SPE-222621-MS

A Fixed Single-Point Mooring Innovation Solution for Offshore LNG-FSRU Import Terminal

Ju Xuanze, Dong Baohui, and Meng Xianwu, Engineering Division, Offshore Oil Engineering Co., Ltd., Tianjin, China; Yin Changquan, Li Chong, Xu Zhendong, Li Chunchao, and Yang Shu, China Harbor Engineering Company, Beijing, China; Chen Hanbao, Luan Yingni, and Shen Wenjun, Tianjin Research Institute for Water Transport Engineering, M.O.T, Tianjin, China; Chiemela Victor Amaechi, School of Engineering, Lancaster University, Lancaster, United Kingdom

Copyright 2024, Society of Petroleum Engineers DOI 10.2118/222621-MS

This paper was prepared for presentation at the ADIPEC held in Abu Dhabi, UAE, 4 – 7 November, 2024.

This paper was selected for presentation by an SPE program committee following review of information contained in an abstract submitted by the author(s). Contents of the paper have not been reviewed by the Society of Petroleum Engineers and are subject to correction by the author(s). The material does not necessarily reflect any position of the Society of Petroleum Engineers, its officers, or members. Electronic reproduction, distribution, or storage of any part of this paper without the written consent of the Society of Petroleum Engineers is prohibited. Permission to reproduce in print is restricted to an abstract of not more than 300 words; illustrations may not be copied. The abstract must contain conspicuous acknowledgment of SPE copyright.

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Abstract

Natural gas plays a critical role in sustainable development and energy transition because it's safe, high-heat and clean energy. LNG-FSRU is an offshore floating storage and regasification unit. Its main function is to receive, store and re-gasify LNG, plus transport the gasified natural gas. It gets transported ashore through subsea pipelines to supply gas to power plants and residential users. However, the mooring system is a key link in the engineering and production of LNG-FSRU. Similar to FPSO, LNG-FSRU has a variety of mooring types, including single-point mooring, multi-point mooring, dynamic positioning and dock moorings. Through comparative study, the Tower Yoke Mooring (TYM) system is widely used in shallow water FPSO, because of its good economic benefits, disconnectability and reliability. Therefore, we innovatively adopted a different berthing mode from the traditional terminal and developed a solution based on FSRU moored by TYM. Compared with the traditional fixed tower mooring system, the Tower Yoke Mooring (TYM) can reduce the overturning moment by reducing the height of the connection point, so as to facilitate the design of the mooring tower and its foundation, and the distance between the mooring point and the FSRU is shortened. Therefore, FSRU can adopt the Tower Yoke Mooring (TYM) solution to carry out overall scheme design research for LNG receiving terminal project. Meanwhile, compared with traditional onshore LNG receiving terminals, this innovative FSRU moored by TYM has the characteristics of a short construction period, rapid market development, smaller land area occupation and high device flexibility. It can be used in economically developed, environmentally sensitive and densely populated coastal areas. It is novel being energy transit, ensuring energy supply security and improving people's living standards in these areas. Thus, it meets the needs of local economic and social development.

Introduction

Considering the high demand for energy sources, there are more facilities developed for extracting the liquefied natural gas (LNG) and other oil contents. The oil and gas industry has increased its activities with recent developments made with marine risers, subsea pipelines, umbilicals, flowlines, marine hoses and mooring lines (Bai and Bai, 2005; Amaechi et al. 2022a, 2022b). Recently, there are various studies that could be adapted to the needs of the operators to consider the engineering, production, transportation and operations for enhanced LNG product delivery. Moreso, transporting these contents, including natural gas, has its challenges which include the need to have some proximity to the sources and the receiving tankers. Thus, there is a need to contain the LNG and other oil contents across longer distances. Considering that it is challenging to achieve this transport with pipelines, since it is LNG product, which is vital for the supply. Another challenge is the diverse types of mooring systems that are used to support the loading and unloading systems (Ja'e et al. 2022; Amaechi et al. 2021a, 2021b, 2022c). While the literature shows that a notable system identified for oil products is the single point mooring (SPM) system, as it is seen with catenary anchor leg mooring (CALM) applications with CALM buoys (Ju et al. 2023; Amaechi et al. et al. 2019, 2021a, 2021b), it has limitations with LNG products. The reason is that the LNG products require more robust systems that can ensure least risk, safer delivery and easier transfer and quicker transport.

Recent studies have considered the developments made in the LNG industry (Zhou et al. 2022; Zhu et al. 2017; Liu 2021; Song et al. 2021; Purwanto, et al. 2016). The transfer systems for LNG products have included both the yokes, the mooring system and moored vessels (Xie et al. 2015; Hu et al. 2021). These vessels include floating production storage and offloading (FPSO) and floating storage and regasification unit (FSRU) (Martins et al 2016). These vessels are adapted on oil and gas products transport and offshore transfer, particularly the LNG products (Kang et al. 2022; Li et al. 2021). Furthermore, there are various LNG structures that are used in the industry such as FSRU (Park et al. 2020; Ji et al. 2017; Bi et al. 2017; Kim et al. 2013), FLNG (Zhao et al. 2017; Zhao et al. 2011), FSRU-LNGC (Yue et al. 2020) and LNG-FSRU (Zhang et al. 2018; Wu et al. 2021; Lee 2020).

Practically, the challenges of the LNG sector include bunkering (Yao et al. 2024), as this affects its productivity and meeting needed deadline. As such, some studies have looked into possible solutions using an optimal scheduling approach and economic analysis of LNG operations for decision making (Trotter et al. 2016; Shin et al. 2016). To have a better outlook on this sector, recent studies have presented the market trends of LNG products reflecting how they are integrated into the energy grid (Yusuf et al. 2023; Huemme et al. 2022; Yehia et al. 2024). However, due to the volatility and flammability of LNG products, an important aspect of managing LNG operations for these onshore/offshore facilities is the risk management (Kang et al. 2022; Lee et al. 2020; Ullah et al. 2024; Ji et al. 2023). Another challenge noted in literature involves making necessary decisions for the supply chain on the LNG products, by using machine learning, automated models and autonomous vehicles (Ji et al. 2023; Devaraj, et al. 2021; Miętkiewicz, 2021). However, mooring mode is still in research and engineering application practice.

As a kind of safe and high-heat quasi-clean energy, natural gas plays a huge role in sustainable economic development, ecological environment construction, energy structure transformation and other aspects. Recent studies presented different energy outlooks and perspectives of LNG products (Yusuf et al. 2023; Huemme et al. 2022; Yehia et al. 2024). LNG-FSRU is an offshore Floating Storage and Regasification Unit (FSRU) of natural gas, whose main function is to receive, store and regasify LNG, and transport the gasified natural gas shore through subsea pipelines. Supply gas to power plants and end resident customers. Since 2005, LNG-FSRUs have been put into use in several cities around the world (including Tianjin, China) and are currently operating maturely. Compared with traditional onshore land-based LNG receiving stations, FSRU has the advantages of low investment, short construction period, high flexibility, and adaptability to natural gas supply in large cities.

Similar to FPSO, LNG-FSRU has a variety of mooring types, including single-point mooring, multi-point mooring, dynamic positioning and dock moorings. Comparatively, the Tower Yoke Mooring (TYM) system is widely used in shallow water FPSO, because of its good economic benefits, disconnectability and reliability. Therefore, there is the need to have a different berthing mode from the traditional terminal that is based on FSRU moored by TYM. Compared to the traditional fixed tower mooring system, the Tower

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Yoke Mooring (TYM) can reduce the overturning moment by reducing the height of the connection point, so as to facilitate the design of the mooring tower and its foundation, and the distance between the mooring point and the FSRU is shortened. Therefore, FSRU can adopt the Tower Yoke Mooring (TYM) solution to carry out overall scheme design research for LNG receiving terminal project. LNG-FSRU mooring system is a key link in the design and production of LNG-FSRU. LNG-FSRU adopts full-sea design, that is, LNG receiving, processing, storage, export and operation and maintenance of LNG-FSRU are carried out in the offshore area far from the shore.

