

18<sup>th</sup> INTERNATIONAL SHIP AND  
OFFSHORE STRUCTURES CONGRESS

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VOLUME 3



COMMITTEE V.2

## NATURAL GAS AND TRANSPORTATION

### COMMITTEE MANDATE

Concern for the safety and design of containment systems for the storage and transportation of natural gas in connection with floating platforms and terminals, and on board ships. This is to include assessing the performance of various containment systems for gas under compression (CNG), liquefaction under cooling (LNG), and combination of the two methods. Particular attention shall be given to the integrity and safety aspects of containment systems under pressure and thermal loads, and the interaction between fluid and structure under static and dynamic conditions. Needs for revision of current codes and regulations shall be addressed.

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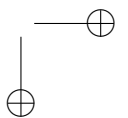
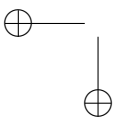
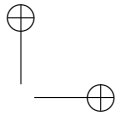
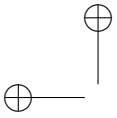
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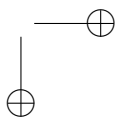
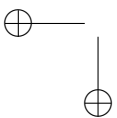
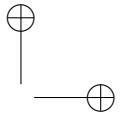
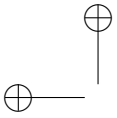
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## 1 DISCUSSION

### 1.1 *Official Discussion by Marcos D. Ferreira*

#### 1.1.1 *Introduction*

It has been a great pleasure the opportunity to serve as the official discussor of this Committee V.2. The Committee members have written a very throughout and comprehensive report addressing a multitude of aspects involved in the natural gas storage and transportation activities.

I will review the subjects in the same order that the chapters were presented in the report and include comments, my personal point of view, and suggestions that I consider relevant and should have been addressed in this review. All sections were commented and suggestions proposed, but not for all subsections, as some of them have recommendations that I considered already established as a current practice and needed no further comments.

#### 1.1.2 *Background*

By showing the safety records of the LNG industry, was clear for the reader that this market can be considered safe, in fact with a much better safety record than general ship transportation. The difficulties associated with the large increase of the fleet during the last ten years and the impact this may have in order to keep the crew well trained and the fleet maintained at the same high standard among a multitude of LNGC operators were also well pointed. LNG handling difficulties associated with future offshore operations and the use of LNG as fuel was also anticipated. These comments motivated remarks that I will present in section 3.3 (Operation and Human Error).

When the committee identified the LNG markets and trends, the FLNG near future possibility of use was pointed but existing challenges, mainly associated with the offloading operations related to the FLNG unit could have been mentioned. I will detail this point in the discussion of section 4.2 (Floating LNG, FLNG, and Floating Storage and Regasification, FSR, Units).

#### 1.1.3 *Safety and Design*

In the description of this section it could be mentioned that LNG is not the only available choice for gas transportation, as there is the CNG (compressed natural gas) alternative, as well as other approaches like the so-called CGL (Compressed Gas Liquids), described for instance in ABS Editor (2008), and proposed by SeaOne, where a hydrocarbon solvent is added to the natural gas stream after it is cleaned of impurities. When this mix is cooled down to -40 degrees Celsius and pressurized to 1400 psi, it will liquefy. Nowadays the market sees the LNG solution as the most attractive approach for ship transportation, and therefore should have the focus of the research, but the other existing possibilities could have been mentioned.

#### *Cargo Containment Systems*

As the committee report details the existent cargo containment systems, it could have mentioned the difficulties associated with inspection and maintenance for some of the concepts. As an example, the FLNG unit concept using membrane tanks as its CCS would require concept changes in the original membrane tank design to allow their offshore inspection if a small leakage is identified in the primary barrier. The installation of scaffoldings inside this type of tank in an offshore environment would

not be a simple task. There are proposals of articulated arms that would enter the tanks transporting workers for the execution of the needed tasks, but this solution would probably use deck area that would not be available in the middle of a liquefying plant. Suggestions regarding possible solutions would be welcome.

Another issue may be identified also with inspection and maintenance for some of the CCS presented in the report for the CNG alternative. A Coselle system would not allow a human inspection to be carried out, and fulfilling all inspections using special instrumented pigs is not yet a common practice, nor an established approach.

#### *Unrestricted Filling*

The reason there is a restriction regarding the CCS usage at any filling level is to avoid, or at least mitigate, the possibility of sloshing occurrence. In my opinion this item would be better located inside the “Sloshing” section.

As mentioned in the committee report, the use of large tank dimensions that arrive from the membrane concept will increase the exposition to the sloshing phenomena, and it could be added that the membrane tank designer (GTT) now proposes different levels of reinforcement to be used in order to stand higher impact loads and allow unrestricted filling, but this has yet to be approved by the classification societies.

#### *Operation and Human Error*

This is an important issue many times neglected in our industry. Operators in general do not enjoy exposing their incidents or assume that an improper behaviour may occur during the conduction of specific operational tasks. Sometimes even from one unity to the other of the same operator fleet, we may find different procedures for the conduction of similar tasks.

