

Review

# An Overview on Bonded Marine Hoses for Sustainable Fluid Transfer and (Un)Loading Operations via Floating Offshore Structures (FOS)

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**Abstract:** Due to the demand for oil production in varying water depth regions, the advantage of flexible buoyant conduits has led to an increase in bonded marine hoses for fluid transfer and (un)loading operations. The fluid transfer system for bonded marine hoses is dependent on floating offshore structures (FOS). This paper presents an overview of different systems for sustainable fluid transfer and (un)loading operations via FOS, such as Single Point Mooring (SPM) systems. SPMs are component aspects of the techno-economic design and FOS operation. This review aims to present sustainable fluid transfer technologies while addressing the subject of bonded marine hoses based on application, configuration, test models, hose selection criteria, hose-mooring configurations and operational views. This paper also includes an overview of the hose dynamics, with the loading and unloading (or discharging) techniques for sustainable fluid transfer via marine bonded hoses, based on operational challenges encountered. To dynamically present the hose performance in this review, an overview of the test methods' guidance as specified in available industry standards was conducted. The pros and cons of marine hose application were also presented. Finally, this study presents different marine hose types and novel design configurations applied in implementing hose-mooring systems. Some concluding remarks with recommended solutions on the technology were presented in this review.

**Keywords:** bonded marine hose; sustainable fluid transfer; hose test methods; single point mooring (SPM); Catenary Anchor Leg Mooring (CALM); buoy; Floating Offshore Structures (FOS); offshore platform



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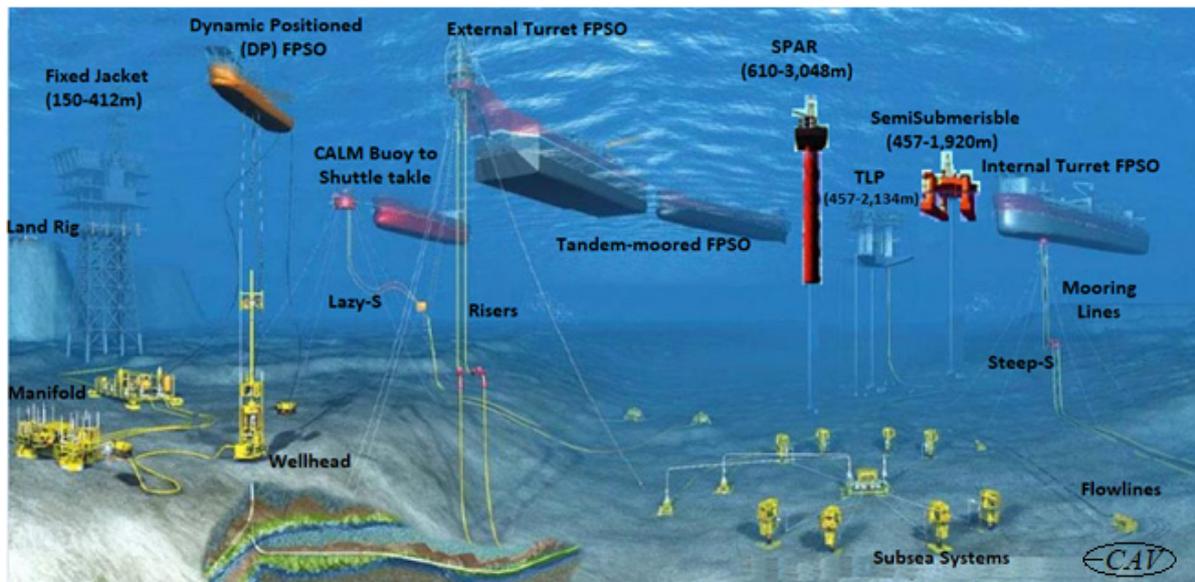


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## 1. Introduction

In recent years, there have been notable significant developments in the offshore marine industry [1–6]. These developments include the application of flexible hoses, flexible risers, and marine composites [7–10]. With composites, more advances have been conducted in marine composite hoses ([9–12]) and marine composite risers ([13–16]. Due to challenges of failures in the use of risers [17,18], more developments have been made [19,20]. By characterisation, a marine hose is a unique type of flexible riser used in fluid transfer [10,11]. By definition, a marine hose is simply a fluid transfer conduit utilised in transferring, discharging, loading, and transporting fluids from an oil well to the platform of a floating platform or a floating structure [21–23]. These platforms could be an FPSO (Floating Production Storage and Offloading) vessel, a CALM (Catenary Anchor Leg Mooring) buoy, a SPAR (Single Point Anchor Reservoir), a floating semisubmersible,

or a TLP (Tension Leg Platform), as depicted in Figure 1. However, due to the weight of the kill lines, marine hoses in chutes, reeling hoses on reel drums, marine risers, and other components on the deck, it is necessary to reduce the deck loads by using lighter and more sustainable materials/technologies. Thus, there is a need for lighter conduits and composite risers cum bonded marine hoses, to reduce the deck loads on CALM buoys, FPSOs and other offshore platforms ([24–31]). The light weight makes it easier to store. Hence, it helps to create spaces on chutes, gangways, and storage racks. It also reduces the platform's dead load.



**Figure 1.** Deep water facilities showing offshore platforms with the configurations for marine risers and mooring lines.

Recently, there has been a campaign in the marine industry for sustainable fluid transfer operations as one of the critical aspects of maritime and naval operations [6]. This development is in line with the UN SDG's goal of sustainability. In the light of that, a review on sustainable fluid transfer and loading operations using marine hose has been conducted in this research. Depending on certain considerations, a variety of offshore mooring terminals are situated at different locations. Three such locations are: the terminals that are sheltered at moor-anchorage regions; the terminals that are located outside-of-port's limits; and the terminals that are within protected mooring ports. In such cases, large ships that are unable to dock near the port may have larger drafts, thus making approaching ports difficult. It could also be that these large vessels may require that terminals are berthed ashore while the cargos are transferred offshore [6,27–29]. Therefore, it is necessary that the different terminals that could be considered for fluid transfer are discussed. In principle, the bonded marine hoses must be suitable for the fluid content; as such, necessary tests have to be carried out, as discussed in this study. Generally, floating offshore structures (FOS) are designed to be load-bearing, with connection components for both moorings and hose-risers. Examples of FOS include the Catenary Anchor Leg Mooring (CALM) buoys or Single Anchor Leg Mooring (SALM) buoys, the shuttle tankers or Floating Production Storage and Offloading (FPSO) vessels. The connection components include the bonded marine hoses, Hose End Valves (HEVs), Marine Breakaway Coupling (MBC), and Pipeline End Manifold (PEM). Conversely, the ancillary components used in attaching the hoses to other hose sections or the tanker/buoy manifolds include the shackles, chain pick-up, and butterfly valves.

All these connection components are utilized on the marine hose via a variety of sustainable mooring methods, such as these three formations. The first form, also known as Multiple Buoy Mooring (MBM), typically consists of the following main components:

mooring system with buoys, mooring legs and anchor points, pipeline end manifold (PLEM), pipeline to shore, subsea control system, and hose string with pick-up arrangement [6,10–12]. The many buoys are fastened to the seabed in a rectangular pattern with mooring lines and marine anchors, allowing safe mooring of a vessel positioned between the buoys with tug assistance. The bow of the ship is tied to the buoy surrounding it using both anchors or forward mooring buoys, while the stern is secured to the buoy around it using the stern and quarter mooring system. It keeps the ship in a fixed position and prevents it from weathervaning. The buoys serve as powerful anchor points for the vessel's on-board mooring lines.

A launch crew takes the tanker lines one at a time and tows them to the numerous mooring buoys as soon as the tanker has approached into position with the help of tugs. The second form is the Single Point Mooring (SPM), which is an anchored loading buoy that acts as a mooring point and an interconnection for tankers loading or discharging liquid or gas contents. Figure 2 is a typical SPM terminal showing an SPM buoy and the Trelleborg's floating hoses. The primary function of this SPM buoy is to maintain the vessel's location concerning the buoy, keeping it in a stable position while allowing the vessels' swinging responses to the ocean and wind [6].



**Figure 2.** SPM buoy hose system from the buoy to the shuttle tanker on an SPM Terminal (Provided by Trelleborg for this paper, and used with permission, Courtesy: Trelleborg).

A tug is frequently stationed aft to keep the ship at a constant angle and distance from the buoy. The buoy is secured by placing it in the middle of 4–8 anchors that are attached to the buoy. One or two cables called hawser(s) are secured aboard the ship's hawser trawl to the bow stopper to connect the ship to the buoy. The vessel always takes the most advantageous position concerning the combination of wind, current, and wave. In addition, the vessel is free to align itself with environmental factors. Since the vessel is well-positioned, with its front facing the prevailing winds/currents head-on, the overall force is below that which reaches a permanently moored vessel that is rarely head-on facing these prevailing circumstances. The ship approaches the buoy using the bow directed towards the dominating environment, giving it the most control while requiring the least amount of tug assistance. This technique works well for dynamic positioned (DP) vessels as well. A tug boat is usually necessary for conventional tankers during offloading and mooring operations to maintain the nominal amount of strain on the vessel's hawsers. This also prevents the tanker from colliding with the buoy and assists with the vessel's weathervane motions. The SPM system comprises four primary components: the buoy's body, mooring and anchoring elements, product transfer system, and ancillary components. For an SPM system, there are no vessel limits. The SPM CALM buoy configuration can accommodate even the largest vessels, including Very Large Crude Carriers (VLCCs). In

general, while approaching single point or single buoy moorings, the weather is crucial in deciding whether to berth the vessel.

The third form is Single Anchor Loading (SAL), which is an offshore loading system that acts as a single mooring point using hawsers to the submarine base-anchor and interconnectivity between tankers discharging or offloading and loading of liquid or gas products [6,27–30]. SAL was created to be a replaceable approach that serves as a cheaper alternative to the Submerged Turret Loading (STL) system for usage when standard CALM buoys are not available. In addition, it is considered when low-cost sustainable technologies are required. Since the SAL is submerged, there is no possibility of a collision between the ship and a typical CALM or SPM buoy. On the SAL system, the vessel always takes the most advantageous position with the combination of wave, current, and wind. Additionally, it has freedom of alignment amidst the applied environmental factors. The SAL system consists of a mooring and a fluid swivel with a single mooring line (hawser) and a flexible hose-riser for fluid transfer attached, both of which are moored to the seabed with a single anchor. The anchor also serves as the seabed export flow line's pipeline end manifold (PLEM). The tanker is connected to the system by connecting the mooring line and the hose and securing the mooring lines from the seabed up to the vessel's bow. The mooring line is fixed there while the hoses are attached to the vessel. The tanker moored to the SAL system may easily weathervane, as dropping the hose and the mooring lines to the seafloor completes the disconnection process [31–35]. These configurations require marine hose for installation, delivery, and various fluid transfer operations, thus the need for this research.

This review aims to present sustainable fluid transfer technologies while addressing the subject of bonded marine hoses based on application, configuration, test models, and operational views. Thus, an overview of marine bonded hoses for loading and discharging operations is presented based on sustainability, safety, and product delivery. This paper identifies some salient design configurations for fluid transfer using bonded marine hoses, such as the SPM mooring systems. An overview of their application and different design configurations, such as CALM buoys, was presented. Discussions were carried out to determine the arrangements, the design forms, benefits, and the challenges for various applications. In this review, Section 2 covers an overview of sustainable fluid transfer at SPM mooring terminals. Section 3 presents model application of bonded marine hoses, Section 4 presents hose tests and model challenges, and Section 5 presents concluding remarks on the review with recommendations.

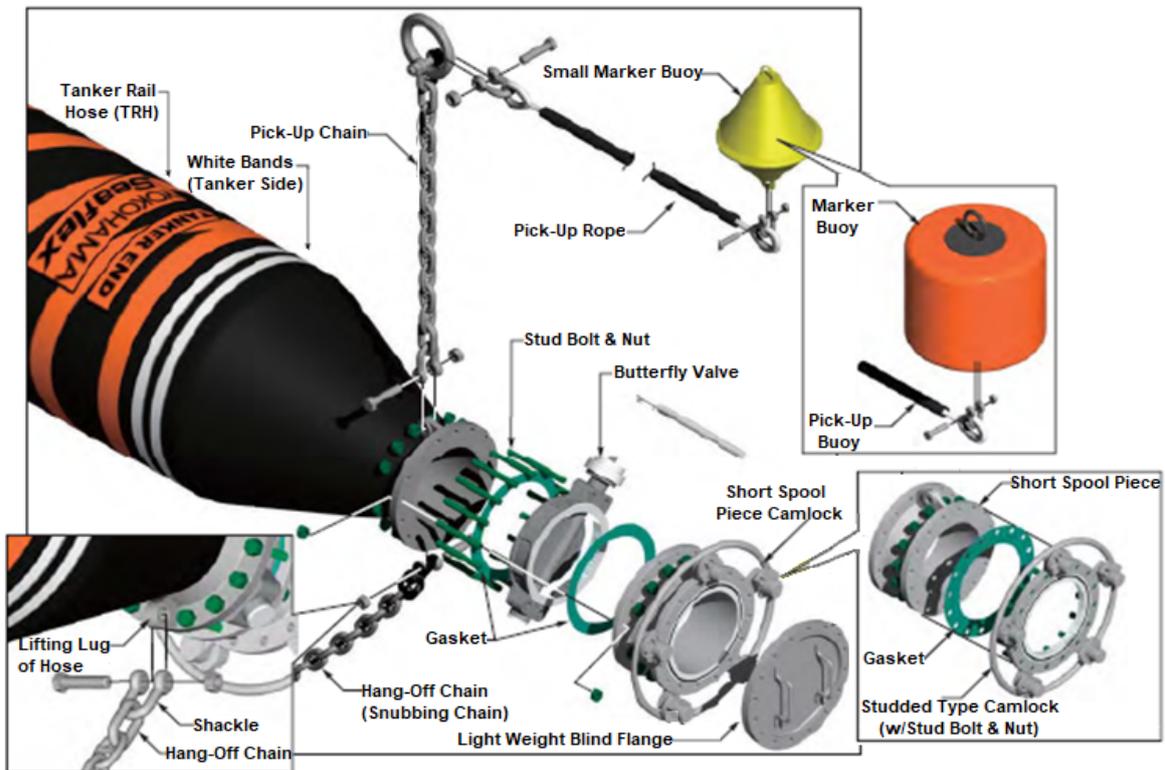
## 2. Sustainable Fluid Transfer at SPM Mooring Terminals

This section presents different procedures to be considered to ensure a safe and sustainable fluid transfer via bonded marine hoses and their mooring systems.

### 2.1. Sustainable Fluid Transfer Operation

The fluid transfer system is at the heart of every SPM, as shown in Figure 2. The design parameters for this system mainly considers its safety for (un)loading operation and its usage for transporting products from the tanker to the seafloor PLEM (Pipeline End Manifold). To connect the hose to the tanker, some ancillary components have to be used, as shown in the tail end hose in Figure 3. It is important to state that a sustainable fluid transfer operation requires some components. These include the following:

- The PLEM and the buoy are connected by flexible subsea hoses known as risers. The arrangement can take the form of a Chinese lantern, Lazy-S, Lazy Wave, or Steep-S depending on depth, sea state, buoy motions, and other factors.
- The buoy is connected to the tanker by floating hose strings.
- Marine breakaway coupling that enables for emergency pipeline disconnection to prevent hose/hawser breakage and associated oil spills.
- The tanker can rotate with relation to the mooring buoy thanks to the product swivel, valves, and piping that connect the geostatic and rotating components of the buoy.



**Figure 3.** Tanker end gear assembly for floating hose line configured using Yokohama’s Seaflex hose (adapted from Yokohama Manual).

### 2.2. Sustainable Incident Reporting on Hose Failure

It is important that there is a sustainable incident report on bonded marine hoses, as this will help hose researchers, hose manufacturers, and industry users to understand the trends on hose failures and successes. Some attempts to obtain detailed incident reports based on bonded marine hoses were conducted, but the hose failures recorded were not solely as hose failures but as flexible riser failures. In an industry survey conducted by HSE UK ([17,18]), hose incidents are part of the reported incidents on sites. These have been noted to be as a result of a number of factors classified into two groups; the immediate causes and the underlying causes, as shown in Figure 4a,b, respectively. They noticed that most of the reported incidents that involved hoses and flexible pipes were reported to have unknown causes. However, corrosion was identified as a major cause of these incidents, with 24 reported incidents. The findings are similar to those reported on failure of flexible risers by PSA [36,37]. The reports in Figure 5a,b show that valve closure has been a challenge on both flexible risers and hoses, from both reports using two databases: the HSE COIN and the RIDDOR databases. It is seen that some valves may fail to close, some might have actuator or pneumatic issues, or some may take too long to close. Some valves may also have small leaks, while others may have bigger leaks with heavy leakage rates. These reports are collaborated by other studies on flexible risers [38–45].

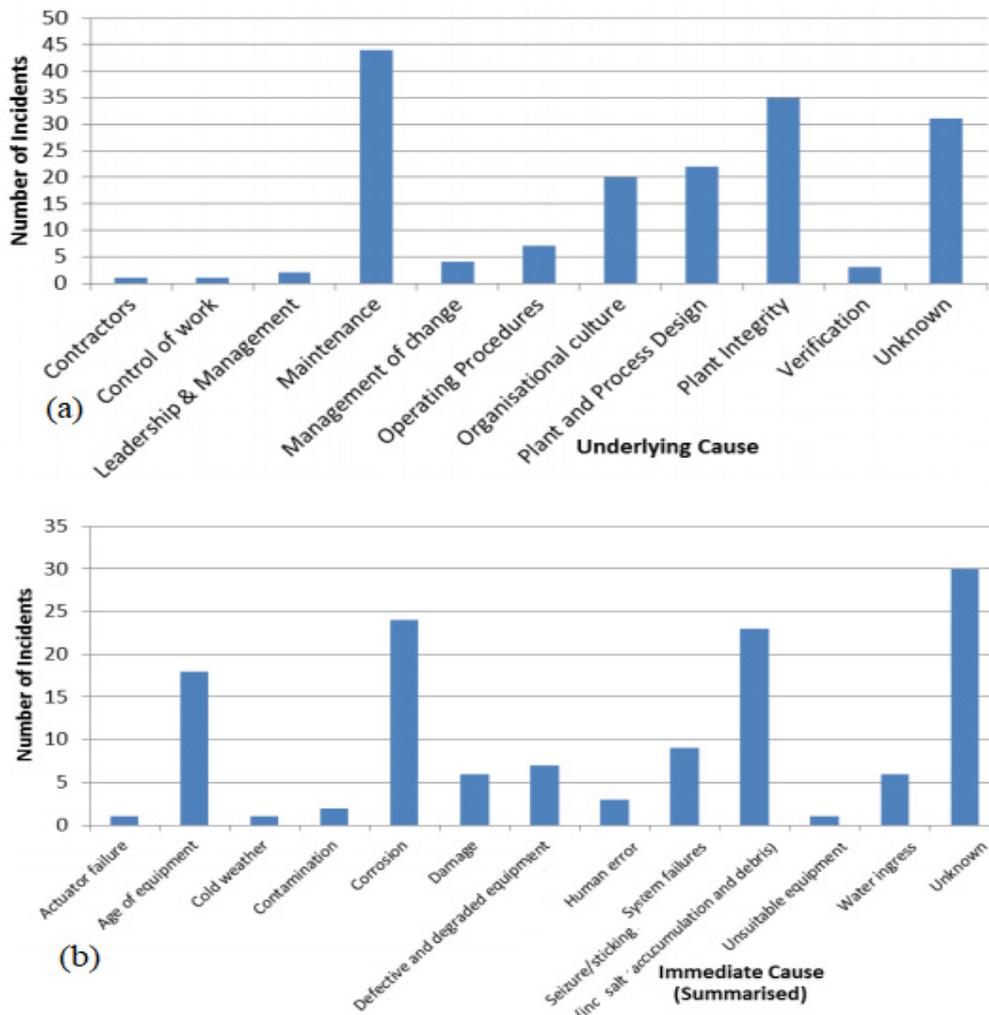


Figure 4. Incidents from riser emergency shutdown valve failures in HSE 2015 report, for (a) underlying causes and (b) immediate causes (Source: HSE UK, in public domain).

