	0	0.00	0.00	83.80	0.00	0
TOTAL BALLAST WATER			65.00	1.14	101.06	0.00	6630

Note: <u>Underlined FSM</u> denotes use of maximum FSM

MULTILOAD



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                                                05 - 03 - 2018    11:00:01    Page: 6
                        CONDITION PROJECT N.O. TO LOME
Seawater Density     : 1.025 MT/M^3              Strength Condition : SEA GOING

                         CONDITION'S  KG' = 8.53 METERS
                         CROSS CURVES KG  = 0.00 METERS
                       RIGHTING ARM  G'Z = GZ - GG' SIN   (θ)
         θ           SIN(θ)            GZ           GG' SIN(θ)          G'Z

        10.0            0.174          1.741           1.482           0.259
        20.0            0.342          3.511           2.919           0.593
        30.0            0.500          5.267           4.267           1.000
        40.0            0.643          6.804           5.486           1.319
        50.0            0.766          7.937           6.538           1.400
        60.0            0.866          8.617           7.391           1.226
        70.0            0.940          8.870           8.020           0.851

      STABILITY CRITERIA (A749)             ACTUAL VALUE              REQUIRED
   AREA FROM 0 TO 30  DEG                       0.234 M RAD          0.055  M RAD
   AREA FROM 0 TO 40.0  DEG                     0.439 M RAD          0.09   M RAD
   AREA FROM 30 TO 40.0  DEG                    0.204 M RAD          0.03   M RAD
   RIGHTING ARM AT 30 DEG                       1.000 M              0.2   M
   MAX RIGHTING ARM                        1.425 M AT 49 DEG     AT ANGLE >=25 DEG
   INIT  METACENTRIC HEIGHT                      1.41 M              0.15 M

      GRAIN STAB.CRIT.(SOLAS74)             ACTUAL VALUE              REQUIRED
   INIT  METACENTRIC HEIGHT                          1.41 M               0.30  M
   ANGLE OF HEEL                                   15.7 DEG       12 DEG. or DK EDGE
                                                                IMMERS ANG = 23.7 DEG
   NET AREA UP TO QMX(40 DEG)                   0.204 M RAD           .075  M-RAD

                             I.M.O  WEATHER CRITERIA   Res.A.749

   Th(DE)            ANGLE OF UPPER DECK IMMERSION                    :   23.68 DEG
   Th(DE)*.80                                                         :   18.94 DEG
   Th(F)             ANGLE OF FLOODING                                :   47.88 DEG
   A                 LATERAL WINDAGE AREA (SHIP UPRIGHT)              :   1849 M2
   H                 WIND PRESSURE LEVER FROM MID DRAFT               :   11.717 M
   DW                STEADY WIND HEELING ARM                          :   0.032 M
   Th(0)             RESULTANT ANGLE OF EQUILIBRIUM                   :   1.299 DEG
   lw2=1.5*lw1                                                        :   0.047 M
   Th(1)             ANGLE OF WINDWARD ROLL DUE TO WAVE               :   19.83 DEG
   Th(c)             ANGLE OF 2nd INTERCEPT OF GZ-curve WITH lw2
   Th(2)             MINIMUM OF Th(F) or 50 deg or Th(c)              :   47    DEG
   AREA A                                                             :   0.096 M RAD
   AREA B                                                             :   0.581 M RAD
   REQUIREMENTS      :  1) Th(0) should be less than 16deg or 80% of Th(DE)
                        2) Area A should be less than Area B


   MULTILOAD
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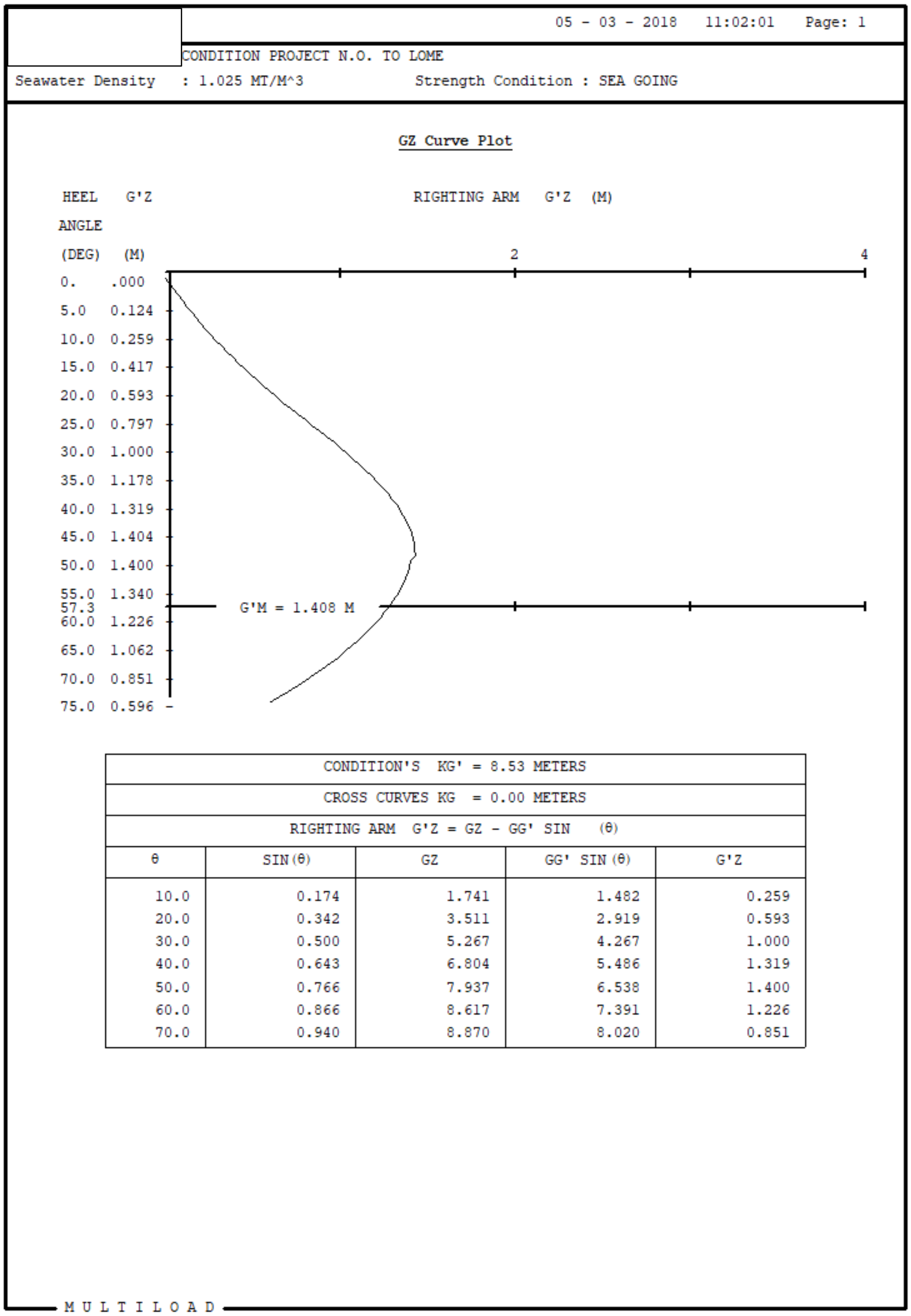
GZ CURVE



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CONDITION PROJECT N.O. TO LOME

Seawater Density : 1.025 MT/M^3 Strength Condition : SEA GOING

GZ Curve Plot

HEEL ANGLE (DEG)	G'Z (M)
0.	.000
5.0	0.124
10.0	0.259
15.0	0.417
20.0	0.593
25.0	0.797
30.0	1.000
35.0	1.178
40.0	1.319
45.0	1.404
50.0	1.400
55.0	1.340
57.3	
60.0	1.226
65.0	1.062
70.0	0.851
75.0	0.596

