New Set of Rules for LNG FPSO

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ABSTRACT

Offshore LNG terminals are broadly considered by the industry since several years. Several developments have been achieved, such as offshore gravity based unit, gas floating terminals moored at quay, or gas carriers discharging in open sea. In order to match these technical developments and to anticipate the developments of LNG FPSO in open seas, Bureau Veritas has completed, in May 2009, the first phase of a rule development project for the classification of floating offshore gas terminals. Combining BV’s return of experience on the classification of liquefied gas carriers and FPSOs and the recent studies done together with major actors of the oil & gas industry.

This resulting guidance note provides requirements for structural safety and cargo containment system assessment. These requirements are applicable for offshore gas units including LNG FPSOs and FSRUs.

The paper will describe the requirements of this guidance note, their reasons and their consequences on LNG FPSO projects. It will also unveil the detail of the complete set of Rules for offshore floating gas terminal that is planned to be issued beginning of 2010. It will include additional features such as requirements for fire safety, topsides and maintenance of class all along the unit life.
INTRODUCTION

The development project of the guidance note NI542 “Guidance Note for the Classification of Offshore Floating Gas Terminals” has been initiated by Bureau Veritas in order fulfil an increasing demand for norms and requirements raised by the oil and gas industry in recent years. Since at least 15 years Bureau Veritas is involved in FLNG and FSRU concept and project development, leading to a first guidance in 2005 (see ref [2]) for offshore gas terminal, floating or not, in steel or in concrete.

The recent evolution of several projects from concept phase to FEED phase and the general trend to consider a steel floating unit, processing liquefied gas (liquefaction for LNG FPSO or revaporisation for FSRU) and that may store LNG have leaded Bureau Veritas to issue a guidance for the classification of steel LNG floating unit. This guidance note was built based on the knowledge gather from:

- Gas carrier vessels. The first ships were built toward the end of 1960’s / beginning of the 1970’s. Huge experience on the LNG containment at sea and in steel structure has to be reviewed and extrapolated for offshore environment.
- Oil FPSO. First FSO were installed in the late 1970’s. The first FPSO developments were based on shipping or on-shore habits. Since this time offshore industry has developed its own norms, rules and methodology, which should be extrapolated to LNG offshore units.
- LPG FPSO. A few LPG F(P)SOs are in service since a bit more than 10 years. The experience from these units should not be neglected with regard to offloading operations, in service inspection/maintenance and containment systems (LPG containment is structurally very similar to LNG SPB tanks).
- Onshore systems: LNG process and offloading systems. These systems will need to be extrapolated for offshore use.

The oil FPSO experience highlights the need for a consistent challenge of on-shore system when put in offshore conditions. The systems should be challenged not only with regards to offshore design (congestion of the deck) and operating conditions (motions and accelerations of the units), but also with regards to safety and offshore escape, to inspection and maintenance constraints. These 2 last points are also relevant for systems use in shipping industry.

Finally the guidance note is consolidating 15 years of work of Bureau Veritas as third party in FSRU or FLNG projects. The paper will describe briefly the offshore regulatory context, the risk approach indispensable for the design of new technology and the content of the 1st part of the guidance note on containment systems and structural integrity.

CONTEXT OF RULES AND REGULATIONS

In general, ships and offshore units are to comply with a large number of rules and regulations, well known as the “rule puzzle”. The most important of these regulations are detailed in this paragraph.
Main Actors

Classification services are contracted with a classification society on a voluntary basis to have the compliance of the design and construction of the ship or offshore unit and of its equipment checked against rules developed by this society, which are covering the structural strength and integrity of essential parts of the ship’s or of the offshore unit’s hull and its appendages, including accommodation and deck equipment, and the reliability and the function of the propulsion and steering systems of the ship, power generation and those other features and auxiliary systems which have been built into the ship or offshore unit in order to maintain essential services on board for the purpose of safe operation. For offshore units in particular, this always includes permanent mooring systems and, on a voluntary basis, topsides process and equipment. In any case the topside integration with the hull structure is one key issue of the offshore unit design review.

Statutory requirements are imposed by the flag administration of the flagged ship or offshore unit through the national regulations. National legislation (coastal state) is applicable when the unit operates on a state shelf or EEZ which is not regulated by international conventions. They are derived from the international conventions adopted by the International Maritime Organisation (IMO) after integration in the national law. In addition, for fixed offshore units, depending on their location within or without the territorial waters or the exclusive economic zone of a given state, specific national regulations will be applicable. The classification society may be granted the delegation of the flag administration to assess the compliance of the ship or offshore unit against the statutory requirements on behalf of the flag authorities.

