



Shell Australia

Guidance On Conducting Sloshing Risk Assessment For Operators Of Membrane LNG Carriers

Originating Company	Shell Australia
Department	Marine
Document Number	OPS_PRE_013666
Revision Number	2.0
Document Type	Procedure [BCD]
Document Status	AFU
Revision Date	30/01/2019
Cyclical Review Date	11/01/2021
Safety Critical Content	true
Technical Reviewer TA ² or SME	Marine Terminal Manager
Process Owner	Marine Terminal Manager
Security Classification	Unrestricted
Export Classification Number	Non-US content - Non Controlled



Ver.	Version Update Description	Date Changed	BCD Development Roles Authors, Reviewers, Approvers	
1.0	Written by Shell Shipping & Maritime (Report No.SST03336-16 th January 2017)	1/10/2018	Joseph Pereira Jorge Adams Jonathan Wilson Enter Name. Enter Name.	Reviewer (SME) Reviewer (IP) Approver (PO) Choose an item. Choose an item.
1.1	Review for Re-Issue In Preparation For Commencing Offloading Operations Section 2.1 – Full section change Section 2.4 – minor alteration to last para Section 3.3 – rewording of several sentences in 2 nd para Section 3.4 – minor amendments to para 5	12/14/2018	Naidu, PremKumar John Kaighin	Author Approver (PO)
1.2	Issued for Approval	1/11/2019	Naidu, Prem Kumar John Kaighin	Author Approver (PO)
2.0	AFU	30-1-19		



Table of Contents

Abbreviations	4
1 Introduction.....	5
1.1 Preamble.....	5
1.2 Background.....	5
1.3 Purpose	5
1.4 Scope	6
1.5 The LNG Carrier Operator’s Responsibility.....	6
2 Guidance to Ship Operators: Managing Sloshing Risk	7
2.1 Conducting Risk Assessment to Manage Risk of Sloshing.....	7
2.2 Planning Cargo Operations for Cargo Consolidation	7
2.3 Planning Ballasting and De-ballasting to Minimize Risk of Sloshing	8
2.4 Contingency Planning	8
3 Providing a Safe Terminal – Management of Sloshing Risks	9
3.1 General	9
3.2 Operability Criteria for Side-by-Side Loading.....	9
3.3 Operational Risk Management	10
3.4 Sloshing Risk Analysis.....	10
3.4.1 Qualitative Risk Assessment.....	11
3.4.2 Quantitative Assessment - GTT Sloshing Risk Evaluation for LNGC Side by Side Operations	15
3.4.3 GTT Sea Keeping Analysis for an LNGC alongside FLNG	15
3.4.4 Sloshing Analysis	15
3.4.5 Assessment of Pump tower loads.....	16
4 Sloshing Risk Assessment: Summary Conclusions.....	16
Appendix A: Definition of Operability Criteria	18
Appendix B: Risk Assessment Matrix.....	19
Appendix C: Explanation of Sloshing Methodology	21
References.....	23



Abbreviations

ALARP	As Low As Reasonably Practicable
As	Roll acceleration
CCS	Cargo Containment System
DAD	Design Appraisal Document (Lloyds Register appraisal document)
EETV	Emergency Evacuation Tug Vessel
FiFi	Firefighting
FLNG	Floating Liquefied Natural Gas
Hs	Significant wave height
ISV	In-Field Service Vessel
LNGC	Liquefied Natural Gas Carrier
LPGC	Liquefied Petroleum Gas Carrier
LTT	Lead Terminal Technician
MLA	Marine Loading Arm(s)
OIM	Offshore Installation Manager
RA	Risk Assessment
RAM	Risk Assessment Matrix
SbS	Side by side
STS	Ship to Ship
Tp	Modal peak period (waves)
TSC	Technip Samsung Consortium
TSC	Technip Samsung Consortium
TTL	Terminal Team Lead



1 Introduction

1.1 Preamble

Lloyds Register and Industry Bodies have produced guidance for membrane LNG carriers operating in exposed locations typically requiring an assessment of the sloshing risks to be submitted for Class approval prior to first operation of each LNG carrier.

This document provides guidance to ship-owners and operators in the preparation of such a sloshing risk assessment. It is based upon generic risk assessments undertaken by Prelude FLNG operators Shell Australia to demonstrate the tolerable sloshing risks for LNG carriers operating alongside Prelude.