CONDITION'S KG' = 8.53 METERS

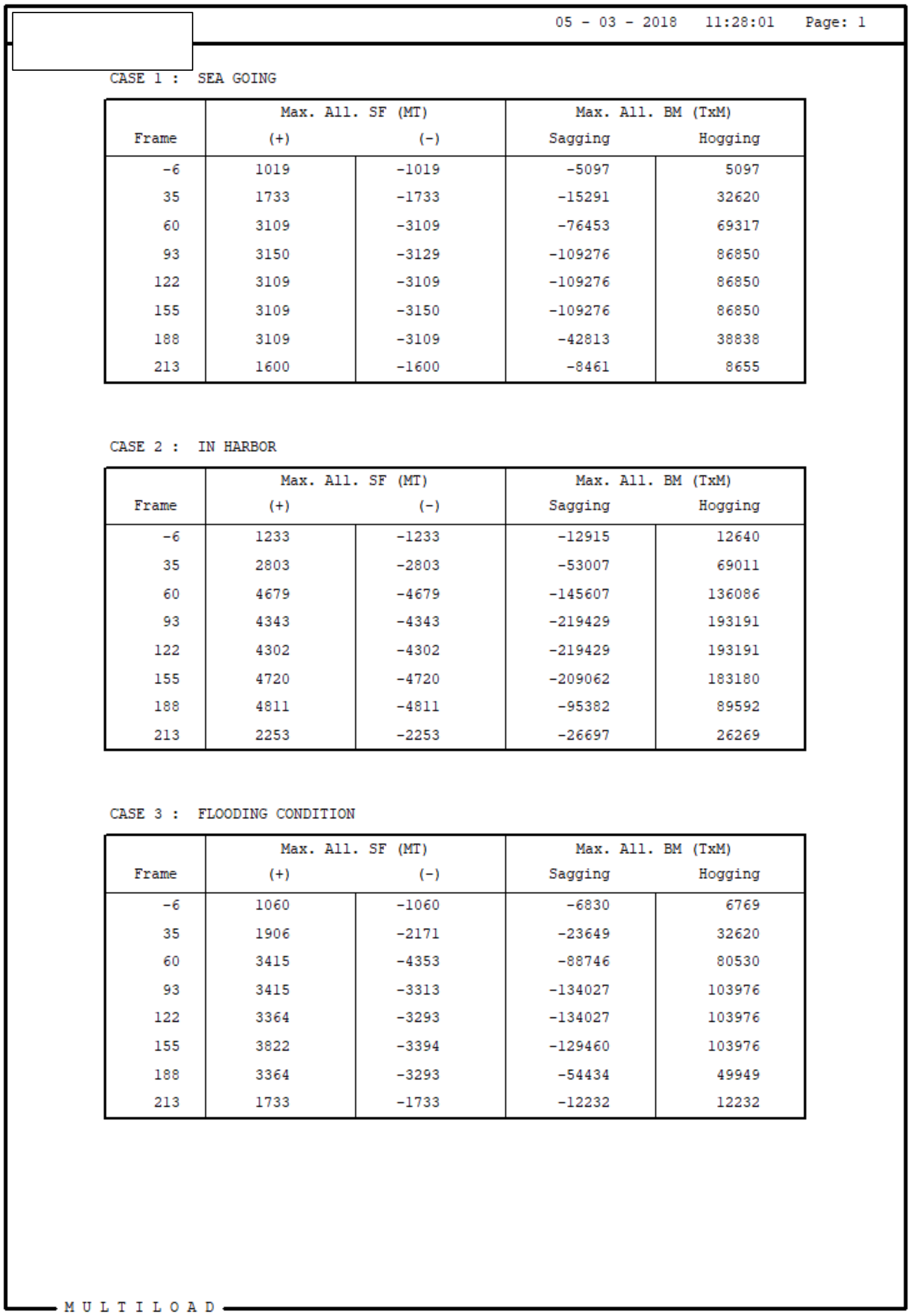
CROSS CURVES KG = 0.00 METERS

RIGHTING ARM G'Z = GZ - GG' SIN (θ)

θ	SIN(θ)	GZ	GG' SIN(θ)	G'Z
10.0	0.174	1.741	1.482	0.259
20.0	0.342	3.511	2.919	0.593
30.0	0.500	5.267	4.267	1.000
40.0	0.643	6.804	5.486	1.319
50.0	0.766	7.937	6.538	1.400
60.0	0.866	8.617	7.391	1.226
70.0	0.940	8.870	8.020	0.851

MULTILOAD

DEFLECTIONS (SF & BM)



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CASE 1 : SEA GOING

	Max. All. SF (MT)		Max. All. BM (TxM)	
Frame	(+)	(-)	Sagging	Hogging
-6	1019	-1019	-5097	5097
35	1733	-1733	-15291	32620
60	3109	-3109	-76453	69317
93	3150	-3129	-109276	86850
122	3109	-3109	-109276	86850
155	3109	-3150	-109276	86850
188	3109	-3109	-42813	38838
213	1600	-1600	-8461	8655

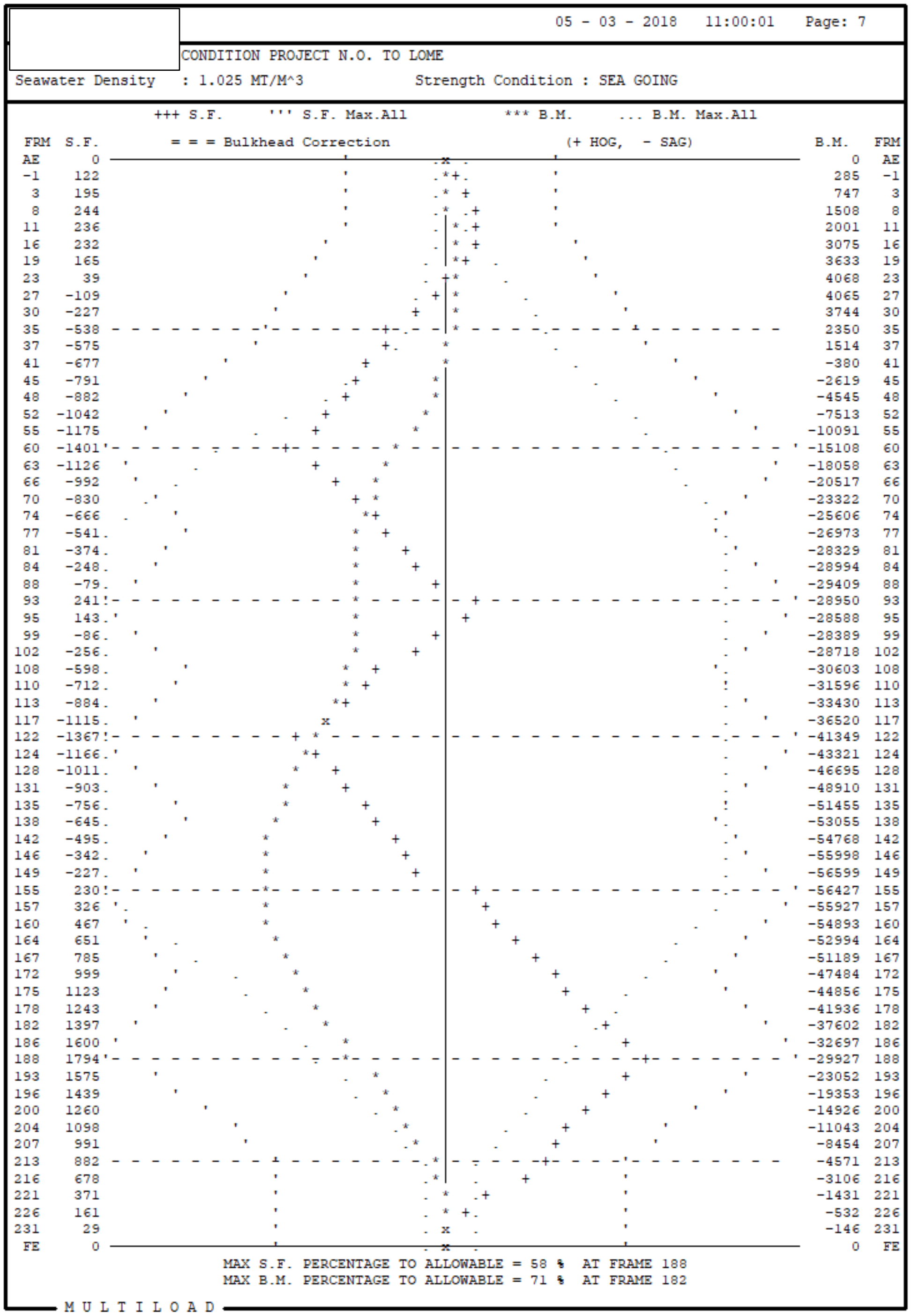
CASE 2 : IN HARBOR

	Max. All. SF (MT)		Max. All. BM (TxM)	
Frame	(+)	(-)	Sagging	Hogging
-6	1233	-1233	-12915	12640
35	2803	-2803	-53007	69011
60	4679	-4679	-145607	136086
93	4343	-4343	-219429	193191
122	4302	-4302	-219429	193191
155	4720	-4720	-209062	183180
188	4811	-4811	-95382	89592
213	2253	-2253	-26697	26269

CASE 3 : FLOODING CONDITION

	Max. All. SF (MT)		Max. All. BM (TxM)	
Frame	(+)	(-)	Sagging	Hogging
-6	1060	-1060	-6830	6769
35	1906	-2171	-23649	32620
60	3415	-4353	-88746	80530
93	3415	-3313	-134027	103976
122	3364	-3293	-134027	103976
155	3822	-3394	-129460	103976
188	3364	-3293	-54434	49949
213	1733	-1733	-12232	12232

MULTILOAD



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               CONDITION PROJECT N.O. TO LOME
Seawater Density  : 1.025 MT/M^3           Strength Condition : SEA GOING

          +++ S.F.    ''' S.F. Max.All         *** B.M.     ... B.M. Max.All

FRM  S.F.        = = = Bulkhead Correction              (+ HOG,  - SAG)        B.M.   FRM
AE       0                                                                        0   AE
-1     122                                                                      285   -1
 3     195                                                                      747    3
 8     244                                                                     1508    8
11     236                                                                     2001   11
16     232                                                                     3075   16
19     165                                                                     3633   19
23      39                                                                     4068   23
27    -109                                                                     4065   27
30    -227                                                                     3744   30
35    -538                                                                     2350   35
37    -575                                                                     1514   37
41    -677                                                                     -380   41
45    -791                                                                    -2619   45
48    -882                                                                    -4545   48
52   -1042                                                                    -7513   52
55   -1175                                                                   -10091   55
60   -1401                                                                   -15108   60
63   -1126                                                                   -18058   63
66    -992                                                                   -20517   66
70    -830                                                                   -23322   70
74    -666                                                                   -25606   74
77    -541                                                                   -26973   77
81    -374                                                                   -28329   81
84    -248                                                                   -28994   84
88     -79                                                                   -29409   88
93     241                                                                   -28950   93
95     143                                                                   -28588   95
99     -86                                                                   -28389   99
102   -256                                                                   -28718  102
108   -598                                                                   -30603  108
110   -712                                                                   -31596  110
113   -884                                                                   -33430  113
117  -1115                                                                   -36520  117
122  -1367                                                                   -41349  122
124  -1166                                                                   -43321  124
128  -1011                                                                   -46695  128
131   -903                                                                   -48910  131
135   -756                                                                   -51455  135
138   -645                                                                   -53055  138
142   -495                                                                   -54768  142
146   -342                                                                   -55998  146
149   -227                                                                   -56599  149
155    230                                                                   -56427  155
157    326                                                                   -55927  157
160    467                                                                   -54893  160
164    651                                                                   -52994  164
167    785                                                                   -51189  167
172    999                                                                   -47484  172
175   1123                                                                   -44856  175
178   1243                                                                   -41936  178
182   1397                                                                   -37602  182
186   1600                                                                   -32697  186
188   1794                                                                   -29927  188
193   1575                                                                   -23052  193
196   1439                                                                   -19353  196
200   1260                                                                   -14926  200
204   1098                                                                   -11043  204
207    991                                                                    -8454  207
213    882                                                                    -4571  213
216    678                                                                    -3106  216
221    371                                                                    -1431  221
226    161                                                                     -532  226
231     29                                                                     -146  231
FE       0                                                                        0   FE
                 MAX S.F. PERCENTAGE TO ALLOWABLE = 58 %  AT FRAME 188
                 MAX B.M. PERCENTAGE TO ALLOWABLE = 71 %  AT FRAME 182