In the oil industry, there is today a JIP (Joint Industry Project) being conducted by Marin called “Offloading operability 3” where the focus will be not only on the measurement of real time metocean conditions and the FPSO and Shuttle ship responses, but also to follow the crew behaviour and choices taken during simulation sessions and possibly also during the real operation. This sort of initiative can lead to an identification of the amount of training that should be required for the crew, as well as a discussion (through debriefing sections) of the actual procedures and possible alternatives for conducting these operations.

A similar initiative could be planned in order to better understand the human activities during the FSRU operations. In the near future, this approach would also be carried involving FLNG operations. Training requirements would be a possible manner to enforce an adequate operational response from the units personnel.

#### *Structural Integrity Management*

There are activities in the oil industry regarding the life cycle management of FPSO structures (LCM JIP, as a recent example conducted by the main Classification Societies with participation of many operators), looking for possibilities of a rationalization of regular inspections and required maintenance of existing FPSO structures (mainly analyzing the impact of corroded structures and the possibility of crack management instead of repair).

This sort of approach may be tried in connection to FSRU’s and in the future FLNG world. Today there are no FLNG units in operation, so for now it will only be possible to plan how similar programs may be developed until the experience with respect to FLNG structural response starts being built.

*Sloshing*

If unrestricted fillings are allowed, wave induced vessel motions will excite liquid motions inside their tanks. Today there are three tank types used as CCS in the LNG transportation by ships. The SPB technology allows the use of internal bulkheads, and sloshing occurrence can be prevented or mitigated. Moss type tanks have a spherical geometry that allows the liquid to sway without causing large impacts on its walls. It should be mentioned that this internal liquid motion will cause cyclic loads on the tank supports, and fatigue stress should be checked for these conditions.

As pointed in the committee report, the motions of fluid inside internal tanks will have significant effects on the dynamic response of the vessels in waves, mainly if the LNG has tanks with large dimensions (as the membrane type in general), partial fillings, and their sloshing critical periods lie in the range of the unit natural periods. This coupled problem has been studied by Kim (2001) and Rognebakke and Faltinsen (2001, 2003) among others, with nonlinear analyses of the interior flow in the tanks, and by Molin *et al.* (2002) and Malenica *et al.* (2003) using linear analyses. The tank dynamics are computed separately from the exterior radiation and diffraction problems. Combining the hydrodynamic forces for the tanks with the floating unit hydrodynamic coefficients and exciting forces, they could solve the coupled equations of motion.

The free-surface panel code Wamit was extended as described by Newman (2004, 2005) in order to analyse the coupled liquid in tank / unit motions, using a more unified approach where the interior wetted surface of the tanks are included as an extension of the conventional computational domain defined by the exterior wetted surface of the body. The same exterior free surface Green function is used for each domain (tanks and exterior flow), with vertical shifts of the coordinates corresponding to the free-surface elevation in each tank. The main advantages of this approach is that any tank geometry can be easily represented by flat panels, and that this representation is the only requirement for carrying the analysis, with no necessity of determining the displacement modes of the internal free surface with periods in the same range of the floating unit responses. In Newman (2004, 2005) a comparison is made between the use of this approach and model tests and computations presented by Molin *et al.* (2002) for a barge with two large internal tanks with rectangular cross sections in both longitudinal and transversal directions.

Table 1: Main Dimensions of Barge with Two Internal Tanks, with a description of the Loading Conditions 1 and 2

Description	Condition 1 (m)	Condition 2 (m)
Barge length	3.0	3.0
Barge beam	2.0	2.0
Barge draft	0.108	0.108
Tank1 length	0.25	0.25
Tank1 beam	0.8	0.8
Tank1 depth	0.19	0.19
Tank2 length	0.25	0.25
Tank2 beam	0.8	0.8
Tank2 depth	0.19	0.39

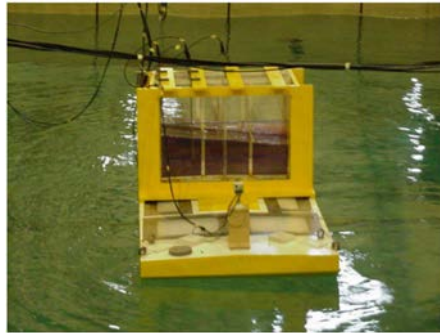


Figure 1: The reduced model used by Molin to compute the coupled motion of liquid and barge. Representation of loading condition 1.

I will present some of the results obtained, in order to claim that this is the best approach for the determination of the coupled response for a wide range of incident wave periods. The main dimensions of the barge and internal tanks are defined in Table 1 for the two conditions simulated. In the first loading condition the two internal tanks have the same filling ratio, and as the tests were performed for beam sea waves, the tanks will present the same response. For the second loading condition, one tank will have a higher filling ratio and we can see a more complex system response.