Therefore, this paper will study the possibility of FSRU's single point mooring mode based on FPSO's single point mooring mode, which is different from offshore open dock mooring mode, and provide a new FSRU innovative mooring mode for the industry to design the overall scheme of future LNG receiving terminal projects. Through this comparative study, different mooring system are explored with respect to the water depth suitability, the vessel type, disconnectability, reliability and economic benefits, among other parameters.

Mooring Methods for FSRU

Mooring methods can be categorized into the following three types.

Jetty Type

This is a popular type for LNG receiving terminals using an FSRU. The FSRU moors at this type of jetty in the same way a regular LNG carrier is moored at an LNG receiving terminal. In case of adverse weather such as a typhoon, an FSRU generally leaves the jetty temporarily for safety due to the risk of damaging the FSRU itself and the jetty.

A type of jetty where the FSRU and LNG carrier moors on either side of a jetty to transfer LNG is called a Cross Jetty. When an LNG carrier is moored on the other side of an FSRU that is moored to a jetty in a Side-By-Side position, it is called a Single Jetty. In this case, the LNG transfer is carried out in a Ship-to-Ship (STS) form.

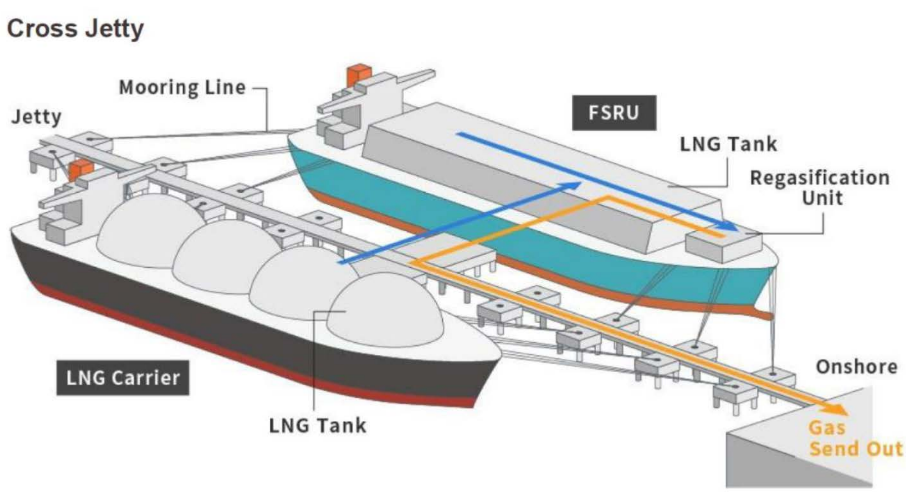


Figure 1—FSRU Moored Schematic of Cross Jetty

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

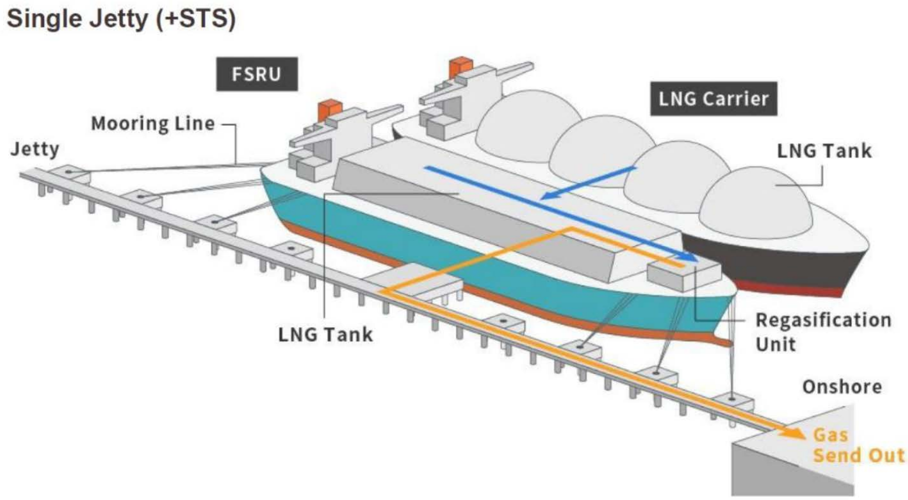


Figure 2—FSRU Moored Schematic of Single Jetty (+STS)

Single Point Mooring Type

In the single point mooring type, the anchored vessel rotates around the mooring point when receiving external force, which makes it possible to keep the vessel anchored even under adverse weather such as a typhoon, as long as it is within certain meteorological and oceanographic conditions.

Two major types within this category are turret type and yoke type. The turret type uses a rotating turret fixed at the bottom of the sea to moor the FSRU. An Internal Turret resides inside the carrier, while an External Turret is positioned outside the carrier. The Tower Yoke is an example of the yoke type mooring. The tower yoke uses a columnar structure in the ocean (the Tower) which is connected to Yoke, the connecting structure on the FSRU. These are typically employed in shallow water area. A new single point mooring type uses a rotational structure under shallow water, with the FSRU moored via a chain.

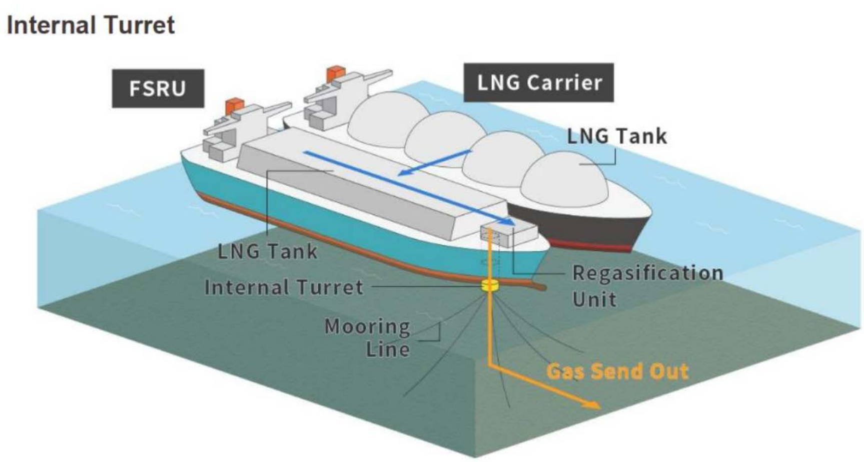


Figure 3—FSRU Moored Schematic of Internal Turret

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

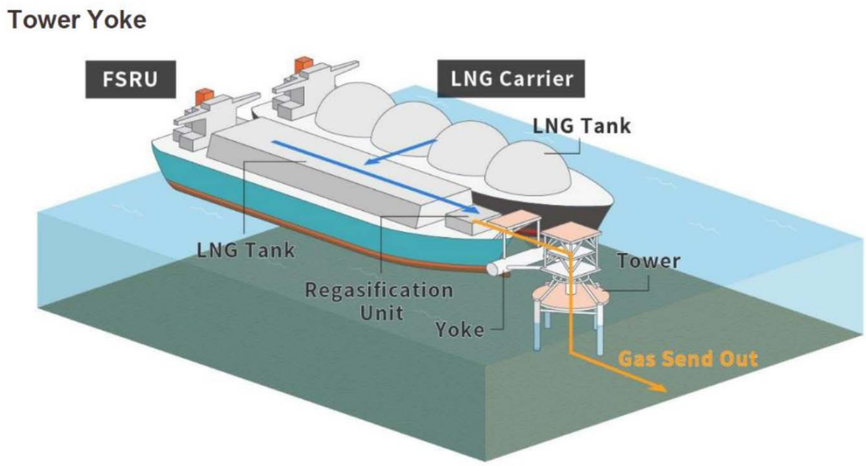


Figure 4—FSRU Moored Schematic of Tower Yoke

Spread Mooring Type

In the Spread Mooring type, multiple mooring lines connecting the FSRU directly to the seafloor are used to fix an FSRU. Mooring lines are typically connected from the bow and stern of a vessel.