    M U L T I L O A D
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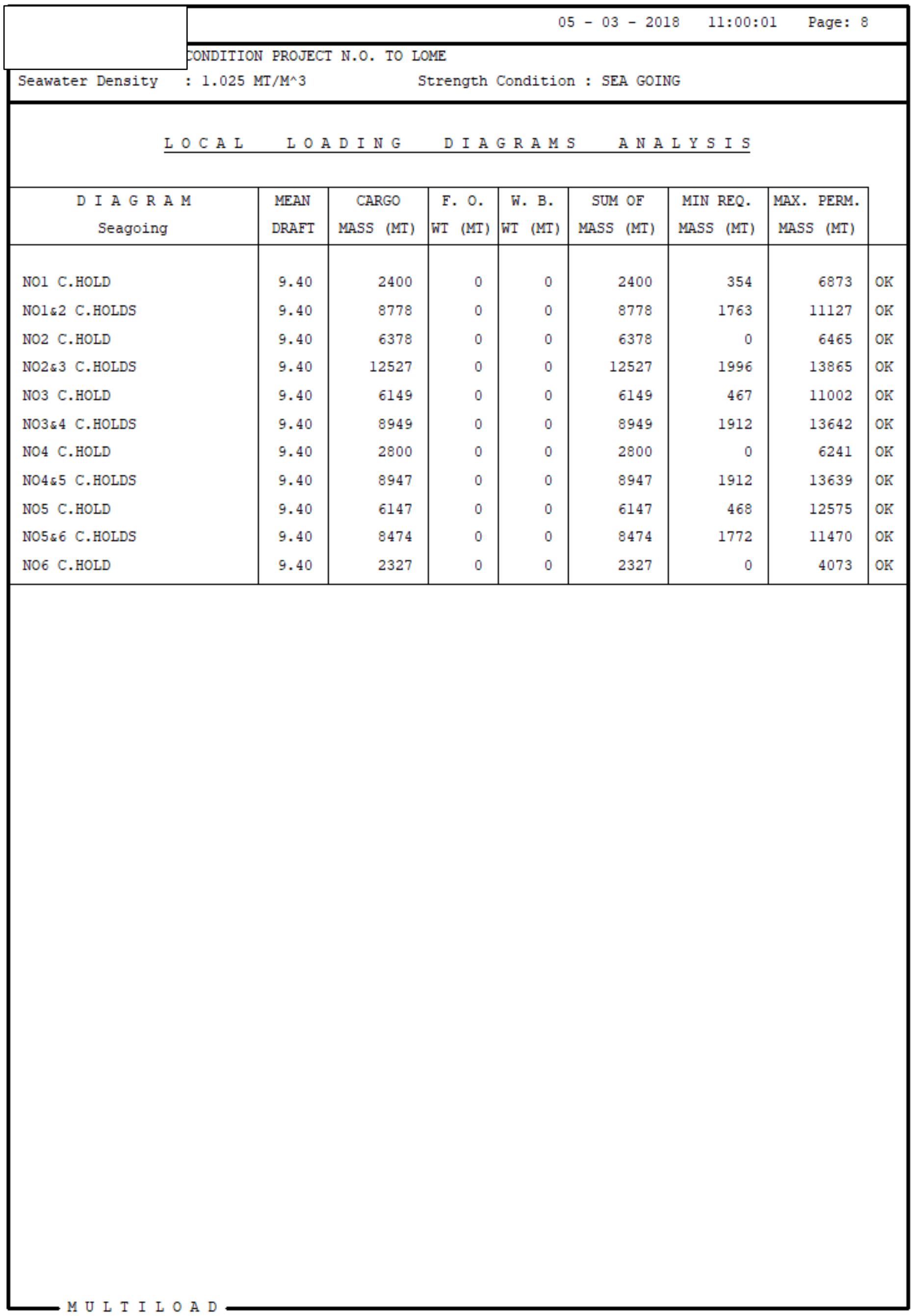
HOLD MASS TABLES



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[redacted]                                      05 - 03 - 2018    11:00:01    Page: 8
           CONDITION PROJECT N.O. TO LOME
Seawater Density   : 1.025 MT/M^3          Strength Condition : SEA GOING

              L O C A L    L O A D I N G    D I A G R A M S    A N A L Y S I S

      D I A G R A M        | MEAN  |  CARGO    | F. O.   | W. B.   |  SUM OF   | MIN REQ.  | MAX. PERM. |
        Seagoing           | DRAFT | MASS (MT) |WT  (MT)|WT  (MT)| MASS (MT) | MASS (MT) | MASS (MT)  |

 NO1 C.HOLD                |  9.40 |    2400   |    0    |    0    |    2400   |     354   |    6873    | OK
 NO1&2 C.HOLDS             |  9.40 |    8778   |    0    |    0    |    8778   |    1763   |   11127    | OK
 NO2 C.HOLD                |  9.40 |    6378   |    0    |    0    |    6378   |       0   |    6465    | OK
 NO2&3 C.HOLDS             |  9.40 |   12527   |    0    |    0    |   12527   |    1996   |   13865    | OK
 NO3 C.HOLD                |  9.40 |    6149   |    0    |    0    |    6149   |     467   |   11002    | OK
 NO3&4 C.HOLDS             |  9.40 |    8949   |    0    |    0    |    8949   |    1912   |   13642    | OK
 NO4 C.HOLD                |  9.40 |    2800   |    0    |    0    |    2800   |       0   |    6241    | OK
 NO4&5 C.HOLDS             |  9.40 |    8947   |    0    |    0    |    8947   |    1912   |   13639    | OK
 NO5 C.HOLD                |  9.40 |    6147   |    0    |    0    |    6147   |     468   |   12575    | OK
 NO5&6 C.HOLDS             |  9.40 |    8474   |    0    |    0    |    8474   |    1772   |   11470    | OK
 NO6 C.HOLD                |  9.40 |    2327   |    0    |    0    |    2327   |       0   |    4073    | OK

M U L T I L O A D
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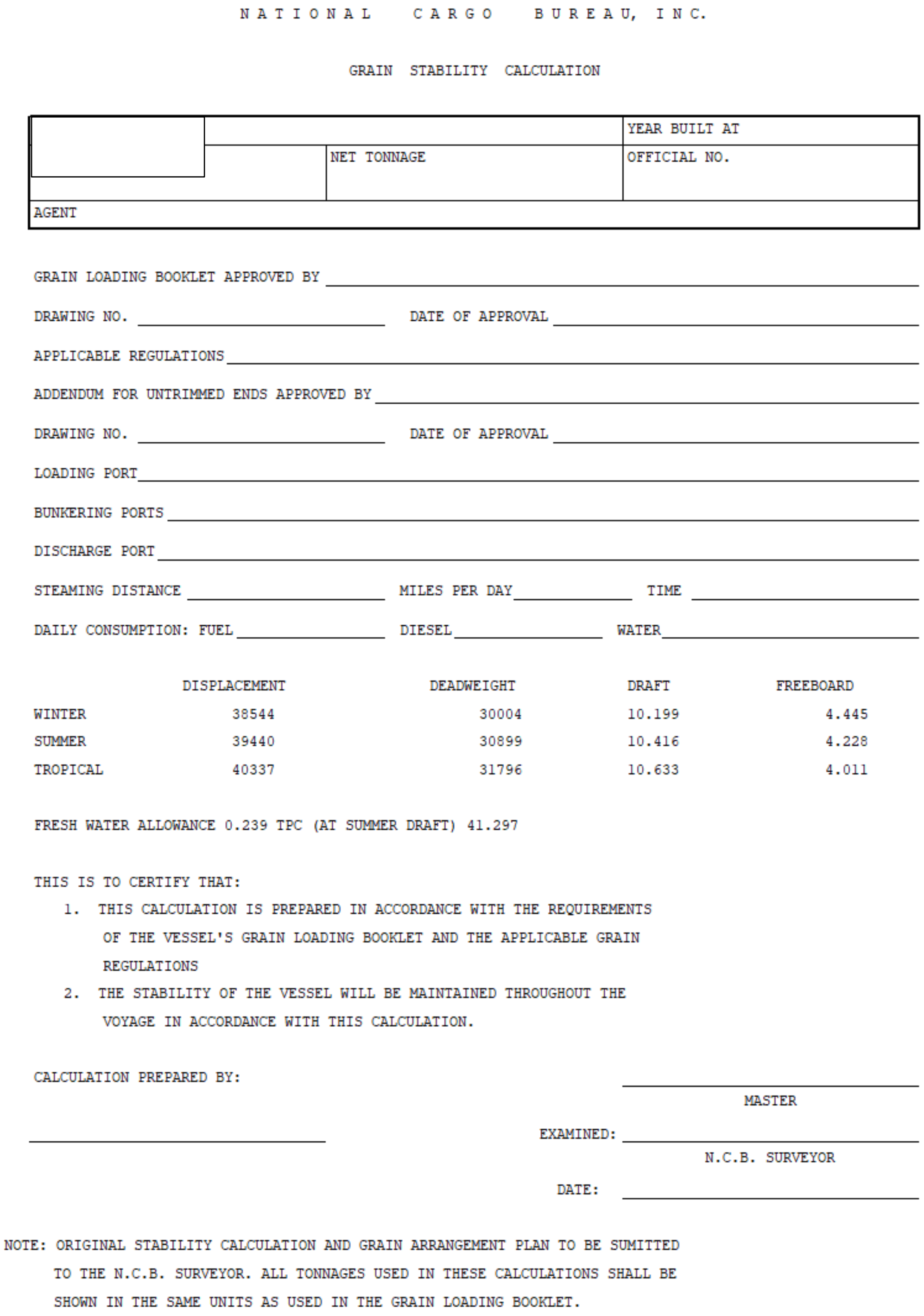
GRAIN STABILITY, SEA GOING CRITERION



NATIONAL CARGO BUREAU, INC.