Owner/Operator specifications may be also requested to be complied with. These rules may be issued by the owner/operator itself, or by international associations as OCIMF or SIGGTO.

In the North Sea, the UK “safety case” is part of the rules that offshore units should meet. But in any case, the QHSE standards and specifications of the owner and of the operator of the offshore unit will apply. Australia has put in place a very similar “safety case” standards.

International Conventions

International conventions issued by IMO, are mainly developed for trading ships, but may be also extended to offshore units. The degree to which IMO requirements are enforced for offshore units depends on the Flag/Coastal State. The most important IMO conventions are the following:

- SOLAS (safety of life at sea, not easily applicable to offshore units)
- MARPOL (pollution prevention, fully applicable to offshore units)
- ILLC (load line convention)
- MODU (safety code for mobile offshore drilling units, fully applicable to offshore units)

For offshore gas terminal and production units, the most important IMO publication is the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).
Comparison with ships

Due to the nature of their operation and of the environmental constraints they are subjected to, ships and offshore units are generally of different designs fit for their intended use. Classification rules, although having the same aim, are different when addressing a ship or an offshore unit. Ships involved in international trade are generally designed and built for worldwide deep sea all year round operations during at least 20 years with two main modes of operation: en route with cargo or on ballast and at port for loading and discharge operations. Fixed offshore units are generally designed and built site specific for a specified operating time where they will operate continuously. Ships are submitted by the class and statutory requirements to a thorough inspection in dry-dock every five years at the occasion of which maintenance and repairs are rather easy to perform as necessary, while offshore units have to be so designed and built as to ensure some level of confidence that no major defect nor maintenance will require to remove the unit from service over its entire period of operation.

The decision as to call for ship rules or offshore rules is project dependent and can well be based on common sense in a first approach. When the projected unit operating pattern leave the option for one or the other rules, in particular if it is planed to have dry-docks every five years, then consideration could be given to flag policies and incentives as applicable to ships or offshore units if relevant.

BUILDING THE OFFSHORE GAS UNITS RULES

The new rules developed by Bureau Veritas for offshore gas terminals and gas production units, through the guidance note NI542, and are integrated in a larger frame of rule documents, as shown in Figure 1. It should be noted that the NI542 should be completed beginning of 2010 as the Rule Note NR 542.

During the development of the guidance note, one of the most important action was to identify the requirements already existing in the main Rules of BV and to extend their application for offshore gas units. The following Rule documents are concerned:

- BV Rules for Offshore Units (NR445), which contains a set of criteria applicable for all offshore units. These criteria cover all the technical aspects related to the classification (design and in-service inspections). The document is organized in four parts, the last one (Part D) being a Rule set applicable for floating storage and production units (FPSO).
- BV Rules for Steel Ships (NR 467), and particularly the section related to the classification of liquefied gas carriers (Part D, Ch 9)
- Other BV rule notes and guidance notes (NR, NI) covering the classification and certification of particular equipments and features, for example: NI 493 “Classification of Mooring Systems for Permanent Offshore Units”, NR 494 “Rules for the Classification of Loading and Offloading Buoys”, NR 426 “Construction Survey of Steel Structure of Offshore Units”
A particular attention has been given to the requirements of IGC Code, as stated above. This code is not directly applicable for offshore units, but it provides requirements related to the safety of liquefied gas containment systems. BV has already implemented an interpretation of IGC Code in the Rules for Steel Ships, and the application for gas carriers has been fully satisfactory for many years. For NI542, these requirements has been carefully investigated and adapted for offshore environment.

Regulations coming from other IMO conventions as SOLAS, ILLC, MODU (as defined above) has been also analyzed and extended to the field of application of NI 542. However, this extension is limited to relevant cross-references to in-force Rules for Steel Ships and Offshore Units.

CARGO PRODUCTS

The application of the new set of Rules is limited to units performing the storage and process of liquefied gases. Different international standards propose different definitions for these products, generating sometimes important problems for practical application. In order to avoid any confusion and to provide a definition of the cargo coherent with the one of its containment system, NI542 undertakes the definitions given in IGC Code, Ch 19.