The barge used in Molin's model tests is shown in Figure 1, for the condition 1, when the two internal tanks have the same filling level. For the tests performed the tanks were located on the deck of the barge. It is easy to notice that the liquid inside both tanks behave in the same manner, as if the test was performed with only one tank.

The roll responses of the ship are presented in Figure 2. It can be observed that the tank acts as a dynamic absorber for the roll motion of the barge, and the roll RAO now presents two peaks instead of one, as it would be expected for the uncoupled barge roll response. The comparison shows experimental results against Molin and Newman linear numerical results, and it can be observed:

- The peaks obtained from the linear numerical computations are in close agreement with the model tests, presenting similar amplitudes. The model tests also

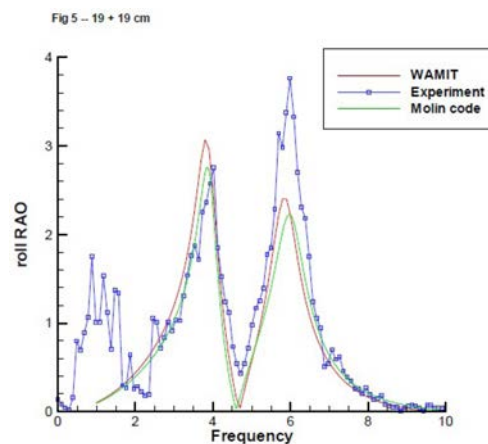


Figure 2: Coupled roll response of the barge (degree/m) under the influence of the liquid motion in the tanks. Loading condition 1.



present some response at lower frequencies, which could not be recovered by the linear simulations, but low frequency vessel motions are not responsible for the most critical sloshing loads.

- These numerical simulations based on potential panel codes are much faster than non-linear CFD computations, and can show the influence of the coupling of the internal liquid motions and the ship dynamics. Linearized damping can also be added to the liquid motions and vessel responses, if needed.

Another loading condition, when the two internal tanks would have different filling levels, was also considered using this approach, and this new arrangement can be seen in Figure 3.

Under this situation, the liquid inside the two tanks will present different resonant periods, leading to a more complex situation for the unit roll response, which will present three response peaks. A similar loading condition can easily occur for the case of a FLNG with large internal tanks, or for a LNG carrier while receiving the LNG load from the FLNG.

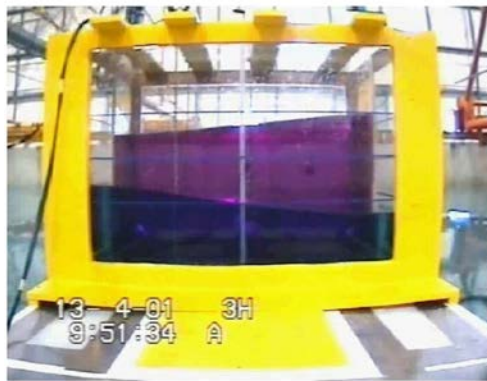


Figure 3: The reduced model used by Molin to compute the coupled motion of liquid and barge, representing loading condition 2.

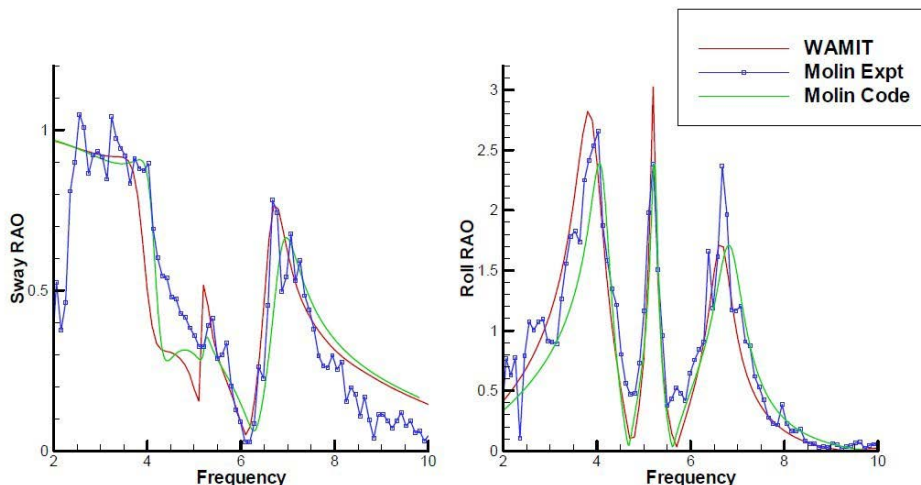


Figure 4: Coupled sway (m/m) and roll (degree/m) responses of the barge under the influence of the liquid motion in the tanks. Loading condition 2.

It can be observed from the results shown in Figure 4 for the sway and roll motions, the good agreement between Molin approach representing the liquid motions by its resonant modes and Newman approach representing arbitrary tank geometries extending the panel method, and that both codes show good comparison against the model tests.