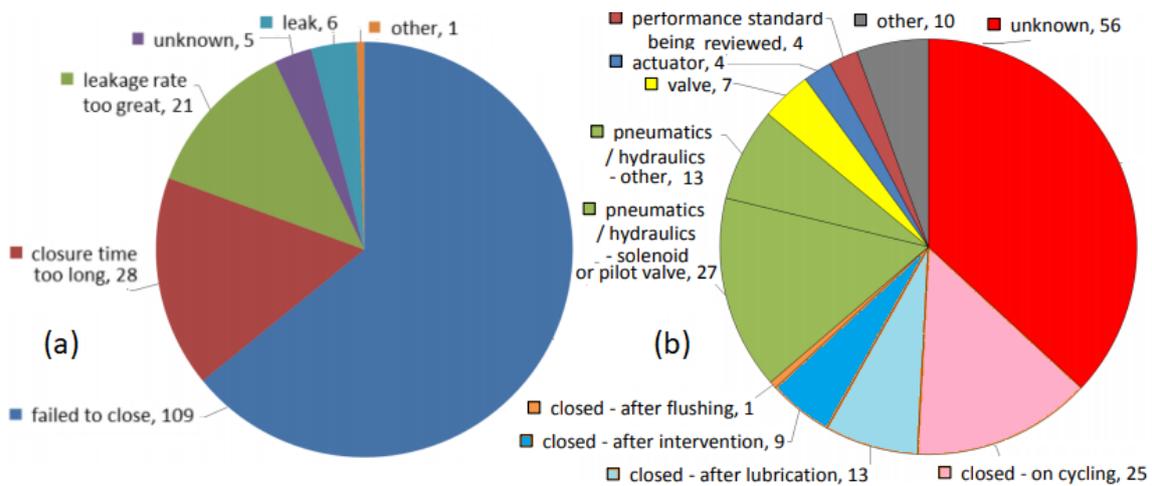


Figure 5. Reports of riser emergency shutdown valve from (a) HSE COIN database, and (b) RIDDOR report (Source: HSE UK, in public domain).

### 2.3. Safety Precautions at SPM Mooring Terminals

Different studies have been conducted on the numerical modelling of hose-mooring systems for marine hoses [46–56], CALM buoys [57–67], and offloading systems [68–78]. Most studies on marine hoses does not include mooring line safety ([36,37,42–45,79–88]). The number of incidents reported on flexible risers from a PSA Norway database, as shown in Figure 6, shows different types of damages /failures, with carcass damage been the highest. Thus, it is important to include necessary safety precautions to avoid accidents that could lead to hose failures and mooring line failures at SPM terminals or mooring stations. The safety precautions at SPM terminals include:

- When not handling lines that are under load or strain, stay away from them.
- Avoid mooring winches, drums, and bitts that have lines attached to them. The handler must not stand too close to the warping drum, capstan, or bitt when handling the line.
- It is not advisable to stand on or around the bights of ropes.
- Avoid the snapback and whiplash zones (area covered by the broken end of the line under recoil). If activity in this zone is unavoidable, exposure time should be kept to a minimum.
- Keep loose things out of the way of the region where lines are handled.
- Do not attempt to physically stop the line from taking charge (uncontrolled running out of line under strain).
- When building quick towlines, the crew should communicate with the tugs verbally or with hand signals to inform the Tug Master of the line's status. Watch out for towlines that have been rigged up quickly onboard.
- All mooring station workers must be aware and vigilant for any possibility of ropes/wires splitting after being secured onboard.
- Ropes should be protected against chafing on sharp edges.
- To avoid losing strength, avoid leading ropes at steep angles or turns.
- The officer on duty is responsible for keeping the bridge informed regarding clearances between vessels and other objects.
- If too much slack is lowered into the water, the ropes may foul the propellers/bow thrusters.
- When the propeller is not clear (i.e., without impediment) for engine movements, the officer on aft stations is responsible for informing the bridge.
- Anti-skid paint should be used to paint the operational area at the winches and the deck walks; the margins of these areas should be accentuated with a contrast colour.

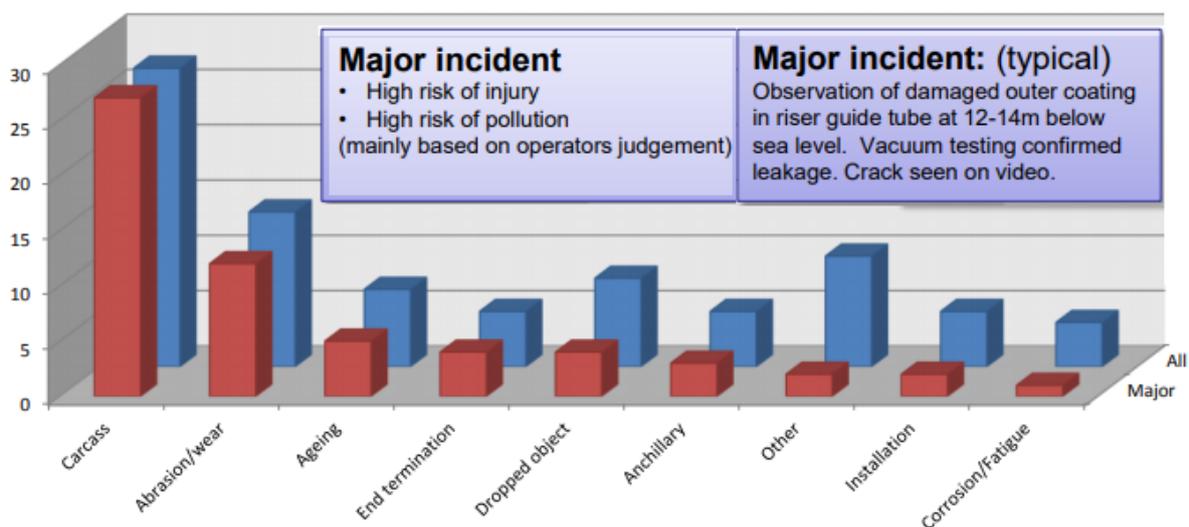
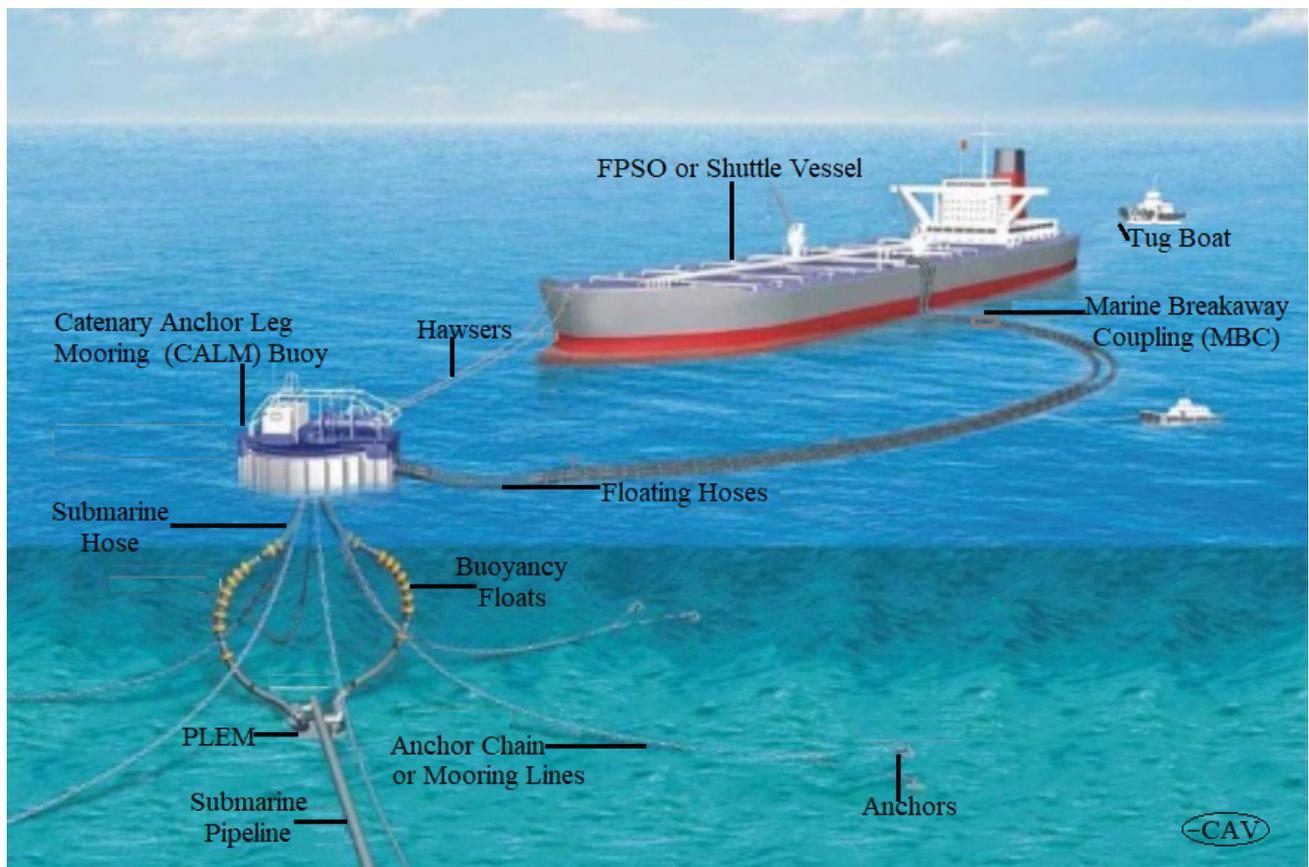


Figure 6. Flexible riser incidents as reported from CODAM to PSA Norway for 1995–2013 data (Source: PSA, in public domain).

#### 2.4. Preparation & Arrangement of SPM Moorings

On Single Buoy Mooring (SBM), the hawser is normally made up of nylon rope shackled to an integrated mooring uni-joint on the buoy deck. A chafing chain is attached to the tanker end of the hawser to prevent damage from the tanker fairlead. To measure hawser loads, a load pin can be attached to the mooring uni-joint on the buoy deck. Depending on the biggest size of vessel that would be anchored to the buoy, hawser systems use one or two ropes, as depicted in Figures 2 and 7. Single-leg or grommet-leg ropes could be the type of ropes used. On the tanker side, these are frequently attached to an OCIMF chafing chain. This can be either type A or B, depending on the maximum size of the tanker and the mooring loads. This chafe chain would then be secured in the tanker's chain stopper.



**Figure 7.** Catenary Anchor Leg Mooring (CALM) Buoy hose system depicting Chinese-Lantern configuration and single point mooring (SPM).

To prepare the mooring for SPM deployment, the following steps are given:

- For picking up rope, a messenger line has been requested.
- It must be fitted in an empty drum at the bow, large enough to hold a 120 m [or longer, depending on terminal advice] Pick Up Rope.
- The messenger must be 100 metres long (or as instructed by the terminal).
- The messenger should be 1"–3" wide, and at its end have one small shackle.
- The afterdeck specification to be used on the Tug Boat should be 02 × 200 Mt.

#### 2.5. Mooring Procedures for SPMs

The mooring procedure for SPMs has been reviewed briefly as presented herein. It has been considered based on general mooring system for SPMs, but each SPM terminal

may have specific guidelines and best practices that are applicable to that port or terminal. The following are some steps for conducting a typical mooring procedure:

Step 1: The vessel will slowly approach the buoy, usually stemming the tide/currents/winds, which is normally the direction in which the hose string is leading, and tug may be employed at some terminals to 'shove the bow' into position, on the recommendation of the Pilot or the Mooring Master.

Step 2: The messenger which is reeved via the smit bracket (or similar) is hooked to the hawser and slowly heaved up at around 120 m from the buoy, and the duty officer/Chief Officer and the mooring Master's helper will be giving the distance and direction from the buoy at all times.

Step 3: After determining the best approach route, the vessel should proceed, approaching the SBM at a suitable speed based on the current conditions.

Step 4: The vessel should only have enough speed for steerage about 1000 m from the SBM.

Step 5: The support boat on the side where the hose will be connected to the manifold should keep the floating hose string away from the tanker.

Step 6: Rather than approaching dead ahead, the vessel should make the final approach with the buoy on the bow. This allows the Master and Pilot on the bridge to always keep an eye on the buoy, and there is no risk of overrunning the buoy if the approach speed is misjudged.

Step 7: If a tug is available, it can be deployed as needed using a powered tug boat.

Step 8: The tanker's approach speed must be kept to a bare minimum while maintaining the ship's manoeuvrability.

Step 9: When a Linesman must climb onto a mooring buoy, extreme caution should be exercised, especially if the tide is causing the buoy to list and/or the wind and waves are causing it to move excessively.

Step 10: Hook-equipped mooring buoys are less harmful than ring-equipped buoys. The mooring line should be passed through the eye of the ring and lashed back onto the standing part with at least three turns secured with a reef knot if a buoy is connected with a ring.

Step 11: If the vessel is required to provide mooring lashings, the Boatmen Supervisor should notify the Master/Pilot as soon as possible.

Step 12: A shackle should be used where the mooring line is a wire, and it should be moused.

Step 13: Rope lashings used to tie a mooring line to a mooring ring should have a minimum diameter of 20 mm and a length of 2 m, and they should be in good, clean condition and be well secured.

## 2.6. Hawser Connection on SPMs

The floating hose is moved aside from the path of the incoming tanker as the vessel approaches the berth. The support boat will bring the hawser pick-up rope (80 mm diameter) and fasten it to the messenger when the vessel is around 300 metres from the buoy and still making way. The pickup rope is flung on deck at the signal of the boat.

Between 45 and 60 metres (150 and 200 feet) from the buoy, the vessel should come to a complete stop. The chafing chain is next hauled into the bow chock and then to the bow chain stopper, where it is secured under the pilot's supervision. During mooring operations, the personnel such as the Mooring Master or assistant and the chain officer, who is the vessel's forecaster, report the distance and location of the SPM in reference to the vessel from the Bridge. Then, the pick-up rope or the messenger rope, as well as the hawser leading from the buoy, are spooled straight onto the empty winch drum. The locking bar is positioned, and a safety pin is inserted when the chafing chain reaches the smit bracket. The ship is considered anchored at this time.

It should be noted that no load should be placed on the pick-up rope under any circumstances, as this will impair the vessel's agility and eventually cause the rope to

collapse. It is not recommended to use the pick-up rope to heave the vessel or maintain its position. Lastly, there is a return to a relaxed grip on the pick-up rope until the weight is lifted.

2.7. The Criteria for SPMs and CALMs

The following are some key requirements for SPMs and CALMs:

- It should have an efficient anchoring mechanism that must keep the CALM buoy in place and assure its survival under harsh loading conditions, while also permitting efficient loading, discharging, and mooring under operational conditions:
- Take into account the waves, significant wave height and tides (if tidal).
- For the duration of the operational life, all components must have sufficient strength, fatigue life, and durability.
- Evaluate and manage corrosion during the design process. Ensure abrasion from bottom contact or contact with other lines must be minimised or possibly avoided.
- If necessary, ensure device self-orientation with incoming wave direction.
- It should be simple to monitor and maintain.
- Use your resources wisely and ensure the right hose type is used (see Table 1).
- Ensure the device’s survival and is free-floating as depicted in Figure 7.
- Reduce the amount of pollution that reaches the seabed or native flora and animals.
- By not interfering with the CALM buoy motion so that its performance for transfer loading or discharging via the hose system’s will not be affected.
- To allow the devices to be positioned near to each other in arrays, take up as little area as possible on the seabed.
- Loads on electrical lines and connections should be reduced or removed.
- Restrain the equipment from leaving its designated area.

Table 1. Showing some Floating and Submarine Hoses with pressure ratings (Hose Courtesy of EMSTEC).

Hose Description	Hose Design
Double Carcass Floating Hose End-reinforced Half (or first-off Buoy)	
Double Carcass Floating Hose Main Line	
Double Carcass Submarine Hose End-Reinforced (no floats)	
Double Carcass Submarine Hose Main Line (no floats)	
Double Carcass Submarine Hose End-Reinforced with floats	
Double Carcass Submarine Hose Main Line with floats	
Double Carcass Submarine Hose Main Line with Half floats	
Double Carcass Tail floating	

Table 1. Cont.

Hose Description	Hose Design
Double Carcass Reducing floating	
Double Carcass Controlled buoyancy	

2.8. Benefits of Having SPMs and CALMs

The benefits of having SPMs and CALMs are as follows:

- The SPM and CALM systems are very economical, as they help to save cost, in terms of fuel and money, as the vessel may not need to come into the port.
- The SPM saves financial and clearance burdens which are usually incurred in the payment of fees, submission for checks, submission for regulation compliance, and waiting times at the port.
- SPMs saves production and transfer time, thereby ensuring a sustainable fluid transfer, especially during tight schedules or short operational time-bound windows to transfer fluid products and complete delivery jobs as scheduled.
- They have the ability of handling extra-large vessels such as VLFS.
- SPM systems has the ability of ease during mooring operations of high draft ships.
- SPM systems have the capacity of easily handling large quantity of cargo.
- They can be operated in shallow and moderate and deep water environments.

3. Model Application of Bonded Marine Hoses

This section presents different applications with their configurations that adapt bonded marine hoses in real marine and offshore-renewable applications. Bonded marine hoses are for loading and offloading purposes. These hoses are used in a wide range of mooring systems. The circumstances under which they must operate also differ based on environmental conditions, size of the oil well, the water depth, the capacity of the terminal, the amount of hoses, the sizes of the hoses, the number of mooring chains (or mooring lines), the number of shuttle vessels, the schedule of daily operation, and the designed (un)loading system. Even within a single system, there are differences in the specifications of the many segments that make it up. The mooring systems are detailed in this section, with a brief discussion on the various types of hoses found within a single system. This necessitates their classification from the type of mooring system to configuration, as classified in Table 1. Finally, hoses are grouped into four (4) primary product lines based on their qualities, and the hose boundary parameters. Based on case study application, Table 2 shows marine hoses in use on both Bohai Sea and South China Sea.

Table 2. Application of offshore hoses in Bohai Sea and South China Sea.

FPSO	Transportation	Hose Diameter (Inches)	Hose Type (Single/Dual Carcass)	Industry Brand	Sea
HYSYS101	Floating	12	Single Carcass	Yokohama	Bohai Sea
HYSYS102	Floating	16	Single Carcass	Goodyear	Bohai Sea
HYSYS109	Reeling	16, 20	Single Carcass & Dual Carcass	Yokohama & Dunlop	Bohai Sea
HYSYS112	Reeling	16, 20	Double Carcass	Dunlop	Bohai Sea
HYSYS113	Reeling	16, 20	Double Carcass	Dunlop	Bohai Sea
HYSYS117	Reeling	16, 24	Double Carcass	Goodyear	Bohai Sea
HYSYS161	Reeling	8	Double Carcass	Goodyear	Bohai Sea
HYSYS103	Reeling	16	Single Carcass	Yokohama	South China Sea
HYSYS104	Floating	12, 16	Single Carcass	Yokohama	South China Sea

Table 2. Cont.

FPSO	Transportation	Hose Diameter (Inches)	Hose Type (Single/Dual Carcass)	Industry Brand	Sea
HYSYS106	Floating	16, 20	Single Carcass	Yokohama	South China Sea
HYSYS107	Floating	16	Single Carcass	Yokohama	South China Sea
HYSYS110	Reeling	16, 20	Double Carcass	Dunlop	South China Sea
HYSYS111	Floating	16	Single Carcass	Yokohama	South China Sea
HYSYS115	Reeling	16	Double Carcass	Goodyear	South China Sea
HYSYS116	Reeling	16	Double Carcass	Goodyear	South China Sea

3.1. Configurations for Submarine Hoses

3.1.1. CALM Buoy Hose Configurations

The Catenary Anchor Leg Mooring (CALM) buoy system comprises a buoy with pivot, called the turntable. Sometimes, it is called the turret buoy or turntable buoy. Figure 7 shows the different configurations of Catenary Anchor Leg Mooring (CALM) buoy systems. The CALM buoy system has different connections, such as the mooring fairlead and hose manifold. The tanker is anchored to the turntable pivot, as it rotates around its vertical axis. The turntable is also connected to the floating hose through the hose manifold at an angle. The tanker is attached to the turntable and connected to the turntable’s floating hose strings. The mooring chains or anchor chains are used to moor the buoy as it aids in the buoy’s stability. A swivel transfers the fluid to the submarine hose strings connected to the undersea pipeline via the pipeline end manifold. The entire system can freely spin due to the forces applied by currents and waves, a phenomenon known as weathervaning. Figure 8 depicts an internal turret FPSO with multiple arrangements of marine hoses and flexible risers on an FPSO.