Basically, three types of products are to be considered in BV Rules:

- liquefied natural gas (LNG) having a boiling point of approximately -165°C; LNG may be contained in membrane tanks of IMO independent tank, mainly of type B and C.
- liquefied petroleum gas (LPG) having a boiling point much higher than LNG (typically -55°C); LPG is very often contained in independent tanks of type A, but all containment systems except the integral tanks may be used.
- condensate (lease condensate) that means heavy hydrocarbons (as C5) collected at the well head. These products have very often a positive boiling point and may be contained in integral tanks.
IN SERVICE MAINTENANCE

For long time, the experience gained in the ship industry was the reference on most aspects regarding in service maintenance and inspections. However one must underline the important differences regarding inspection and repair campaigns, as FPSOs shall stay at site in general during the whole life of the field without be disconnected or removed from the mooring system. Consequently, dry-docking (required for inspections and repairs of ships) is not envisaged: inspections and repairs have to be performed on site and generally under continuous operation, taken into account that the hull has mainly 2 functions

- to support the topsides and accommodations.
- to store product (gas, oil, water etc…)

The last one is in particular responsible for most of the operational constraints for the inspection and repair of offshore units’ cargo tanks.

When looking at FPSO inspections feedback, another critical point is the preparation of the tanks: cleaning, gas freeing, ventilation, access to every part of the tanks, possible need for scaffolding in case of repair. Particular attention should be paid to the possibilities to access a tank contaminated with hazardous products such as mercury.

Typical defects that can be found on 20 years old offshore units

For this reason FPSO designer now include in their loading manual loading/offloading sequences for inspection and repair to be carried out in each of the hull main tanks (ballast and cargo).

For gas floating unit, the challenge of inspection and repair should also be addressed for every part of the gas tanks:

- Containment system:
  - Membrane and inner hull for membrane containment systems
  - Supports or keys, and insulation for SPB.
- Pump
  - Is it possible to remove and replace a cargo pump, taking into account offshore environment
- Tank’s equipment
PROVEN TECHNOLOGIES?

Despite the long experience in gas transportation by sea (first gas carriers were built 40 years ago) and in offshore floating unit (first FSO were installed 30 years ago), FSRU projects need to indentify the risk induced by transferring new technologies either from shipping or from onshore industry to offshore.

Classification societies have guidelines to follow developments of unproven technologies which can also be applied in the case of transfer of technology from one domain to another.

On the technical side, a qualification process using risk identification and hazard review is necessary. The qualification process is intended to prove with an acceptable level of confidence and in a cost effective manner that a technology is fit for purpose, that it complies with the specifications that the designer developed and that it is sufficiently reliable and is safe for the people and the environment.

The time frame and the costs are also important parameters: it is often impossible to perform tests for the duration of the entire expected life of the product that uses a non proven technology and the qualification is to be cost effective with regards to the expected results.

The basic principle of qualification is to simulate, as realistically as possible, the service conditions for which an unproven technology is designed. The qualification process should combine both theoretical analytical modelling and physical tests either at reduced scale or at full scale when possible. Before establishing the qualification plan and in order to optimise it, it is useful to perform an analysis of the possible failures of the technology and of their possible consequences. Techniques such as Functional Analysis and Failure Mode and Effect Analysis (FMEA) can be used to structure this analysis.

The failure analysis makes it possible to highlight the most critical points of the technology under consideration and to decide on which points more effort is to be made as well as the types of tests that are needed to further investigate them. Regarding the physical tests, the model’s size and the test’s duration should be as close as possible to the size and the design life time of the equipment. Since it is not always feasible to come close to these conditions, reduced models can be used as well as accelerated time testing procedures.

The use of repeated tests is a means to reduce the uncertainty on the results and on the extrapolation to real systems by using statistical methods. However, this is only possible for component produced in important series or at low cost.

Finally, the decision making process at the end of the qualification process is an important step in the methodology. Its goal is to help solving the trade-off between the level of qualification, the resulting costs and the expected results in terms of confidence in the unproven technology.

When designing a qualification program, the technology and the individual products must be carefully examined. The performance, quality and reliability aspects of the products must be fully understood and taken into consideration as the qualification program is developed. The design and failure modes that would contribute to reduced performance, quality, and reliability must be addressed in the qualification program to ensure that failures do not occur in field applications.
The design, manufacturing, testing, quality controls, and product quality and reliability assessment necessary to demonstrate that the product initially and continuously meets the specified requirements must be addressed and included in the qualification requirement. In addition, to the greatest extent possible, intended applications and operating environments must also be understood and considered.

In order to accomplish these objectives, product design, manufacturing materials, workmanship, conformance testing, and surveillance should be evaluated. Each of these elements should be reviewed and considered for applicability to the technology and products being considered for qualification.

The methodological approach is based on a four main steps process as follows:

- **Functional analysis**: definition of functions of the system under analysis and its associated components;
- **Failure Mode Effect and Criticality Analysis (FMECA)**: definition of failure modes for each function / component and calculation of criticality with regard to frequency, consequences and detection capability classifications;
- **Cost/benefit analysis** to determine the level of qualification needed to achieve the desired uncertainty reduction
- **Recommendations** regarding design, qualification and inspection/maintenance of equipment as to reduce/maintain the deviation from specified performances and/or risk to/under an acceptable level.