From these comparisons and the nonlinear CFD simulations presented in the literature and summarized in the committee report, it can be concluded:

1. CFD nonlinear simulations have improved in the last years and give great contribution for a better understanding of the flow characteristics and computation of the impact loads.
2. Performing uncoupled ship motions computation and using the RAO to obtain the movements of the tanks for a posterior nonlinear CFD simulation of the internal liquid motions is not adequate, as these liquid motions have large influence on the ship responses.
3. Carrying coupled ship time domain and CFD nonlinear analysis is time consuming and in many cases will be a difficult task for obtaining good convergence of the overall coupled motion response.
4. The best approach would be to solve the linear coupled problem and as this analysis can give reliable results in the wave excitation range, select the possible critical cases with respect to extreme ship motions (in general sway and yaw). For these selected cases a nonlinear CFD analysis can be performed and results compared to further validate the linear approach.

Also mentioned in the report was the need for a better understanding of the local flow behaviour, through drop tests and breaking waves in a flume. In this context, the ISOPE 2012 conference presented an extensive programme entitled “Sloshing Dynamics and Design”, from which interesting papers can be selected, contributing to a better understanding of the sloshing impact phenomenon. In particular there were articles in connection with the SlosheI project, as Lafeber *et al.* (2012b,a), that defined elementary loading processes (called ELP) that could describe the local effects, and could be defined as (ELP1) the direct impact characterized by an instantaneously loaded area, the subsequent (ELP2) building jet along the structure and finally, when there is entrapped air, the (ELP3) compression of this entrapped or escaping gas, giving rise to a pulsating load with a loading area that will be a function of the amount of entrapped gas. Physically, ELP1 is related to liquid compressibility, ELP2 to liquid change of momentum and ELP3 to gas compressibility.

The work of Lafeber *et al.* (2012b) and Pasquier and Berthon (2012) also researched in the scaling effects of sloshing studies, and so far the general conclusions are that the global flow can be well represented by the reduced (1 : 40) model, but deviations have been found in some of the records and further research is still needed.

#### *Temperature Control of Hull Structures*

The discussion about the use of longitudinal bulkheads in FLNG design is an interesting topic raised in this subsection, and I will comment in section 4.2, as the committee report concentrated most of this discussion in this section.

#### *Spillage Control*

Research must be carried for a better understanding of a large LNG spill in seawater, in the case of future FLNG units, and how realistic it would be to guarantee that the LNG spill would be diverted far enough from the side of the hull, inside coamings or scuppers, and also taking in account the possible motions of the unit at this time.

#### 1.1.4 Safety and Design for Specific LNG Applications

In this section the committee report concentrated in new applications to the gas market, by making a description of the complete Offshore LNG Chain and later concentrating in some links of the chain, mainly the FLNG and the FSRU possibilities.

##### *Offshore LNG Chain*

The description of the FSRU only mentions the possibility of locating it at offshore, exposed areas. But there are a number of operating FSRU that have been installed in sheltered areas, as Guanabara bay (Golar FSRU, operating in Rio de Janeiro, Brazil), Pecem (Golar FSRU, operating in Ceara, Brazil), Bahia Blanca (Excelerate FSRU, operating in Bahia Blanca, Argentina) and Dubai, among others. In all previous locations the FSRU remains moored to a jetty and the LNG carrier can moor to the jetty in opposition to the FSRU, or side by side to the FSRU. When the carrier moors to the jetty, cryogenic loading arms will be employed, and when the carrier moors side by side to the FSRU, cryogenic hoses with specialized supports are employed. Both technologies are field proven technologies.

##### *Floating LNG, FLNG, and Floating Storage and Regasification, FSR, Units*

Probably due to the vast number of subjects being covered by this committee and their connection, some were addressed a number of times in different parts of the report. One of these subjects is the need of longitudinal bulkheads in FLNG units. On this topic, I would mention that:

- The large deck load due to the liquefying plant put a strong requirement in favor of the use of a longitudinal central bulkhead (addressed in the report).
- There is actually one FLNG design using this longitudinal bulkhead (Shell's FLNG for Prelude field, in Australia), and its size is huge (total length of 488 m and a beam of 74 m), which also puts a pressure for the use of at least one longitudinal central bulkhead (partially addressed in the report).
- For the Prelude FLNG, it was decided to employ membrane tanks, which are not allowed yet to operate at unrestricted filling levels, but will have to show that its use is possible taking into consideration (1) the metocean conditions at the site and (2) a detailed sloshing computation. Aside from the possibility of hurricanes, the wave conditions in the Prelude field can be considered benign, and the use of a central bulkhead will favour the mitigation of the sloshing phenomena in its tanks (not explicitly mentioned in the report).
- A central longitudinal bulkhead will have to be designed as a cofferdam, and heated like today's transversal cofferdam bulkheads in existing LNG ships (as suggested in the report).