GRAIN STABILITY CALCULATION

		YEAR BUILT AT
	NET TONNAGE	OFFICIAL NO.
AGENT		

GRAIN LOADING BOOKLET APPROVED BY

DRAWING NO. DATE OF APPROVAL

APPLICABLE REGULATIONS

ADDENDUM FOR UNTRIMMED ENDS APPROVED BY

DRAWING NO. DATE OF APPROVAL

LOADING PORT

BUNKERING PORTS

DISCHARGE PORT

STEAMING DISTANCE MILES PER DAY TIME

DAILY CONSUMPTION: FUEL DIESEL WATER

	DISPLACEMENT	DEADWEIGHT	DRAFT	FREEBOARD
WINTER	38544	30004	10.199	4.445
SUMMER	39440	30899	10.416	4.228
TROPICAL	40337	31796	10.633	4.011

FRESH WATER ALLOWANCE 0.239 TPC (AT SUMMER DRAFT) 41.297

THIS IS TO CERTIFY THAT:

1. THIS CALCULATION IS PREPARED IN ACCORDANCE WITH THE REQUIREMENTS OF THE VESSEL'S GRAIN LOADING BOOKLET AND THE APPLICABLE GRAIN REGULATIONS
2. THE STABILITY OF THE VESSEL WILL BE MAINTAINED THROUGHOUT THE VOYAGE IN ACCORDANCE WITH THIS CALCULATION.

CALCULATION PREPARED BY:

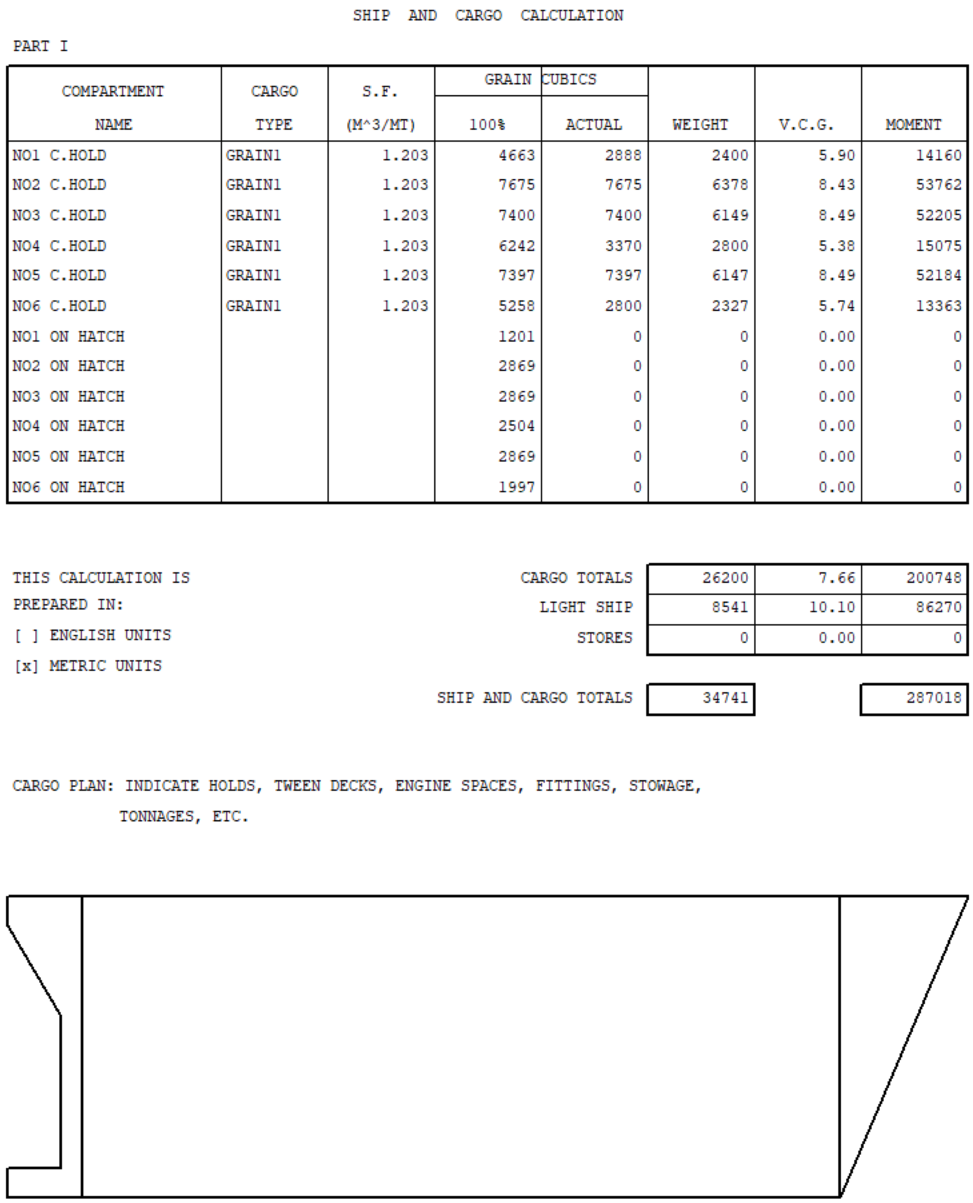
MASTER

EXAMINED:

N.C.B. SURVEYOR

DATE:

NOTE: ORIGINAL STABILITY CALCULATION AND GRAIN ARRANGEMENT PLAN TO BE SUMITTED TO THE N.C.B. SURVEYOR. ALL TONNAGES USED IN THESE CALCULATIONS SHALL BE SHOWN IN THE SAME UNITS AS USED IN THE GRAIN LOADING BOOKLET.