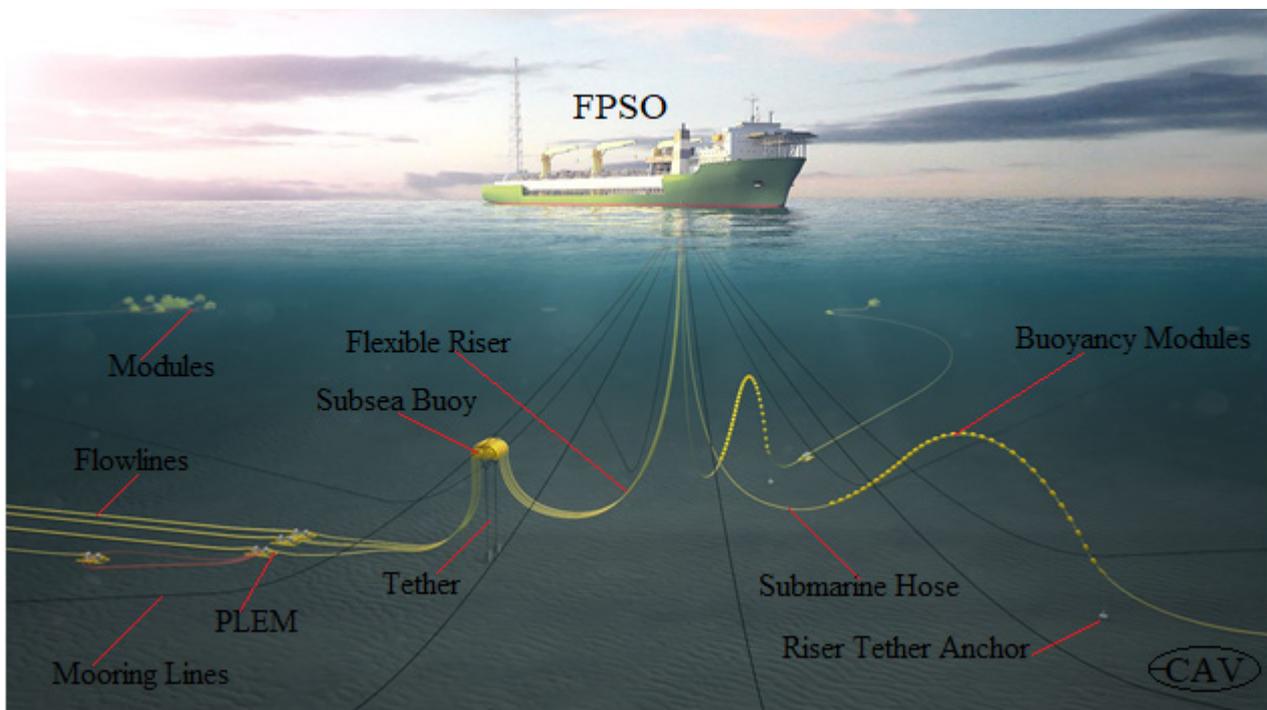


Figure 8. An internal turret FPSO with multiple marine hoses and flexible risers showing different configuration and the following components: modules, flowlines, flexible riser, subsea buoy, tether, PLEM, mooring lines, submarine hose, riser tether anchor, buoyancy modules and internal turret system.

### 3.1.2. Chinese-Lantern Hose Configurations

Underwater floats are tied to the hose string, which should keep its shape even under the harshest situations. To avoid concentrated bending strains, the hoses connecting to the pipeline end manifold should be strengthened at the attached end. A typical system for Chinese-lantern hose configuration is given in Figure 9.

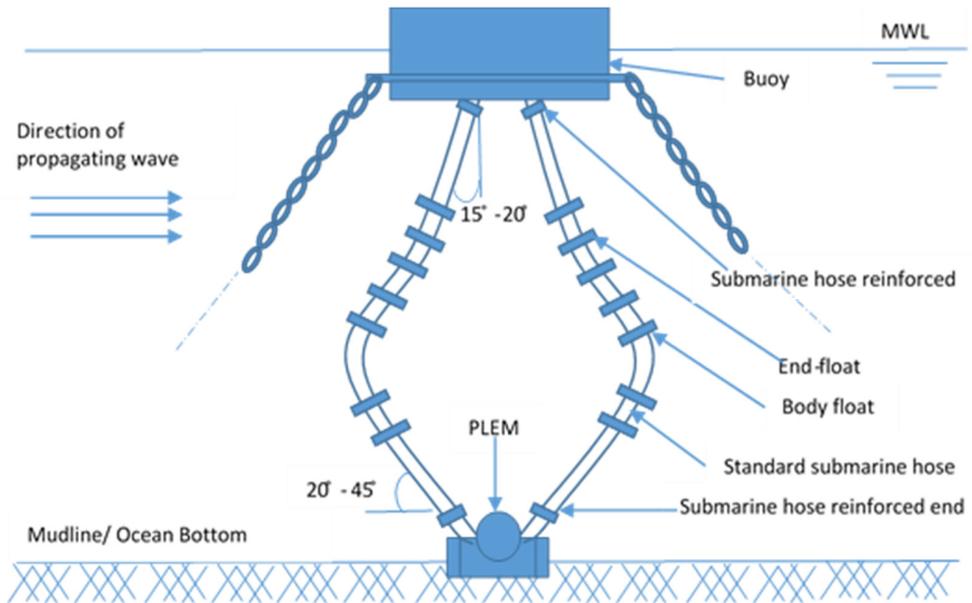


Figure 9. An illustration of Chinese-lantern hose configuration.

### 3.1.3. Lazy-S Hose Configurations

To obtain the optimum hose arrangement, floatation in the form of bead floats or adjustable buoyancy tanks is given. This is done just to avoid kinking or wear upon this hose. A typical system for Lazy-S hose configuration is given in Figure 10.

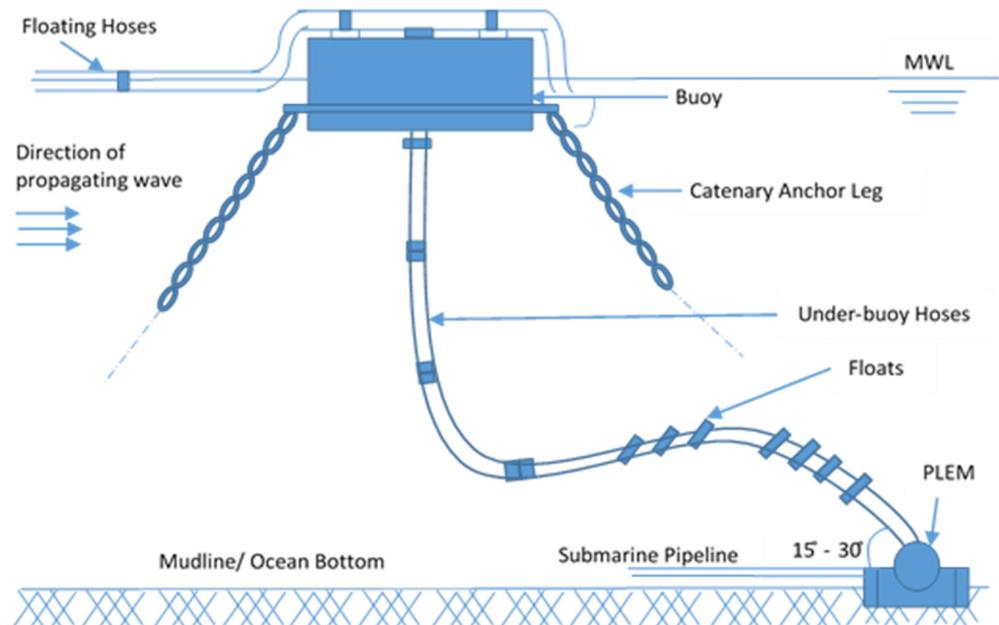
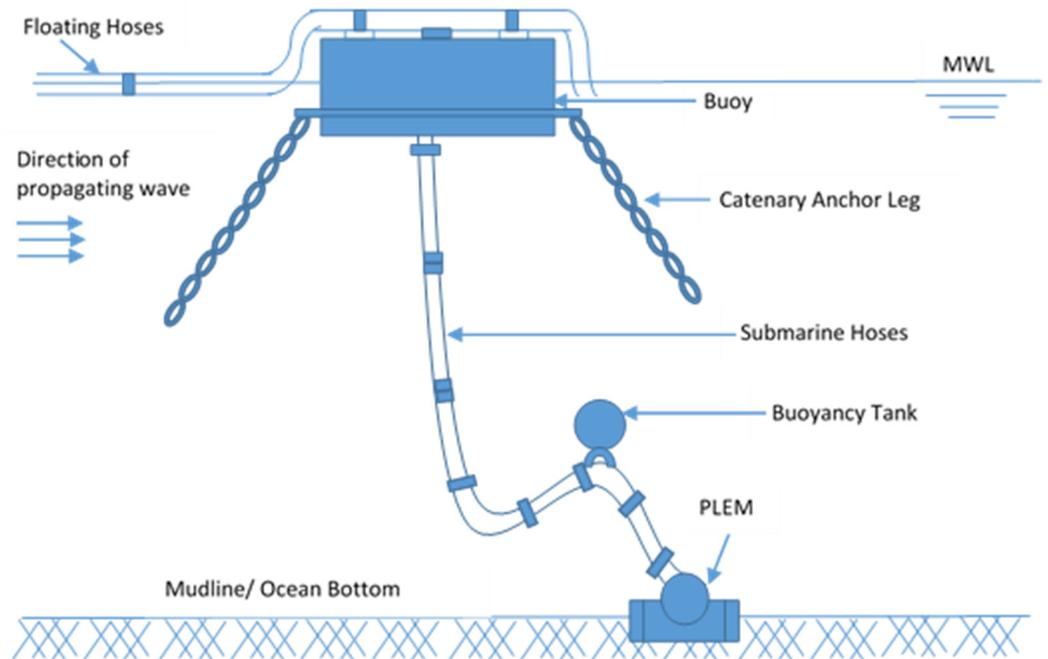


Figure 10. An illustration of Lazy-S Hose Configuration.

### 3.1.4. Steep-S Hose Configurations

CALM buoys in water depths greater than 45 metres benefit from this design. The buoyancy tanks' capacity must be sufficient to sustain positive buoyancy for hoses in both oil and water filled conditions. A typical system for Steep-S hose configuration is given in Figure 11.



**Figure 11.** An illustration of Steep-S hose configuration.

## 3.2. Configurations for Floating Hoses

### 3.2.1. SALM Buoy Hose Configurations

The SALM (Single Anchor Leg Mooring) system consists of a mooring buoy connected to a gravity or piling foundation by an anchor chain with a swivel for rotation, as in Figure 12. The tanker moors with one or more hawsers to the buoy in the CALM system, but the hose strings in the SALM system go directly to the pipeline end manifold. A fluid swivel is positioned concentrically around the anchor leg to allow fluid to pass through while rotating in reaction to the motions of the moored vessel. The fluid swivel is connected to the submarine hose string. The hose arm can be pivoted around the horizontal axis, allowing the angle at which the hose leaves the fluid swivel to vary, or it can be locked at a specific angle. The hose string might be shaped in an S-shape or can vertically and gradually curve towards the horizontal water plane. To achieve the correct shape, buoyancy must be used. Integral floatation or hose floats can be used to accomplish this. Integral floatation, on the other hand, does not work effectively in the presence of a substantial hydrostatic head. Between the submarine and the floating hoses, there must be enough buoyancy to prevent the floating hose from being pulled underwater. To spread the bending stresses caused by the transition between the undersea and floating hoses, hose pieces with reinforced ends must be employed.

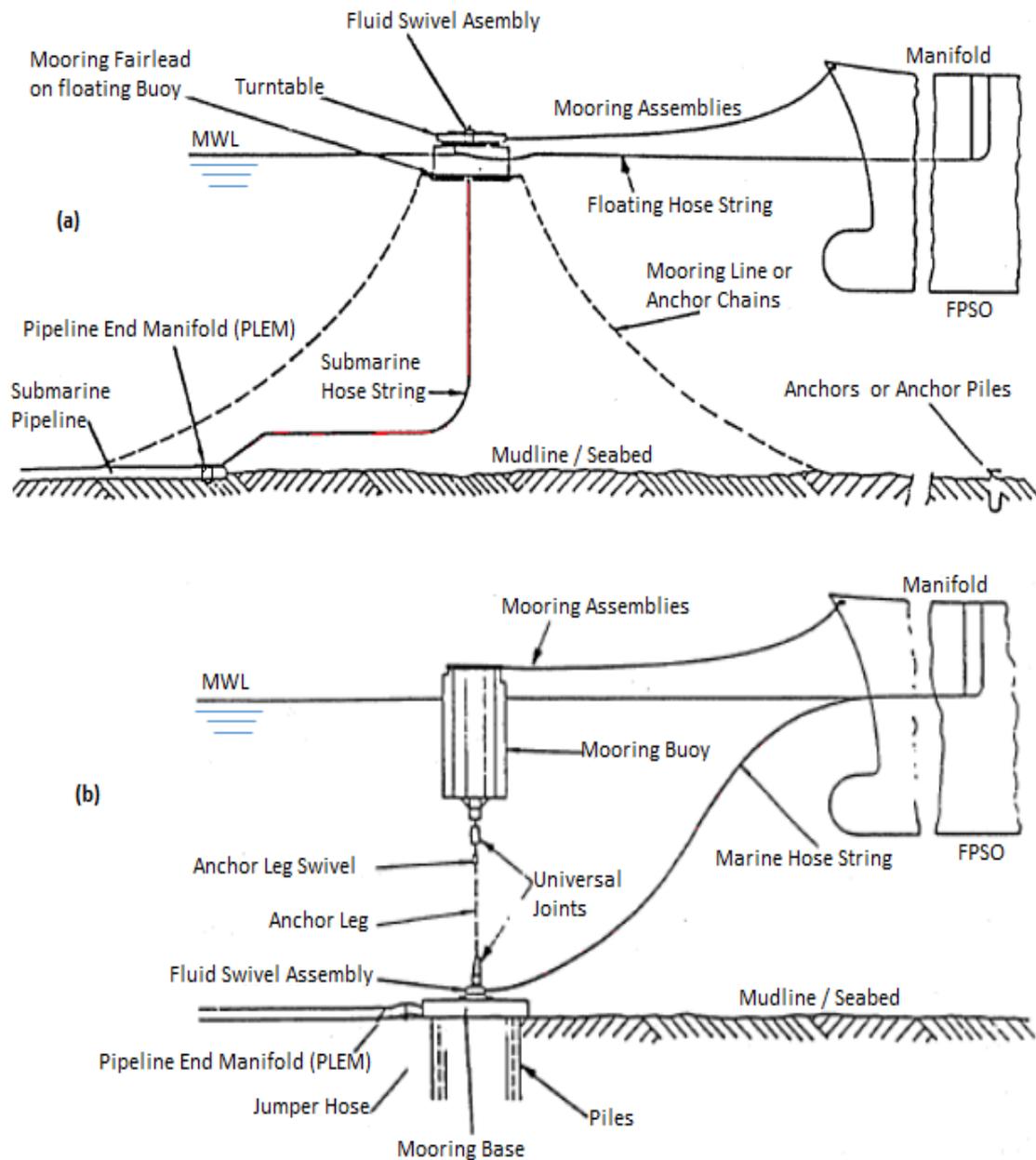


Figure 12. Buoy systems showing (a) CALM and (b) SALM buoy systems.

### 3.2.2. Floating Tandem Mooring Hose Configurations

Tandem mooring is a technique for transporting oil and oil by-products from FSOs, FPSOs, FSUs, FSRUs, and other extraction facilities to shuttle tankers. It can be floating or submerged, and it can be hung from the ship’s side or wound around a reel. A retention rope and revolving spool component secure the string to the vessel, resulting in the “Goose-Neck” design. Depending on the environmental circumstances, a floating or submarine string can be used. In some circumstances, the oil is extracted from the well using a Floating Production Storage and Offloading (FPSO) system. As shown in Figure 13, these ships are anchored with a turret and anchor lines. The arrangement of the tandem mooring given in Table 3 is for the hose positions in Figure 13.

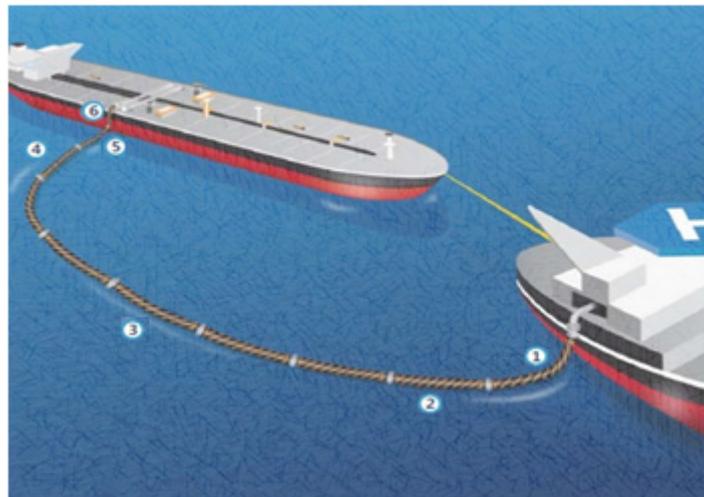


Figure 13. Tandem mooring floating hose configuration.

Table 3. Arrangement of tandem mooring floating hoses.