One interesting point that was raised in this section of the committee report is the offloading operations. There are some issues related to offloading operations involving FLNG units that were not fully covered, like:

- As the FLNG will be located offshore, the side by side offloading strategy will not be an option in general, unless the sea state is very benign. Simulations and model tests carried out in different JIPs (as Safe-Offloading, or Offloading Operability 2), indicated a maximum sea state condition with significant wave heights around 1.5 ~ 2.0 m, for peak periods in the range of 8 ~ 18 s. The behaviour will vary depending on the size of the units involved (FLNG and LNG carrier), and this statement can not be taken as a rule, but as an indication that extensive simulations and tests should be conducted if significant wave heights

larger than  $2.0\text{ m}$  for typical wave periods are expected to occur during side by side offloading operations.

- The use of tandem offloading approach will also require detailed simulations and analyses of the operations involved, associated with the use of cryogenic hoses, which can be either aerial or floating. In both cases the distance between the FLNG and the LNGC participating in the offloading operation will not be as large as the distances used for tandem oil offloading operations today (around at least  $160\text{ m}$ ), staying in the range of  $70$  to  $90\text{ m}$ . This limitation is imposed by the size of the structure needed to lift the aerial hoses or due to current loads in connection with the large diameters required for the floating hoses.
- If a tandem configuration is required for the offloading, the best LNGC configuration will include a bow loading system and dynamic position facilities, which associated with the partial filling conditions pointed in the last item, will require a dedicated ship that most probably will only operate between a gas terminal and the FLNG, and will have a larger cost than a similar size ordinary LNGC.
- During oil offloading operations in tandem, using DP oil shuttles, from time to time there are occurrences of DP incidents, like drive-off, in general due to a failure in the evaluation of the relative positions (sensor problems) or any less common failure. The reduced distances between shuttle and FLNG will magnify the chance that such incident become more serious. Research on this subject is required.
- The LNGC ship receiving the LNG load will be subjected to partial filling conditions in the tanks during the offloading operations, which will have to be considered. Also if any contingency occurs interrupting an offloading operation, this partial filling condition will remain until the carrier arrive at the discharge location.

As stated in the committee report, there are different products produced at the FLNG (LNG, LPG and condensates), and there are projects that involve the use of different carriers for the LNG load and LPG and condensates load. This will increase the number of offloading operations, and the risk involved. We should also consider that the LPG carrier will in general be smaller than the LNG carrier, and present larger motion responses in waves, imposing another challenge for the operation. One possibility to mitigate the risks involved during offloading is to increase the size of the tanks, allowing the operation to abide longer for favourable weather conditions. The total number of offloading operations will be the same as if the tanks were smaller, as they only depend on the production amount and size of the shuttle ships, but there may be more time available to choose more adequate weather conditions.

The other unit mentioned in this section of the committee report is the FSRU. There are units of this type operating offshore (in general Excelerate FSRU using the STL disconnectable turret system), but also FSRU moored to a jetty in shallow waters, receiving LNG loads from carrier ships mooring to the other side of the jetty or side by side to the FSRU. In both situations, if there is the possibility of the occurrence of some wave excitation, despite the FSRU remaining moored inside a bay or a region with breakwater protection, there is the need of a good estimate of the local sea states, because:

- Wave drift forces and second order slowly varying forces increase significantly when the water depth becomes shallow.
- The FSRU mooring natural periods will be in the range  $20 \sim 100\text{ s}$ , so these

drift forces will probably be the main source of excitation close to the mooring natural periods.

- Not only the water depth may be important to define the wave action, but also the local bathymetry, which can affect substantially the wave profile close to the FSRU.

In the last years there have been some activity regarding a more accurate estimation of the wave action in shallow waters in the presence of variable bathymetry, and its influence in the mooring of ships. I would mention the work presented by Buchner (2006), which motivated further research like Ferreira and Newman (2009) and Pinkster (2011). This is still an area of research, and so far most analyses indicate that considering a constant local mean water depth as an approximation of the detailed bathymetry can lead to first order motion responses that are close to the real situation, but some discrepancies can occur to the drift forces estimation, mainly in the low frequency range.

Second order slowly varying forces computed from the complete first and second order wave potentials in the presence of a bathymetry have not yet been accomplished. This is still a research topic.

The JIP HAWAI (and its sequel, HAWAII) coordinated by Marin with the participation of Bureau Veritas, Deltares and SBM, had focus on (1) the estimate of the local wave activity by propagating waves from offshore locations, where supposedly there are more accurate information about the sea states distribution and on (2) the ship response to the waves at the moored location.

One problem arriving from this situation is that as the waves progress to shallower waters, there will be an increase on the amount of second order bounded (set-down) waves, which can be computed through the idealization of the sea state as composed by first order linear components, and the subsequent evaluation of the second order components that arrive from the interaction of pairs of this first order waves. This waves will be bounded to the pair of the first order linear waves, but as the waves become too steep, encounter discontinuities at the bottom, or reflect at barriers, some part of their energy can get free from this constraint, and travel with the celerity of a free wave obeying the dispersion relation.