The use of mooring lines makes it suitable for securing an FSRU further away from the shore compared to the jetty type or the turret type, or for a shore without developed berth or facilities. However, this type is more susceptible to waves due to the distance from the shore, and is typically used in calm waters to ensure stability of the operation.

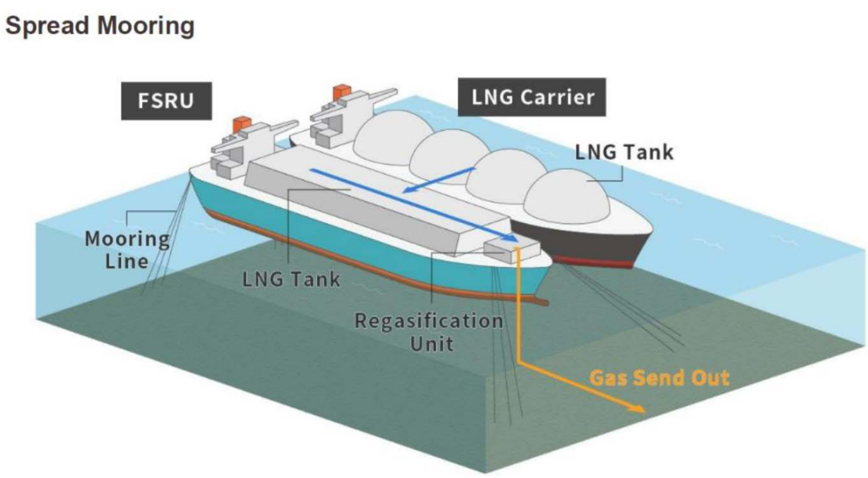


Figure 5—FSRU Moored Schematic of Spread Mooring

Investigation of FSRU Moored SPM Type

In the field of SPM system, there are some major experienced types had been investigated, as following

Tower Yoke Mooring (TYM)

The Tower Yoke Mooring (TYM) as a SPM system is used to permanently moor an FSRU. LNG Carriers will be moored side to side (STS) to offload LNG to the FSRU. In addition to providing a fixed mooring for the FSRU, the Tower Yoke will provide the interface between the subsea pipelines allowing the transfer of gas to shore. Due to the shallow water depth at the proposed site, the SPM shall be configured as a Tower Yoke Mooring System, with a fixed jacket structure, a rotating assembly (turntable), and an articulated

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

mooring yoke. The risers piping on the jacket structure of the SPM connects to a nearby platform. The yoke shall be attached to a structural frame that is mounted on the bow of the FSRU vessel with articulated struts.

Figure 6—FPSO/FSRU Moored by Tower Yoke Mooring (TYM)

The system includes a Swivel Stack Assembly to transfer gas (export) from the FSRU and to transfer electric power, control signals, and communications data between the Tower Yoke (geostationary) equipment and the vessel (rotating) equipment as the FSRU weathervanes (rotates) about the tower. The Mooring Support Structure (MSS) shall be installed on the bow of the FSRU at the shipyard with sufficient strength and approved by Classification Society (CS). Equipment used to connect the yoke, such as winches, sheaves, and necessary fittings shall be permanently installed on the FSRU vessel at the shipyard, with consideration of the maintenance, repair, and renewal works during the service life.

The Classification Society / Certifying Authority for the SPM will be set to match the Classification Society of the FSRU. The Tower Yoke Mooring System, consisting of a tower fixed at the seabed and a mooring yoke assembly connecting the FSRU with the tower, will be designed to safely moor the FSRU vessel at the SPM site for a service life of fifteen (15). The 100-year Storm conditions and other specified operational conditions are fundamental design requirements. The mooring system serves to restrain and control the excursion of the FSRU while allowing it to weathervane (rotate) around the tower. A series of articulating members with structural bearings at their connections allow the FSRU to roll, yaw, pitch, heave, surge, and a slewing of the FSRU in 100- year storm conditions, as well as during operational periods with LNG Carriers moored STS to the FSRU.

Table 1—Project experience list-Tower Yoke Mooring Systems

No.	Project Name	Location	Contract Awarded date	Region
1	FPSO Miamte – MV34	Gulf of Mexico, Mexico	Oct 2018	Americas
2	PGN FSRU Lampung Tower Yoke - Indonesia	Lampung Field, Indonesia	Nov 2012	Asia Pacific
3	FSO Gagak Rimang - Indonesia	Banyu Urip Field, Indonesia	Jan 2012	Asia Pacific
4	FPSO HYSY113 - China	BZ25-1S Field, China	July 2011	Asia Pacific
5	FSO Kome-Kribi 1 - Cameroon	FSO Kome-Kribi 1 - Cameroon	July 2001	Africa
6	FPSO Bohai Shi Ji - China	Qinhuangdao (QHD32-6) Field, China	Dec 1999	Asia Pacific

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Soft Yoke Mooring Systems (SYMS)

Soft Yoke Mooring Systems (SYMS) herewith presented its solution for the requested quick release mooring system for an FSRU with 156,000m^3 storage capacity in 15.5m water depth offshore. The SYMS is a Single Point Mooring System connecting the FSRU to a fixed tower by ballasted yoke arms. The SYMS allows the FSRU to freely weathervane around the tower, with and without a side-by-side moored LNG carrier.

Figure 7—FPSO/FSRU Moored by Soft Yoke Mooring Systems (SYMS)

The SYMS consists of the following main components that are further explained in the sub sections:

- A tower structure with pigging platform, fixed by means of piles to the seabed;
- A rotating head, with the main bearing and product swivel;
- A disconnectable mooring yoke assembly, with bearings and a ballast tanks suspended with pendulums from the mooring structure on the bow of the FSRU;
- A mooring structure, integrated in the bow of the FSRU;
- Three (3) 12" flexible risers and umbilical between the top of the rotating head and the hang-off platform on the FSRU.

Table 2—Project Experience-Tower Mooring Systems

No.	Year of Install	Field Operator	Location/Field	Water Depth (m)	Tanker Range (DWT)
1	2015	GAZPROM NEFT	OB-TAZ river mouth, NOVIY PORT, RUSSIA	10.4	55,000
2	2008	LUKOIL	CASPIAN SEA YURI KORCHAGIN FIELD, RUSSIA	22	30,000
3	2009	CONOCOPHILLIPS	PENGLAI FIELD, BOHAI BAY, CHINA	27	300,000
4	2005	EXXON NEFTEGAS LIMITED	SAKHALIN ISLAND	45	110,000
5	1996	TEXACO / ANGOLA	LOMBO FIELD, OFFSHORE ANGOLA	37.5	270,000
6	1985	SOVEREIGN OIL & GAS, DAVY OFFSHORE / NORTH SEA	EMERALD FIELD, NORTHERN NORTH SEA	150	200,000
7	1982	HUDBAY OIL / MALACCA STRAIT, MALAYSIA	SUMATRA, INDONESIA	23	140,000

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Catenary Anchor Leg Rigid Arm Mooring (CALRAM)

The CALRAM system is a mooring system that will permanently moor the FSRU. The CALRAM includes a turret type buoy, consisting of a round buoy body with a turret in the centre and a chain spider underneath the buoy. A 3x3 mooring system and riser is connected to the chain spider. The rigid arm connects the buoy body to the FSRU with hinges at FSRU side. The FSRU can weathervane freely around the turret to minimize the loads from wave, wind and current. The system is especially suitable for shallow waters with harsh wave conditions. The robust CALRAM system is characterised by its predictable behaviour for the mooring system and the riser.