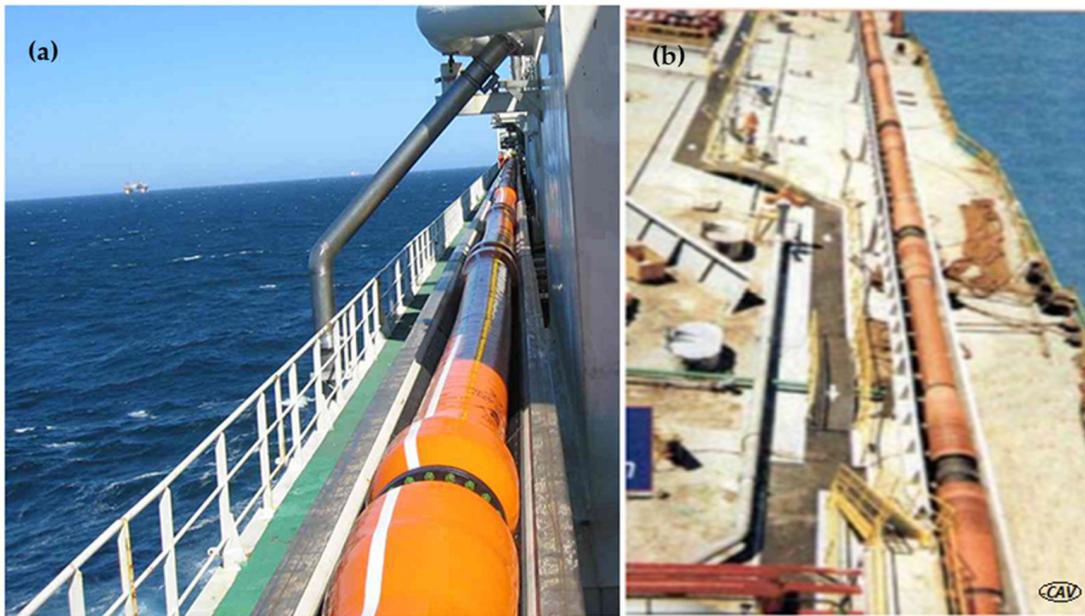
No.	Location	Description	Hose Type	Optional Type	Characteristics	Application
1	FPSO Connection	Off take connection	Floating	Reel	Reinforced hose end, at one end	Connected to shuttle tanker bow loading point or FPSO
2	Reduced Buoyancy	Reducer	Floating	Reel	Reduced buoyancy or Neutral	Often next to 2–3 hose sections on the string
3	Mainline	Mainline	Floating	Reel	Fairly flexible	Main part of the floating hose string
4	Operational Taper	Taper	Floating	Reel	Integral reducing bore	Connection of smaller bore tail hose and larger bore mainline
5	Tail	Tail Hose	Floating	Reel	Electrically discontinuous	Smaller bore diameter compared to mainline. Links tanker end to handle rail hose
6	Rail	Rail Hose	Floating Rail	Reel	Higher flexibility during lug lifting	Over rail hose for connecting to the manifolds of conventional midships

### 3.2.3. Stored Hose (or Hose Reel) Tandem Mooring

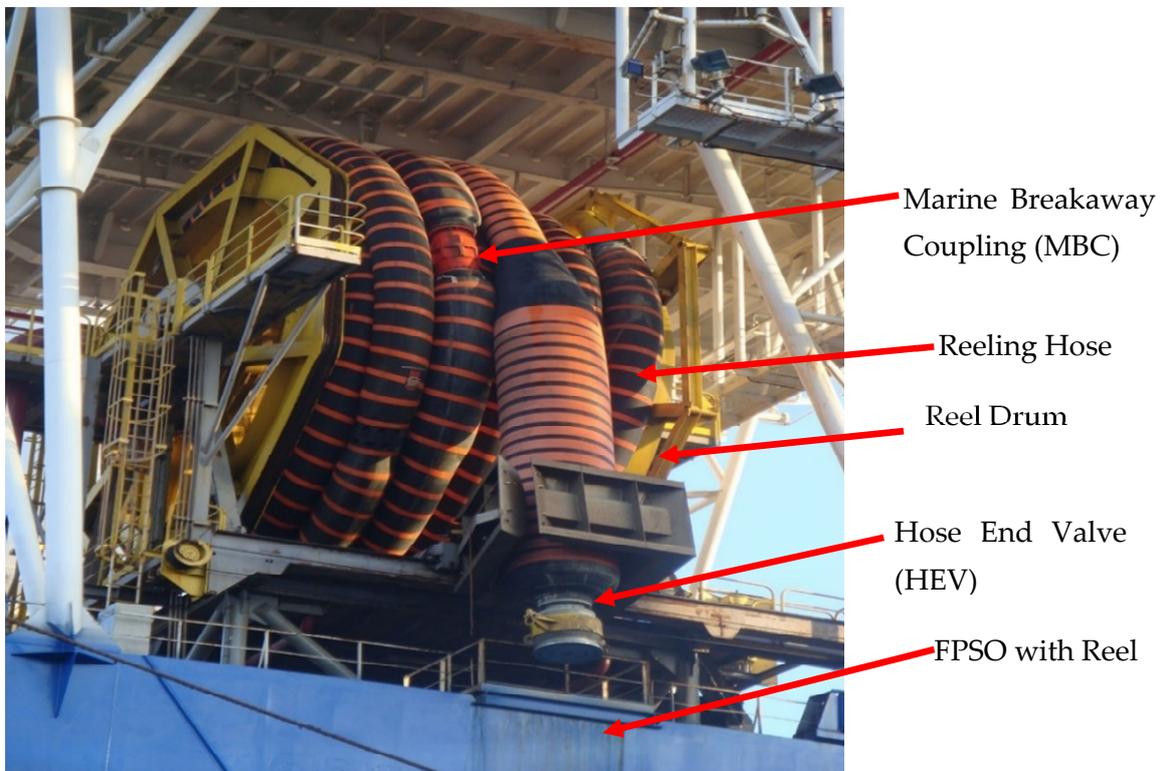
In this case, the mooring is done in a tandem configuration once more. However, the hose is employed as an in-air catenary, floating on the water, as shown in Figure 14. When not in use, the offloading hose is stored on the FPSO in a chute (as seen in Figure 14) or on a hose reel (as seen in Figure 15). The goal of the reeling hose configuration is to be able to recover and store the hose on the FPSO during bad weather. Hoses of this type must have a high flexibility reserve, bend radius tolerance, and axial strength. In the event of an emergency release, the catenary design also has intrinsic buoyancy, ensuring that the hose string is not lost, even when filled with water.

### 3.2.4. Deepwater Export Lines

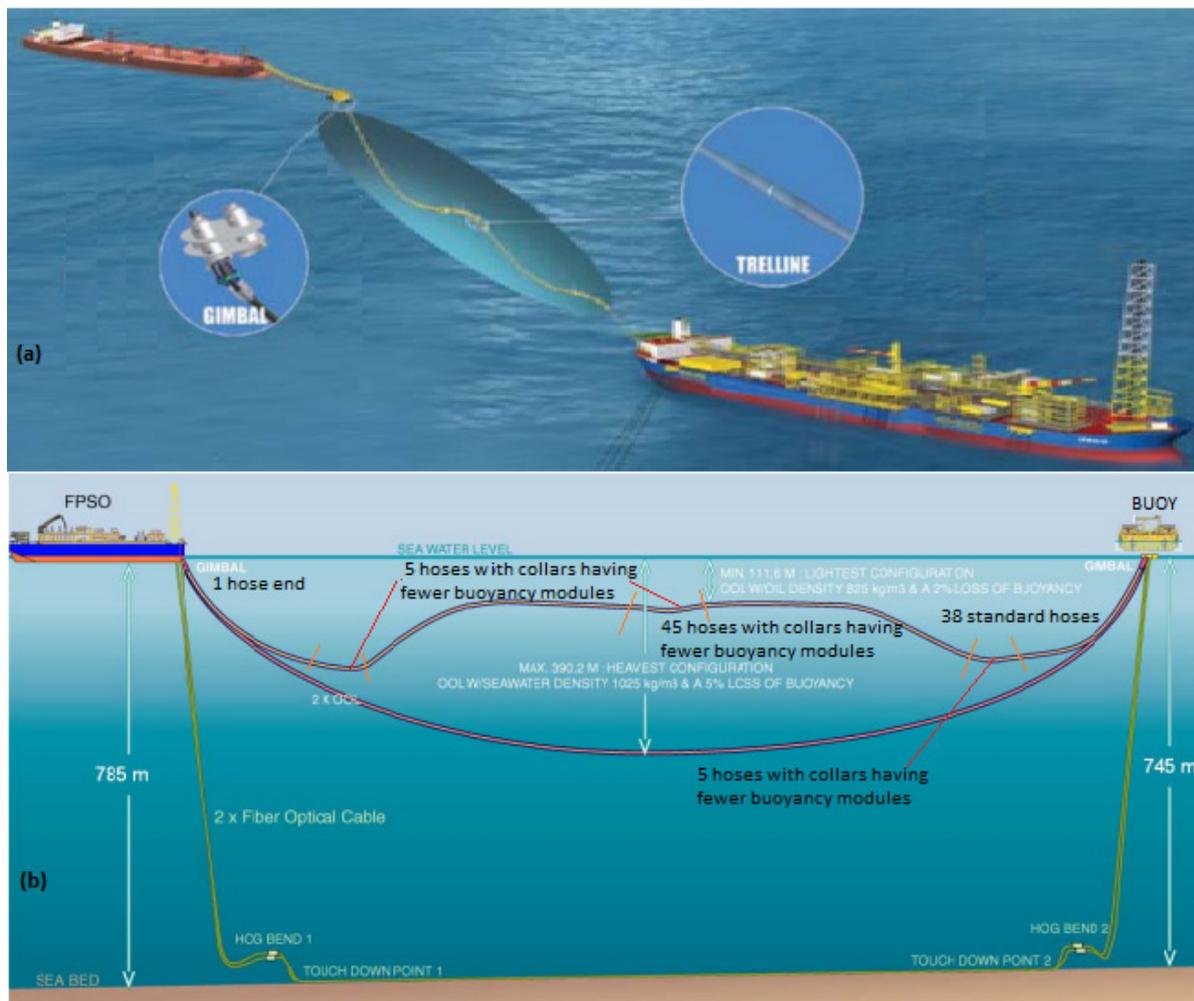
Spread mooring is frequently employed instead of a turret mooring system in projects having locations with relatively light environmental conditions. The issue this creates is that, due to the practicalities resulting from the large expanse of seawater required, it consumes more resources. In addition, the FPSO’s fixed position and the tandem mooring with the shuttle tanker make it quite challenging to achieve. Typical materials for such deepwater export lines have been reported by Trelleborg [89–93]. A deepwater export connection to a CALM buoy, where the shuttle tanker moors, could be one possibility [91–93], as in Figure 16. The tankers may weathervane here without having to worry about colliding with the FPSO. The hose’s deepest point is generally between 200 m and 300 m deep.



**Figure 14.** Two different hose storage systems in the chutes of floating FPSOs, showing (a) loading hose stowed on deck's chute along the FPSO's wall, which could also be a free-hanging catenary hose, and (b) loading hose stowed in the chute on a lower area of FPSO's deck inside its deck trays between loadings, with the hose string winched onboard over a stern roller chute.



**Figure 15.** Offshore reeling hose stored on the reel-drum showing reel, Marine Breakaway Coupling (MBC) and Hose End Valve (HEV).



**Figure 16.** Deepwater Export Line showing (a) typical offloading line (OOL) called Trelleborg’s trelline and gimbal with spread moorings, and (b) Pazflor OOL configuration. It shows the deepwater OOL array used as: 1 hose end, 38 hoses with collars having fewer buoyancy modules, 5 hoses with collars having fewer buoyancy modules, 45 hoses with collars having fewer buoyancy modules, 5 hoses with collars having fewer buoyancy modules, 38 hoses with collars having fewer buoyancy modules (Adapted, Courtesy: Trelleborg).

### 3.3. Configurations for Catenary Hoses

#### 3.3.1. Submarine Tandem Mooring Hose Configurations

The tandem mooring also has another variation called the submarine tandem mooring hose configuration. It is as shown in Figure 17 with the hose arrangement presented in Table 4. As represented in Figure 17, these ships are anchored with a turret and anchor lines. The tanker connects to the other vessel, which can be a turret FPSO. The turret functions similarly to a single point mooring (SPM) method. Since it might weathervane, the FPSO’s position is governed by the forces applied by the wind and the sea. A shuttle tanker moors to the FPSO’s stern by connecting with a hawser when the FPSO wants to unload its oil. Then, there is the FPSO’s flexible hose that floats in the water. Integral floatation or bead floats must be used to provide buoyancy. The shuttle tanker is now linked to this hose string, allowing the FPSO to discharge its products. The two ships travel in lockstep, and the shuttle tanker follows the FPSO. When the shuttle tanker is full, the hose string is detached and placed aboard the FPSO or left floating in the water.

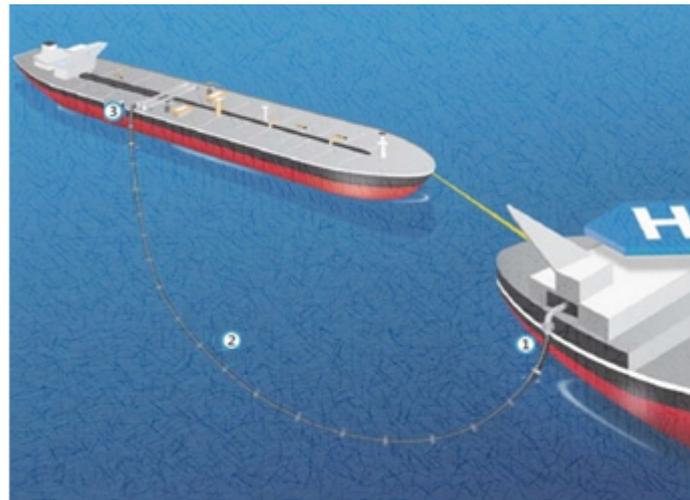


Figure 17. Tandem mooring submarine hose configuration.

Table 4. Arrangement of tandem mooring submarine and catenary hoses.

No.	Location	Description	Hose Type	Optional Type	Characteristics	Application
1	FPSO Connection	Off take connection or bow connector hose	Submarine	Reel	Reinforced hose end, at one end	Connected to shuttle tanker bow loading point or FPSO
2	Mainline	Mainline	Submarine	Reel	Reduced buoyancy or Neutral	Main part of the catenary
3	Rail Hose	Rail Hose	Submarine	Reel	Higher flexibility during lug lifting	Over rail hose for connecting to the manifolds of conventional midships

### 3.3.2. Catenary Tandem Mooring Hose Configurations

The third tandem mooring is the catenary tandem mooring hose configuration. As shown in Figure 18, it has a similar arrangement as the submarine tandem mooring explained in Table 4. However, it differs in its hose design length and the application of a catenary reeling system. With the reeling system, the line can be kept in a catenary tandem moored design to enable sustainable fluid transfer operations to be undertaken successfully.

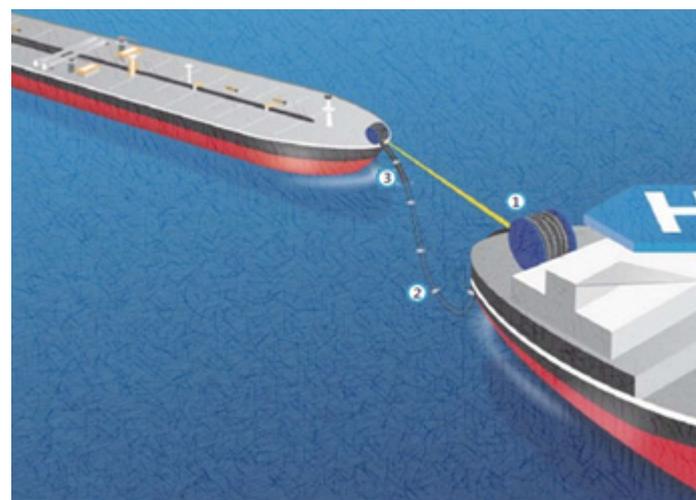


Figure 18. Tandem mooring reel catenary hose configuration.

### 3.3.3. Multi Buoy Mooring (MBM) Hose Configurations

The Multi Buoy Mooring (MBM) Hose configuration is a peculiar mooring hose configuration. Multiple buoys are moored to the bottom using mooring lines and marine

anchors in Multi Buoy Mooring (MBM), also known as Conventional Buoy Mooring (CBM). The three to six buoys are permanently fixed in a rectangular arrangement that allows a vessel to moor safely between the buoys. The tanker is moored near a submarine string sitting on the seabed in an idle posture and is picked up by a rope/buoy coupling. They are often employed in shallow water, wherein quay facilities are not always accessible for loading and offloading crude oil products from oil wells to refineries. It is as shown in Figure 19, with the arrangement tabulated in Table 5.

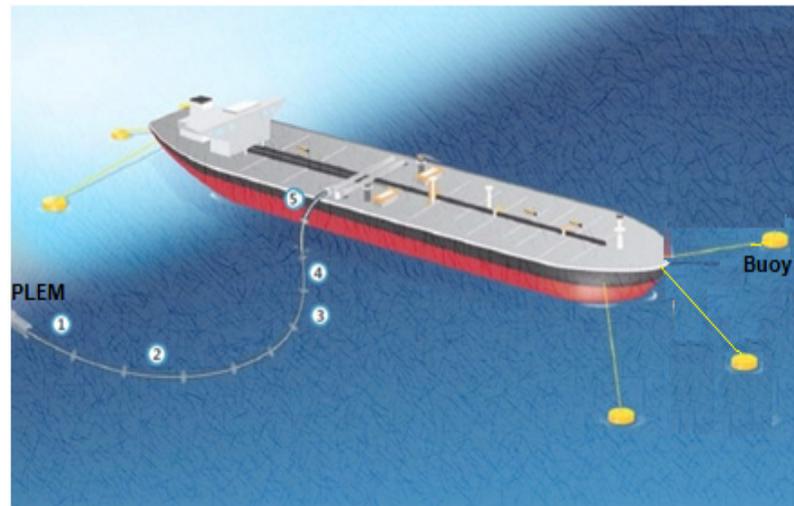


Figure 19. Multi buoy mooring (MBM) hose configuration.

Table 5. Arrangement of the multi buoy mooring system.

No.	Location	Description	Hose Type	Optional Type	Characteristics	Application
1	PLEM Connection	PLEM connection	Submarine	—	Reinforced hose end, at one end	Connected to shuttle tanker bow loading point or FPSO
2	Mainline	Mainline	Submarine	—	Reduced buoyancy or Neutral	Main part of the floating hose string
3	Operational Taper	Taper	Submarine	—	Integral reducing bore	Connection of smaller bore tail hose and larger bore mainline
4	Tail	Tail Hose	Submarine	—	Electrically discontinuous	Smaller bore diameter compared to mainline. Links tanker end to handle rail hose
5	Rail	Rail Hose	Submarine	—	Higher flexibility during lug lifting	Over rail hose for connecting to the manifolds of conventional midships

### 3.4. Types of Marine Hoses

The different types of bonded marine hoses are presented in this sub-section.

#### 3.4.1. Floating Hose String

Through inherent flotation, the hose string requires floatation media via integral floatation. To help transmit tension between the string and the ship’s manifold and between the string and the buoy, the string normally has varied degrees of stiffness. With a diameter of up to 750 mm, mainline hose-strings for single or twin hoses are employed. The diameter of the rail hose (hose closest to the ship) is normally limited to 400 mm due to the lifting capacity of the ship’s derrick. When needed, tapered hoses are utilised to lower the diameter gradually. An additional floatation material is required for the rail hose to compensate for the additional weight of the installation devices linked to the hose. The floating hose string is used in CALM, SALM, and floating tandem mooring systems, and it requires a 20% buoyancy reserve [64]. It can be bent to a bending radius of six times the nominal diameter (6D) under all conditions [94]. A lower bending radius, on the other hand, is preferable.

### 3.4.2. Submarine Hose String (<100 m)

Submarine hoses are made up of one or more strings, although usually not more than three. The arrangement must prevent the strings from becoming overstressed as a result of being overextended. Furthermore, the string cannot be made excessively long, since this would cause the hose strings to kink or be destroyed by abrasion on the seabed. The underwater hose is available in three different configurations. All three variants must be dimensioned to keep their proper configuration in both oil and seawater-filled circumstances. The decision is based on environmental and operational factors. In CALM and SALM systems, this product line is frequently utilised for the undersea parts of the hose strings since a differential pressure of 3 to 5 bars might exist due to the hydrostatic head of seawater (the string always remains filled with seawater, oil, or condensate). For the submarine hose, OCIMF 2009 [94] recommends that the bend radius must be at least four times the nominal diameter (4D).

### 3.4.3. Catenary Hose String

Only in tandem mooring systems, where the hose is deployed from the FPSO and left dangling between the FPSO and shuttle tanker, does this product line appear. Since the string must carry its own weight, an axial strength of 37 tonnes is required. Although a bend radius of four times the nominal diameter is necessary, a more flexible design is generally preferred due to hose reel space constraints.

### 3.4.4. Reeling Hose String

The deployment of a rotational reeling drum positioned aboard an FPSO is one means of launching risers into service. This provides a solution to dynamic or permanently located fossil fuel producing assets in new waters with undiscovered reservoirs, as well as an effective technique of production for the FPSO. The drum rotates to deploy or retract the hose-riser as needed, allowing for compact storage of the hose-riser equipment while also storing a long riser structure for deep-sea extraction. This form of hose-riser implementation saves time because an entire hose-riser structure can be spooled out and put for extraction much more quickly than typical riser structure configurations. There are several steps involved in reeling. The hose-riser is first spooled onto the FPSO drum using onshore spooling procedures, which involves reeling the pre-constructed riser onto the drum. Secondly, the hose-riser is spooled off in the place where it will be used for extraction, which is offshore at the reservoir. Following that, the hose-riser is bent over one or more aligner wheels so that it is straight and relaxed in the position it needs to be for extraction, while also applying tension to the hose-riser structure via these wheels so that it is taught and straight within the defined limits of movement the riser has been quoted. The asset can be declared active once the hose-riser has been deployed and safely set up from the reel drum to the extraction point. Figure 15 shows an example of a reeled hose system. Although equipping an FPSO with the appropriate equipment to facilitate the reeling deployment of oil risers comes at an enormous initial capital cost and can take a couple of years, it is a cost-effective method of fossil fuel extraction. This is because reeling is a very mobile extraction technology that may be utilised for short or long-term production. Depending on the length of the extraction, several anchoring systems may be required for the FPSO to withstand adverse weather conditions.