The correct calculation of the amount of second order wave energy that will become free is a challenge, and Olaf (2009) showed in the HAWAI JIP that this mechanism may also be the source of spurious waves in model tests, generated by the presence of the wave maker, the beach, and possible bottom discontinuities, inducing a higher amount of free waves in the model tests than would be expected in full scale situations, and this must be adjusted.

The best practice, or the recommended computationally feasible way to proceed with this computation is still in debate.

#### 1.1.5 Conclusions

The areas of investigation raised by the committee are consistent with the subjects covered throughout the report. I would complement, based on the points I mentioned in the discussion, the need for research on:

- With respect to the CCS sloshing computation, I would suggest to establish the use of a linear panel method with the definition of the tanks to be used as a first step in order to evaluate the coupled ship response under the influence of the internal liquid motions. This analysis can be also checked against coupled CFD

results and model tests, for the most critical conditions. I understand that the critical situations for the ship motions coupled response will be better defined using this approach than starting with a nonlinear analysis.

- Also in the CCS alternative using membrane tanks, there is nowadays a proposal of different types of support boxes, under the name of various reinforcement alternatives, with the claim that this approach would allow partial filling utilization. Research must be conducted to relate coupled ship motions, sea states, computed sloshing loads for a partial filling condition and the allowed membrane reinforcement type, if any.
- Regarding spillage control, also in connection with the FLNG possibility, research should be carried regarding the efficiency of diverting the LNG spill and also on the design of the coamings and scuppers, as their location may subject them to wave impact loads during rough weather conditions.
- Definitions on the requirements for longitudinal cofferdam bulkhead alternatives for the FLNG unit.
- FLNG offloading operations including definition of allowed cryogenic hoses and suggested requirements for the offshore operation (minimum distances and relative positions) and numerical simulations in different conditions (side by side and tandem).
- Determination of wave conditions on shallow waters based on the sea state characteristics on deep waters, including an estimate of bound and free waves amount and bathymetry influence on the wave loads computation.

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## 1.2 Floor and Written Discussions

### 1.2.1 Masanobu Toyoda

With regard to sloshing, the report describes countermeasures for damage from sloshing by avoiding resonance. The successful safety record of LNG carriers due to the restrictions of LNG filling level at almost full or empty in tanks was also reported.

Avoidance of resonance is fundamental approach for structural design. For instance, VLCC is requested to confirm the effectiveness of a swash bulkhead with the CSR rule formula and the resulting opening ratio of the bulkhead.

Furthermore, new precautions designed to protect people and port facilities against the effects of tsunamis are discussed. When a ship carrying dangerous cargo moors in a port and loading/unloading is in process, the ship should stop that process and leave the port within 1 hour of an earthquake's occurrence. It is possible that the shuttle tankers for FLNG will need to move away quickly in the process of loading and unloading in case of emergency.

It is more beneficial to ship's operators and port authorities for the safety level or operational instructions against sloshing including the emergency case to be indicated in something like a unified notation.

With regard to the safety level of independent tank type (3.1.2 Independent Tanks), the IGC code requests both a relatively safe side and unsafe side prescriptions for each tank type with good balance, and for all tank types have comparable safety levels including redundancy for possible events considered by the industry.

Type A

- Safe side: Full secondary barrier required
- Unsafe side: Complete strength analysis not required

Type-B

- Safe side: Extensive large-scale analysis, leak before failure, etc., required
- Unsafe side: Partial secondary barrier accepted

Type-C

- Safe side: High-pressure design and reduction of fatigue damage risk, increase of safety level with simple structures
- Unsafe side: Secondary Barrier not required

These measures for each tank type are compensatory such that the resulting safety levels including redundancy are comparable.

### 1.2.2 Rene Huijsmans

I would like to point out recent developments on wave climate computations in shallow water which are important for mooring LNG carriers. They were reported by JIP HAWAII and HAWAII. It was shown that complex wave-wave interactions from different wave directions could also be included in the computations of the QTF's of LNG carriers.

### 1.2.3 *Spyros Hirdaris*

The committee is congratulated for their report. I would like to mention a couple of issues for general information:

- An extended review of the Sloskel project was provided under the review of committee I.2 on loads. Equally, a very good report is provided by the ITTC Seakeeping Committee. I should like to suggest that your group refers to these references.
- Lloyd's Register published a Keynote in the IMDC 2012 Conference on "Green Shipping Technologies". The paper co-authored by Hirdaris and Cheng refers to a recent Lloyd's Register study on the cost of implementation of LNG as a fuel and the appetite of the market to make use of this technology for LNG fuelling.

### 1.2.4 *Yukichi Takaoka*

I appreciate your efforts to summarize and discuss such a wide range of technical issues on natural gas storage and transportation.

New IGC and IGF codes are now being developed at IMO. Thus, the committee should also discuss the necessity of these rules from the results of your study. Please show us your viewpoints on these new rules.