1.2 Background

Prelude LNG is located to the North West of Australia some 200 km off shore. The facility is designed to produce and liquefy predominately natural gas from subsea offshore reservoirs. Produced LNG will be stored on board and routinely offloaded to membrane and independent Type B LNG carriers moored alongside Prelude FLNG.

The cargo will be transferred through FMC designed Marine Loading Arms (MLA) in a similar manner to a shore based loading terminal. Prelude FLNG is designed to accommodate membrane and Moss-Rosenburg LNG carriers in the range 135,000m³ to 175,000m³.

Typically the LNGC will arrive at Prelude in a cold condition with a small amount of heel remaining in some or all of its cargo tanks. Loading to multiple cargo tanks concurrently (LNGC stability permitting) is the expected operating practice. This will result in tank filling levels passing through the normal critical filling range - approximately 10% to 70% tank height (H) at primary barrier level for membrane LNG carriers of this size range - which may result in moderate to severe sloshing if the sea state is sufficiently adverse. With the exception of cyclone events, when no LNG offloading is possible, the Metocean conditions at Prelude are considered to be relatively benign. However the wave climate is complex and both wind and multiple swell waves can be present.

1.3 Purpose

The operator and Master of each visiting LNG carrier is responsible for the safety of their own vessel, but Prelude operator recognizes that the terminal has a role to play in the provision of a safe operating environment. This document seeks to serve the following purposes:

- 1) To provide guidance to ship operators on carrying out a risk assessment to ensure that the sloshing risks whilst operating alongside Prelude are acceptable. The document recommends the procedures and measures to reduce the risks to 'as low as reasonably practicable' (ALARP).



- 2) To demonstrate to all stake holders, through qualitative and quantitative risk assessment, that typical membrane LNG carriers can load at the facility with acceptably low risk of sloshing damage provided that the operational, organisational and engineering controls discussed in this document are in place.

This document should be read in consultation with other industry guidance, namely:

- Classification Society guidance such as Lloyd's Register Guidance on the Operation of Membrane LNG Ships to Reduce the Risk of Damage due to Sloshing January 2012 [Ref: 1].
- Gaz Transport & Technigaz, General Guidance for Ships Emergency Departure with Tanks at Non-Approved Filling Levels, External Document No 3202

1.4 Scope

This document is applicable to managing sloshing risks on membrane LNG carriers moored alongside Prelude FLNG. The document applies to membrane LNGCs between 138,000m³ and 175,000m³.

(Independent tanks are not considered in the document for which guidance should be sought from the relevant Classification Society as applicable. Moss Type B tanks do not have restricted filling ranges and have lower exposure to risk from sloshing damage, due to their spherical shape and self-supporting structure of the tanks.

Other independent tank types may be required to demonstrate adequate strength against sloshing loads in partial fill conditions if not considered in the tank design. Although this document specifically does not apply to LNG carriers with independent tanks, elements of the risk assessment are relevant to these vessels and best practices outlined in this document will enhance operational safety).

1.5 The LNG Carrier Operator's Responsibility

The information provided in this document is for general use and information only and is not specific to a particular LNG Carrier's specifications or requirements for safe loading. It is expected that the operator of the LNGC has conducted its own due diligence with regards the requirements and loading of the LNGC, and remains solely responsible at all times for the vessel (including the safe loading of the vessel). As operator of the Prelude terminal, Shell Australia Pty Ltd and any of its affiliates make no representations nor give any warranties in relation to fitness or suitability of the service or information provided in this guidance document or any other document provided in relation to it.

Doc Number: OPS_PRE_013666	Unrestricted	Page 6 of 23
<i>All printed copies of "Copy No 01" are to be considered uncontrolled.</i>		



2 Guidance to Ship Operators: Managing Sloshing Risk

The master of each visiting LNG Carrier is responsible for the safety of their vessel. It is recognised that loading a LNGC alongside an FLNG may be first of a kind operation for LNGC masters and operators. Prior to first call at Prelude terminal, the LNG Carrier's operator is recommended to conduct a risk assessment as part of their due diligence to confirm the capability of the LNG Carrier to load alongside Prelude within the terminal operating parameters and environmental hindcast data. The LNG operator should be guided by their vessel's Classification Society and containment system designer.

2.1 Conducting Risk Assessment to Manage Risk of Sloshing

As part of the Compatibility Assessment process the vessel operator will be required to demonstrate their assessment of 'sloshing' risk. The Prelude Offshore Lifting Coordinator and Compatibility Assessor are to be advised during the Assessment stage of any class enforced operating restrictions for the nominated LNGC to safely load at Prelude FLNG Marine terminal.