### 3.4.5. Deep Water Underwater Hose String (>300 m)

This product line is typically utilised in deepwater export lines with FPSOs moored with spread anchors. However, if depths of 100 metres are exceeded, it is sometimes employed in SALM and CALM buoys. Figure 16 shows an example of this hose-string. A differential pressure of 15 bars must be tolerated by the hose. Due to the string's length, it must endure greater internal pressure, resulting in a pressure rating of 24 bars.

### 3.5. Marine Hose Hang-Off and Marine Breakaway Coupling

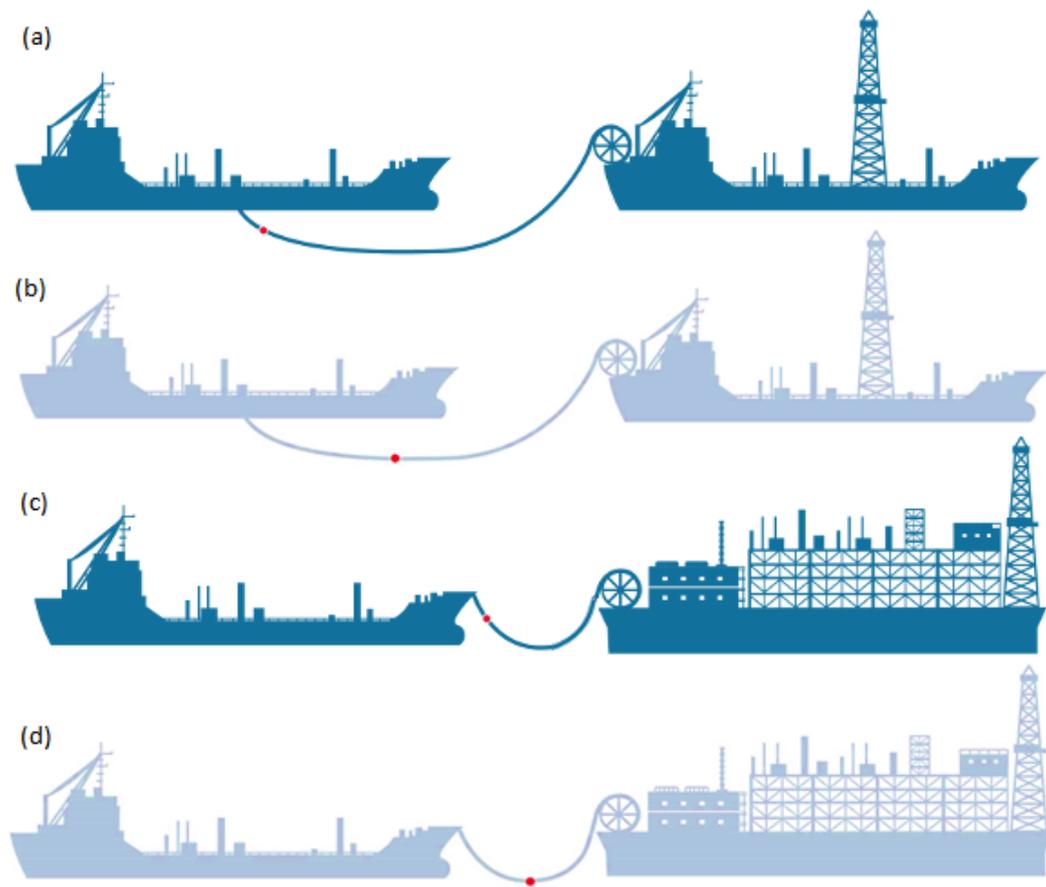
Marine hose hang-off is very important in sustainable fluid transfer, as summarised in Table 6. By classification, three hang-off systems are considered: the flex joint, tapered joint, and pull tube systems. The design conditions considered for the marine hoses are bend test, hydrostatic test, vacuum test, burst test, and materials analysis. As such, the hose has to be able to withstand the different loadings, according to OCIMF GMPHOM [94–96] standards. Due to the application of reeling hoses as depicted in Figure 15, it is important to control the flow of the hose. To control the hose hang-off or disconnection, Marine Breaker Couplings (MBC) and Hose End Valves (HEV) are used, such as the Petal MBC in Figure 20. The MBC and HEV are two important components of a marine hose system, as shown in Figure 20. As shown in Figure 21, there are two different configurations for installation of MBCs on the hoses. These are namely: the MBC installation for tanker midship configuration and the bow loading configuration. These are used to control surge pressure and avoid oil spills during transfer, or (un)loading of oil products. A list of some oilfield FPSO reels and the MBCs used are given in Table 7.

**Table 6.** Pros and Cons of various hang-off systems.

Hang-Off System	Pros	Cons	Limitation
Flex Joint	Decoupling the riser from the platform pitch and roll motions, which reduces the stresses in the upper region of the riser and supporting porch structure; better accommodating variations in riser performance characteristics; a reliable technical solution particularly for fatigue design	A relatively sophisticated component; requires good fatigue design and more checks on the stress effect.	Appropriate inspection procedures needed under high temperature and pressure fluctuation environment
Tapered Stress Joint (TSJ)	A one-piece metallic component without any moving parts—less complicated than a flex joint.	As the riser size increases or the severity in the platform pitch and roll motions increases, the TSJ becomes more challenging	Suitable in cases where the relative rotation between the platform and the riser is not excessive.
Pull Tube	Avoiding the use of any subsea mechanical connections on the riser which is economical and simple	Little room for flexibility; potential for wear between the riser and the end of the pull tube, and requires good inspection procedures.	



**Figure 20.** Marine Breakaway Couplings (MBC) showing a Cam-lock MBC on reel (LHS) and a Petal MBC (RHS).



**Figure 21.** MBC Installation options for Tanker Midship Manifold configurations in (a) position 1, (b) position 2, and for Bow Loading configurations in (c) position 3, (d) position 4.

The MBC, as a coupling, is a device with a flexible hose pipe that breaks when an axial load or internal pressure exceeds a predetermined value. The couplings are designed differently depending on whether they are used in liquefied gas or oil transfer systems. Onshore (marine) oil terminals that use flexible hoses, offshore rig activities, and offshore marine terminals that use catenary suspended hoses and floating hoses for bulk oil transfers are areas where Marine Breakaway Couplings can be used, as seen in Figure 20.

The common types of MBCs are the flip valve MBC, petal MBC, underbuoy MBC, and cam-lock coupling MBC. MBC has a unique mechanism that enables its usage in marine (onshore/offshore) oil terminals. MBCs are usually passive devices because they have a general unit composition linked in two halves, including a shut-off valve that does not necessitate a control source or external power for its activation. The valves are mechanically locked in the open position and include a fail-safe feature to close once engaged. When a load or a surge is given to it, the halves separate, causing the valves to close. In the event of double closure fittings, the liquid flow of the material on the transfer ceases when the unit is split, and then containment is done on either half of the separated hose. There are two types of breakaway couplings: single closure fittings and double closure fittings. The single closure fittings close the upstream end of the separation on the hose, while the double closure fittings close both the downstream and upstream ends of the hose. Although the MBC unit can be passive, it is kept together by a unique mechanism during separation. It has break bolts designed to sustain pressure surges and axial loads up to the specified calculations, but snap when the loads surpass the limit. As a result, break bolts keep the units functionally connected. The break bolts are made of a material that has a high tensile load-breaking predictability. Hence, these bolts are crucial for the unit's reliability. They are designed to break the break bolts only under tensile loads, but not shear loads. In small-bore applications where the couplings use a flap valve, breakaway couplings are

used. Different designs could be considered in such scenarios. Due to the restriction in the bore (internal diameter), mounting the valves within the bore of the unit may result in a drop in the system's pressure. In such cases seen during offshore fluid transfer systems from ship-to-ship (STS), the flap valve-equipped MBCs are used.

**Table 7.** FPSO reels with MBCs used (Source: [97]; Shows some combined with a Bow Loading Coupler in floating, submerged, and in air catenary applications).

Name of FPSO	MBC Size (")	Coupling Type	Hose Type
Enfield	16	CDC	Floating hose string
Ngujima Yin	16	CDC	Floating hose string
Seillean	12	CDC	Floating hose string
Anchieta	20	CDC	Floating hose string
Seillean	8	CDC	Floating hose string
Girassol	6	SCC	Floating hose string
Girassol	6	SCC	Floating hose string
White Rose	20	SCC	In air Catenary
McCulloch	16	SCC	In air Catenary
Guillemot/Teal	16	SCC	In air Catenary
Guillemot/Teal	16	SCC	In air Catenary
Curlew	16	SCC	In air Catenary
Triton	16	SCC	In air Catenary
Triton	16	SCC	In air Catenary
Bleo Holm	16	SCC	Submerged Catenary
Ettrick	16	SCC	Submerged Catenary
Golfinho	20	CDC	Floating hose string
Wenchang LPG	6	DNCC F/F	Floating hose string
Wenchang	16	SCC	Floating hose string
Wenchang 2	16	SCC	Floating hose string
Bongkot	10	SCC	Floating hose string
Bongkot	10	SCC	Floating hose string
Sakhalin	16	CDC	Floating hose string
Sakhalin	16	CDC	Floating hose string
Kraken	16	CDC	Submerged Catenary
Aoka Mizu	16	SCC	Submerged Catenary
Sable	16	SCC	Submerged Catenary
P17	20	CDC	Floating hose string
Capixaba	20	CDC	Floating hose string
Okha	16	CDC	Floating hose string
Nganhurra	16	CDC	Floating hose string
Marlim Sul	20	CDC	Floating hose string
Prelude	16	CDC	Floating hose string
Culzean	16	CDC	Floating hose string

Note: CDC—Controlled Double Closure, DNCC—Double Non-Controlled Closure, MBC—Marine Breakaway Coupling, F/F—Female to female Coupler, SCC—Single Controlled Closure, FPSO—Floating Production Storage and Offloading.

Notably, the MBC is used to control the flow of hoses, but it has other unique purposes. Mooring hawser failure, probable rupture of the loading hoses as a result of a tanker drifting which causes over-stress to the hose, and tanker breakout which creates excessive axial loading on the hose are all scenarios where Marine Breakaway Couplings are used. Another function of an MBC is to reduce surge pressure, which can be caused by loading valves closing against loading pressure in full flow, potentially damaging the hose. Several factors influence the application of Marine Breakaway Coupling. These include protection from high pressure surge, prevention of oil spills, better hose control measures, etc. MBCs are frequently used to protect the system's weaker components, such as the tiny diameter tail hoses in a floating string. Surface floating, subsea, and catenary hoses all use MBCs. An MBC should be required as a result of a risk assessment of the loading system, taking into account the terminal location, product flow rates, product pressures, environmental conditions, operational restrictions, and configuration. These couplings reduce hose reel stress, save weight and time, and are extremely safe.

### 3.6. Marine Hose Arrays

The several types of offloading systems that are now in use are reviewed. Most systems require multiple types of hoses, and some hoses are used in multiple systems. A CALM buoy and a tandem mooring configuration are represented in Figures 22 and 23, respectively. Based on the review, it is evident that many of the hoses are the same or have similar configurations. Different functionalities apply to different portions of the hose string within each system. Without going into depth regarding the exact features of each segment of the hose, the four primary properties that are adjusted to achieve the desired design are introduced here. These are as follows:

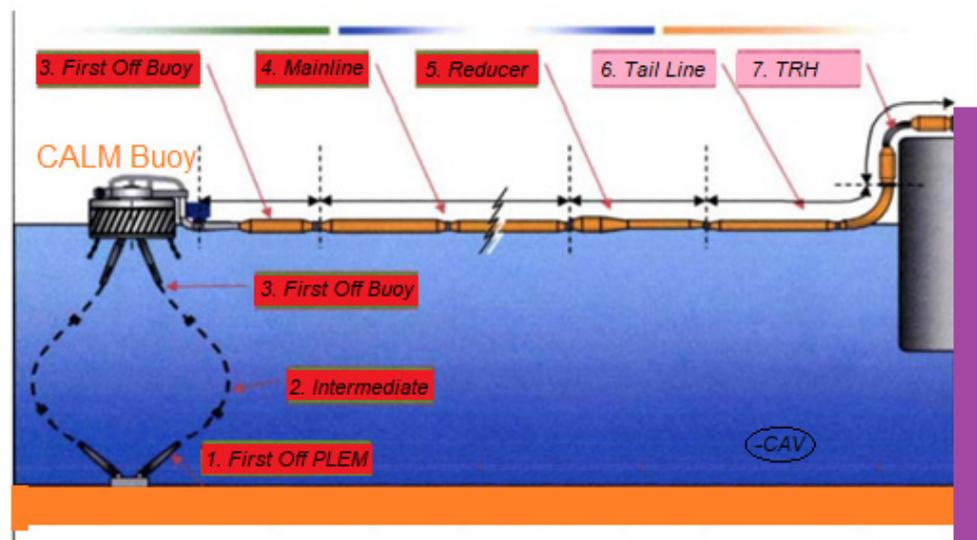
- (a) Hose bore or internal diameter: The hose segments that travel from the water surface to the manifold on the tanker or FPSO frequently have a lower diameter due to the limited lifting capacity of the utilised derrick. As a result, tapered hoses with a smaller diameter in the longitudinal direction are required.
- (b) Bending stiffeners upon end reinforcements: Certain hose strings on FPSOs, tankers, buoys, or PLEMs that link the floating or hanging hose string to rigid piping require gradual reinforcing to avoid a concentration of bending loads near the concerned flange.
- (c) Length of hose-string: The length of the hose-string is a function of the water depth, the distance between the buoy and the FPSO and the choice of hose configuration for the loading and unloading operation.
- (d) Floatation material quantity and placement: Floating hose strings require enough buoyancy to stay afloat. Certain portions with a lot of ancillary equipment require a bigger buoyancy reserve. Floatation material is required at particular points on hose segments that change from hanging to floating or floating to submerged.

### 3.7. Marine Hose Categories

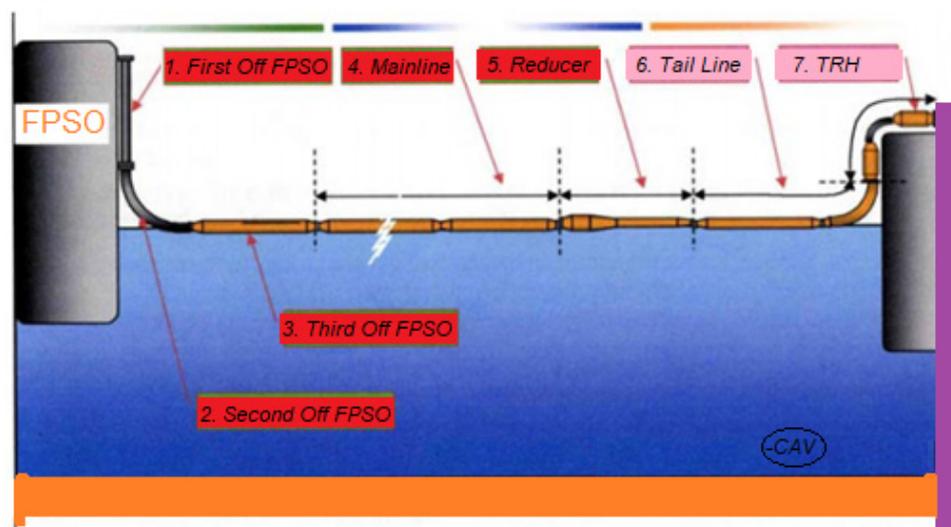
Regardless of variances between individual segments of the hose string, all hoses can be categorised into five types based on key characteristics. It is important to remember that within each product line, there is the existence of variations such as those indicated earlier. Based on categorisation, these are the primary specifications specified by the Oil Companies International Marine Forum (OCIMF [94]), which apply to all conventional hose types. This section presents some of the product line differences. The floating hose string, the catenary hose string, the submarine hose string (100 m), and the deepwater submarine hose string (300 m) are the five types of loading and unloading hoses. The typical features and moorings for the floating buoy system in which each product line can appear are mentioned for each product line of bonded marine hose. The application of offshore hoses in the industry has been identified in Offshore West Africa, Gulf of Mexico (GoM), Bohai Sea, South China Sea, and other seas. Some marine hoses are specified for 15 bar, 19 bar, and 21 bars, depending on the design, with standard hose lengths of 9.1 m,

10.7 m, and 12.2 m. Basic specifications for the typical marine hose for application on FPSOs or CALM buoy systems are presented as follows:

- Diameter: 150 mm <math>D < 600 \text{ mm}</math>
- Resistance to: Petroleum products with a 25% aromatic content
- Axial strength: 37 tons for  $D = 600 \text{ mm}$
- Pressure ratings: 15 bar, 19 bar and 21 bar (depends on design)
- vFlow at  $D < 400 \text{ mm}$ : 21 m/s
- vFlow at  $D > 400 \text{ mm}$ : 15 m/s
- Fluid temperature range:  $82 \text{ }^\circ\text{C} > T > -20 \text{ }^\circ\text{C}$
- Ambient temperature range:  $52 \text{ }^\circ\text{C} > T > -29 \text{ }^\circ\text{C}$
- Permanent elongations: <math> < 0.7\% </math> (relates to materials)
- Temporary elongations: <math> < 2.5\% </math> (relates to materials)
- Operating pressure:  $-0.85 \text{ bar gauge to designated pressure rating}$



**Figure 22.** Hose array on a CALM buoy hose system, showing 7 different types of hoses utilized on a classical SPM terminal, namely: (1) first off PLEM, (2) intermediate, (3) First off Buoy, (4) Mainline, (5) Reducer, (6) Tail line, and (7) Tanker Reeling Hose (TRH).



**Figure 23.** Hose array on a tandem hose system, showing 7 different types of hoses utilized on a classical FPSO tandem terminal, namely: (1) First off FPSO, (2) Second off FPSO, (3) Third off FPSO, (4) Mainline, (5) Reducer, (6) Tail line, and (7) Tanker Reeling Hose (TRH).

### 3.8. Marine Hose and Marine Riser Categories

Regardless of the marine component, if a riser or a hose, the design requirement of offshore hoses and other components of SURP is presented in this sub-section. The ranking of different hose configurations, the environmental aspects, installation requirements, and costs are summarized in Table 8. The presented matrix is adapted based on a hose study and an IKM’s Ocean Design in-house data. As observed from this matrix, three configurations are suited for hostile weather and shallow water. These are: Lazy-S, pliant wave, and touchdown chain added wave. Wave loads may generate roll and impact on the floating structure in the Lazy-S configuration, as in the event of very shallow water (less than 50 m), causing slack in one of its mooring chains and creating impact load, vibration, and shock. Some standard configurations with alternatives for offshore hoses, flexible marine risers, and Steel Catenary Risers (SCRs) are given in Figure 24.