Finally, this is a comment. At the explanation of Type-C, although the report noted that the type-C tanks are usually not used for LNG transportation, I would like to add that Type-C tanks are suitable for domestic LNG transportation and Ship-to-Ship LNG transfer using small-size LNG carriers due to the advantage of the easiness of keeping the boil-off gas.

### 1.2.5 *Byeong Seog Kang*

This presentation give several old agenda such as sloshing of LNG, longitudinal BHD issue for very large FLNG, steel grade of T. BHD and heating and interaction between liquid (LNG) and CCS (Cargo Containment System). Discusser, however, ask that more advanced method or technology or design proposal be given in spirit of better and richer contents of presentation. And the other side, big FLNG project design already started. And in some aspect, the technology relating to these practical solution is being matured. I would propose that next committee is kindly asked to investigate in deep insight and practical aspect.

## 2 REPLY BY COMMITTEE

### 2.1 *Reply to Official Discussion*

First of all, the Committee would like to thank the Official Discusser, Dr. Marcos Ferreira, for his valuable comments and supplementary contributions, including some important additional references that helped us to clarify some of the technical aspects of our report.

I would like to reply to Dr. Ferreira's discussion step by step.

#### 2.1.1 *Safety and Design*

As pointed out by the Official Discusser, some alternative concepts for the sea transportation of natural gas have been proposed in addition to LNG and CNG. Dr. Ferreira mentioned CGL (Compressed Gas Liquid). In the committee report, we reviewed some of the new concepts only very briefly due to page limitation. Besides CGL, there are other concepts that appear to have advantages, for example, NGH (natural gas hydrate), a method by which we can transport natural gas at  $-20^{\circ}C$  and at ambient



pressure, a very favourable character in cargo handling, although the weight efficiency is less advantageous.

### 2.1.2 Cargo Containment Systems

The Official Discusser correctly pointed out that there is difficulty in the inspection and maintenance stages of FLNG, for example, the need to inspect the primary barrier of the membrane tank. As indicated in the conclusion of the committee report, we believe that innovation is certainly required in the inspection and monitoring of the containment tanks.

### 2.1.3 Unrestricted Filling

As the Official Discusser mentioned and we also stated in the committee report, a membrane tank with large tank dimensions will increase the exposure to the sloshing phenomena. The Official Discusser introduced the notion that a new measure of reinforcement, designed to withstand higher impact loads and allow unrestricted filling, is being developed in the industries. We think that this is one of the ways to solve the problem. Another possible solution may be to minimize sloshing events, rather than trying to design structures to withstand the sloshing load. Recently, several research groups have proposed ways to mitigate the sloshing in membrane tanks. Figure 5 shows a few examples.

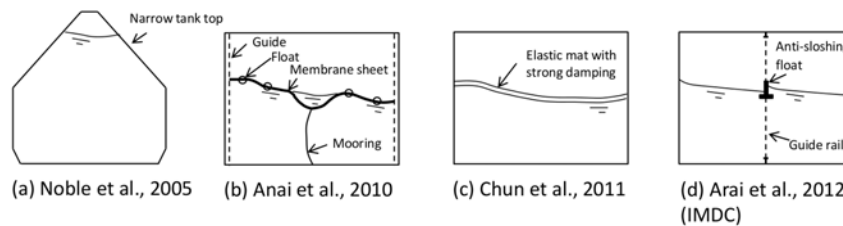


Figure 5: Anti-sloshing concepts

### 2.1.4 Operation and Human Error

The Committee would like to thank the Official Discusser for introducing the Joint Industry Project called “Offloading operability 3”, where the focus is not only on the measurement of real-time metocean conditions and the FPSO and Shuttle ship response, but also on examining the crew behaviour. We agree with the Official Discusser about the importance of such research and application of the obtained results to the crew training, and hope the application of a similar approach to the FSRUs and in the future FLNGs will lead to a better understanding of the human activities during operations of those facilities. Decreasing the possibility of human error will certainly upgrade the safety of such facilities.

### 2.1.5 Structural Integrity Management

The Official Discusser mentioned the Joint Industry Project called “LCC JIP”, which pertains to the life cycle management of FPSO structures. Much like our response to the Official Discusser’s comments about the “operation and human error”, we think this type of approach for FPSO can be a good reference for the FSRU and FLNG cases.

### 2.1.6 Sloshing

The Official Discussor pointed out the possible problem in the fatigue strength of the tank supports in the Moss system that may be caused by the cyclic internal liquid motion during partial filling condition. This is a new topic to be studied if unrestricted filling becomes a regular practice.

The Official Discussor introduced several important research reports about the SlosheI project that appeared at the ISOPE 2012 conference. We certainly regret that we could not review them, since the committee report was submitted to the ISSC secretariat before the ISOPE conference was held. We believe that the next Committee will review the advancement of the project.