SHIP AND CARGO CALCULATION

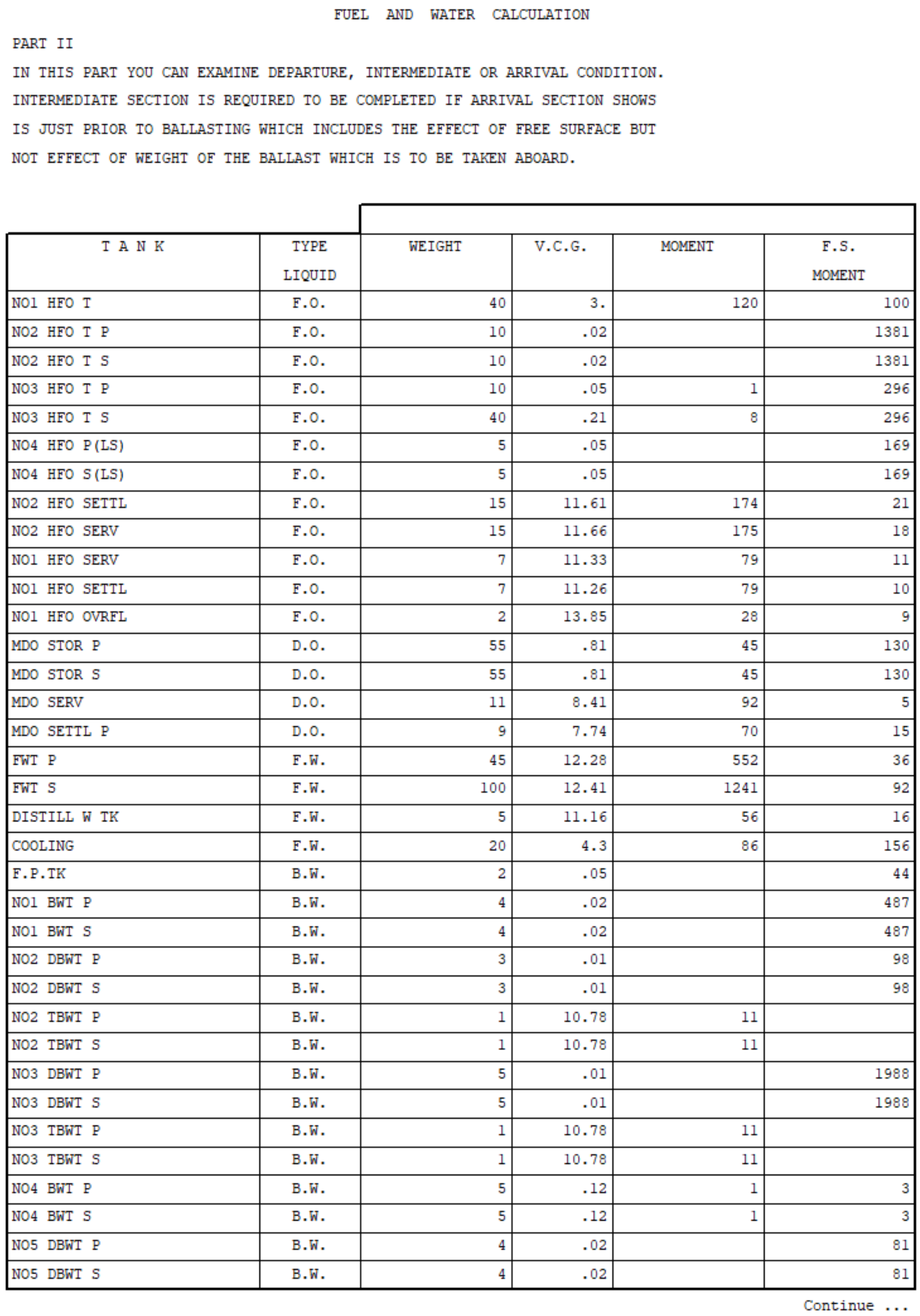
PART I

COMPARTMENT NAME	CARGO TYPE	S.F. (M^3/MT)	GRAIN CUBICS 100%	ACTUAL	WEIGHT	V.C.G.	MOMENT
NO1 C.HOLD	GRAIN1	1.203	4663	2888	2400	5.90	14160
NO2 C.HOLD	GRAIN1	1.203	7675	7675	6378	8.43	53762
NO3 C.HOLD	GRAIN1	1.203	7400	7400	6149	8.49	52205
NO4 C.HOLD	GRAIN1	1.203	6242	3370	2800	5.38	15075
NO5 C.HOLD	GRAIN1	1.203	7397	7397	6147	8.49	52184
NO6 C.HOLD	GRAIN1	1.203	5258	2800	2327	5.74	13363
NO1 ON HATCH			1201	0	0	0.00	0
NO2 ON HATCH			2869	0	0	0.00	0
NO3 ON HATCH			2869	0	0	0.00	0
NO4 ON HATCH			2504	0	0	0.00	0
NO5 ON HATCH			2869	0	0	0.00	0
NO6 ON HATCH			1997	0	0	0.00	0

THIS CALCULATION IS
PREPARED IN:
[ ] ENGLISH UNITS
[x] METRIC UNITS

CARGO TOTALS	26200	7.66	200748
LIGHT SHIP	8541	10.10	86270
STORES	0	0.00	0
SHIP AND CARGO TOTALS	34741		287018

CARGO PLAN: INDICATE HOLDS, TWEEN DECKS, ENGINE SPACES, FITTINGS, STOWAGE,
TONNAGES, ETC.



FUEL AND WATER CALCULATION

PART II

IN THIS PART YOU CAN EXAMINE DEPARTURE, INTERMEDIATE OR ARRIVAL CONDITION.

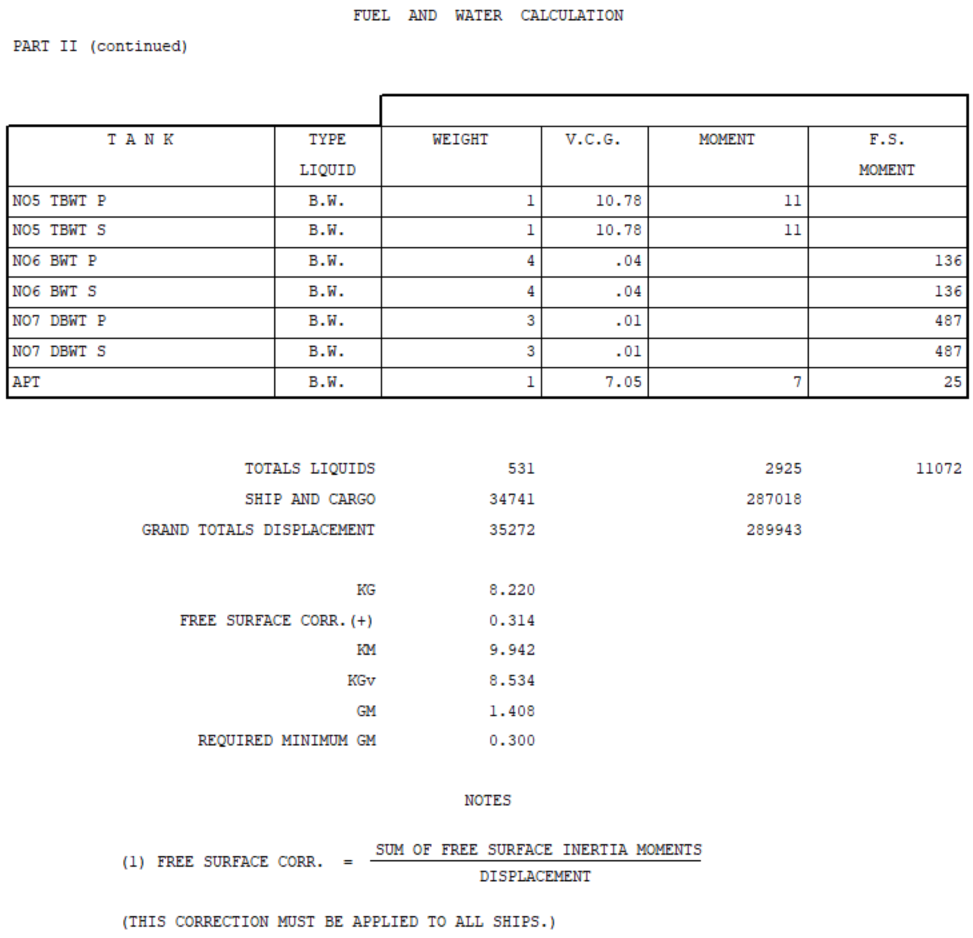
INTERMEDIATE SECTION IS REQUIRED TO BE COMPLETED IF ARRIVAL SECTION SHOWS

IS JUST PRIOR TO BALLASTING WHICH INCLUDES THE EFFECT OF FREE SURFACE BUT

NOT EFFECT OF WEIGHT OF THE BALLAST WHICH IS TO BE TAKEN ABOARD.

T A N K	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO1 HFO T	F.O.	40	3.	120	100
NO2 HFO T P	F.O.	10	.02		1381
NO2 HFO T S	F.O.	10	.02		1381
NO3 HFO T P	F.O.	10	.05	1	296
NO3 HFO T S	F.O.	40	.21	8	296
NO4 HFO P(LS)	F.O.	5	.05		169
NO4 HFO S(LS)	F.O.	5	.05		169
NO2 HFO SETTL	F.O.	15	11.61	174	21
NO2 HFO SERV	F.O.	15	11.66	175	18
NO1 HFO SERV	F.O.	7	11.33	79	11
NO1 HFO SETTL	F.O.	7	11.26	79	10
NO1 HFO OVRFL	F.O.	2	13.85	28	9
MDO STOR P	D.O.	55	.81	45	130
MDO STOR S	D.O.	55	.81	45	130
MDO SERV	D.O.	11	8.41	92	5
MDO SETTL P	D.O.	9	7.74	70	15
FWT P	F.W.	45	12.28	552	36
FWT S	F.W.	100	12.41	1241	92
DISTILL W TK	F.W.	5	11.16	56	16
COOLING	F.W.	20	4.3	86	156
F.P.TK	B.W.	2	.05		44
NO1 BWT P	B.W.	4	.02		487
NO1 BWT S	B.W.	4	.02		487
NO2 DBWT P	B.W.	3	.01		98
NO2 DBWT S	B.W.	3	.01		98
NO2 TBWT P	B.W.	1	10.78	11	
NO2 TBWT S	B.W.	1	10.78	11	
NO3 DBWT P	B.W.	5	.01		1988
NO3 DBWT S	B.W.	5	.01		1988
NO3 TBWT P	B.W.	1	10.78	11	
NO3 TBWT S	B.W.	1	10.78	11	
NO4 BWT P	B.W.	5	.12	1	3
NO4 BWT S	B.W.	5	.12	1	3
NO5 DBWT P	B.W.	4	.02		81
NO5 DBWT S	B.W.	4	.02		81

Continue ...



FUEL AND WATER CALCULATION

PART II (continued)

TANK	TYPE LIQUID	WEIGHT	V.C.G.	MOMENT	F.S. MOMENT
NO5 TBWT P	B.W.	1	10.78	11	
NO5 TBWT S	B.W.	1	10.78	11	
NO6 BWT P	B.W.	4	.04		136
NO6 BWT S	B.W.	4	.04		136
NO7 DBWT P	B.W.	3	.01		487
NO7 DBWT S	B.W.	3	.01		487
APT	B.W.	1	7.05	7	25