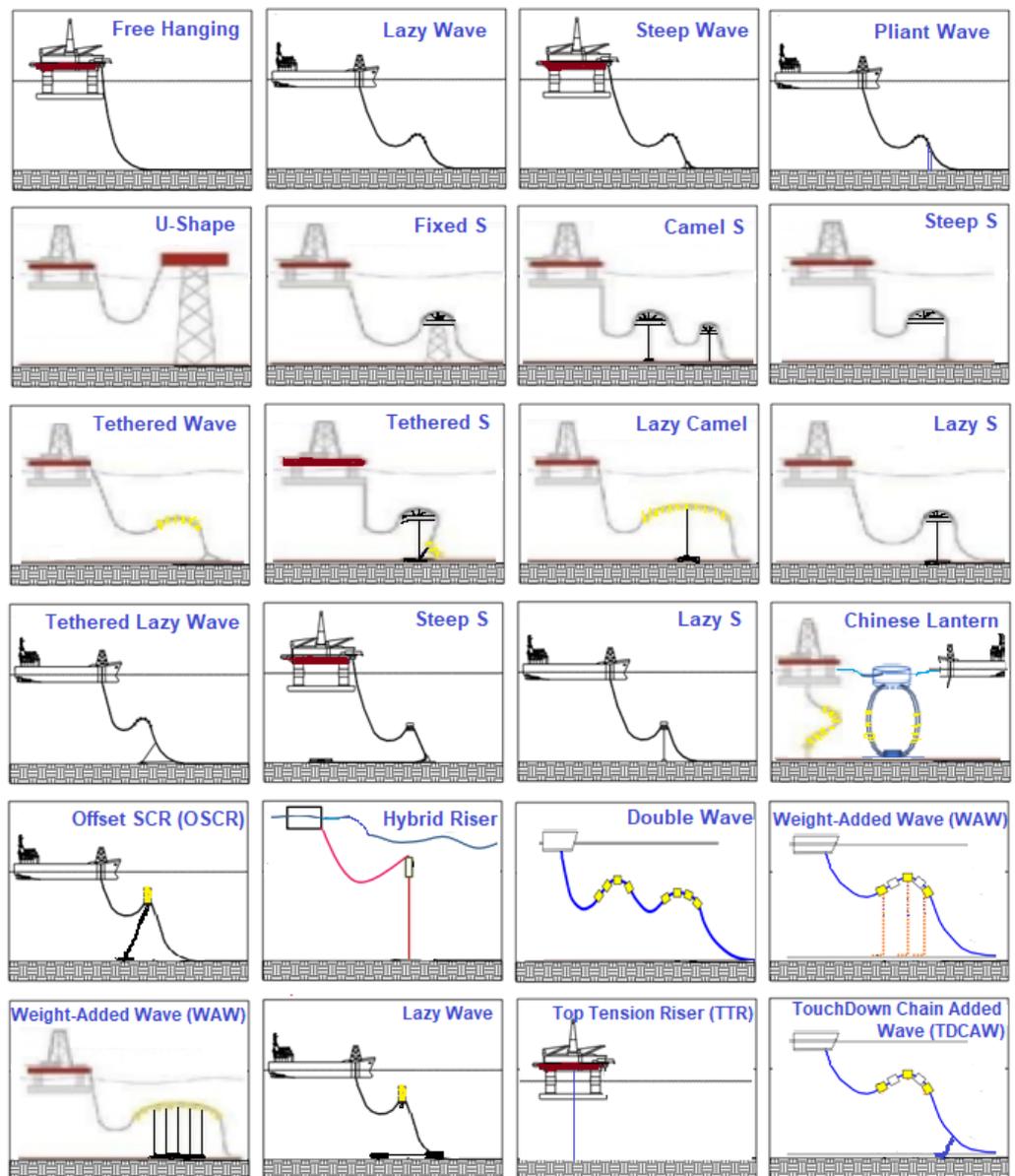


Figure 24. Standard configurations with alternatives for offshore hoses, flexible marine risers, and steel catenary risers (SCRs).

**Table 8.** Riser Configuration Selection Matrix, (adapted from IKM Ocean Design in-house data).

	Free Hanging	Steep-S	Lazy-S	Steep Wave	Lazy Wave	Pliant Wave	Weight Added Wave	Touch Down Chain Added Wave	Chinese Lantern
Dynamic behaviour									
Hostile weather, shallow water	Poor	Limited	Good	Good-	Poor	Good	Good-	Good	Good
Hostile weather, deep water	Limited	Good	Good	Good+	Good-	Good+	Limited	Good-	Good
Fair weather, shallow water	Limited	Good-	Good+	Good	Good-	Good	Good-	Good	Good
Fair weather, deep water	Good	Good	Good	Excellent	Excellent	Excellent	Good	Excellent	Good
Installation ease	Excellent	Poor	Good	Good-	Excellent	Good	Good-	Good	Good
Economic profile									
One line	Excellent	Limited	Good-	Good-	Good+	Excellent	Good-	Good+	—
Several lines	Excellent	Good-	Good+	Good-	Limited	Good-	Good	Good+	Limited
Adaptability—No. Lines	Excellent	Excellent	Excellent	Good-	Limited	Good-	Good	Good+	Limited

#### 4. Hose Tests & Model Challenges

Marine bonded hoses have been presented both from the application to the structural modelling aspects. Details on the hose bending behaviour, the snaking phenomenon and the hydrodynamics of marine hoses has been presented in earlier publications [97–100]. This section discusses the hose test methods, hose modelling issues, storage issues, and application benefits and challenges during real-life application on SPMs.

##### 4.1. Hose Design Test Methods

The mathematical design of hoses cannot be complete without presenting some hose design models, while discussing some test methods on the performance of hoses.

##### 4.1.1. Allowable Axial Load of Hose

According to the recommendations of OCIMF 2009 standard [94], there is a limit that must be considered as the hose allowable axial load. This is usually the ratio of the lowest predicted damaging load to the safety factor (*S.F*) of 3, which the hose manufacturer should define, as given in Equation (1). This will help in the design verification as hose failure can occur due to damage from over load, over stretch, over bend, or related, as shown in Figures 4–6 on statistics of hose failure. Since hoses have complex structures, they can undergo damage or failure due to different conditions when subjected to a force acting in-line with their centre-line axis.

$$Allowable\ Axial\ Load = \frac{Lowest\ Predicted\ Damaging\ Load}{S.F\ of\ 3} \tag{1}$$

##### 4.1.2. Tensile Load of Hose

According to the recommendations of OCIMF 2009 standard [94], tensile testing should be conducted on hoses when empty and when pressurized. To conduct it on a prototype hose, there should be an incremental application of tensile load equivalent to  $1.5 \times$  Allowable Axial Load in 10 equal increments. However, at each increment, the extension of the hose should be measured, and then the load held at  $1.5 \times$  Allowable Axial Load for 15 min. At this point, the hose extension should be taken every 5 min, then the load is removed over 5 min and the hose extension measured again. After the test, it is expected that there should not be any damage observed. Thus, a graph of load versus extension can be obtained and the slope of the curve measured. The hose extension can be obtained from Equation (2), and used to obtain the relationship of the axial stiffness as given in Equation (3), where *EA* is the axial stiffness, *F* is the applied load, *L* is the length of

the hose section,  $\Delta L$  is the displacement in the length of the hose section, and  $x$  is the hose extension per unit length. The tensile load is illustrated in Figure 25.

$$x = \frac{\Delta L}{L} \tag{2}$$

$$EA = \frac{F}{x} \tag{3}$$

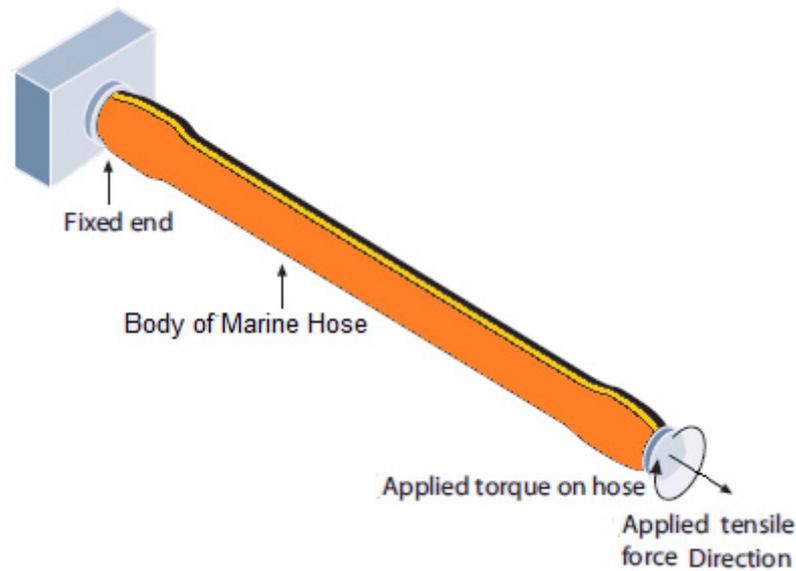


Figure 25. Illustration of torsion and tensile tests on marine hose.

#### 4.1.3. Torsional Load

Due to the application of marine bonded hoses on different manifolds, couplings, and hose-lines, it is required to conduct torsion tests. However, the same hose used for stiffness test and minimum bend radius can be subjected to torsion testing, using an empty hose. To achieve this, the hose is twisted with a torque magnitude of 0.9 deg/m, in both anti-clockwise and clockwise directions, five (5) times in each direction and recorded at each twist direction. It is expected that there will be no damage, and then the torsional stiffness in both directions can be obtained as in Equation (4), where  $GI$  is the torsional stiffness,  $T$  is the averagely measured torque, and  $a$  is the applied twist per unit length (in radians). A simple illustration of the torsion is depicted in Figure 25.

$$GI = \frac{T}{a} \tag{4}$$

#### 4.1.4. Hydrostatic Pressure Load

According to the stipulations of OCIMF 2009 standard [94], hydrostatic pressure testing can be conducted on hoses using kerosene or water as the test medium. First, the hose is laid straight and then levelled on supports to ensure that the hose can freely move when pressure is exerted. The hose is then filled with water, and pressure gauge and twist monitoring devices are attached to the test rig. The hose displacement is obtained for two cases, by considering the temporary and permanent elongations as given in Equations (5) and (6), whereby  $L1$  is the overall length of the hose assembly measured during the initial pressure application of 0.7 bar,  $L2$  is the overall length of the hose assembly measured during the next pressure application of 0.7 bar increased over a period of 5 min to half the Rated Working Pressure (RWP), and  $L3$  is the overall length of the hose assembly measured after

the final pressure application of 0.7 bar from of  $1.5 \times \text{RWP}$  over a period of 15 min, as depicted in Figure 26.

$$\text{Permanent elongation (\%)} = \times 100 \tag{5}$$

$$\text{Temporary elongation (\%)} = \times 100 \tag{6}$$

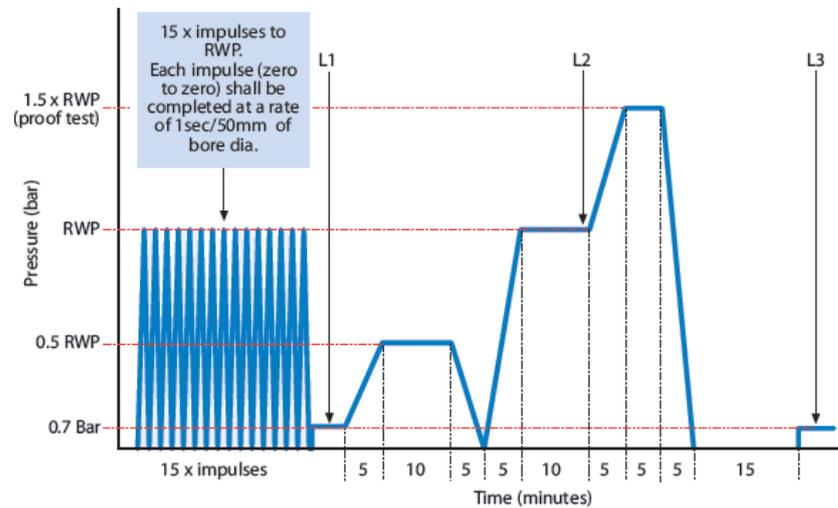


Figure 26. Depiction of hydrostatic pressure test showing applied pressures.

#### 4.1.5. Hose Crush Load

Within the stipulations of OCIMF 2009 standard [94] is prescribed the criteria for the hose crush load, using a 500 mm nominal length of hose section positioned on a flat surface with supports. The crushing load is applied using a flat profiled beam of 400 mm widthwise and 500 mm lengthwise, as shown in Figure 27. Once the force is applied at the top of the flat profile, the hose sample is measured for changes in external diameter and internal diameter, using both planes X–X and Y–Y. The load is then increased incrementally in 15 equal increments to  $1.5 \times$  calculated Crush Load of the hose. This procedure is used to obtain a deflection-force plot for both temporary deflection and permanent deflection.

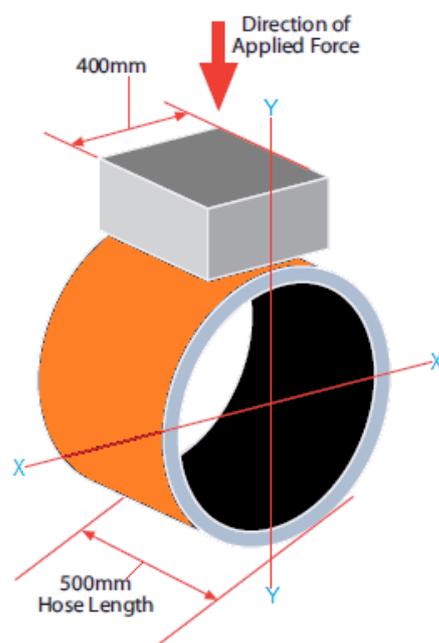


Figure 27. Depiction of crush load test on hose.

#### 4.1.6. Burst Load

Within the stipulations of the OCIMF 2009 standard [94], the burst test (or internal pressure test) should be conducted on a level surface with some rollers, as depicted in Figure 28. It is then pressurized internally using the RWP or the design pressure of the hose, as the case may be. This testing process is done repeatedly to investigate the effect of burst load on the hose.

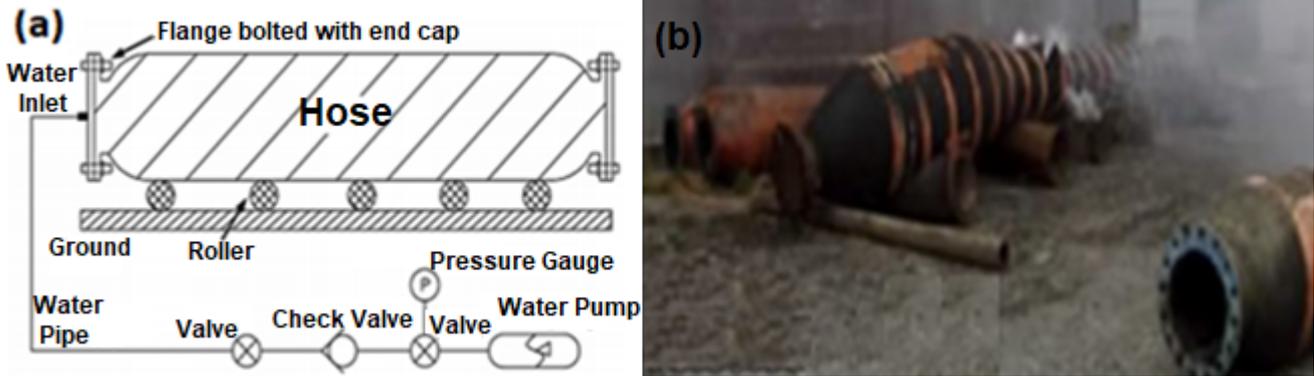


Figure 28. Two setup diagrams for Burst Test on OCIMF offshore hose, showing (a) the circuit diagram for burst test, and (b) the typical burst test on a marine hose.

#### 4.1.7. Bending Stiffness Load

Within the stipulations of the OCIMF 2009 standard [94], the bending stiffness test should be conducted by using two fixed ends, to bend condition the hose, as depicted in Figure 29. As it bends towards its Minimum Bend Radius (MBR), the hose can be adjusted slightly by swinging its arc and recording the dimensions for the chord of the bending arc as  $C$ , the hose offset as  $H$ , the moment arm as  $L$ , the bending radius at the hose’s centre as  $R$ , the bending moment at the hose’s centre as  $M$ , and the force as  $P$ , to deduce  $EI$ , which is the stiffness parameter, using Equations (7)–(9).

$$EI = MR \tag{7}$$

$$M = PL \tag{8}$$

$$R = \frac{(C^2 + 4H^2)}{8H} \tag{9}$$

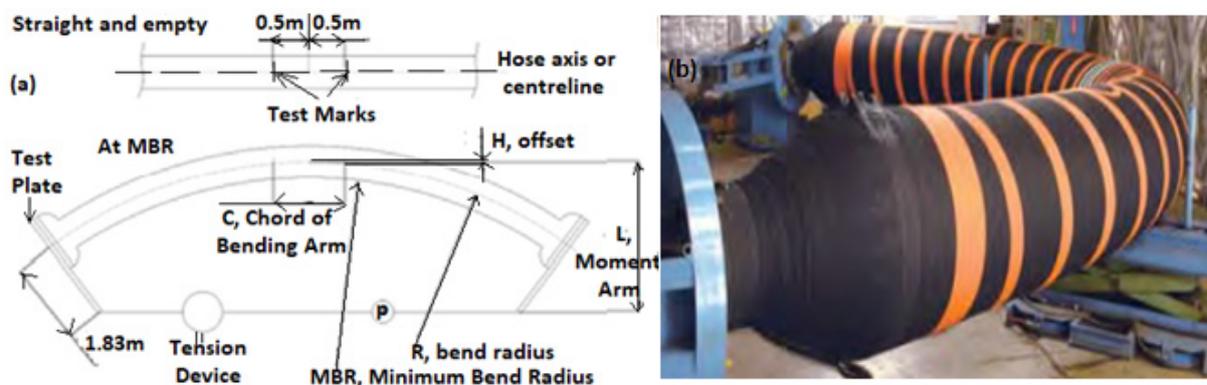
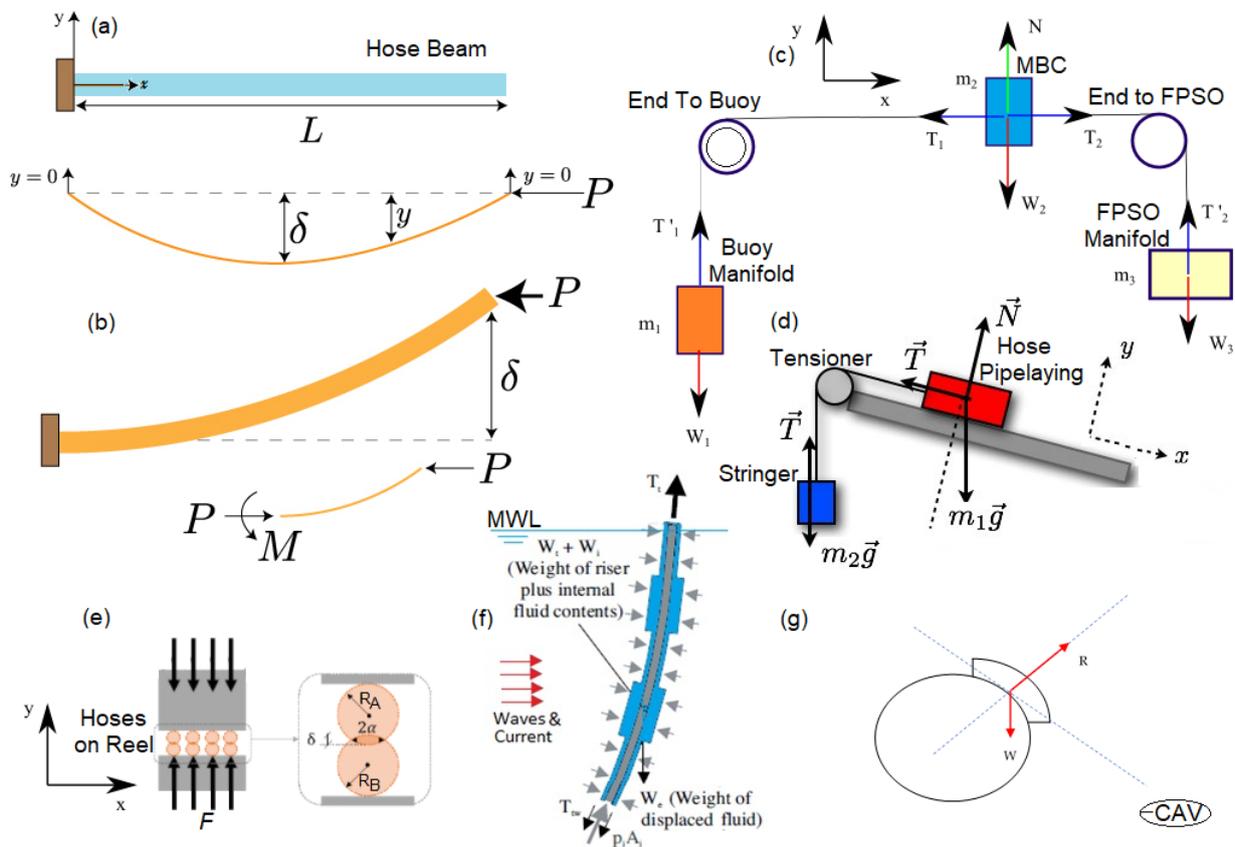


Figure 29. Two setup diagrams for OCIMF Bending Stiffness Test on marine hose, showing (a) the circuit diagram for bending stiffness test, and (b) the typical bending stiffness test on a marine hose.

