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A literature review on the technologies of bonded hoses for marine applications

Chiemela Victor Amaechi [1,2,*], Facheng Wang [3,**], Idris Ahmed Ja'e [4,5,+], Aboshio Aaron [6,++], Charles Agbomerie Odijie [7,*+], Jianqiao Ye [1,*ɵ]

[1]*Department of Engineering, Lancaster University, Lancaster, Lancashire, LA1 4YR, UK.*
[2]*Standards Organisation of Nigeria (SON), 52 Lome Crescent, Wuse Zone 7, Abuja, Nigeria.*
[3]*Department of Civil Engineering, Tsinghua University, Beijing, 100084, China.*
[4]*Department of Civil Engineering, Universiti Teknologi PETRONAS, Seri Iskander, Perak, 32610, Malaysia.*
[5]*Department of Civil Engineering, Ahmadu Bello University, Zaria, Kaduna State, 810107, Nigeria.*
[6]*Department Civil Engineering, Bayero University, PMB 3011, Kano, Kano State, 700006, Nigeria.*
[7]*Department of Engineering, MSCM Ltd., Coronation Road, High Wycombe, Oxfordshire, HP12 3TA, UK.*

* Correspondence: c.amaechi@lancaster.ac.uk or chiemelavic@gmail.com; ORCID: *0000-0001-6712-2086*
** Correspondence: wangfacheng@tsinghua.edu.cn; ORCID: *0000-0003-2325-9341*
\+ Correspondence: idris_18001528@utp.edu.my; ORCID: 0000-0002-9366-9779
\++ Correspondence: aaboshio.civ@buk.edu.ng; ORCID: *0000-0002-9627-4246*
*+ Correspondence: charlesodijie@hotmail.com; ORCID: *0000-0002-4683-0048*
*ɵ Correspondence: j.ye2@lancaster.ac.uk; ORCID: *0000-0002-1039-1944*

Abstract

Marine bonded hoses are conduit-tubular structures used for loading, discharging, transferring and transporting fluid products like oil, gas, and water. These marine conduits are applied in the offshore industry by utilising novel marine materials and sustainable technologies. Based on sustainability, there are advances made as solutions for challenging environments. These challenges include scouring gases, deep water regions, changing sea water temperatures, platform loads and vessel motions. These environments also require sustainable materials like marine composites. This paper reviews historical timeline and patent development of hoses in the marine environment. It highlights key developments on marine hoses and their configurations. These configurations include FPSO-FSO with hose attachments in catenary configurations and CALM buoy-PLEM in Lazy-S configurations. The review also discusses the evolutions in the hose designs, potentials of the hoses, and recent state-of-the-art developments in the industry. Comprehensive discussions with necessary recommendations are made for fluid applications in the offshore industry.

Keywords:

Bonded Marine Hose; Flexible Marine Risers; Floating Offshore Structure (FOS); Offshore Platform; Offshore Industry; Hose Development; Mechanics; Catenary Anchor Leg Mooring (CALM) buoy; Sustainable Fluid Transfer.

Abbreviation List:

3D – Three Dimensional
ABS – American Bureau of Shipping
API – American Petroleum Institution
BSI - British Standards Institution
BV - Bureau Veritas
CALM - Catenary Anchor Leg Mooring
CAPEX- Capital Expenditure
CFD Computational Fluid Dynamics
CL - Chinese-lantern (hose configuration)
COOL™ - Cryogenic Offshore Offloading and Loading
DC - Dual Carcass or Double Carcass
DNVGL - Det Norkse Veritas & Germanischer Lloyd
DOM -Dunlop Oil & Marine
DOE - Design of Experiment
DP - Dynamic Position
D/t -Diameter/thickness
DWS - Dual Warning System
EN- Europäische Norm ("European Norm") Standards
FAT - factory acceptance test
FEA- Finite Element Analysis
FEM- Finite Element Modelling
FLNG - Floating Liquefied Natural Gas
FMECA -Failure Mode, Effects, and Criticality Analysis
FOS - Floating Offshore Structure
FPSO – Floating, Production, Storage and Offloading
FSO - Floating storage and offloading
FSP - Floating storage and processing
GMPHOM – Guide to Manufacturing and Purchasing Hoses for Offshore Moorings
HAZID - Hazard identification
HEV - Hose End Valve
ID – Inner Diameter
IMO – International Maritime Organisation
IMS - Integrated Monitoring Systems
IOFBS - Inflatable Offshore Fender Barrier Structures
ISO- International Standards Organisation
KGK- Kautschuk und Gummi Kunststoffe
LNG - Liquified Natural Gas
LPG - Liquid Petroleum Gas
MBR - Minimum Bending Radius
MCI - Metal Composite Interface
NIS - Nigerian Industrial Standards
OCIMF - Oil Companies International Marine Forum
OIL – Offshpring International Limited
OLL – Offloading / Loading Lines
OOL- Offshore Offloading Lines
OPEX – Operational Expenditure
PLEM- Pipeline End Manifold
PLUTO- PipeLine Across The Ocean
SALM - Single Anchor Leg Mooring
SC - Single Carcass
SCR - Steel Catenary Risers
SLF - Stress Loading Factors
SON- Standards Organisation of Nigeria
SPM - Single Point Mooring
SRSH -Special Reinforced Submarine Hose
SS - Seaflex Super stream
STD - Standard Type
SURP - Subsea Umbilical Risers And Pipelines
SWIR - Sea-Water Intake Riser
TWS - Twist Warning System
UK - United Kingdom
US - United States