On the classification side, several type of approval can be achieved from basic approval to final concept approval:

- **Basic approval** could be issued as soon as pilot studies are completed. This approval refers to the project qualitative studies. It confirms that its outlines are consistent with both the state of the art and the applicable rules. It can also be used to discuss the main actions to be taken to further qualify the technology with a design approval.

- **Design approval** could be issued as soon as the project studies are sufficiently advanced based on project development chart and first quantitative studies. The design approval states that the design of the project is consistence with rules or criteria that are listed in the certificate. The certificate will also include a list of the analyses, model or real tests to be performed with a view to the final approval. Successive design approval certificates can be issued to follow the design progress.

- **Final concept approval** is the step prior to the classification or certification. It could be issue when all steps of the development chart and listed in the design approval certificate have been carried out. At this stage all limitations liable to interfere with either the manufacturing process (such as inspections to be performed, material specifications…) or the use of the system (limitations such as thermal limitations, sea conditions…) or its maintenance should be properly mentioned.

Finally the **classification** (or certification) of the system will follow its construction to insure that the design specifications are properly applied. In case of classification the system will also be inspected by class surveyor all along its service life.
DIRECT CALCULATIONS REQUIREMENTS

Sloshing

Sloshing impact is the impact in the tank due to internal liquid motion. This impact is directly linked to the liquid motion and thus of the resonance period of the unit and of the tank itself. Sloshing effects are critical in case of liquefied gas storage units in offshore environment, due to the particular configuration of the containment system, to the low density of cargo and to the continuous filling of tanks. For the purpose of rules included in NI542, BV requires a direct analysis of sloshing loads, based on a methodology balancing between CFD computations and reduced scale model tests. Basically, model tests are used to calibrate different parameters of CFD computations. The flowchart of this methodology is given in Figure 5. BV has published a separate guidance note including a detailed description of this methodology, as well as several requirements related to numerical tools. Reference can also be made to several previous papers (see reference [7], [8] and [12]).

![Figure 5: BV methodology for sloshing analysis](image)

Two types of results can be targeted through a direct analysis of sloshing: liquid motion (to design the pump mast for example) and liquid impact pressures (to design the possible reinforcement on the tank boundaries).

Metocean and Hydrodynamics analysis

Hydrodynamic and structural analyses are using wave’s relative heading, i.e.: the wave direction as seen by the hull. Metocean data give the wave heading with respect to the north. In case of spread moored units, the change of coordinate is straightforward. However, in case of a weathervaning unit the relative heading is more difficult to get and a heading analysis is necessary. Once the vessel heading, and hence the relative headings of each environmental
force, are known the hydrodynamic responses of the vessel can be computed. To compute the responses of the vessel several steps are needed:

- **Seakeeping analysis**: The sea-keeping calculations are aiming at determining wave induced loads and ships responses under a prescribed sea state. This step of the analysis is vessel specific, but not site specific. It will compute the response of the vessel in term of motions, accelerations, hull girder loads (such as wave bending moments and vertical shear) and wave pressure. Recent developments take into account the liquid motion inside cargo tank in the vessel response.

- **Spectral computations**: The second step of this analysis is to combine the vessel response computed previously with the site sea-state. The results of the spectral analysis will give the wave loads effects at the required return period, such as the wave vertical bending moment at 100 years return period, of the roll angle at 10 years.

- **Non linear analysis**: Depending of the site conditions the hydrodynamic analysis can continue through non linear analyses such as slamming analysis (wave impact on the bow of forward bottom), green-water analysis (wave going on the main deck), side by side offloading motions.

![Figure 6: BV methodology for heading analysis and hydrodynamic analysis](image)

**Mooring Analysis**

Mooring analyses are mandatory for offshore unit. These analyses are described in a specific guidance note (NI 493) and common to FPSO requirements. The LNG unit specificity will be the offloading capability. Today projects are clearly moving to side by side offloading. The calculations of the limiting sea states for such conditions is of prime importance since it will be sue to define the availability of the offloading system and thus the capacity of the storage unit.

The side-by-side analysis should take into account the multi-body interaction, i.e. the fact that the motion of the shuttle will induced motion on the unit and vice-versa. This phenomenon is computed through numerical approach and basin test. This first analysis will give relative motion and acceleration of the 2 units. A second step will be the mooring analysis to compute the mooring line (hawsers) tensions depending of the mooring configuration.
Structural Analysis

Bureau Veritas approach is based on the analysis of the stress level acting in the structure (for yielding, buckling and fatigue strengths) and on its verification according to permissible stresses ratios. The general flowchart of structural assessment procedure implemented in NI542 is given on Figure 12.
The structural requirements also include the LNG containment system, as described in the section.