4.2. Descriptive Hose Scenarios by Application

There are different applications of marine bonded hoses based on descriptive scenarios. These include ship-to-ship connections, tandem moorings, catenary moorings, reeling hose connections, hose pipelaying, CALM buoy-to-FPSO connections, CALM buoy-to-PLM, FPSO-to-MBC, etc. Figure 30 depicts a free-body diagram (FBD) for different load scenarios of marine hose applications showing (a) hose beam simply supported, (b) hose beam under tension and torsion, (c) hose connected between buoy and FPSO, (d) hose during pipelaying, (e) hoses on a reel from section view, (f) Crush load for a section of the hose on with valve, and (g) hose segment showing fluid content and waves. These marine bonded hoses are challenged by modelling environmental and operational issues that threaten their service life and structural integrity. Generating accurate data on hose failures that are correctly reported is another challenge. Recently, some reported industry incidents have reported reeled hoses and looped riser constructions seriously having critical failures much before the stated theoretical in-service life of the hose-riser system. As a result, extensive research has been conducted into the failure modes that risers can undergo as a result of the reeling process. The process involves constant tension throughout the riser structure and the simultaneous effects of the oceanic environment on the riser structure. This implies that the riser is subjected to constant stress throughout the structure due to the riser’s self-weight, crush load from the reeling drum, internal fluid within the riser, and internal and external pressures.



**Figure 30.** Free-Body Diagram (FBD) for different load scenarios of marine hose applications showing (a) hose beam simply supported, (b) hose beam under tension and torsion, (c) hose connected between buoy and FPSO, (d) hose during pipelaying, (e) hoses on a reel from section view, (f) hose segment showing fluid content and waves, and (g) Crush load for a section of the hose on with valve; Where  $R$  (Crush load of hose riser) =  $W \cos \theta$ ,  $W$  = (Self weight of hose riser + internal fluid weight),  $\theta$  = Angle between weight ( $W$ ) and reaction vector respectively,  $m_1$  = mass of hose riser,  $T$  = Tension force of hose,  $P$  = force acting in direction towards hose end,  $F$  = force acting on the side of the hoses on a reel, MWL = mean water level,  $M$  = the moment and  $\delta$  = the displacement.

While the hose is under constant fluid flow within the structure, there will be the added weight of the fluid as well as the actual weight of the riser acting downward, as illustrated in the FBD shown in Figure 30. In engineering mechanics, the FBD is one of the best methods used in representing known and unknown forces in a system, by using a sketch of the outline shape of the body depicting when it is in isolation from its surrounding environment. This represents various scenarios of marine hose application with loads acting on them. For instance, on the illustration in Figure 30g, there will also be a reaction force from the drum acting on the riser applying force to the reeled riser structure. However, this simple FBD is not very representative, such as Figure 30f, which shows fluid weight on the hose-riser segment. This force can induce structural failure of the riser or possibly delamination of the interface bonds between the riser layers if it exceeds the permitted limits for applied stress to the materials employed in the riser layers.

Due to pressure fluctuations and even spikes caused by unanticipated irregular flow rates of extracted fossil fuel, the internal pressure and the weight of the fluid flowing within the riser can both sometimes increase within the structure of the hose. Thus, the hose is structurally stressed within this condition as well as subjected to increased internal pressure. However, there have been a number of distinct failure mechanisms seen within the industry due to a combination of tensile stress and bending on the asset within the dynamic environment it functions in, resulting in the aforementioned asset failing before its estimated life span. This, combined with a general absence of industry specifications and rules for composite flexible pipeline, creates ambiguous quality benchmarks that make it difficult for the asset to function as expected, resulting in a large amount of uncertainty in the asset's actual performance.

#### 4.3. Hose Failure vs. Flexible Riser Failure Issues

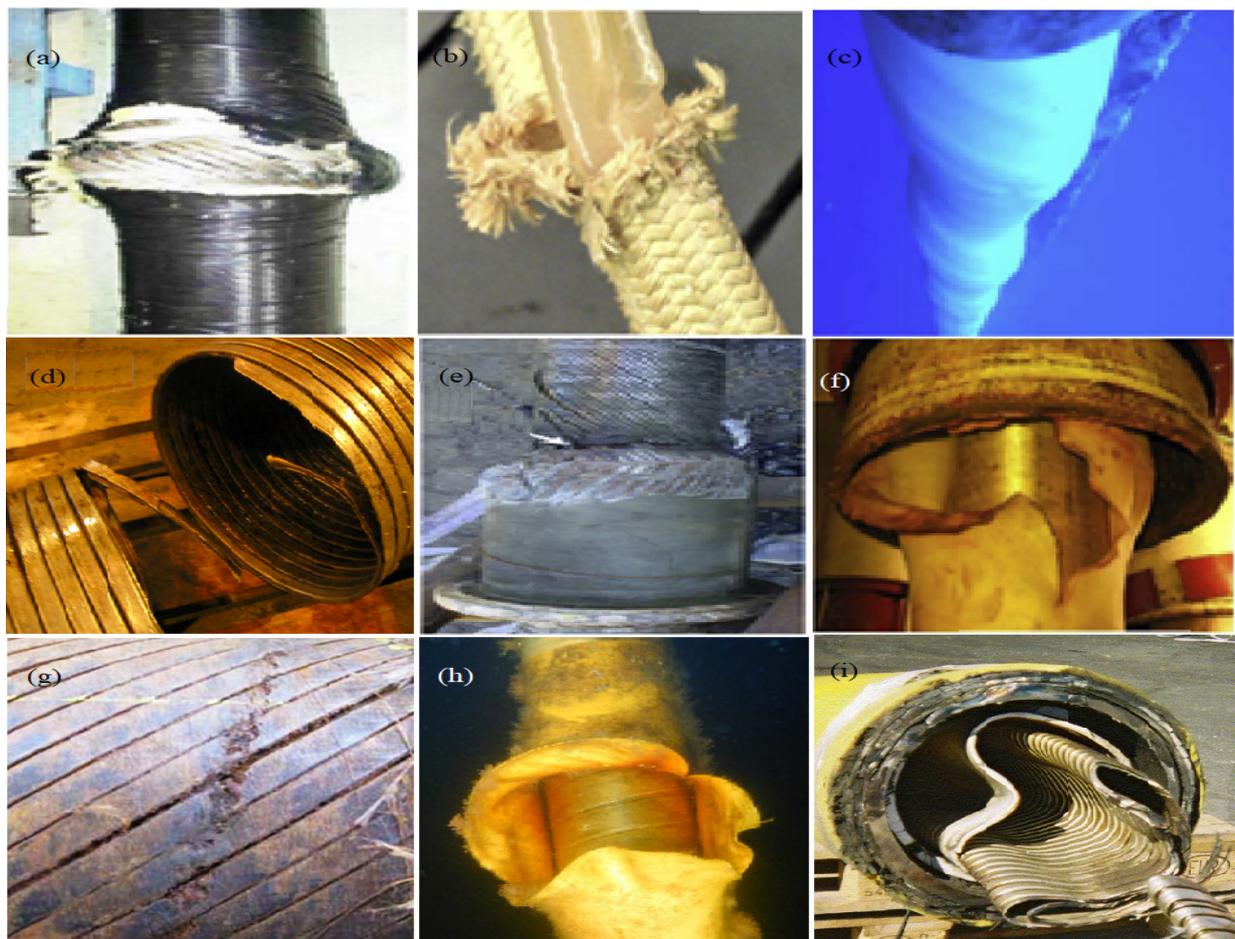
Marine bonded hoses have been identified to pose peculiar failures, as well as some failures that are common to both marine bonded hoses and other flexible risers. Multiple industry failure scenarios have been identified on unbonded flexible pipes, and bonded flexible pipes or marine bonded hoses [36–41], as respectively depicted in Figures 31 and 32. These represented failure collages show different peculiarities in the designs, failure modes and damage routes which are mostly seen during operation. As observed on Figure 31, the failures on the flexible pipes and flexible risers are observed to include burst failure, corrosion, carcass collapse, wire ruptures, and failure of tensile armours. (a) bird caging; (b) aramid hose layer rupture from burst showing crease region; (c) torsion at riser top due to ruptured armour wires; (d) carcass damage; (e) tensile armour wire rupture due to fatigue; (f) rupture of external sheath from blocked vent tubes; (g) armour wire corrosion; (h) burst external sheath from blocked vents; and (i) carcass collapse. It can be noticed that internal pressure and external pressure has been a commonality in the failure of these systems in both Figures 31 and 32. Corrosion is another commonality found, as it occurs on end fittings and flange joints on both systems. However, based on the reinforcements, the tensile armour of the flexible risers easily damages due to corrosion, unlike the marine hoses where its helical reinforcements are well embedded and protected against corrosion.

Similar observations on Figure 32 include (a) hose cover failure for repair and beyond repair with exposed reinforcement, (b) hose cover damage, (c) heavy wear of the hose flange after 14 years-service, (d) abrasion damage on hose, (e) floating hose after a propeller cut (f) crushed 16 inches submarine hoses after excessive load landed on it, (g) Pressure test with leaking liner, (h) hose wall damage due to hose kinking, (i) cover abrasion damage down to breaker fabric, (j) bonding defect near end-fitting detected in pressure test and excessive external corrosion on hot dip galvanised nipple after 3 years-service in offshore Vietnam, (k) cracking in outer cover of hose, and (l) hose damage for repair showing cut on cover. It can be observed that the marine hoses have issues with cover a lot more than the other flexible risers. Secondly, the cover of the marine bonded hoses are susceptible to changes in environment, as such they have cracks more than on other flexible risers. Thirdly, the mode of failure does not have an exactness in form, based on the materials used in

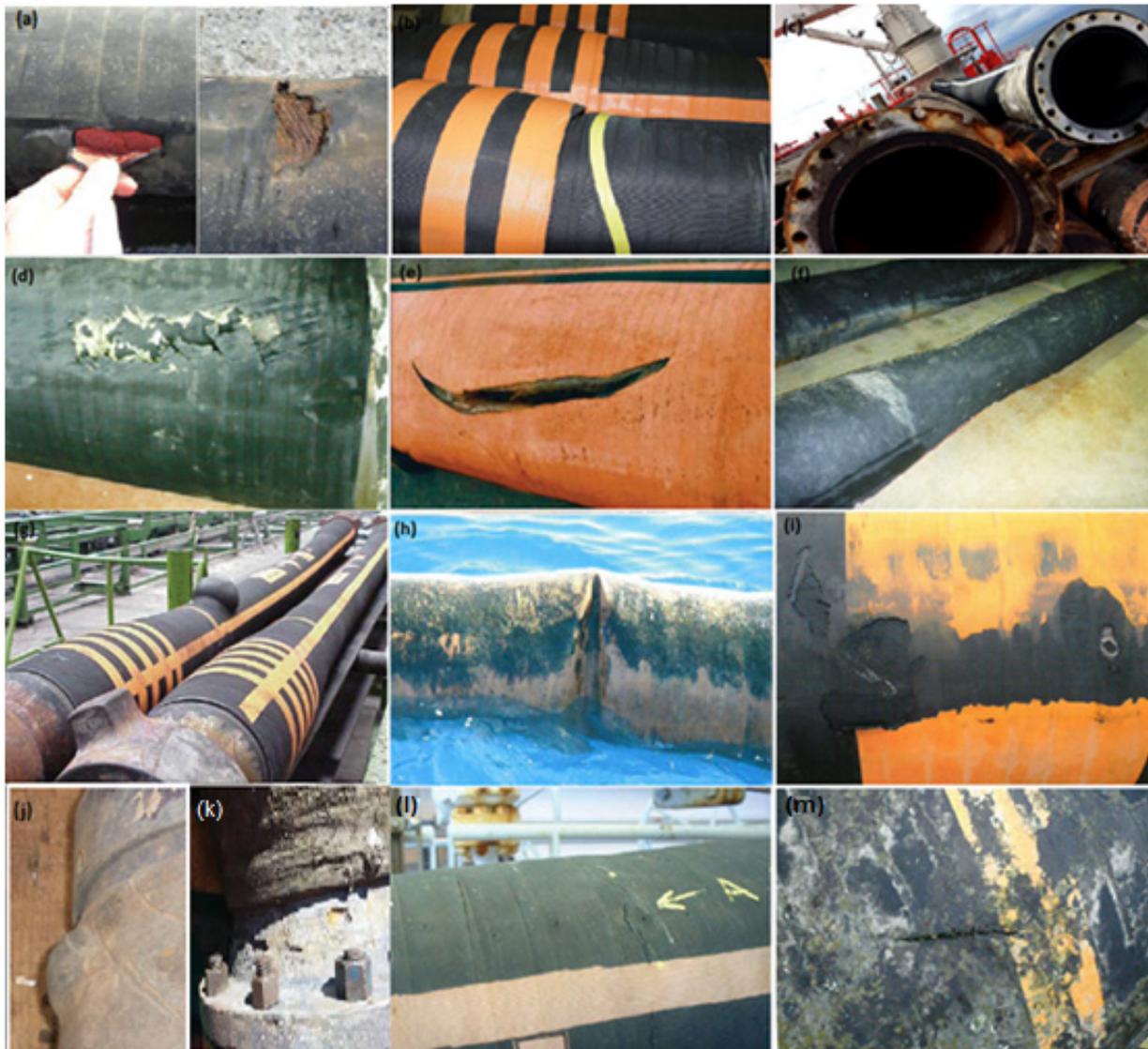
designing the marine bonded hoses. Thus, further inspection of material behaviour of marine hoses after failure would be based on the bonding of the hose layers. Sometimes, the failure is noticed outside, such as a bulge seen in Figure 32j which is a near defect from excess pressure during hose testing. According to information from incidence databases, input from stakeholders, and other reported incidents, degradation and damage of hose covers are highly reported, followed by damages from valve failures. However, the most common marine hose failures are caused by damage to the cover, unlike for other flexible risers that are from deterioration of the internal and exterior polymer sheath. Unlike the marine hoses, when the outer sheath fails, it creates a dangerous environment in the annulus, increasing the probability of numerous failure modes. Internal pressure sheath degradation jeopardises fluid containment integrity and is difficult to detect. To control the annulus environment, it is recommended to have a well-functioning annulus vent system connected to a monitoring system.

#### 4.4. Protection of Marine Hoses

Due to the high pressure (HP) demand of offshore loading and offloading hoses, it is important that these hoses are adequately protected against different loadings. These protections are classified into three, as presented in this sub-section.



**Figure 31.** Image collage of unbonded flexible pipeline failure types observed showing failure modes of flexible risers: (a) bird caging; (b) aramid hose layer rupture from burst showing crease region (c) torsion at riser top due to ruptured armour wires; (d) carcass damage; (e) tensile armour wire rupture due to fatigue; (f) rupture of external sheath from blocked vent tubes; (g) armour wire corrosion; (h) burst external sheath from blocked vents; and (i) carcass collapse (Sources: [36–41]).



**Figure 32.** Image collage of some hose failure modes, showing (a) hose cover failure for repair and beyond repair with exposed reinforcement, (b) hose cover damage, (c) heavy wear of the hose flange after 14 years-service, (d) abrasion damage on hose, (e) floating hose after a propeller cut (f) crushed 16 inches submarine hoses after excessive load landed on it, (g) Pressure test with leaking liner, (h) hose wall damage due to hose kinking, (i) cover abrasion damage down to breaker fabric, (j) bonding defect near end-fitting detected in pressure test, (k) excessive external corrosion on hot dip galvanised nipple after 3 years-service in offshore Vietnam, (l) cracking in outer cover of hose, and (m) hose damage for repair showing cut on cover (Sources: [36–41], Courtesy: Trelleborg & ContiTech).

#### 4.4.1. Preventive Maintenance

Preventive maintenance (PM) is the process of maintaining equipment, infrastructure, and assets on a regular basis in order to keep them running and avoid expensive unplanned downtime due to unexpected equipment breakdown. Or, simply, preventive maintenance (PM) is the process of preventing asset and equipment breakdowns. This maintenance method is carried out on a regular basis, which means that even if there are no indicators of failure, the equipment is inspected. This way, any equipment failure is minimised as much as possible, ensuring the assets’ correct operation and safety. An effective maintenance strategy is proactive as it necessitates the scheduling, preparing and planning of equipment repair before a problem arises, such as an overload that can lead to hose failure. The activities on the preparation of preventative maintenance plans for equipment and facilities include avoiding breakdowns and lowering the likelihood of equipment failures that

disrupt operations. This preventive maintenance routine is designed using maintenance plans, which allows the responsible department to keep track of activities and know ahead of time which components or resources are needed. Furthermore, preventative maintenance maintains equipment reliability because all activities are performed at pre-determined intervals and have no bearing on the performance of the hose manufacturer or service company. Preventive maintenance is important because hose life depends on the quality of the maintenance, as well as its design and operation conditions. It is recommended that marine hoses need to be inspected routinely to prevent massive damage. Repairing any damage as soon as it appears and planning for superficial damage to be repaired onshore may prevent it from becoming worse or even irreversible and catastrophic. As such, preventive maintenance is carried out to keep the hose-string fully operational for a new oil offloading operation. During hose design, the service life of each hose type must be determined to ensure quality and efficiency of the maintenance, anticipate the hoses replacement in time and ensure efficient project management of the onshore stock of spare parts. According to the OCIMF standard ([94]), the following inspections/tests are performed following a maintenance plan: visual inspection, hydrostatic test, vacuum test, electrical/continuity test, weight test, dimensional measurement, burst test, and bending test. Some of these are also found in industry manuals for CALM buoy hoses [101–106] and hose manufacturers recommendations [107–114], and others in standards on SPM/marine hoses such as API 17K [115–120].

#### 4.4.2. Curative Maintenance

The external hose body can be repaired only if it is superficially damaged, i.e., when steel carcasses are not damaged. In general, floating hoses, catenary hoses, submarine hoses, and reeling hoses that are used in offshore applications are exposed to several risks. As illustrated in Figure 32, these include the following: tears resulting from passing under the hull of tankers at berth, external tears caused by propellers, attack by marlins, accidental contacts with sharp metallic structures, and chafing under the hulls of tankers or tugboats. Curative maintenance can be considered as repair of defective or damaged equipment. It can be associated with other types of maintenance: preventive or corrective maintenance. It is generally related to the end of the life of a machine or one of its components. Unlike palliative corrective maintenance, which involves temporarily fixing equipment, curative maintenance is used when a machine or installation, such as silos and hoppers, has failed and cannot be repaired. In this instance, the equipment must be replaced in part or in its entirety. This curative maintenance could happen after a preventative or corrective maintenance. It is not indicated if the defective equipment interferes with the process or not in the context of curative maintenance. As a result, it could be a little or large repair. A hose fatigue testing machine with a non-working resistance, for example, will no longer function properly. To restore the equipment's principal function, it is necessary to intervene and modify the resistance. A hose with a broken hose cover that had been fixed with a patch (palliative corrective maintenance) but then broke open or burst again would need to be replaced: this is curative maintenance. It might be a hose system with a butterfly valve for control during offloading operation the industry. If this valve becomes clogged due to corrosion or deformed due to a shock, the product can no longer be transferred sustainably. It will need to be changed in order to restore offloading and loading operations. This will ensure proper product supply during the (un)loading operations. In a nutshell, curative maintenance is the process of repairing or replacing defective or damaged equipment. It usually refers to the hose, the hose transfer machine or one of its components reaching the end of its useful life.