It is the Vessel Operator's responsibility to engage with their relevant Classification Society to ensure the vessel operates within class recommendations for membrane type LNG vessels loading at "exposed terminals" where sloshing is deemed a risk. N.B This is mandatory requirement for some classification societies.

The Prelude Terminal environmental parameters are detailed in OPS_GEN_004647 Prelude FLNG Terminal Information Book – LNG.

2.2 Planning Cargo Operations for Cargo Consolidation

A safe Contingency Plan for each LNG Carrier visiting Prelude terminal will be expected to include a cargo consolidation plan, available in the event that the LNG carrier is required to depart the terminal prior to cargo completion.

The terminal procedures will require verification that all visiting LNGCs plan their cargo operations, such that cargo consolidation, by internal transfer, to achieve permissible 'at sea' tank levels can be carried out within 8 hours from any stage of loading. The Contingency Plan, including cargo consolidation plan, will be included in the pre-arrival exchange of information between FLNG and LNGC.

GTT has undertaken a consolidation study which demonstrates that a representative 145,000m³ LNGC will be able to internally transfer LNG to achieve unrestricted filling levels within 8 hours.



2.3 Planning Ballasting and De-ballasting to Minimize Risk of Sloshing

Lloyd's Register guidance (Ref 1) indicates that sloshing risk increases significantly when the wave encounter period is close to both the roll natural period (producing the largest motions) and the tank natural period (producing resonant LNG cargo motions).

It is expected that Prelude terminal and the ship operator will cooperate and agree on measures to minimise LNG carrier motions to limit the risk of steel contact and potential for mooring issues. In this regard, the terminal will facilitate and assist the ship-operator to minimise the risks from sloshing whilst alongside.

The natural roll period, together with roll angle, are key motions that can lead to potential sloshing impacts, as well as potential steel contact between LNGC and FLNG. It is suggested that cargo and ballast operations should be planned so that the natural roll period (TNPr) of the LNGC remains outside the range 12.5 to 15.5 seconds, for the maximum duration of operations. Keeping natural roll period outside the above mentioned non-desirable range as far as possible should assist with limiting the amplitude of LNGC roll motions and sloshing impact pressures (while the cargo levels pass through the 10%H to 70%H range).

Shell, together with Babcock International Group, has conducted extensive studies into alternative ballasting philosophies. Studies suggest that retaining maximum ballast until 25% cargo has been loaded on-board ensures that the natural roll period of the vessel moves through the non-desirable range of 12.5-15.5 seconds in minimum time.

2.4 Contingency Planning

It is recognised that risk of sloshing will be increased if LNGC is required to un-berth prematurely with partially-filled cargo tanks due to unforeseen events, such as an emergency on-board either FLNG or LNGC, unfavourable weather conditions or other causes. As part of the LNG carrier's Contingency Plan, cargo consolidation should specify the actions to be taken prior to and after a premature departure event.

Actions prior to premature departure from Prelude Terminal :

Prior to un-berthing, as time permits, action should be specified to re-distribute and consolidate cargo to ensure the tank levels are either within the 'permissible' filling levels for trading LNG carriers (typically below 10% and above 70% of the tank height (H)). Priority should be given to moving any tank levels out of the most critical range (between 10%H and 40%H) and the consolidation plan should reflect this priority. (If necessary, cargo consolidation should be completed as soon as possible after departing the berth through internal transfer).

Should the LNG cargo on-board be insufficient to bring tanks within authorised range i.e. less than 10% H (or as stipulated in the loading manual) or greater than 70% H, then efforts should be made to prolong the loading operation until



sufficient LNG is loaded to achieve authorised levels through internal transfer. If it is impossible or unsafe to prolong the loading operation, then cargo should be consolidated in each cargo tank to avoid the most critical range of filling level, typically between 10%H and 40%H.

Actions after departure from Prelude Terminal:

If not already consolidated, cargo should be consolidated immediately if it is safe to do so after departure. The Master should take appropriate actions to mitigate sloshing risk until consolidation to permissible levels is achieved. Prudent seamanship to assess the prevailing and forecasted weather and manoeuvre the vessel to adopt the most favourable heading and speed to avoid roll and pitch resonant periods is a standard action. Classification Society guidelines e.g. [1] recommend that the LNG carrier returns to complete loading before performing a sea passage, if practicable.

3 Providing a Safe Terminal – Management of Sloshing Risks

3.1 General

Prelude has a loaded displacement of approximately 634,000 tonnes at a draft of 19.1m and, as such, provides a stable platform for LNGCs to berth alongside.