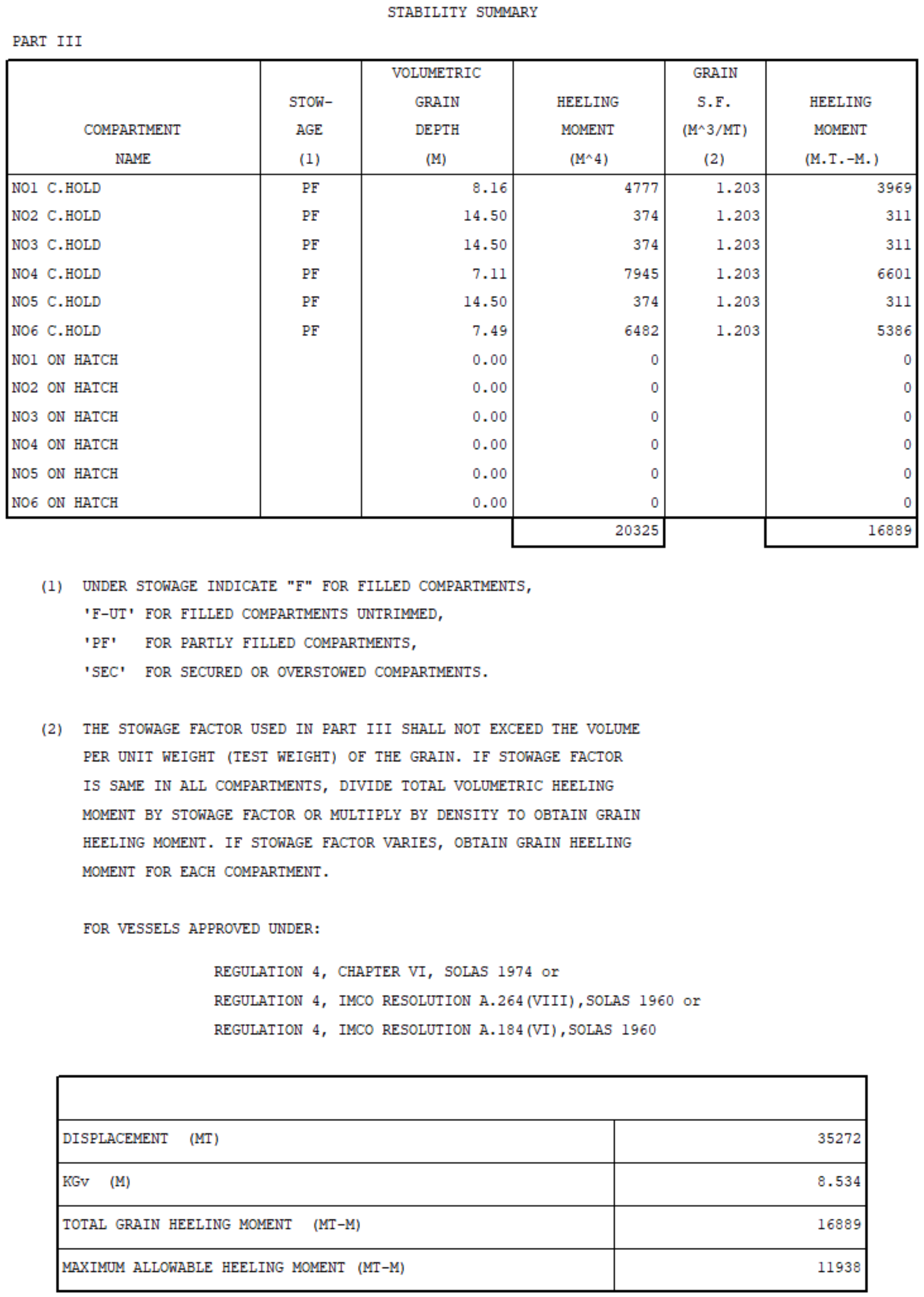
TOTALS LIQUIDS	531	2925	11072
SHIP AND CARGO	34741	287018	
GRAND TOTALS DISPLACEMENT	35272	289943	

KG	8.220
FREE SURFACE CORR.(+)	0.314
KM	9.942
KGv	8.534
GM	1.408
REQUIRED MINIMUM GM	0.300

NOTES

(1) FREE SURFACE CORR. $= \frac{\text{SUM OF FREE SURFACE INERTIA MOMENTS}}{\text{DISPLACEMENT}}$

(THIS CORRECTION MUST BE APPLIED TO ALL SHIPS.)



STABILITY SUMMARY

PART III

COMPARTMENT NAME	STOW-AGE (1)	VOLUMETRIC GRAIN DEPTH (M)	HEELING MOMENT (M^4)	GRAIN S.F. (M^3/MT) (2)	HEELING MOMENT (M.T.-M.)
NO1 C.HOLD	PF	8.16	4777	1.203	3969
NO2 C.HOLD	PF	14.50	374	1.203	311
NO3 C.HOLD	PF	14.50	374	1.203	311
NO4 C.HOLD	PF	7.11	7945	1.203	6601
NO5 C.HOLD	PF	14.50	374	1.203	311
NO6 C.HOLD	PF	7.49	6482	1.203	5386
NO1 ON HATCH		0.00	0		0
NO2 ON HATCH		0.00	0		0
NO3 ON HATCH		0.00	0		0
NO4 ON HATCH		0.00	0		0
NO5 ON HATCH		0.00	0		0
NO6 ON HATCH		0.00	0		0
			20325		16889

(1) UNDER STOWAGE INDICATE "F" FOR FILLED COMPARTMENTS,
'F-UT' FOR FILLED COMPARTMENTS UNTRIMMED,
'PF' FOR PARTLY FILLED COMPARTMENTS,
'SEC' FOR SECURED OR OVERSTOWED COMPARTMENTS.

(2) THE STOWAGE FACTOR USED IN PART III SHALL NOT EXCEED THE VOLUME PER UNIT WEIGHT (TEST WEIGHT) OF THE GRAIN. IF STOWAGE FACTOR IS SAME IN ALL COMPARTMENTS, DIVIDE TOTAL VOLUMETRIC HEELING MOMENT BY STOWAGE FACTOR OR MULTIPLY BY DENSITY TO OBTAIN GRAIN HEELING MOMENT. IF STOWAGE FACTOR VARIES, OBTAIN GRAIN HEELING MOMENT FOR EACH COMPARTMENT.

FOR VESSELS APPROVED UNDER:

REGULATION 4, CHAPTER VI, SOLAS 1974 or
REGULATION 4, IMCO RESOLUTION A.264(VIII),SOLAS 1960 or
REGULATION 4, IMCO RESOLUTION A.184(VI),SOLAS 1960

DISPLACEMENT (MT)	35272
KGv (M)	8.534
TOTAL GRAIN HEELING MOMENT (MT-M)	16889
MAXIMUM ALLOWABLE HEELING MOMENT (MT-M)	11938

10.6- APPENDIX 6

EXCEL SPREADSHEET WITH CALCULATION OF THE PERIOD OF ROLL USING VARIOUS METHODS

CALCULATION OF ROLL PERIOD OF THE VESSEL USED AS MODEL

ARRIVAL WITHOUT BALLAST

METHOD PROPOSED BY E.C. TUPPER (BASIC SHIP THEORY)

DATA

PARAMETERS	SYMBOL	VALUE	UNIT
DRAFT EXREME	T	9.4000	M
KEEL THICKNESS	KT	0.0160	M
GM FLUID	GM	1.4100	M
F (C0NSTANT)	F	0.1250	
BREADTH EXTREME	B	23.7000	M
DEPTH EXTREME	D	14.6440	M
LENGTH OVERALL	L	185.0000	M
LENGTH BET PERP	L PP	178.0000	M
BLOCK COEFFICIENT	CB	0.8663	
GRAVITY	g	9.806	$\mathrm{M\ X\ SEC}^2$
PI	π	3.1416	

PARAMETERS TO CALCULATE				**FORMULA**
LENGTH SUPERST	L SUPERST	19.2000	M	From frame 35-11 = 24 frames X 0.8M = 19.2M
WIDTH SUPERST	W SUPERST	13.8500	M	31.95 - 18.1 = 13.85 (from GA, heights over BL)
AREA ERECTIONS	A ERECTIONS	265.9200	M	A ERECTIONS = L SUPERST x W SUPERST x COS 0
LENGTH DECK	L DECK	139.8000	M	Fr 209-35 = 174 frs x 0.8M = 139.2 + 1fr x 0.6M = 139.8 M
WIDTH DECK	W DECK	0.5000	M	Camber = 0.5
AREA DECK	A DECK	69.9000	M2	A DECK = L DECK x W DECK x COS 0
AREA FREEBOARD	A FREEBOARD	933.4320	M2	A FREEBOARD = L PP x (D-T)
AREA LATERAL PROJECT DECK	A1	1269.2520	M2	A = (A ERECTIONS + A DECK + A FREEBOARD)
WINDAGE LATERAL A	A2	1849.0000	M2	FROM COMPUTER RESULTS (APPENDIX
EFFECTIVE DEPTH	H1	21.7746	M	H = D + A1/LPP

EFFECTIVE DEPTH	H2	25.0316	M	H = D + A2/LPP
DECK COEFFICIENT	CU	0.000228		CU = 1/LB
DRAFT MOULDED	TM	9.3840	M	TM = T - KT
RADIUS OF GYRATION	K1	7.6995	M	$K = B\,x\,\sqrt{F\left[C_B C_U + 1.10 C_U \left(\frac{H}{T} - 2.20\right) + \frac{H^2}{B^2}\right]}$
RADIUS OF GYRATION	K2	8.8513	M	
PERIOD OF ROLL 1	**$T\Phi$**	**13.0099**	**SEC**	$T_\phi = 2\pi \frac{K}{(g\ GM_T)^{\frac{1}{2}}}$
PERIOD OF ROLL 2	**$T\Phi$**	**14.9560**	**SEC**	

METHOD PROPOSED BYA.B.BIRAN (SHIP HYDROSTATICS AND STABILITY)

PARAMETERS	SYMBOL	VALUE	UNIT
GM FLUID	GM	1.4100	M
BREADTH EXTREME	B	23.7000	M

PARAMETERS TO CALCULATE				**FORMULA**		
RADIUS OF GYRATION	im	7.9000	M	im = B/3	Costaguta, 1981	
	im	8.2950	M	im = 0.35B	Shipyard	
CONSTANT	C	0.6667		C = 2im/B	for Costaguta	
	C	0.7000		C = 2im/B	for shipyard	
PERIOD OF ROLL	**$T\Phi$**	**13.3060**	**SEC**	$T_\phi = \frac{cB}{\sqrt{GM}}$	for Costaguta	**MEAN VALUE**
	$T\Phi$	**13.9713**	**SEC**		for shipyard	**13.6386504**