Figure 8—FPSO/FSRU Moored by Catenary Anchor Leg Rigid Arm Mooring (CALRAM)

The rigid arm is fitted with walkways to have easy access to the buoy. A deckhouse is installed on the buoy. The swivel and other equipment are installed in the deckhouse, protected from the environment and possible intruders.

The gas transfer system can be designed for 80 barg. It includes piping, a single path swivel and subsea risers. The riser connects the buoy transfer system to the PLEM, which is equipped with pigging facilities. The dedicated and proprietary riser arrangement for gas is suitable for shallow water conditions and the environmental conditions. The swivel is proprietary designed and fabricated by Bluewater, based on proven gas sealing technology.

The CALRAM is equipped with the required features and equipment for installation, operation and maintenance. This includes installation aids, safety systems, a process control system, monitoring systems, navigation aids and a deluge system. The power for these systems and the firewater is supplied by the FSRU.

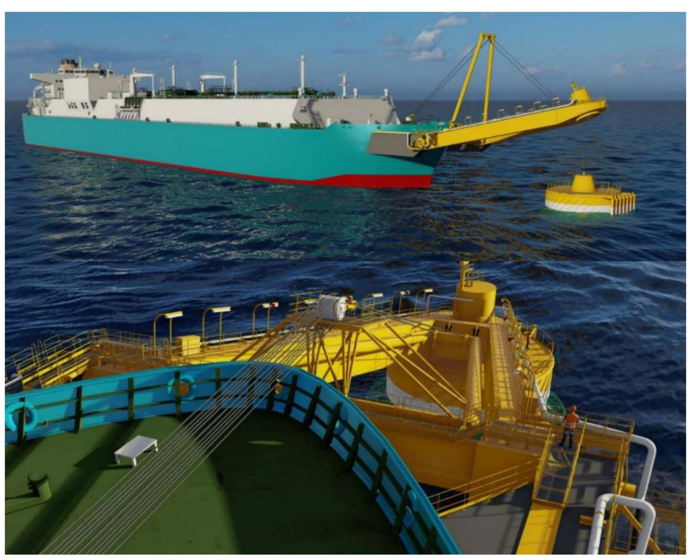


Figure 9—Catenary Anchor Leg Rigid Arm Mooring (CALRAM) Releasing Operation

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Table 3—Project Experience-Tower Mooring Systems

No.	Year of Install	Field Operator	Location/Field	Water Depth (m)	Tanker Range (DWT)
1	1995	HAMILTON OIL	LIVERPOOL BAY / DOUGLAS	30	116,500
2	1982	PHILLIPS PETROLEUM	IVORY COAST / ESPOIR	87	240,000
3	1981	UNION OIL OF THAILAND	SOUTH CHINA SEA / ERAWAN	68	85,000

Submerged Swivel and Yoke (SSY)

For the turret mooring system of the FSRU, Submerged Swivel and Yoke (SSY) system can be used. The FSRU will be single point moored at the bow with a SSY system free to weathervane, located in shallow waters, at approximately 18-20m water depth. A gas pipeline will connect the SSY to the power plant onshore. The LNG will be transferred from a gas carrier to the FSRU side by side, and after regasification it will be transferred through the riser and pipeline to the power plant onshore.

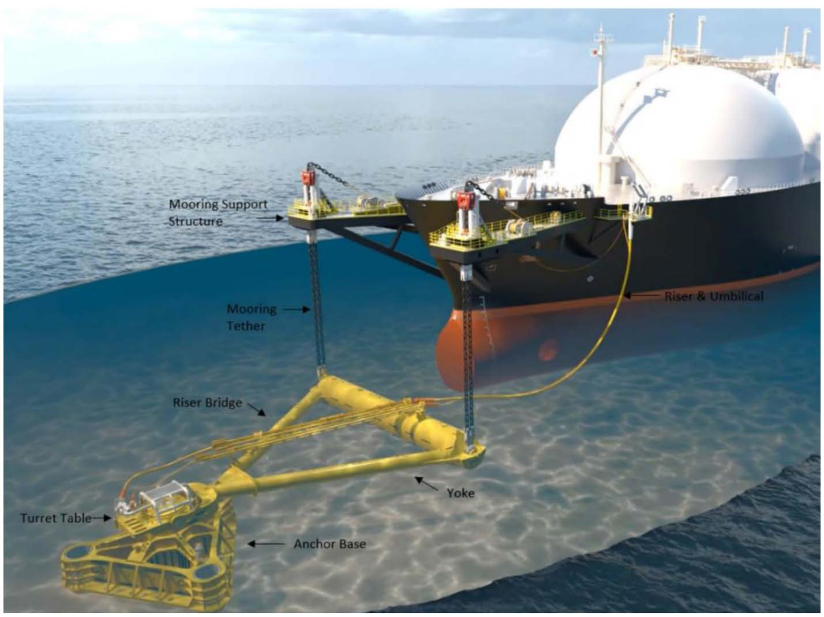


Figure 10—FPSO/FSRU Moored by Submerged Swivel and Yoke (SSY)

The SSY system provides passive mooring for the FSRU and in addition provides a flow-line system that makes it possible for the FSRU to offload gas through the flow-line and into the subsea pipeline that brings it to shore where the power plant is located. The SSY will also handle a side-by-side condition where an LNG carrier unloads its LNG to the FSRU. The vessel(s) are free to weather vane 360 degrees.

The SSY system comprises the following main components:

- SSY Base Assembly
- Yoke and Mooring Tether Assembly
- Fluid Transfer System
- Shipboard Structure and Equipment

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Table 4—Project Experience-Submerged Swivel and Yoke (SSY)

No.	Year of Install	Field Operator	Location/Field	Water Depth(m)	Tanker Range (DWT)
1	2018	CELSE	SERGIPE, Brazil	20	170,000
2	2017	GOLAR	KRIBI/SANAGA SUD, Cameroon	20	125,000

Submerged Yoke Tower (SYT)

SYT system also is a selection for mooring the FSRU. Most standard turret mooring systems are ruled out due to the limited water depth at the location.

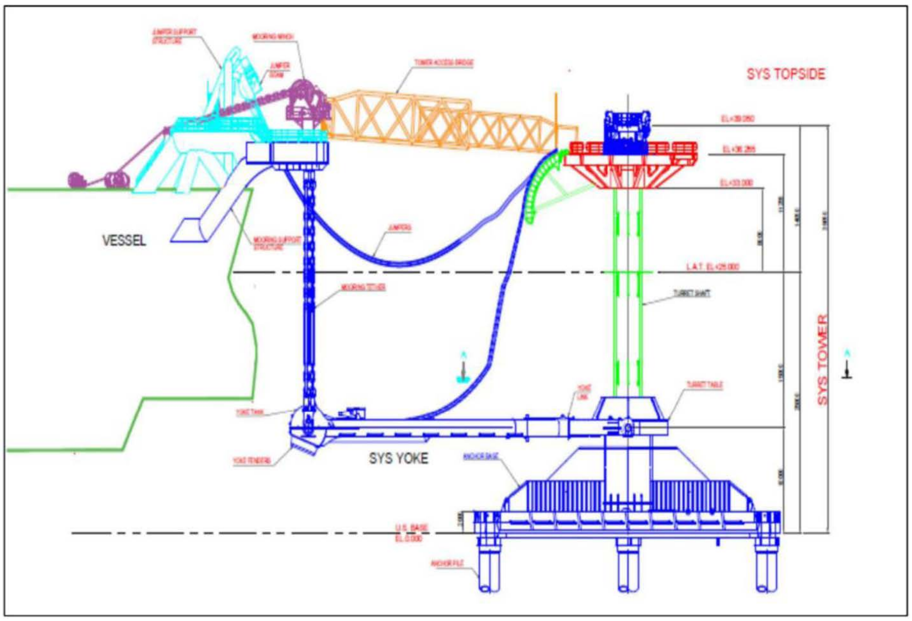


Figure 11—FPSO/FSRU Moored by Submerged Yoke Tower (SYT)

The complete SYT system is divided into the following main assemblies:

- Subsea Assembly (Pile Base, Turret Table, Yoke, Anchor Piles)
- Topside Assembly
- FSRU Structural Arrangement

The pile base structure with foundation transfers the mooring forces from the mooring yoke to the sea bed via the turret table bearing arrangement. The tower serves as support for the jumper hoses and flexible riser jumpers. The jumpers are connected about 25 m above still water line. The topside structure with the jumper connections follows the rotation of the turret table (i.e. driven by the mooring yoke rotation, and thus follows the weathervaning of the FSRU).