This section presents the assessments undertaken to define the sloshing risks and measures to control sloshing risks. Prior to commencing manoeuvring and berthing operations, a weather window that meets the terminal limiting environmental criteria will be sought. The weather window will be for the pre-determined duration of the LNGC port call.

This section is further divided into three subsections:

- Operability criteria for side by side loading
- Operational risk management
- Sloshing risk analysis.

3.2 Operability Criteria for Side-by-Side Loading

Limiting criteria have been defined for side by side operations of LNGC at Prelude. These limitations define criteria for:-

- safe operability of tugs,
- absolute and relative vessel motions,
- fender and mooring loads,
- operating envelopes for loading arms.



The criteria are further defined in Appendix A.

With respect to sloshing risks of a visiting membrane LNG carrier, the terminal operator has defined environmental conditions for performing alongside cargo operations; these conditions are based on detailed side by side dynamic analysis, risk assessments performed by the membrane tank designer, GTT and guidance from Lloyd's Register.

The above limitations will become an integral part of the terminal's operating procedures.

3.3 Operational Risk Management

Although the Met-ocean conditions at Prelude are considered to be relatively benign, the wave climate is complex and both wind and multiple swell waves can be present. This may lead to instances where operability criteria, referred to in section 3.1, might be exceeded. To manage this risk, the Met-ocean conditions and motions of both the FLNG and the LNGC will be assessed before every offloading operation and the carrier will not be berthed unless a sufficient weather window is forecast to complete the transfer operation within the operability criteria.

An environmental assessment guidance tool to compare measured and predicted motions with the operability criteria for a range of wind and wave headings and strength has been developed. Using monitored motions and real-time Met-ocean data, the tool will identify, for a specified time period, the heading that will enable a complete loading operation without exceeding the set criteria. Where necessary the natural heading can be modified by utilising the Prelude thrusters to maintain a heading within the permissible heading sectors to meet the operating criteria.

3.4 Sloshing Risk Analysis

The risk of sloshing on a LNGC with standard membrane cargo containment has been assessed using both qualitative and quantitative approaches.

In the qualitative assessment, a standard Risk Assessment Matrix was used to rank the risks at two threat levels: (i) sloshing damage to the cargo containment (at a level deemed by Class to be requiring repair) and (ii) sloshing damage leading to low temperature brittle fracture of the ship's structure. Barriers to manage these sloshing risks comprise engineered systems on FLNG, organisational structures and procedures that take into consideration the constraints for berthing and maintaining the LNGC safely moored alongside.

The quantitative sloshing assessments performed by GTT utilised the project defined environmental constraints (berthing and moored alongside) and site Met-ocean conditions to evaluate the sloshing risks and define limits of sloshing



operability in accordance with GTT’s standard assessment methodology and Lloyd’s Register’s risk acceptance criteria.

The assessment quantified the risks to provide contour plots of significant wave height, modal wave period and heading direction relative to the moored LNG carrier.

As part of the assessment, GTT has compared the predicted loads on pump towers for LNGC moored alongside Prelude against the design loads for reference LNG carriers in the range being considered; this aims to provide an easier assessment of pump tower arrangements for individual LNG carriers in accordance with the relevant Class requirements.

Note: The Prelude generic risk assessment study does not specifically consider the risk of deformation of the primary barrier corrugations for Mark III CCS within Class permitted tolerance as it does not adversely affect the integrity of the CCS. Ship owners should undertake their own assessment as they deem necessary for their specific case. GTT is able to advise the ship owner on the probability of deformation taking into account the individual ship’s arrangement and degree of any Mark III reinforcements.

3.4.1 Qualitative Risk Assessment

Problem Definition					
<p>The project premise is to provide assurance that a membrane LNGC fitted with standard CCS reinforcement will not be exposed to damaging sloshing conditions whilst loading at Prelude FLNG or during temporary evacuation in a partially loaded condition.</p> <p>The premise is further defined to restrict the problem to intermediate filling levels (currently between 10% above primary barrier level and 70% of tank height at primary barrier level (or as specified for particular vessel)) for membrane LNG vessels sized between 138,000m³ and 175,000m³. Filling levels above and below this intermediate filling range are considered to be within the normal assurance provided by GTT and accepted by Class as being ALARP under conditions of prudent seamanship.</p>					
HSE Issues and Potential Risk					
Hazard	Scenario	RAM risk			
		People	Asset	Environment	Community
Damage to membrane LNGC cargo tanks due to cargo sloshing	LNG vessel motions leading to cargo motions which result in damaging	2B	4B	1B	3B



whilst alongside Prelude.	sloshing impacts on the CCS.				
Cargo tank sloshing damage leading to brittle fracture of ship's structure.	Sloshing damage leading to breach of the primary and secondary barrier and low temperature brittle fracture of ship's structure.	3A	5A	2A	3A

(See Appendix B for description of the RAM ratings used).