METHOD PROPOSED BY ISC / WAWRZYNNSKI AND KRATA

PARAMETERS	SYMBOL	VALUE	UNIT
GM FLUID	GM	1.4100	M
BREADTH EXTREME	B	23.7000	M
DRAFT EXREME	T	9.4000	M
LENGTH WATERLINE	L WL	181.9400	M

PARAMETERS TO CALCULATE				
CONSTANT	C	0.3528		C = 0.373 + 0.023B/T - 0,043L/100

PERIOD OF ROLL **TΦ** **14.0813** **SEC**

$$\boxed{T_\phi = \frac{2cB}{\sqrt{GM}}}$$

CALCULATION OF ROLL PERIOD OF THE MODEL

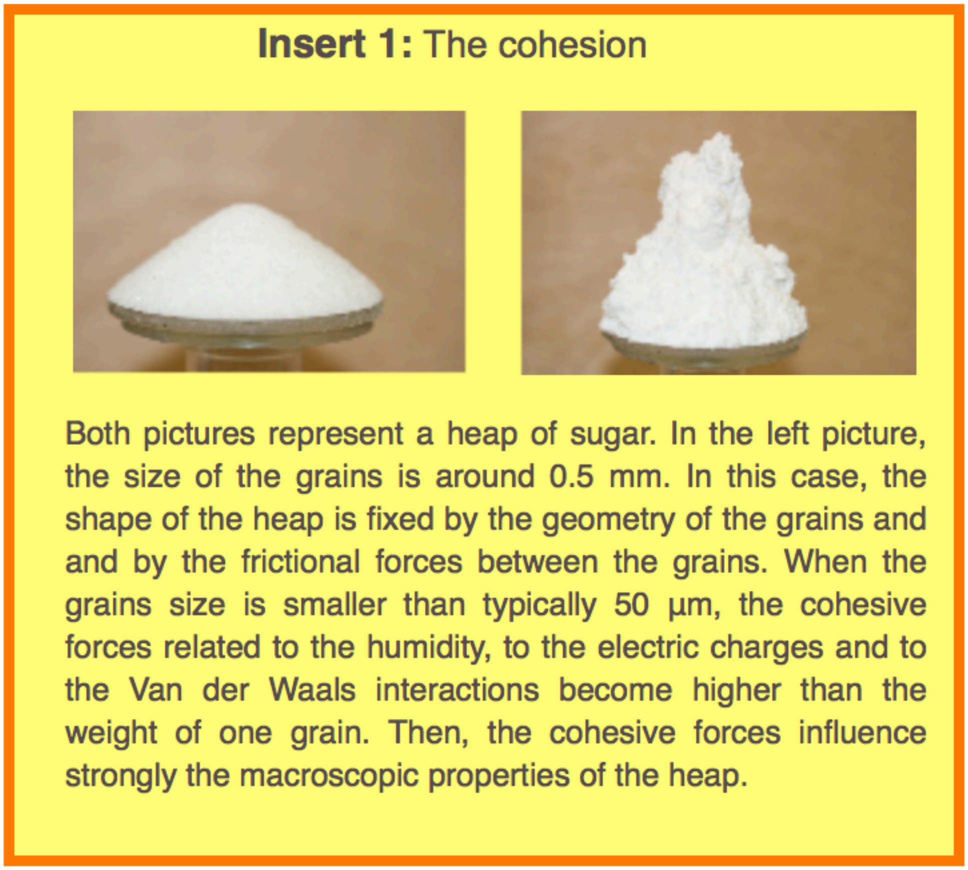
METHOD PROPOSED BYA.B.BIRAN (SHIP HYDROSTATICS AND STABILITY)

PARAMETERS	SYMBOL	VALUE	UNIT
GM FLUID	GM	0.0353	M
BREADTH EXTREME	B	0.5925	M

PARAMETERS TO CALCULATE				**FORMULA**		
RADIUS OF GYRATION	im	0.0049	M	im = B/3	Costaguta, 1981	
	im	0.0052	M	im = 0.35B	Shipyard	
CONSTANT	C	0.6667		C = 2im/B	for Costaguta	
	C	0.7000		C = 2im/B	for shipyard	
	C	0.4290		C = 0.373 + 0.023B/T - 0,043L/100		for ISC / W&K
PERIOD OF ROLL	**TΦ**	**2.1039**	**SEC**	$\boxed{T_\phi = \frac{cB}{\sqrt{GM}}}$	for Costaguta	**MEAN VALUE**
	TΦ	**2.2091**	**SEC**		for shipyard	**2.34026786**
	TΦ	**2.7079**	**SEC**		for ISC/W&K	

10.7- APPENDIX 7

COHESION EXPERIMENT (VANDEWALLE ET LUMAY)

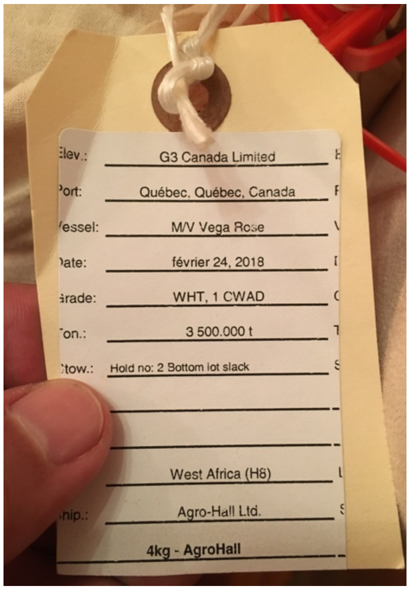


Insert 1: The cohesion

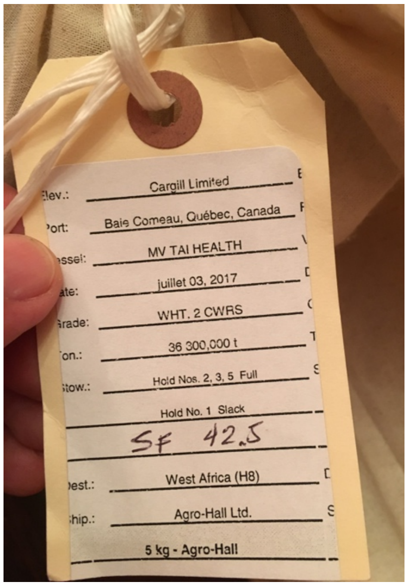
Both pictures represent a heap of sugar. In the left picture, the size of the grains is around 0.5 mm. In this case, the shape of the heap is fixed by the geometry of the grains and and by the frictional forces between the grains. When the grains size is smaller than typically 50 µm, the cohesive forces related to the humidity, to the electric charges and to the Van der Waals interactions become higher than the weight of one grain. Then, the cohesive forces influence strongly the macroscopic properties of the heap.

10.8- APPENDIX 8

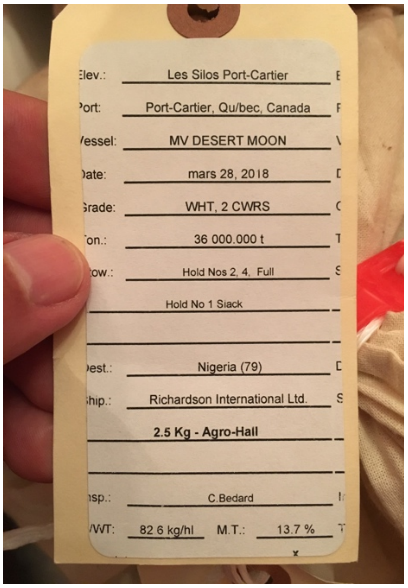
ORIGINAL TAGS WITH DATA OF SAMPLES USED



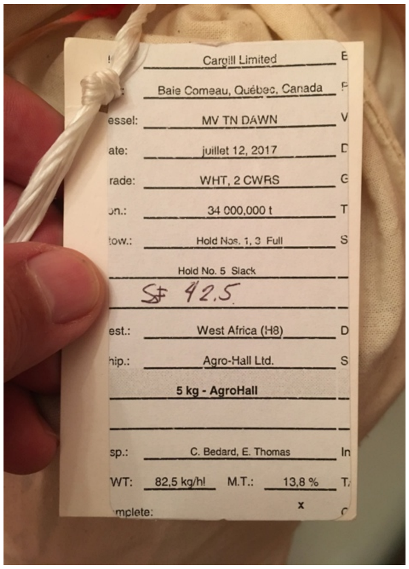
lev.: G3 Canada Limited
ort: Québec, Québec, Canada
essel: M/V Vega Rose
ate: février 24, 2018
rade: WHT, 1 CWAD
on.: 3 500.000 t
tow.: Hold no: 2 Bottom lot slack
West Africa (H8)
hip.: Agro-Hall Ltd.
4kg - AgroHall



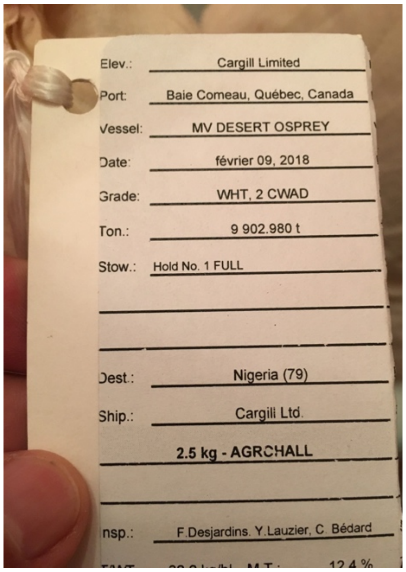
lev.: Cargill Limited
ort: Baie Comeau, Québec, Canada
ssel: MV TAI HEALTH
ate: juillet 03, 2017
rade: WHT. 2 CWRS
on.: 36 300,000 t
tow.: Hold Nos. 2, 3, 5 Full
Hold No. 1 Slack
SF 42.5
est.: West Africa (H8)
hip.: Agro-Hall Ltd.
5 kg - Agro-Hall