Comparative analysis for FSRU Moored by Different SPM Type

Single point selection principle needs to fulfill the requirements of the project, safety, environmentally friendly, high reliability, easy to operate and maintain, and good economy throughout the life cycle. Therefore, the main aspects of comparison are as following shall be considered.

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Quick Release

Quick Release is one of the requirements of this project. The design requirement of SPM system is to be able to withstand 50-years return environmental condition . FSRU should be quick released in survival condition (harsher than 50-years return environmental condition) to avoid accident. The duration of release for FSRU should be less than 12 hours if possible.

Compared with the permanent system, the Quick Release SPM system has the following features: Increase in safety due to the Quick Release capability—The Quick Release SPM system is considered safer because the FSRU can effectively avoid extreme wind and waves by releasing the mooring lines/yoke and the hoses, and sail to safe harbor. After release, the mooring lines/yoke and the hoses should be protected from environmental loads.

Sea Condition adaptability

The weathervaning capability of the SPM system reduces the loads due to wind, waves, and current, so that the dimensions of the mooring lines are effectively minimized. SPM systems for FSRU have great adaptability to work in different environmental conditions. For this project, the challenge of sea condition adaptability is from 2 risks:

a. SPM system should be able to withstand 50-Year return environment load with FSRU connected to SPM and be able to withstand 100-year return without FSRU connected to SPM.
b. Collision between FSRU and yoke due to the motion of FSRU

High-quality engineering demonstration and fabrication can avoid the situations above.

Shallow Water adaptability

The FSRU will be installed at approximately 5.00 km offshore in a water depth of approximately 18.0m(after dredging). For this water depth, the Tower yoke and the submerged yoke are the best choice. They are designed for shallow water. For the deeper water location, floating turret or buoy mooring system are better. The only risk for the tower yoke and the submerged yoke is the possibility of touching seabed due to the motion of FSRU. The hydrodynamic analysis and the model test may be necessary to control this risk.

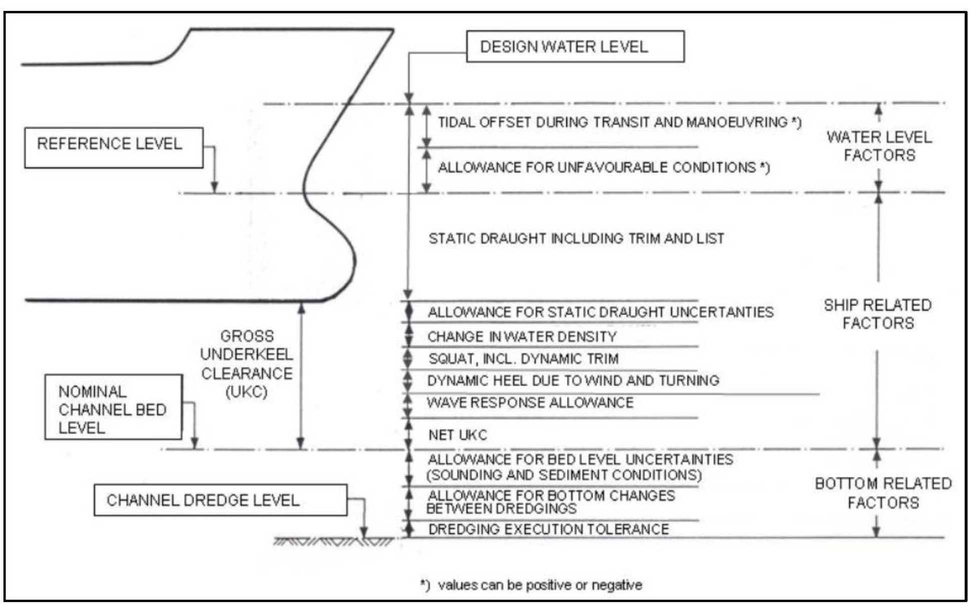


Figure 12—PIANC-Harbour Approach Channels Design Guidelines, for illustration

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Reliability

The factors that affect the reliability of SPM are:

a. Durability of key components, such as swivel, bearing, rotating head of yoke.
b. Tolerance of key rotating components.
c. Corrosion.
d. Lubrication System of Bearing.
e. Fatigue loads
f. Durability of Material
g. Operating conditions, environment

It is difficult to say which supplier's product is more reliable, it depends on the supplier's engineering experience, product quality control and the rationality of the product design. But according to the existing projects of SPM, the Equipment above the water surface is easier to maintain and inspect regularly. Two perspectives for determining reliability in this report are:

a. Supplier's capability and project experience
b. The reliability of the SPM type existing in the world

The accidents of the submerged yoke SPM are significantly more than that of the tower yoke SPM, the main reason is that the main components of submerged yoke SPM is underwater and it is difficult to observe/ inspect minor defects during operation condition. When the environment become worse, tiny defects will cause severe problems.

Maintainability

Maintenance is very important for SPM system. Required maintenance works are:

a. Inspection for structure defects.
b. Inspection for rotating parts
c. Maintenance of lubrication system for bearing.
d. Inspection seal of swivel
e. Inspection for leak of whole piping (including swivel)
f. Flushing or pigging
g. Inspection for corrosion

Inspection for the underwater components of SPM is a big challenge for maintenance. The maintainability of tower yoke SPM is much better than submerged yoke SPM. The reliability and durability of the components of submerged yoke is very important because the maintenance is very difficult to be performed for this system.

Economy

The economy of SPM depends on two aspects: one is the cost of initial investment, and the other is the cost of maintenance and repair. The initial investment cost is mainly evaluated by the manufacturer's quotation, including fabrication and installation. Maintenance and repair costs depend on whether the components are durable, and how easy it is to repair and replace them after damaged.

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Different Type SPM Selection Analysis

Tower Yoke Mooring (TYM)

- Quick Release
  The Tower Yoke Mooring system is a disconnectable permanent single point mooring system without quick release function, the design goals are to keep the FSRU connected to the tower yoke assembly under 100-year Storm conditions and other specified operational conditions.
- Sea Condition adaptability
  The Tower Yoke Mooring system adopts the permanent mooring system, and the 100-year Storm conditions and other specified operational conditions are fundamental design requirements. The maximum significant wave (Hs) is assumed to be 5m (100-yr condition).
  Sea Condition adaptability of tower yoke SPM is good based on existing projects. TYM is a tradition jacket fixed platform and it is strong enough for environmental loads. TYM is better than others because it can provide stronger bending resistance under environmental loads.
- Shallow Water adaptability
  Tower yoke or submerged yoke is specifically designed for shallow water condition. It is a nonlinear mooring system which can only provide a soft initial restoring stiffness at small vessel offsets and provides large stiffness at relatively large offsets. According to the experience applied for FPSO project, it is noticed that an oil filed project in China Bohai Bay is very similar to moor a FSRU. The maximum DWT of that FPSO is also approximately 160,000 t, and the water depth is 18m. The shallow water adaptability of TYM is good.
- Reliability
  TYM is a traditional SPM system widely used in shallow water mooring FPSO\FSRU. There are a lot of existing projects using TYM system. The reliability of TYM is good and can be trusted.
- Operability
  The operability of TYM is better and no special operation was required during operation procedure.
- Maintainability
  The design of the TYM system keeps the Yoke above water at all times. The Yoke is designed to remain clear of the tower and the FSRU bow in all sea states. The benefit of mounting the yoke above the water is that eliminate the possibility of the Yoke reaching the sea floor which is a possible scenario for a submerged yoke system. In addition, the Yoke can be monitored and is 100% inspectable after severe storms.
  All key components of TYM are above water and can be accessed / repaired easily. Routing inspection and replacing key component are also easy. The maintainability of TYM is excellent.
- Economy
  TYM structure including a traditional jacket and a large topside requires more steel making it less economical. The structure exposed above water also increases the wave load and wind load, which leads to a larger size of the structure . The cost of fabrication is high, and economy is not good.