Threat Hazard	Damage to membrane LNGC cargo tanks due to cargo sloshing whilst loading at Prelude
Barriers	Merits
ENGINEER:	
FLNG equipped with three 5MW stern thrusters capable of adjusting and maintaining a heading up to 30 degrees or more modified from the natural heading.	Predictive software will influence heading control to effectively align FLNG heading as necessary (prior to berthing LNGC) to reduce the anticipated adverse motions to ensure sloshing risk is maintained within permissible levels.
In-Field Service Vessel's (ISV - Tugs) with >100t bollard pull will be in attendance during the side by side operation.	A minimum of two ISVs will be available at all times. ISVs are equipped to act as in-field EETV including FiFi 1 designation.
Accurate local sea state monitoring, wave consolidation and weather forecast data is essential for decision-making against defined criteria.	Prelude FLNG will be supplied with specific live on site environmental data including wave and wind. It will also receive 6-hourly site-specific weather forecasts. Live and forecasted environmental data together with live motion data from FLNG and LNGC are fed directly into the environment assessment guidance tool.
ORGANISATION:	
Terminal procedures control risks associated with LNGC manoeuvring operations and cargo transfer.	Clearly articulated and agreed procedures defining responsibilities, actions, limits and emergency measures to reduce and control the risks.
Clearly established roles and responsibilities; Ship's Master remains responsible at all times for	Implementation of the environment assessment guidance tool together with the collaboration of the OIM, Ship's Master and Terminal Team Lead (TTL)



Threat Hazard	Damage to membrane LNGC cargo tanks due to cargo sloshing whilst loading at Prelude	
Barriers	Merits	
safety and integrity of LNGC crew and vessel.	ensuring that the safety of the operation is achievable and maintained throughout.	
TTL and Lead Terminal Technician (LTT) will transfer from FLNG to LNGC to advise/liase with the Master throughout all aspects of the operation.	Direct formal communication link between FLNG and LNGC key personnel - TTL/LTT will provide pilotage and specific knowledge and advice on all aspects of the interface activities between FLNG and LNGC. Both TTL and LTT remain on board LNGC throughout the operation providing operational oversight to ensure compliance with terminal procedures.	
PROCEDURES:		
Maximum environmental limitations are stipulated to address all aspects of the FLNG/LNGC operational interface.	The wider constraints to manage safety of personnel during ISV, berthing, mooring, un-berthing operations, ensuring no contact between FLNG/LNGC and manoeuvring the loading arms overlap to a large extent with the sloshing constraints identified by GTT sloshing assessments, providing a higher degree of robustness to the operational limitations.	
Weather window for entire side by side operation will be stipulated by terminal operating procedure, facilitated by integrated monitoring and environmental assessment guidance.	Determines whether weather-vanning or a thruster assisted optimum heading is required to ensure that the set criteria are not exceeded during the total time necessary to complete the full activity.	
A moored alongside LNGC roll motion limit of 3 degrees (single amplitude) has been established	Roll angle together with period are key motions leading to potential sloshing impacts and steel to steel contact. The 3 degree roll angle limit will prevent steel to steel contact and assist with limiting the sloshing impact pressures.	
Limitations on loading within defined combinations of significant wave height, heading and wave period where there is an unacceptably high risk of sloshing damage.	Specific restricted zones identified as posing an unacceptable probability of sloshing damage by GTT. Probability levels set at 10e-3/yr. level or lower.	
Ensure all visiting LNGC cargo loading plans allow for cargo consolidation	Cargo plan consolidation requirement will be included as a specific item in the pre-arrival exchange of information procedure between FLNG and LNGC.	