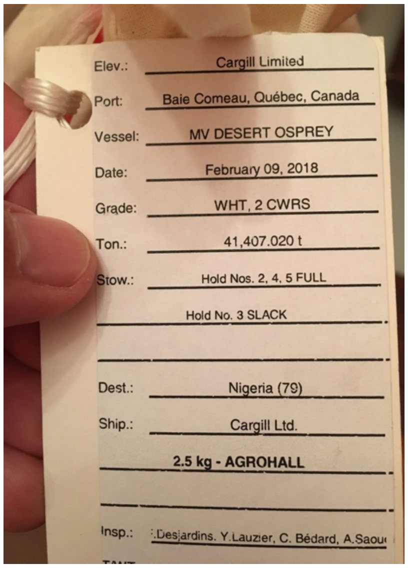
lev.: Les Silos Port-Cartier
ort: Port-Cartier, Qu/bec, Canada
essel: MV DESERT MOON
ate: mars 28, 2018
rade: WHT, 2 CWRS
on.: 36 000.000 t
ow.: Hold Nos 2, 4, Full
Hold No 1 Siack
est.: Nigeria (79)
hip.: Richardson International Ltd.
2.5 Kg - Agro-Hall
nsp.: C.Bedard
WT: 82 6 kg/hl M.T.: 13.7 %
x



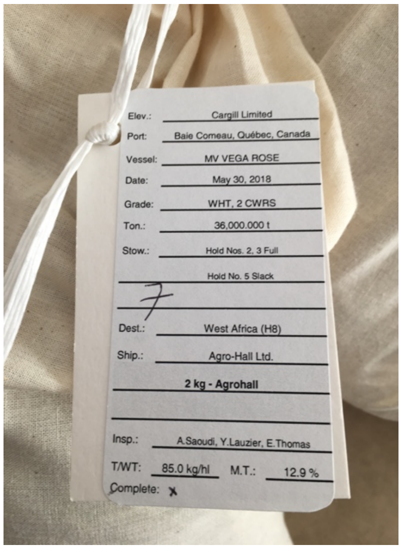
Cargill Limited
Baie Comeau, Québec, Canada
essel: MV TN DAWN
ate: juillet 12, 2017
rade: WHT, 2 CWRS
on.: 34 000,000 t
tow.: Hold Nos. 1, 3 Full
Hold No. 5 Slack
SF 42.5
est.: West Africa (H8)
hip.: Agro-Hall Ltd.
5 kg - AgroHall
sp.: C. Bedard, E. Thomas
WT: 82,5 kg/hl M.T.: 13,8 %
x
mplete:



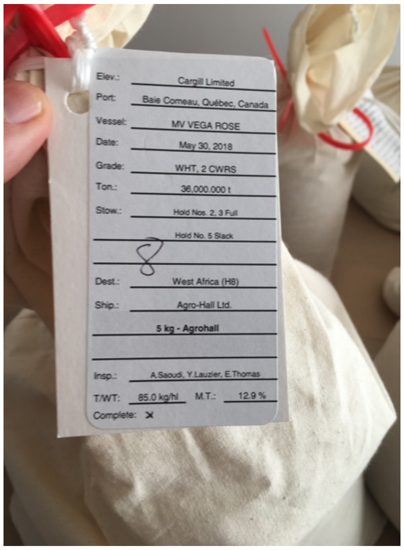
Elev.: Cargill Limited
Port: Baie Comeau, Québec, Canada
Vessel: MV DESERT OSPREY
Date: février 09, 2018
Grade: WHT, 2 CWAD
Ton.: 9 902.980 t
Stow.: Hold No. 1 FULL
Dest.: Nigeria (79)
Ship.: Cargill Ltd.
2.5 kg - AGROHALL
nsp.: F.Desjardins. Y.Lauzier, C. Bédard



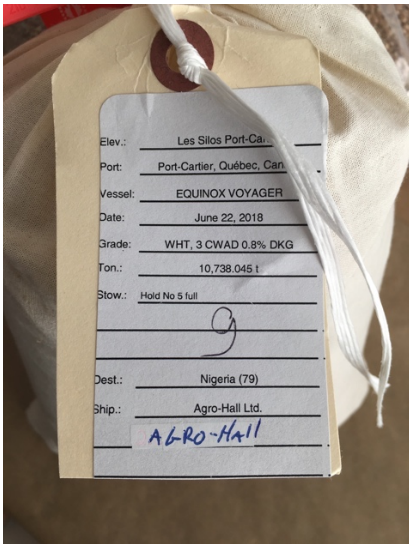
Elev.: Cargill Limited
Port: Baie Comeau, Québec, Canada
Vessel: MV DESERT OSPREY
Date: February 09, 2018
Grade: WHT, 2 CWRS
Ton.: 41,407.020 t
Stow.: Hold Nos. 2, 4, 5 FULL
Hold No. 3 SLACK
Dest.: Nigeria (79)
Ship.: Cargill Ltd.
2.5 kg - AGROHALL
Insp.: .Desjardins. Y.Lauzier, C. Bédard, A.Saou



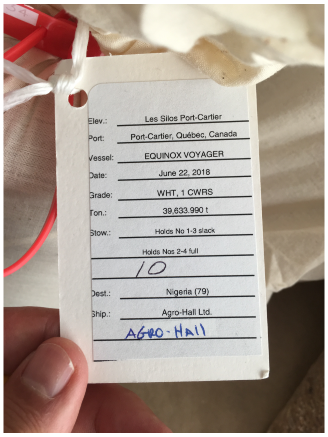
Elev.: Cargill Limited
Port: Baie Comeau, Québec, Canada
Vessel: MV VEGA ROSE
Date: May 30, 2018
Grade: WHT, 2 CWRS
Ton.: 36,000.000 t
Stow.: Hold Nos. 2, 3 Full
Hold No. 5 Slack
7
Dest.: West Africa (H8)
Ship.: Agro-Hall Ltd.
2 kg - Agrohall
Insp.: A.Saoudi, Y.Lauzier, E.Thomas
T/WT: 85.0 kg/hl M.T.: 12.9 %
Complete: ✗



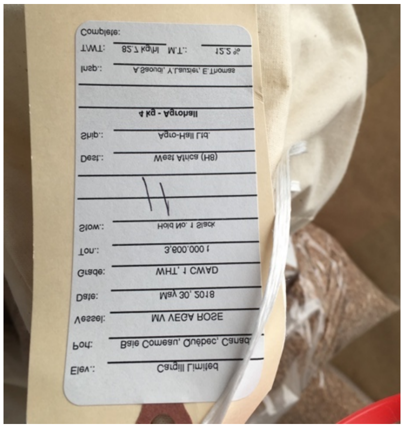
Elev.: Cargill Limited
Port: Baie Comeau, Québec, Canada
Vessel: MV VEGA ROSE
Date: May 30, 2018
Grade: WHT, 2 CWRS
Ton.: 36,000.000 t
Stow.: Hold Nos. 2, 3 Full
Hold No. 5 Slack
8
Dest.: West Africa (H8)
Ship.: Agro-Hall Ltd.
5 kg - Agrohall
Insp.: A.Saoudi, Y.Lauzier, E.Thomas
T/WT: 85.0 kg/hl M.T.: 12.9 %
Complete: ✗



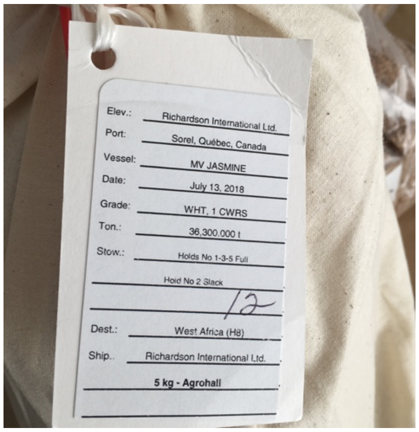
Elev.: Les Silos Port-Ca
Port: Port-Cartier, Québec, Can
Vessel: EQUINOX VOYAGER
Date: June 22, 2018
Grade: WHT, 3 CWAD 0.8% DKG
Ton.: 10,738.045 t
Stow.: Hold No 5 full
9
Dest.: Nigeria (79)
Ship.: Agro-Hall Ltd.
AGRO-HAll



Elev.: Les Silos Port-Cartier
Port: Port-Cartier, Québec, Canada
Vessel: EQUINOX VOYAGER
Date: June 22, 2018
Grade: WHT, 1 CWRS
Ton.: 39,633.990 t
Stow.: Holds No 1-3 slack
Holds Nos 2-4 full
10
Dest.: Nigeria (79)
Ship.: Agro-Hall Ltd.
AGRO-HAll



Elev.: Cargill Limited
Port: Baie Comeau, Québec, Canad
Vessel: MV VEGA ROSE
Date: May 30, 2018
Grade: WHT, 1 CWAD
Ton.: 3,600.000 t
Stow.: Hold No. 1 Slack
11
Dest.: West Africa (H8)
Ship.: Agro-Hall Ltd.
4 kg - Agrohall
Insp.: A.Saoudi, Y.Lauzier, E.Thomas
T/WT: 82.7 kg/hl M.T.: 12.2 %
Complete:



Elev.: Richardson International Ltd.
Port: Sorel, Québec, Canada
Vessel: MV JASMINE
Date: July 13, 2018
Grade: WHT, 1 CWRS
Ton.: 36,300.000 t
Stow.: Holds No 1-3-5 Full
Hold No 2 Slack
12
Dest.: West Africa (H8)
Ship.: Richardson International Ltd.
5 kg - Agrohall

2CWRS 13.
protein 13.1
moisture 13.2

#2 CWRS 14
13.5% protein