Soft Yoke Mooring System (SYMS)

- Quick Release
  SYMS have a quick release mooring yoke assembly with bearings and a ballast tanks suspended by pendulums from the mooring structure on the bow of the FSRU. A winch to support the yoke tip for quick release purposes and Mechanical handling systems for the swivel and the jumper hoses are pre-installed to the system. The yoke is connected to the tower rotating head by means of a

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

double pivoting disconnectable hinge, hence, the yoke can be quick release from the tow structure when required. The dis-connectability of SYMS is excellent.

- Sea Condition adaptability

  Sea Condition adaptability of SYMS is good. SYMS consists of a piled substructure with a braced central column. Only 1 column across the water surface, environmental load on tower is less than traditional tower. It can meet the environmental conditions of the project.

- Shallow Water adaptability

  Tower yoke or submerged yoke is special designed for shallow water condition. It is a nonlinear mooring system which can only provide a soft initial restoring stiffness at small vessel offsets and provides large stiffness at relatively large offsets. Shallow Water adaptability of SYMS is as good as TYM. The difference is at the base structure. TYM is a jacket structure and SYMS is a single column with skirt pile's structure.

- Reliability

  SYMS is similar to traditional Tower Yoke Mooring system. The reliability is also good and can be trusted. The only difference lies in its quick disconnecting function. There are only a few project applications, and its reliability needs further research.

- Operability

  Due to the quick disconnecting function, operating procedures are relatively complex to the traditional TYM system. The typhoon relief procedures need to be developed and implement.

- Maintainability

  The SYMS comprises sensitive components above water. It can be accessed / repaired easily, this significantly increases the reliability and maintainability of the system and minimizes the operational expenditures.

- Economy

  Compared to Traditional TYM system, SYMS has quick release function. In order to implement the function, a set of hydraulic caliper device should be added, and the mooring support structure mounted on FSRU bow is large and complex. Therefore, the economy of SYMS is also not good.

Catenary Anchor Leg Rigid Arm Mooring (CALRAM)

- Quick Release

  Catenary Anchor Leg Rigid Arm Mooring (CALRAM) system is a disconnectable permanent mooring system without quick release function, the whole system is simpler than a SYMS. The rigid arm connects the FSRU with hinges at FSRU side to a turret type buoy, the buoy is then moored by a 3*3 mooring system. The connection between the rigid arm and the buoy is secured by bolting. Then the mooring is completed.

- Sea Condition adaptability

  As for the CALRAM system, it is suitable for mooring the FSRU beyond the 100-yr return period conditions. And this is confirmed through previously mooring assessments performed by Bluewater for a 170,000m3 FSRU in conditions up to 7.6m Hs.

- Shallow Water adaptability

  As for the CALRAM system, the turret buoy is moored to the seabed by catenary anchor legs, the buoy contains a bearing system that allows a part of it to rotate around the moored geostatic part. The mooring system is always specifically designed to match the vessel's requirements and local environmental conditions.

  According to the working principle of catenary mooring system, it needs a certain water depth to form the catenary configuration. As the water depth becomes shallow, the stiffness of the system

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

increases sharply. Not only the design of mooring system is a challenge, but also the design of submarine hose.

According to above 13 project experiences, the water depth of the shallowest project is 25m. Therefore, the shallow water adaptability of CALRAM is not good.

- Reliability

  The turret buoy is a further development of the turntable-style buoy with some major adaptation, Less than 25 have been installed so far. This type of buoy also has failed cases, for example, for the turret-style buoy served in Ravva Oil Field in 1998, the main bearing had failed led to the total failure of the turret-style CALM buoy after less than 2 years in service, and this is the first known catastrophic failure of a marine terminal.
- Operability

  Underwater inspection by diver is needed.
- Maintainability

  The CALRAM system is robust and characterized by its predictable behavior for the mooring system and the riser. The rigid arm is fitted with walkways to have easy access to the buoy. A deckhouse is installed on the buoy. The swivel and other equipment are installed in the deckhouse, protected from the environment and possible intruders. Submarine hose should be replaced regularly every 5-8 years.
- Economy

  CALRAM can be installed in the same way as a typical CALM buoy with local tugs and anchor handling vessels, without the need for special heavy lift vessels. The rigid arm is installed on the FSRU at the FSRU conversion yard. This installation system avoids the need of expensive heavy lift vessels during installation and hook-up of the CALRAM system. But the installation of the PLEM and anchor pile also need a lift vessel. The installation process is slightly complex and the installation duration is longer. The economy during full life cycle of CALRAM is not good.

Submerged Swivel and Yoke (SSY)

- Quick Release

  The FSRU will be single point moored in the bow with an SSY system free to weathervane. Generally, the SSY system is a disconnectable permanent mooring system without quick release function, while it can be designed into a quick release system by some necessary changes, these main changes involve the re-design of riser system, Fluid Transfer System and Mooring Pull-In Equipment.

  The following several improvements for quick release system could be further studied.

a. Riser and umbilical system are replaced by a single riser system. The riser is integrated with an optical fiber cable and electrical conductors for controlling the SDV valve and getting feedback of readings subsea, as pressure, temperature, valve status etc.
b. Inline swivel will have seals activated by a pressurized barrier system.
c. Fluid Transfer System at Anchor base will include the following additional equipment:
   - Subsea Control Unit
   - Subsea Hydraulic Valve Control
   - Subsea Accumulator Rack, that can be refilled by ROV or Diver every 5 years.
d. Mooring pull-in equipment: A-frame replaced with Wildcat Winches allowing for quick release of SSY.

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

- Sea Condition adaptability

  The Submerged Swivel and Yoke (SSY) system proposed by APL is designed for 100-year return period storm condition which is usually defined as the 100 years return period wave combined with the 100 years return period wind and the 10 years return period current
- Shallow Water adaptability

  Tower yoke or submerged yoke is specifically designed for shallow water condition. It is a nonlinear mooring system which can only provide a soft initial restoring stiffness at small vessel offsets and provides large stiffness at relatively large offsets. Based on APL experience from previous projects, studies, and model tests, it is recommended that a water depth of 20m should be adopted for the SSY system. Whether it meets the requirements of 18m water depth needs further clarification.
- Reliability

  SSY is a new type of SPM system developed. The first SSY was installed in 2017. The reliability of SSY needs more time to check.
- Operability

  Underwater inspection by diver is needed.
- Maintainability

  The maintainability of SSY is not easy because main bearing/yoke/swivel of SSY is under water and hard to inspect/maintain.
- Economy

  SSY has less structures and the cost of structure fabrication is significantly less than that of the traditional TYM system. The offshore installation cost is also less. Due to the underwater structure, the later inspection and maintenance are inconvenient, and the later maintenance cost needs pay more attention.

Submerged Yoke Tower (SYT)

- Quick Release

  Submerged Yoke Tower (SYT) is designed to keep the FSRU passively moored in a 100-year return period non-hurricane design condition, and also the FSRU can be quick released from the SYT in case of hurricanes and named storms.