Threat Hazard	Damage to membrane LNGC cargo tanks due to cargo sloshing whilst loading at Prelude
Barriers	Merits
within 8 hours during any stage of loading	
Decision support service or system, where enabled (such as offered by GTT), to advise the optimum sequence from any stage.	Optimised time for real-time advice to ship's staff.
Retention of maximum ballast on-board, other than that required for trim and list adjustments, till 25% Cargo on-board.	Studies have shown that retaining maximum ballast until 25% cargo is on-board significantly reduces the time taken for the natural roll period (TNPr) of the vessel to pass through the non-desirable roll period range of 12.5-15.5 seconds. The natural roll period, together with roll angle, are key motion parameters leading to potential sloshing impacts and steel to steel contact. Maintaining TNPr outside this non-desirable range will assist with limiting the sloshing impact pressures. Submission of the Cargo Plan, including ballasting / de-ballasting sequence, will be included as a specific item in the pre-arrival information procedure between FLNG and LNGC.



3.4.2 Quantitative Assessment - GTT Sloshing Risk Evaluation for LNGC Side by Side Operations

The quantitative assessment evaluates the sloshing risks for LNG carriers performing cargo loading operations alongside Prelude FLNG.

In the quantitative sloshing assessments for loading alongside Prelude FLNG, the analysis was based on reference GTT LNG carriers selected to be representative of the LNGC membrane fleet within the range 138,000m³ – 175,000m³. To capture the different motion responses, the fleet was divided into two ranges of cargo capacity: 138,000 – 155,000m³ and 170,000 – 175,000m³. The selected representative vessels were as follows:-

NO96	Mark III
Capacity (100%)	
145,000m ³	155,000m ³
170,000m ³	170,000m ³

3.4.3 GTT Sea Keeping Analysis for an LNGC alongside FLNG

Assessments were made for LNG carrier when alongside the Prelude using 39-year hind cast weather data. These considered full hydrodynamic coupling between the FLNG and LNGC including dynamic coupling of cargo on LNGC and the effects of the fender and mooring loads.

Prelude FLNG naturally weather-vanes at a heading aligned close to the wind direction. This is not expected to be significantly influenced by a LNGC moored alongside.

A study was undertaken to include the hydrodynamic coupling effects and influence of the FLNG, fenders and moorings on the LNGC motions. It is clear from this study and from experimental model tests that roll accelerations are significantly reduced due to the coupling effect of the FLNG.

3.4.4 Sloshing Analysis

A long term and short term approach was taken to evaluate the sloshing risks at the Prelude site by taking into account the LNGC’s operating profile. The long-term risk assessment considered the operating profiles of the ships to evaluate the exposure risk per ship per annum (assuming a regular call pattern for a dedicated shuttle service). The short-term assessment considered the risk per loading operation. GTT presented sloshing risks with recommendations for operability limits in the form of Polar plots of significant wave height, wave peak period and direction.

See Appendix C for further details.



3.4.5 Assessment of Pump tower loads

In discussions with Lloyd's Register, an assessment of pump tower loads during loading operations alongside Prelude terminal has been undertaken. This has been performed by comparison with the design basis for pump towers in membrane LNG carriers, which considers standard navigating conditions with filling levels outside the intermediate filling range in 40 year winter North Atlantic conditions.

GTT has performed a sloshing assessment for 170k m³ class vessels at 4 intermediate filling levels for Prelude loading conditions with coupled side by side motions. The maximum force on the pump tower has been evaluated under these conditions assuming all tanks at filling levels 10%H, 25%H, 40%H and 70%H. This assessment indicates that the pump tower loads for all filling levels in side by side loading conditions are significantly below the design basis for the 170k m³ reference vessel.

This was extended to the 155k m³ reference vessel and the maximum loading force is comparable with the same ratio for the 170k m³ vessel.

The generic risk assessment indicates that the pump tower loads are well below the design loads for the GTT reference ships- variance of pump tower strength for specific ships can be readily assessed by GTT on behalf of the ship-owner within the individual risk assessment for a LNGC according to the requirements of the relevant Class Society.

4 Sloshing Risk Assessment: Summary Conclusions

- a) The operator and master of each visiting LNG carrier is responsible for the safety of their own vessel, but Prelude operator recognizes that the terminal has a role to play in the provision of a safe operating environment.
- b) Prelude terminal has undertaken qualitative and quantitative risk assessments to demonstrate that membrane LNG carriers can load at the facility with acceptably low risk of sloshing damage provided that the operational, organisational and engineering controls discussed in this document are in place. The generic risk assessment has been reviewed by Lloyd's Register and 'approved in principle'.
- c) This document provides guidance to LNG ship operators to assist in their preparation of a risk assessment to demonstrate that the sloshing risks whilst operating alongside Prelude are acceptable. The document recommends the procedures and measures to reduce the risks to as low as reasonably practicable (ALARP).
- d) In the Prelude environment, the risk of LNGC sloshing damage is considered to be low provided operating procedures are clearly defined and transfer operations are only completed in pre-established operating conditions. The terminal operating procedures also contain environmental conditions for LNGC manoeuvring, berthing, alongside cargo operations and for unberthing. The environmental operating limits have been established based on 'safe' limits for tug operations, mooring line loads, marine loading arm envelopes, and absolute and relative roll motions of LNGC and FLNG.