#### 4.4.3. Corrective Maintenance

Corrective maintenance is a type of maintenance that involves locating, isolating, and correcting a fault so that the failed equipment, machine, or system can be brought back into service within the tolerances or limits defined for in-service operations. Corrective

maintenance is the process of identifying, isolating, and repairing a fault in order to get equipment, a machine, or a system back into working order so it can perform its intended function. Troubleshooting, disassembly, adjustment, repair, replacement, and realignment are all examples of corrective maintenance, which is frequently connected with breakdowns or reactive maintenance. Corrective maintenance tasks can be scheduled or unscheduled, and they can occur for one of three reasons: firstly, when condition monitoring identifies a problem; secondly, when a possible flaw is discovered during routine inspection; and thirdly, when a piece of machinery fails. The maintenance staff are frequently forced to respond to equipment breakdown or failure, necessitating corrective maintenance. However, relying primarily on corrective maintenance over other types of maintenance, such as preventive maintenance, can be a terrible idea. Corrective maintenance is fine when an asset can be simply fixed or replaced with readily available parts, but it can also result in unexpected and costly downtimes in other cases. Experts agree that preventative maintenance should account for 80% of your upkeep and corrective maintenance should account for 20% [121].

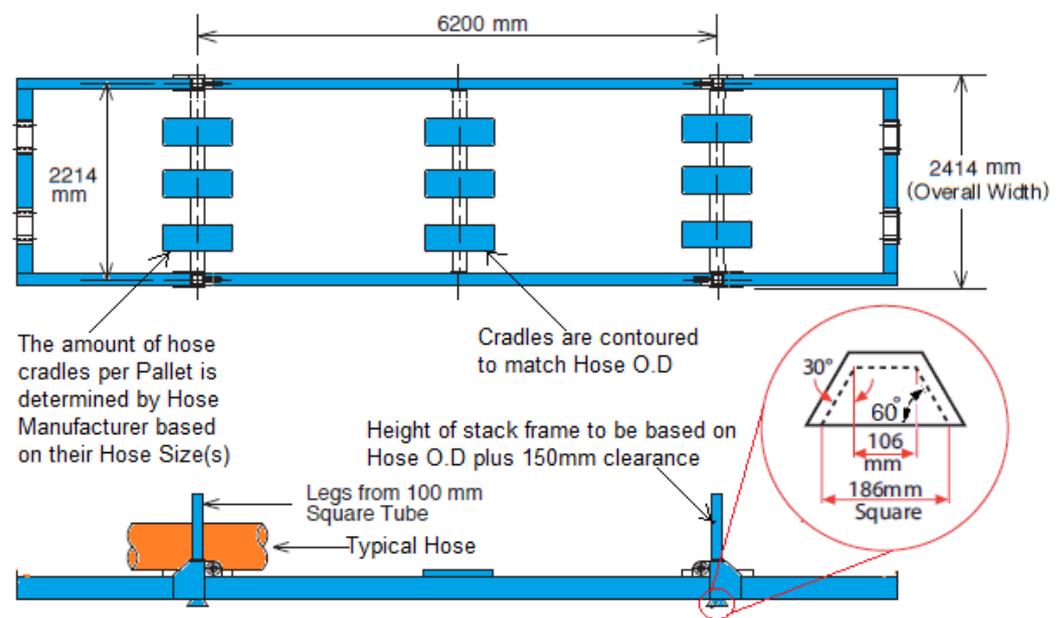
Different Types of Corrective Maintenance exist, and these types of corrective maintenance tasks can be classified into many groups. It's the US Army's Engineering Handbook [122], for example, uses five (5) types of corrective maintenance:

- Fail Repair—Repairing a failing asset to get it back up and running.
- Overhaul—Completely restoring any asset to its original operating condition as defined by maintenance standards.
- Salvage—Disposal of non-repairable parts and replacement with salvaged parts from non-repairable assets.
- Servicing—This is the process of making last stage of corrective maintenance by concluding fixes and minor adjustments after bigger corrective fixes or bigger remedial activities have been completed.
- Rebuild—Disassembly and replacement of worn components in accordance with original norms and specifications.

Corrective maintenance tasks might be planned (scheduled) or unplanned (unscheduled) in each of these afore-listed five categories. The unscheduled (or unplanned maintenance) refers to repairs that must be completed right away, whereas scheduled (or planned corrective maintenance) refers to operations that can be postponed. Budgets, time restrictions, and staffing limits may all be factors in this delay. Maintenance that is scheduled or planned is best as it helps in hose maintenance. There are two types of planned maintenance, namely: run-to-failure maintenance and preventive maintenance. The term "run-to-failure" refers to allowing an asset to run until it fails, at which time it is repaired or replaced, and it is not recommended for hoses. Only non-critical or redundant systems that are easy to replace or repair are eligible for this type of corrective maintenance strategy. During maintenance inspections, faults are found and treated as part of preventive scheduled maintenance, which is commonly undertaken as part of condition-based maintenance. For unscheduled or unplanned maintenance, the challenge occurs when a breakdown happens suddenly, thereby the corrective maintenance is also unplanned. This could occur due to a lack of a maintenance plan or an asset failing before its planned inspection or repair activity. As such, routine maintenance is best recommended for marine hoses systems.

#### 4.4.4. Storage Maintenance

Hose packing has been identified as an ergonomic model which is important in the service life of the hoses. Adequate calculations need to be conducted and the hoses need to be spaced apart during packing to ensure safety of the hoses during delivery, as well as durability assurance based on the manufacture and tested hose products. Details of the hose-packing and pellets is shown in Figure 33.



**Figure 33.** Packing pallet with the array for marine hoses.

Steel framed pallets are used for packing the hoses for storage, delivery, and transportation. Each of the pallets is made up of four supporting legs, which allows safe stacking to a height of three pallets. These can be arranged and customised into sizes, such as 40 feet top container in dry or open cases. In compliance with OCIMF 2009 recommendations ([94–96]), hoses are to be stored in racked pallets, such as may be located within storage yards. The hoses must also be kept on these special steel racks that are shaded from the sun's ultra-violet (UV) rays. The reason is that humidity, temperature, corrosive vapours, corrosive liquids, solvents, oils, sunshine, UV light, ozone, rodents and insects can all shorten the life of hoses while in storage. In addition, the steel rack cradles have to be kept in especially good condition to ensure that the hoses are protected.

#### 4.5. Pros and Cons of Marine Hoses

On this review, it is pertinent to discuss some advantage and disadvantages of marine hoses, as summarised in Table 9. This can be used a metric to be considered during design, purchase, storage and maintenance. With this comparative analysis, hose designers can make better analysis in choosing hose types, hose materials and application, in place of flexible risers. Typical hose section chart on the capabilities of marine hose product lines for two (2) hose manufacturer-Trelleborg and Continental Dunlop is shown in Table 10. It shows Trelleborg's typical hose product lines (Sealine, Kleline, Reeline, Treeline) [123–126], and Dunlop's typical product lines (Safloote, Safgard, Selfloote, SCS) [127–130], against conventional hose types (floating, submarine) and their configurations. These configurations that would be conforming for such hose products include Lazy-S, Chinese-lantern, Steep-S, STS, CBM, ship-to-shore, flowline, riser, jumper, reel, etc. [131–137]. For instance, Trelleborg's Reeline is a specialised reeling hose for marine reeling purposes, both on reel drums, reeling vessels and other reeling operations. On the other hand, Dunlop has a product called Selfloote which was the world's first integrally floated marine hose for fluids like oil and gas. Its single carcass design was as distinctive back then as it is now, with the current generation of Selfloote serving as the benchmark. Selfloote currently combines enormous strength with flexibility, and it is capable of withstanding the rigours of the world's most exposed offshore facilities, thanks to ongoing programmes of new technical advancement. The design has been reviewed to have fit for use, been tried and proved to be true, highly adaptable with flexibility, has a second lining with its patented design, has an outstanding fatigue resistance, has high service history of over 40 years, has designs with specialised fittings and it is resistant to seawater ingress floatation bonding system.

**Table 9.** Pros and Cons of offshore hoses.

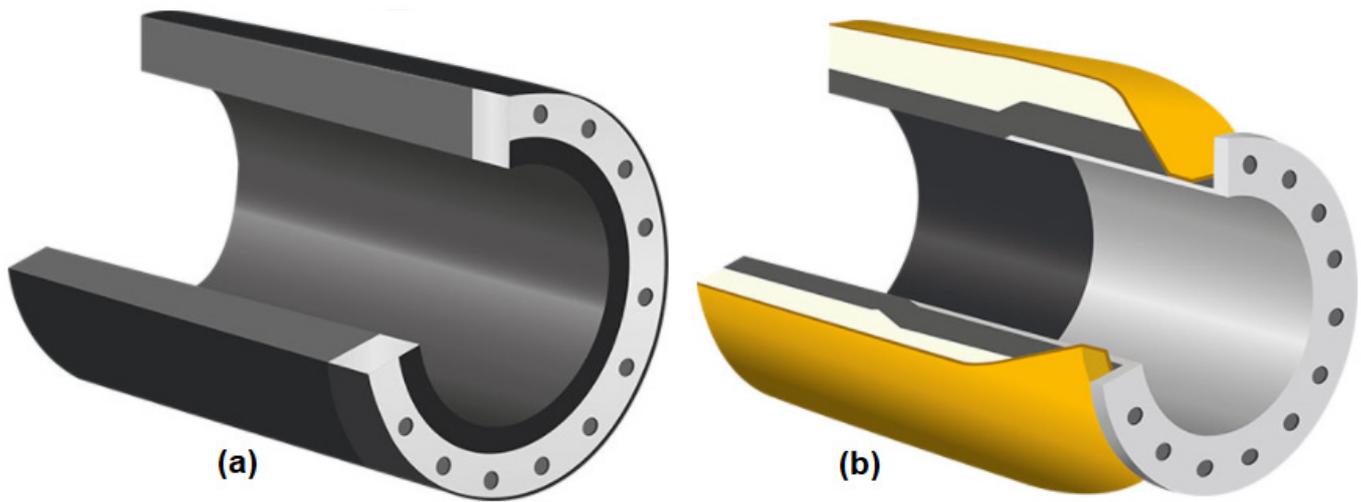
Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Used in Platforms with short service life</li> <li>• High pressure application as it is a composite structure</li> <li>• Fatigue Resistance</li> <li>• Impact Resistance</li> <li>• Light structure</li> <li>• Wind ability</li> <li>• Ease of transportation</li> <li>• Chemical Corrosion resistance</li> <li>• Resistance to internal pressure</li> <li>• Can be repaired if the damage is minimal.</li> </ul>	<ul style="list-style-type: none"> <li>• Failure due to high pressure on the covers, or outer sheath</li> <li>• Cannot be used in long service-life platforms</li> <li>• Cannot be used for general purpose but for specific purposes</li> <li>• More maintenance is required</li> <li>• Some have short service life of hoses (1–5 years)</li> <li>• Susceptible to cuts from propellers</li> <li>• The hoses require space for storage.</li> </ul>

There are two types of hose designs which Trelleborg has patents on: the nipple and the nippleless hose designs (NB: However, it should be noted that each product line was not reviewed in the present paper, but an overview). Both designs have unique advantages which also gives it an advantage in deployment and usage, such as with MBCs. In the case when the MBC is connected to a nipple hose type, it causes a hose wrapping disparity on the FPSO reel, as shown in Figure 15. With a coiled hose, the MBC is used where there is a noticeable break in the Coil’s otherwise natural radius, due to limit in hose length. It can be observed that there is a discrepancy in the hose adhesion onto the FPSO reel. This is a function of the length of the nipple within the connecting hoses adjacent to the MBC, and the reel radius at the moment of MBC location. As a result, the degree of imperfectness from the hose adherence onto the FPSO reel is determined by the nipple hose specification, as well as the bend stiffness at zero system pressure. The illustrations in Figure 34 are both of these examples are simple representations of the differences between nippleless and nipple hose designs. Due to the level of hose adherence on the FPSO reel, the length of the nipple may influence hose wrapping disparity.

**Table 10.** Hose selection for different configurations (based on author’s research \*).

Parameters Hose Selection	Hose Product Lines by Trelleborg				Hose Product Lines by Dunlop			
	Sealine	Kleline	Reeline	Trelline	Saflole	Safgard	Selflole	SCS
Typical Floating Configurations								
CALM	X	X			X	X	X	X
TANDEM	X	X			X	X	X	X
SALM	X	X			X	X	X	X
REEL			X				X	
Typical submarine configurations								
ALP		X						
SHIP-TO-SHIP		X			X	X	X	
SHIP-TO-SHORE	X	X			X	X	X	
CBM/MBM	X	X			X	X	X	
CHINESE-LANTERN	X	X		X	X	X	X	X
LAZY-S	X	X		X	X	X	X	X
STEEP-S	X	X		X	X	X	X	X
FLOWLINE	X	X		X	X	X	X	X
RISER		X		X	X	X	X	X
JUMPER		X		X	X	X	X	X
REEL			X	X			X	X
DEEP WATER OOL				X				X

Note \*: This is classified based on author’s research and not official hose manufacturer, and X is used to show that its capability for that selected parameter. Check hose manufacturer’s official website/brochures for details.



**Figure 34.** Two different hose fittings showing (a) nippleless and (b) nipple hose designs.

### 5. Concluding Remarks

This paper presents an overview of different systems applied in sustainable fluid transfer and (un)loading operations via these marine structures. These CALM buoys and SPM systems are component aspects for the techno-economic design and operation of marine floating structures (MFS) [138–140]. The objective of this review is to address the subject of bonded marine hoses based on application, configuration, test models and operational views. This paper also includes an overview of the loading and unloading (or discharging) techniques for sustainable fluid transfer via marine bonded hoses, based on challenges encountered in operations. To dynamically present the hose performance in this review, an overview on the design developments, test regimes, hose types, hose controls such as couplings, hose-mooring configurations, hose selection, and guidance for the test methods as specified in available industry standards are presented. The pros and cons of marine hose application were also presented. Moreover, the developments and new improvements in the examined applications have been clearly stated and commented in this review. Finally, this study presents different marine hose types and novel design configurations that are applied in implementing hose-mooring systems.

The highlights of this review are as follows:

- Marine hose developments, current application of SPM hose connections, review on marine hoses, CALM buoys and SPM moorings.
- Sustainable fluid transfer, safety precautions at SPM mooring terminals, model application of marine hoses on different configurations.
- Overview on SPM, SALM, CALM, tandem moorings and other configurations for marine applications.
- Overview on hose testing, hose failure prevention, and comparisons between failure modes for marine hoses and other flexible risers.
- Discussion on marine hose storage, hose maintenance, hose design selection and application of MBCs.

The literature review on CALM buoy hoses, single point moorings, hose-mooring array analyses, and hose configurations has been carried out. Some hose failures were identified from burst (internal pressure) loads, collapse (external pressure) loads, fatigue loads, and other severe loadings. Some presentations on SPMS and CALMs have been conducted, with emphasis on their benefits. The review also presents discussions with some steps and safety precautions for typical mooring procedures. Presentations were made on different configurations for hose-mooring systems, the design arrangements, the application recommendations, and uniqueness of each configuration. An aspect of the

design, the application of loading and offloading hoses has been significantly reviewed. However, due to its broad nature of the subject area, it cannot be exhausted in the present review. Another aspect of hose application is the control, using MBCs. The application of MBCs on offloading hose systems is encouraged in this review. The MBC is designed to respond by breaking its 'breaknut' whenever the stress on the 'breakstuds' exceeds the calibrated tolerances. The degree of hose adherence on the FPSO reel could thus cause a bending force on the MBC, which could result in an inadvertent activation. However, this challenge can be solved in one of two ways. The first step is to construct the setup so that the MBC is suspended from the reel rather than wound to it. This Hanging Vine reel configuration in Figure 15 is a cost-effective approach that keeps the hose adhesion on the FPSO reel discrepancy to a bare minimum. The MBC can be used on any of the hose designs, so it makes no difference whether the hose is Nipple or Nippleless, as in Table 10. The second option is to state clearly at the time of MBC specification that the MBC will be wound to the reel and to provide actual configuration data. This allows the MBC tolerances to account for the additional variables presented by hose adherence on the FPSO reel discrepancy as a result of the hose type used and the reel design. In order to deliver the best solution, it is recommended that the MBC manufacturer should be involved in the design phase as early as possible, preferably at the FEED (Front End Engineering Design) stage.

Based on the hose failure investigated in this research, comparisons were made between marine hoses and other flexible risers. According to information from incidence databases, input from stakeholders and other reported incident, degradation and damage of hose covers are highly reported, followed by damages from valve failures. However, the most common marine hose failures are caused by damage to the cover, unlike for other flexible risers that are from deterioration of the internal and exterior polymer sheath. When the outer sheath fails, it creates a dangerous environment in the annulus, increasing the probability of numerous failure modes. Unlike the marine hoses, the internal pressure sheath degradation jeopardises fluid containment integrity and is difficult to detect. To control the annulus environment, it is recommended to have a well-functioning annulus vent system connected to a monitoring system. The maintenance of these marine hoses are very important, which could be preventive, curative, corrective maintenance. The most promising approach currently being integrated into these flexibles are the fibre optics. This would allow for continuous temperature monitoring of the riser and pipeline, which could be used to assess temperature degradation, detect cover cracks, detect outer sheath breaches, and observe fluid level in marine hoses. Based on existing hoselines, a variety of integrity management techniques are being developed, including magnetic stress monitoring, ultrasonic testing, radiography, and other Offshore Monitoring Systems (OMS). These techniques are all very valuable individually, but when combined, they could more productive as multipurpose monitoring tools. Thus, these techniques are very necessary from this assessment on sustainable fluid transfer. In summary, the developments discussed have also portrayed some challenges that can arise during fluid transfer operations such as hose ancillary connections, hose installations, reeling, and hang-off operations. The developments, and new improvements in mooring applications were also discussed. Finally, the hose selection, materials needed for hose tests, and implementation of hose-mooring systems are detailed in this study. This review will help in assessing various design concepts, reliability, and practicality decisions. Some discussions on their use based on the pros and cons of marine hoses, the respective inputs required must be made to achieve the best balance between processing requirements and achieving the best outcome with accuracy.

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## Abbreviations

PC Semi	Paired Column Semisubmersible
6DoF	Six Degrees of Freedom
ALP	Anchor Leg Platform
CALM	Catenary Anchor Leg Mooring
CBM	Conventional Buoy Mooring
CODAM	Corrosion and Damage [a database by PSA Norway]
COIN	Corporate Operational Information System [a database by HSE UK]
DAF	Dynamic Amplification Factor
DC	Double Carcass
DP	Dynamic Positioning (or Dynamic Positioned)
FBD	Free Body Diagram
FEA	Finite Element Analysis
FEED	Front End Engineering Design
FEM	Finite Element Model
FOS	Floating Offshore Structure
FPSO	Floating Production Storage and Offloading
FSO	Floating Storage and Offloading
FSRU	Floating Storage and Regasification Unit
FSU	Floating Storage Unit
GoM	Gulf of Mexico

HEV	Hose End Valves
HP	High Pressure
HSE	Health and Safety Executive
LHS	Left Hand Side
MBC	Marine Breakaway Coupling
MBM	Multi Buoy Mooring (or Multiple Buoy Mooring)
MBR	Minimum Bend Radius
MFS	Marine Floating Structure
MWL	Minimum Water Level
OCIMF	Oil Companies International Marine Forum
OLL	Oil Offloading Lines
OMS	Offshore Monitoring System
PLEM	Pipeline End Manifold
PSA	Petroleum Safety Authority
RAO	Response Amplitude Operator
RHS	Right Hand Side
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations
RWP	Rated Working Pressure
SAL	Single Anchor Loading
SALM	Single Anchor Leg Mooring
SBM	Single Buoy Mooring
SCR	Steel Catenary Riser
SC	Single Carcass
SCS	Single Carcass Submarine Hoses
SDG	Sustainable Development Goals
SON	Standards Organisation of Nigeria
SPAR	Single Point Anchor Reservoir
SPM	Single Point Mooring
STL	Submerged Turret Loading
STS	Ship-to-Ship
SURP	Subsea Umbilicals, Risers and Pipelines
TDP	Touch Down Point
TLP	Tension Leg Platform
TM	Theoretical Model
TRH	Tanker Reeling Hose
TTR	Top Tensioned Riser
UK	United Kingdom
UN	United Nation
UV	Ultra-Violet
VIV	Vortex Induced Vibration
VLCC	Very Large Crude Carrier
VLFS	Very Large Floating Structures
SC	Single Carcass
DC	Double Carcass
SCS	Single Carcass Submarine Hoses
Safloote	Double Carcass floating hoses
Safgard	Double Carcass submarine hoses
Selfloote	Single Carcass floating hoses

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