The Official Discussor proposed a process of sloshing analysis to take into account the coupled ship motion. The Committee agrees with the proposed process utilizing the linear theory for screening the critical condition. However, we would also like to point out the importance of the non-linear analysis in sloshing. For example, as shown in Figure 6, the free surface motion in the fore tank becomes very complicated if the tank has this configuration. And even for an ordinary shaped tank if the tank has almost the same tank length and tank breadth, so called swirling motion may occur. It is difficult for the linear theory based method to reproduce these highly non-linear free surface motions.

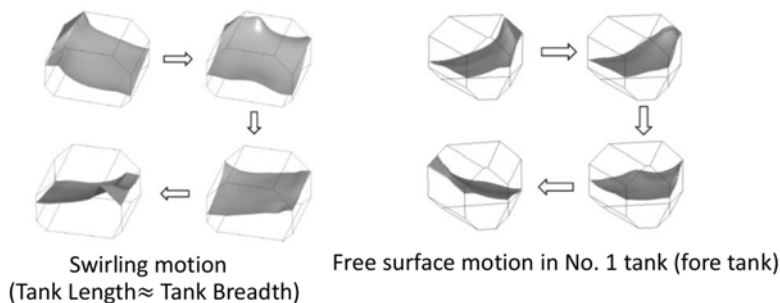


Figure 6: Highly non-linear free-surface motion (Wang and Arai, 2011)

### 2.1.7 Floating LNG, FLNG, and Floating Storage and Regasification, FSR, Units

The Official Discussor pointed out that there exist many challenges in the offloading process of FLNGs. The main focuses of our committee's discussions were safety aspects of the cargo containment systems, and we did not discuss deeply the operation of the facilities. However, as the Official Discussor indicated, there are some important items related to the offloading process, such as collisions between FLNG and shuttle tankers, problems related to the use of cryogenic hoses, and so on. We would like to encourage the next committee to start with a review of the offloading operation.

The Official Discussor's proposal of increasing the tank size of FLNG to allow the operation to abide longer in cases of favourable weather conditions is very interesting. However, we would like to comment that there may be an opposite idea about the tank size. That is, if the tank size is smaller, it would allow a quicker passing of the "danger" filling levels during offloading operation. Optimization of the total system must be carried out.

The Official Discussor indicated the importance of the good estimation of the local sea states, which will affect the response of FSRU moored in shallow water. The possibility

of the increase of the wave drift forces and second-order slowly varying forces when the water depth becomes shallow was pointed out. This problem was also pointed out by the previous 2009 ISSC Committee I.1 "Environment". We would like to encourage the next Committee V.2 to cooperate with the Committee I.1 in evaluating the recent advancement related to this topic.

The Committee would like to thank the Official Discussor for his fruitful discussion. The discussion is certainly very interesting addition to our report and it also provides us with some motivations for future work.

## **2.2 Reply to Floor and Written Discussions**

### *2.2.1 Masanobu Toyoda*

For the first comment of Dr. Toyoda, we fully agree with his concerns about the emergency that may occur during the loading and offloading operation. If unrestricted filling is applied in not calm weather conditions, some kind of measures are necessary which are effective in the case where loading or offloading is discontinued due to some unexpected reason. Increasing the strength of the tank system might be one measure but there might be other alternatives such as the anti-slosh devices we showed in Figure 5. Another practical way might be the use of batch tanks, which are small tanks used as buffers for the loading and offloading process. This would allow a briefer time spent at the "dangerous" filling levels during such operations. Research group in Norwegian University of Science and Technology studied the optimisation of operation based on this idea (Rokstad *et al.*, 2010).

About the second discussion for the safety level of independent tanks, as Dr. Toyoda mentioned, the three types of the tank have different advantages and disadvantages. If the tank has a particular safety disadvantage, a proper measure is introduced. One example is the second barrier concept. After applying the various measures, the three tank types are considered to have equivalent safety levels. This is our understanding about the IGC code. Therefore, if we introduce a new storage system in the future, the new system should have equivalent safety performance to the conventional ones.

### *2.2.2 Rene Huijsmans*

Thank you for your comments, which provide valuable input to be evaluated during the next term of this committee.

### *2.2.3 Spyros Hirdaris*

We appreciate your information on the review of the Sloskel project and the Lloyd's Register's study about LNG as a fuel.

### *2.2.4 Yukichi Takaoka*

Dr. Takaoka asked us our viewpoints on future IGC and IGF codes. As we showed in the presentation, there are some items which are not covered by the IGC code. For example, there are many new LNG containment systems proposed and they do not fit into the IGC code. New offshore applications such as FLNG also request some modification and addition to the code. One example is the design of the longitudinal cofferdam. As for fuel, LNG can be applied for any type of ships and LNG fuel tanks may be located in other areas than cargo area. As shown in the conclusion of our report, this may challenge the established safety philosophy of an LNG containment system. Safety aspects should be carefully evaluated during the code development of IGF.

*2.2.5 Byeong Seog Kang*

Our committee's main tasks are to review the published information and discuss the state-of-the-art technologies according to the obtainable information. It is very difficult for an ISSC committee like ours to access and evaluate technological developments inside the industry.