- e) Real-time monitoring of Prelude and LNG carrier motions will alert the operators should motions exceed safe mooring limits, for example, due to unexpected vessel behaviour. A roll motion criterion of 3-degrees single amplitude has been established for a LNGC moored alongside to ensure there is no 'metal-to-metal' contact between FLNG and LNGC.
- f) All visiting LNG carriers will be required to have a plan to consolidate cargo between tanks on-board at any stage of loading within 8 hours, so that all tank levels could be outside the barred fill range within this time. GTT has demonstrated viability on a typical LNGC in the 138k to 155k m³ class and has a software tool to advise the optimum sequence from any stage. Each LNGC visiting Prelude FLNG will be required to provide, prior to arrival and in conjunction with the Cargo Plan, a consolidation procedure which is acceptable to the LNGC operator, demonstrating ability to consolidate within 8 hours, with prepared guidance for ship's staff.
- g) If a LNGC has to unmoor from the terminal before completion of loading a full cargo for any reason, the LNGC is potentially exposed to sloshing motions during the consolidation period. This is perhaps the period of greatest risk of sloshing damage to a membrane LNG carrier. Priority should be given to moving any tank levels out of the most critical range (between 10%H and 40%H) and the consolidation plan should reflect this priority. The vessel should adopt the most favourable heading and speed to avoid roll and pitch resonant periods. Guidance for the ship's master is provided by Class (for example Ref [1]) and GTT has a document under preparation to provide guidance for emergency departure from terminals. Decision support (predictive) software and sloshing monitoring are available or under development to provide additional support.
- h) GTT has provided recommendations to manage the sloshing risks for LNG carriers loading at Prelude terminal. The GTT recommendations consider the applicable LNGC fleet in two size bands: 138,000m³ – 155,000m³ and 170,000m³ – 175,000m³. GTT has divided the applicable fleet of membrane LNGCs (at end 2015) in the range 138,000m³ to 175,000m³ into one of these bands.
- i) Within the established operating procedures, Shell does not consider the sloshing risks for a LNG carrier loading at Prelude terminal to be any greater than for some shore-based facilities; indeed the ability to use thrusters to control the heading of the FLNG can potentially provide a more sympathetic environment for offloading vessels to mitigate the motion risk.



Appendix A: Definition of Operability Criteria

Operability criteria are the limits that define whether a sea state allows offloading operation or not. They are defined in the Prelude side-by-side mooring design basis.

For reference, they are listed hereunder: -

- Maximum $H_s = 3\text{m}$
- Maximum allowable carrier roll motion: $\pm 3^\circ$
- Acceptance criteria for tension in berthing lines:
If either one of the two following situations is met, sea state is unacceptable:
 - Two tensions peaks above 50% MBL in any line in the same direction of service within a 2minutes period
 - More than 5 peaks above 50%MBL in 3 hours, whatever the line
- Acceptance criteria for fender deflection: 60% deflection maximum is allowed
- Minimum steel to steel clearance between FLNG and carrier: 1m
- Allowable relative motions between loading arms and manifold:
- MLA VENDOR has defined operating envelopes.
- Tug criterion:
Criteria for comfortable operations for the tugs are:
 - $H_{s,sea} \leq 2.5\text{m}$ for $T_{p,sea} = 6.5\text{s}$
 - $H_{s,sea} \leq 2.8\text{m}$ for $T_{p,sea} = 9.0\text{s}$

Both criteria apply in combination with a swell of $H_{s,swell} = 0.8\text{m}$.

For wave periods between 6.5s and 9s, the limit for $H_{s,sea}$ can be found by interpolation.