  SYT is similar to SPM systems from FPSO used in an oil filed of China Bohai Bay. The connection/dis-connection of submerged yoke is similar to SSY. More detailed information of jumper hoses quick release/re-connection needs further clarification.
- Sea Condition adaptability

  SYT is designed as a quick release system, when the FSRU is connected to the subsea system via the SYT, the harshest design condition is the 100-year return period normal/non-hurricane condition. This corresponds to a maximum significant wave height of 1.5m. While the harshest condition for the FSRU to be released from the SYT is the 100-year return period hurricane condition, which corresponds to a significant wave height of 5.0m.
- Shallow Water adaptability

  Tower yoke or submerged yoke is specifically designed for shallow water condition. It is a nonlinear mooring system which can only provide a soft initial restoring stiffness at small vessel offsets and provides large stiffness at relatively large offsets. Shallow water adaptability of SYT is as good as SSY. Therefore, the minimum water depth for the project is 25m at least.
- Reliability

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

The reliability of SYT is not good because submerged yoke SPM is designed in the underwater, and it is difficult to observe/inspect minor defects during operation condition. When the environment condition becomes worse, tiny defects will cause severe problems.

There are two failure cases in China Bohai Bay. The SPM type is the same as SYT. One was replaced by TYM, the other was replaced by a new one of the same type.

- Operability

The operability of SYT is good, and no special operation required during operation procedure.

- Maintainability

The maintenance of SYT is not easy because main bearing/yoke of yoke is designed in the underwater and hard to inspect/maintain.

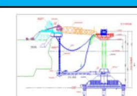
- Economy

The economy of TYS is good in initial and fair in maintenance since the submerged yoke SPM has less structures and the cost of structure is significantly less than traditional TYM system.

Selection Summaries

According to above discussion , a summary of FSRU mooring selection is listed in Table 1. It is easy to find pros and cons of each SPM system.

Table 5—Selection Summaries

Mooring Type	TYM	SYMS	CALRAM	SSY	SYT
Typical Figure					
Disconnectable	Yes	Yes	Yes	Yes	Yes
Quick Release	No	Yes	No	Yes	Yes
Sea Condition Adaptability	★★★★	★★★★	★★★☆	★★★☆	★★★☆
Shallow Water Adaptability	★★★★	★★★★	★	★★★	★★
Reliability	★★★★	★★★	★★★	★★	★
Operability	★★★★	★★★☆	★★★	★★★	★★★
Maintainability	★★★★	★★★★	★★★	★★	★★
Economy	★★	★	★★	★★★	★★
Project Experiences	★★★	★	★★★	★	☆
Final Evaluation	★★★☆	★★★	★★☆	★★☆	★★

As per the above score evaluation, the main FSRU mooring selection conclusions as following,

- For disconnectable permanent SPM system without quick release function, the TYM is recommended.
- For quick release SPM system, the SYMS is recommended.

Conclusions

There are many mooring system types available for LNG-FSRU, mainly including single point mooring system, multi-point extended mooring system, dynamic positioning system and dock mooring. The offshore open dock mooring mode has been widely used and developed. However, mooring mode is still in research and engineering application practice. Through the investigation of FSPO mooring system in oilfield development projects, and considering safety, environmentally friendly, high reliability, easy to operate and maintain, and good economy throughout the life cycle, etc., the selection of mooring mode of FSRU had been studied. As a system suitable for shallow sea area, the Tower Yoke Mooring (TYM) has good

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

economic benefits and release. It is widely used in shallow water FPSO project and is one of the important choices for FSRU mooring. Compared with the traditional fixed tower mooring system, the Tower Yoke Mooring (TYM) can reduce the overturning moment by reducing the height of the connection point, so as to facilitate the design of the mooring tower and its foundation, and the distance between the mooring point and the FSRU is shortened. Therefore, FSRU can adopt the Tower Yoke Mooring (TYM) solution to carry out overall scheme design research for LNG receiving terminal project.

Acknowledgments

Acknowledging the completion of this paper is a momentous task, and I want to express my appreciation for everyone who played a role. The authors are greatly grateful to the referees for their helpful comments and suggestions, which help improve this paper.

References

Zhou Shouwei, Zhu Junlong, Shan Tongwen, et al; Development status and outlook of natural gas and LNG industry in China. *China Offshore Oil and Gas*, 2022,**34**(01):1–8.

Zhu Li-Xiang, Di Zhan-Zhen, Gu Wen-Qiang. The key design issues of general layout of LNG terminal at Qasim, Pakistan. *China Harbour Engineering*, 2017,**37**(05):36–40+52.

Liu Yunzhu. Development Trend of Liquefied Natural Gas Terminals. *Gas & Heat*, 2021, **41**(09):11–15+45.

Song Wei-Hua, Li Tian, Cheng Han-Yi, Zhang Yong, Qin Jie. Characteristics and design points of FSRU terminal. *Port & Waterway Engineering*, 2021(04): 39–43+69.

Ji Peng, Chen Zhenzhong, Li Chan, Zheng Xuefeng, Pan Hongyu, An Xiaoxia, Bai Gailing. Comparison, selection and development trend of FSRU key system. *Oil & Gas Storage and Transportation*, 2017,**36**(11):1320–1325.

Xie Min, Tang Yong-Sheng, Zou Tao. Research and Development of Liquefied Natural Gas Offshore Transfer System. *Naval Architecture and Ocean Engineering*, 2015,**31**(06):13–19.

Zhang Fengwei, Kuang Xiaofeng, Qi Xiangyang. Hydrodynamic study of soft yoke moored LNG-FSRU. *The Ocean Engineering*, 2018,**36**(06):38–45. DOI:10.16483/j.issn.1005-9865.2018.06.005.

Bi Xiaoxing, Liu Yang, Peng Yanjian. Study on wind speeds for the safe operation of the mooring systems of FSRU. *China Offshore Oil and Gas*, 2017, **29**(02):162–165.

Wu Yong-Qiang, Zhang Yu-Ping, Cao Yu. Comparative research on LNG-FSRU mooring arrangement at home and abroad. *China Harbor Engineering*, 2021, **41**(03):50–53+58.

Amaechi, C. V., Wang, F., Hou, X., & Ye, J. (2019). Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy. *Ocean Engineering*, **171**, 429–442. https://doi.org/10.1016/j.oceaneng.2018.11.010

Amaechi, C. V., Wang, F., & Ye, J. (2021a). Mathematical Modelling of Bonded Marine Hoses for Single Point Mooring (SPM) Systems, with Catenary Anchor Leg Mooring (CALM) Buoy Application: A Review. *Journal of Marine Science and Engineering (JMSE)*, **9**(11), Article 1179. https://doi.org/10.3390/jmse9111179

Amaechi, C. V., Chesterton, C., Butler, H. O., Wang, F., & Ye, J. (2021b). An Overview on Bonded Marine Hoses for Sustainable Fluid Transfer and (Un)Loading Operations via Floating Offshore Structures (FOS). *Journal of Marine Science and Engineering (JMSE)*, **9**(11). https://doi.org/10.3390/jmse9111236

Kim, B.W., Hong, S.Y., Sung, Hong & Hong, S.W. (2013). Dynamic coupled multi-body analysis of FSRU and mooring system. *Proceedings of the International Offshore and Polar Engineering Conference*. 927–933.

Park, Taeyoon, Junhwan Jeon, Jung Kim, Sangbae Jeon, Bongjae Kim, and Dongyeon Lee. Development of a Pile Mooring System for Large Scale FSRUs. *In International Conference on Offshore Mechanics and Arctic Engineering*, vol. **84324**, p. V02AT02A064. *American Society of Mechanical Engineers*, 2020. https://doi.org/10.1115/OMAE2020-19179.

Zhao, Dongya, Zhiqiang Hu, and Gang Chen. Experimental investigation on dynamic responses of FLNG connection system during side-by-side offloading operation. *Ocean Engineering* **136** (2017): 283–293. https://doi.org/10.1016/j.oceaneng.2017.03.034.

Kang, Zhuang, Zonglin Li, and Jichuan Kang. Risk management framework of LNG offshore transfer and delivery system. *Ocean Engineering*, **266**(2022), Part 4, 113043. https://doi.org/10.1016/j.oceaneng.2022.113043.