The Figure 13 and Figure 14 show some typical coarse finite element models of FPSO and LPG FPSO. The required analysis should continue with fine mesh (size of element is around 900mm) and very fine mesh (size of element is around 50mm) for extreme conditions with corresponding yielding and buckling criteria. Site fatigue analysis, which may include full spectral analysis, is also mandatory with 3D FEM model for the most critical details.

![Figure 13: Full ship model of an FPSO, including topsides](image)

![Figure 14: Primary members analysis of an LPG FPSO](image)

### STEEL GRADES REQUIREMENTS

BV Rules for Offshore Units and Steel Ships include specific requirements related to the choice of steel grades for a given set of in operation. The properties and characteristics of steel grades are provided in NR216 “Materials and Welding”. However, particular requirements applicable for offshore gas units have been developed through NI542, taking into account the specificities of these units and mainly the storage of cargoes having a very low temperature.

The method required in NI542 combine the principles of existing BV Rules and IGC Code, providing diagrams of steel grades versus plate thickness and design temperature, as well as specific criteria for chemical composition of steels in contact with low temperature cargo.

### CONTAINMENT SYSTEMS

The containment systems applied in case of offshore gas terminals are directly derived from shipping industry. In NI542, the following types of tanks are considered:

- Integral tanks (only for products having a boiling point lower than -10°C)
- Membrane type containment system,
- IMO Type A independent tank, generally used for LPG products
- IMO Type B independent tanks, as MOSS (spherical) or SPB (prismatic)
- IMO Type C independent pressurized tanks.

These containment systems are currently applied to ships and consequently, are sea proven. However, the application of these containment systems to gas terminals leads to application of
different criteria, and in particular for fatigue. This is particularly relevant for non accessible and
critical areas listed below.

The following connections are to be subject of fatigue analysis:

- Membrane type containment system:
  - knuckles in double hull,
  - membrane connection with cofferdam bulkhead,
  - pump tower base support,
  - tank dome…
- Spherical type containment system (Moss type):
  - Equatorial ring,
  - Skirt connection with foundation deck,
  - Connection between tank cover and main deck.
- Independent tank (SPB type):
  - Vertical supports,
  - Anti rolling keys.
- Cylindrical pressurized type C LNG:
  - Vertical supports.

The supports, keys or stiffening rings are to be assessed through fine mesh finite element models, and different criteria are proposed for each type of independent tank.

**Explosion, Dropped objects, Collisions**

In offshore rules 3 types of analyses can be submitted to the class, which are not mentioned in ship rules:

- explosion
- Dropped objects
- Collision

The purpose of these 3 analyses is to check the damaged strength and safety of the vessel in case of explosion above the deck, dropped objects from a crane on lay-down area or collision with a supply vessel. Procedures to perform these analyses are defined in typical oil & gas standards such as American (API) or Norwegian (NORSOK)

In case of a FSRU/FLNG, we can highlight the criticality of the collision analysis, due the side by side transfer. In this case collision analyses should be performed taking into a gas carrier and not only the supply vessel. Moreover, even if gas storage designs are all double sided units, containment systems such as membrane and SPB, will be directly impacted by the risk of collision. Despite completely different load profile, this question of strength of side shell of FSRU/FLNG and of the effects on the containment system was also raised with for ice conditions.
CONCLUSIONS

The actual Guidance note covers general arrangement, structural integrity and containment system of a gas offshore unit. Currently under finalisation the second issue of the guidance will also address safety, stability, access and ventilation, piping system, revaporisation or liquefaction plant and LNG offloading system. This guidance note will soon become part of the Offshore Rules.

This guidance note is a good example of building Rules for a new technology at the same time that the concept analysis and basic design are in progress. The requirements are based both on extrapolation of similar technologies such as gas carrier vessels or oil and LPG FPSOs, but also on risk analysis and close follow-up with concept designer for systems that can not be easily extrapolated from existing application such as offshore offloading system.

The coming steps of this guidance will be the common evolution of a Rule, based on continuous feedback from projects, research department and international regulation and norms. Of course the in-service requirements already available for offshore gas storage units will also need to be confronted to the offshore conditions and operations.

REFERENCES

[9] P. BIASOTTO, A ROUHAN, Surveys and Inspections management for FPSOs, OMAE 2004