If swell is higher, the limit for $H_{s,sea}$ is reduced so that $H_{s,total}$ remains constant, where $H_{s,total}$ is given by:

$$H_s = \sqrt{H_{s,sea}^2 + H_{s,swell}^2}$$



Appendix B: Risk Assessment Matrix

SEVERITY	CONSEQUENCES				INCREASING LIKELIHOOD				
	People	Assets	Community	Environment	A	B	C	D	E
					Never heard of in the Industry	Heard of in the Industry	Has happened in the Organisation or more than once per year in the Industry	Has happened at the Location or more than once per year in the Organisation	Has happened more than once per year at the Location
0	No injury or health effect	No damage	No effect	No effect					
1	Slight injury or health effect	Slight damage	Slight effect	Slight effect					
2	Minor injury or health effect	Minor damage	Minor effect	Minor effect					
3	Major injury or health effect	Moderate damage	Moderate effect	Moderate effect					
4	PTD or up to 3 fatalities	Major damage	Major effect	Major effect					
5	More than 3 fatalities	Massive damage	Massive effect	Massive effect					

Risks ranked in the yellow (non 5A/B) areas of the RAM require specific actions aligned with general risk management practice to:-

- 1 Where Reasonably Practicable, eliminate Hazards or
- 2 Substitute Hazards with ones having lower Risk.
- 3 Identify and implement Controls and Recovery Measures to reduce the Risks to ALARP.
- 4 Maintain a Hazards and Effects Register.

Risks in the yellow 5A/5B and red areas of the RAM generally require additional risk management typically in the form of a Bow-Tie assessment or equivalent methodology which should include the following:-

- Identify Barriers to prevent a Top Event, to prevent Escalation Factors and to reduce the Consequences should the Top Event occur.
- Identify at least one HSSE Critical Activity to maintain each Barrier.
- Assign HSSE Critical Activities to the designated HSSE Critical Positions or within HSSE Critical Processes.



- Identify HSSE Critical Equipment and performance criteria for assigned HSSE Critical Activities.
- Assign maintenance through HSSE Critical Activities or within HSSE Critical Processes.
- Identify criteria for ALARP determination and consistently apply these criteria. Provide a Documented Demonstration of ALARP for the Bow-Tie or equivalent methodology.



Appendix C: Explanation of Sloshing Methodology

Both short-term and long term risks were assessed for each vessel type and size as follows.

The long-term risk assessment considered the operating profiles of the ships to evaluate the exposure risk per ship per annum (assuming a regular call pattern for a dedicated shuttle service) as follows: -

- 2.7% of time being in ship to ship operations,
- 35% probability of being in the critical sloshing range (as GTT analysis indicates this range extends from 10%H to 40%H, no sloshing restrictions apply above 40%H) during the ship to ship operation,
- Four tanks being loaded simultaneously,
- FLNG heading distribution,
- Wave heights for ship to ship operations being restricted to 3 meters Hs.

The short-term assessment considered the risk per loading operation by relating to each three hours sea state the statistical duration of high sloshing impact occurrences associated with the exposure risk present during each loading operation. GTTs recommendation from this conservative approach was to limit ship operations in the non-standard filling range to 3 meters significant wave height or less depending on wave period and heading, with associated probability levels of damage of 1×10^{-3} per ship per annum for MKIII and $\{1 \times 10^{-3}; 1 \times 10^{-4}\}$ per ship per annum for NO96, considering the total capital risk over a ship life time being not spent over one loading operation.

The long term assessment considers annualised risks for an LNGC calling at Prelude on average 17 times per annum over a period of 40 years for each containment type and reference ship. GTT accounted for the coupling between the FLNG and the LNG carrier in modelling the motions for each case.

In each case 17 loading operations per year were considered, with simultaneous loading of all cargo tanks giving equal probability of being in the sloshing dangerous filling zone for each tank. The heading distribution corresponding to the FLNG being on site for the full 39 years was calculated and significant wave heights under or equal to 3m were considered.

The sloshing analysis highlighted sloshing critical ranges of 10%H to 40%H (tank height at primary barrier level). Analysis indicates that no sloshing restrictions apply above 40%H for LNGCs in the relevant size range alongside Prelude within the intended operating limits.

For the critical 10% - 40% tank height filling range, GTT compared the statistical sloshing pressures at the probability levels shown in Table 2 with the strength capacities for NO96 standard (single cover), NO96 standard reinforced and Mark



III 130kg/m³ density foam containment systems to define sloshing restricted conditions in terms of relative heading, significant wave height and peak period.

Sloshing operability and recommended restrictions were defined by GTT in the form of polar plots relating significant wave heights, pre-dominant swell wave direction and peak period.



References

1. Lloyd's Register, January 2012: 'Guidance on the Operation of LNG Membrane Ships to Reduce the Risk of Damage due to Sloshing'.
2. LR DAD MTES/HULL/4720003906/1, 29 July 2016: Generic Risk Assessment for 138k – 175k m3 LNG Carriers Fitted with GTT CCS Loading at Prelude FLNG Terminal'