Li, Tongtong, Xiao He, and Pan Gao. Analysis of offshore LNG storage and transportation technologies based on patent informatics. *Cleaner Engineering and Technology*, **5**(2021), 100317, https://doi.org/10.1016/j.clet.2021.100317.

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

Purwanto, Widodo Wahyu Yuswan Muharam, Yoga Wienda Pratama, Djoni Hartono, Harimanto Soedirman, Rezki Anindhito. Status and outlook of natural gas industry development in Indonesia. *Journal of Natural Gas Science and Engineering*, **29** (2016), 55–65. https://doi.org/10.1016/j.jngse.2015.12.053.

Zhao, W.H., Yang, J.M., Hu, Z.Q. and Wei, Y.F. Recent developments on the hydrodynamics of floating liquid natural gas (FLNG). *Ocean Engineering*, **38**(2011), 1555–1567. https://doi.org/10.1016/j.oceaneng.2011.07.018.

Devaraj, Devasanthini, Eoin Syron, Philip Donnellan. Diversification of gas sources to improve security of supply using an integrated Multiple Criteria Decision-Making approach. *Cleaner and Responsible Consumption*, **3**(2021), 100042. https://doi.org/10.1016/j.clrc.2021.100042.

Hu, Jinqiu, Faisal Khan, and Laibin Zhang. Dynamic resilience assessment of the Marine LNG offloading system. *Reliability Engineering & System Safety*, **208**(2021), 107368. https://doi.org/10.1016/j.ress.2020.107368.

Yue, Jingxia, Weili Kang, Wengang Mao, Pengfei Chen, and Xi Wang. Prediction of dynamic responses of FSRU-LNGC side-by-side mooring system. *Ocean Engineering*, **195**(2020), 106731. https://doi.org/10.1016/j.oceaneng.2019.106731.

Martins, Marcelo Ramos, Marco Aurélio Pestana, Gilberto Francisco Martha de Souza, and Adriana Miralles Schleder. Quantitative risk analysis of loading and offloading liquefied natural gas (LNG) on a floating storage and regasification unit (FSRU). *Journal of Loss Prevention in the Process Industries*, **43**(2016), 629–653. https://doi.org/10.1016/j.jlp.2016.08.001.

Lee, Sangick. Quantitative risk assessment of fire & explosion for regasification process of an LNG-FSRU. *Ocean Engineering*, **197**(2020),106825. https://doi.org/10.1016/j.oceaneng.2019.106825.

Miętkiewicz, Rafal. LNG supplies' security with autonomous maritime systems at terminals' areas. *Safety Science*, **142**(2021), 105397. https://doi.org/10.1016/j.ssci.2021.105397.

Ji, Chenxi, Shuai Yuan, Zeren Jiao, James Pettigrew, Mahmoud M. El-Halwagi, Hans J. Pasman. Risk informed floating storage and re-gasification unit (FSRU) location selection for local natural gas supply. *Ocean Engineering*, **268**(2023), 113357. https://doi.org/10.1016/j.oceaneng.2022.113357.

Trotter, Ian M., Marília Fernandes Maciel Gomes, Marcelo José Braga, Bjørn Brochmann, Ole Nikolai Lie. Optimal LNG (liquefied natural gas) regasification scheduling for import terminals with storage. *Energy*, **105**(2016), 80–88. https://doi.org/10.1016/j.energy.2015.09.004.

Shin, Seolin, Yongseok Lee, Kiwook Song, Jonnggeol Na, Seongho Park, Yeongbeom Lee, Chul-Jin Lee, Chonghun Han. Design and economic analysis of natural gas hydrate regasification process combined with LNG receiving terminal. *Chemical Engineering Research and Design*, **112**(2016), 64–77. https://doi.org/10.1016/j.cherd.2016.06.003.

Yao, Akoh Fabien, Maxime Sèbe, Laura Recuero Virto, Abdelhak Nassiri, Hervé Dumez. The effect of LNG bunkering on port competitiveness using multilevel data analysis. *Transportation Research Part D: Transport and Environment*, **132**(2024), 104240. https://doi.org/10.1016/j.trd.2024.104240.

Noor Yusuf, Rajesh Govindan, Luluwah Al-Fagih, Tareq Al-Ansari. Strategic and flexible LNG production under uncertain future demand and natural gas prices. *Heliyon*, **9**(2023), e16358. https://doi.org/10.1016/j.heliyon.2023.e16358.

J.C. Huemme, S.A. Gabriel, P. Chanpiwat, T. Shu. An analysis of the U.S. - China Trade War's impact on global natural gas markets and the U.S. Coast Guard's LNG inspection workforce. *Journal of Natural Gas Science and Engineering*, **97**(2022), 104198. https://doi.org/10.1016/j.jngse.2021.104198.

Fatma Yehia, Akram Ali Nasser Mansoor Al-Haimi, Yuree Byun, Junseok Kim, Yesom Yun, Gahyeon Lee, Seoyeon Yu, Chao Yang, Lihua Liu, Muhammad Abdul Qyyum, Jihyun Hwang. Integration of the single-effect mixed refrigerant cycle with liquified air energy storage and cold energy of LNG regasification: Energy, exergy, and efficiency prospectives. *Energy*, **306**(2024), 132567. https://doi.org/10.1016/j.energy.2024.132567.

Ju, X., Amaechi, C.V., Dong, B., Meng, X. and Li, J., 2023. Numerical analysis of fishtailing motion, buoy kissing and pullback force in a catenary anchor leg mooring (CALM) moored tanker system. *Ocean Engineering*, **278**, p.114236. https://doi.org/10.1016/j.oceaneng.2023.114236

Amaechi, C. V., Reda, A., Butler, H. O., Ja'e, I. A., & An, C. (2022a). Review on Fixed and Floating Offshore Structures. Part I: Types of Platforms with Some Applications. *Journal of Marine Science and Engineering (JMSE)*, **10**(8). https://doi.org/10.3390/jmse10081074

Amaechi, C. V., Reda, A., Butler, H. O., Ja'e, I. A., & An, C. (2022b). Review on Fixed and Floating Offshore Structures. Part II: Sustainable Design Approaches and Project Management. *Journal of Marine Science and Engineering (JMSE)*, **10**(7), e973. Article 973. https://doi.org/10.3390/jmse10070973

Amaechi, C. V., Wang, F., Ja'e, I. A., Aboshio, A., Odijie, A. C., & Ye, J. (2022c). A literature review on the technologies of bonded hoses for marine applications. *Ships and Offshore Structures*, **17**(12), 2819–2850. https://doi.org/10.1080/17445302.2022.2027682

Ja'e, I. A., Ahmed Ali, M. O., Yenduri, A., Amaechi, C. V., Nizamani, Z., & Nakayama, A. (2022). Optimization of mooring line design parameters using Mooring Optimization Tool for FPSO (MooOpT4FPSO) with the

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024

consideration of integrated design methodology. *Ocean Engineering*, **264**, Article 112499. https://doi.org/10.1016/j.oceaneng.2022.112499

Ullah, S., Xiaopeng, D., Anbar, D.R., Amaechi, C.V., Oyetunji, A.K., Ashraf, M.W. and Siddiq, M., 2024. Risk identification techniques for international contracting projects by construction professionals using factor analysis. *Ain Shams Engineering Journal*, **15**(4), p.102655. https://doi.org/10.1016/j.asej.2024.102655

Bai, Yong, & Qiang Bai. Subsea pipelines and risers. Vol. **3**. Elsevier Science, Oxford, UK. 2005. https://doi.org/10.1016/B978-0-08-044566-3.X5000-3

Downloaded from http://onepetro.org/SPEADIP/proceedings-pdf/24ADIP/24ADIP/D041S157R006/4117452/spe-222621-ms.pdf/1 by Xuanze Ju on 25 November 2024