1.0 Introduction

The oil and gas sector requires new flexible methods, designs, and conduits that can be deployed to implement explorations at some well sites. This is conducted using more sustainable and energy efficient methods to reduce carbon emissions (Wang et al. 2019; Zhang et al. 2019; Odijie et al. 2017a, 2017b; Ali et al. 2020), as energy consumption globally is expected to rise by 28% before 2030 (IEA 2017; Doyle & Aggidis 2019). Thus, more sustainable approaches have also been considered in recent times by using marine composites in the development of marine bonded hoses, despite its size, service functionality, and application in the ocean. The ocean itself covers over 75% of the earth's surface and has the highest source of fossil energy resources, natural gas deposit and crude oil deposits which are been extracted, explored but not effectively harnessed. Figure 1 shows an ocean environment with different offshore platforms and applications of marine bonded hoses. However hoses have some attributes like bending stiffnesses, vertical bending moments and axial forces (O'Donoghue & Halliwell 1990; O'Donoghue 1988; Quash & Burgess 1979; Pinkster & Remery 1975; Antal et al. 2012; Ryu et al. 2006; Chakrabarti 1994; Young et al. 1980; Tschoepe & Wolfe 1981). Despite the availability of various patents on marine hoses, marine risers, pipelines, there are still limited reports on full-scale developments on marine bonded hoses despite the progress that has been made in industry and its commercialisation.

One method of achieving sustainable fluid transfer is by the use of marine hoses in the offshore industry. By definition, marine bonded hoses are conduit-tubular structures used for loading, discharging, transferring, and transporting fluid products- oil, gas, and water. By rationalisation, it creates a new way of sustainable work delivery and enhances better investment in the supplier/manufacturer relationships. Sustainability creates a growing realisation that leads to engagement in long-term solutions on the issues of fluid transfer. These issues include flexible platform needs and easier configurations. Based on product development, the dichotomy that is conspicuous between academic research and industrial applications. However, it also creates some technical issues, slows down development and limits research outputs. Thus, the streamlined provisions of the industrial standards available -OCIMF GMPHOM (OCIMF 2009) and API 17K (API 2017), have been helpful for design specifications and structural detailing. By classification, these hoses could be subsea hoses (or submarine hoses), floating hoses, catenary hoses, dredging hoses, cryogenic hoses or reeling hoses (OCIMF 2009; Bluewater 2009, 2020a; ContiTech 2017, 2020a). By functionality, marine hoses are either supply hoses or production hoses. By design, each hose type is designed uniquely for specific functionalities, environments and configurations. The configurations can be ship-to-ship, catenary, lazy-S, steep-S, lazy-wave, Chinese-lantern or tandem configuration (Yokohama 2016; ContiTech 2020b; Trelleborg 2016a, 2020; Bluewater 2020b). These configurations are adaptable on different offshore platforms and floating structures, like CALM (Catenary Anchor Leg Mooring) buoys and FPSO (Floating Production Storage Offloading) units, as depicted in Figure 1. Recently, Trelleborg presented a Pazflor configuration using treeline OLLs and gimbals (Prischi et al. 2012; Rampi et al. 2006; Mayau D. et al. 2006; Lagarrigue et al. 2014). Generals, hose configurations can be applied on typical different permanent platforms or mobile set ups of dry platforms, moored to a certain location with a network of marine hoses (Stearns 1975; Nooij 2006; Sparks 2018; Bai & Bai 2005; Amaechi et al. 2019a, 2019b, 2021a). Additionally, hoses have different sizes, as seen in Antal et al. (2012a)'s comparative study, which shows that hoses can also be extremely massive in size, such as the dredging hoses, in comparison to floating hoses, as shown in Figure 2.

This review comprehensively presents the technologies on bonded hoses for marine applications in the offshore industry. Section 1 provides a detailed analysis of the advances in marine bonded hoses research for these offshore marine applications. Section 2 presents an overview of marine bonded hoses and explores the design of marine hoses. Section 3 presents hose technologies, the application benefits and challenges with explorations on the advances of the useful art (or technology) and patents on marine bonded hoses. Section 4 gives the concluding remarks on hose technologies, sustainable fluid transfer, current gaps and future trends for collaborative synergies.

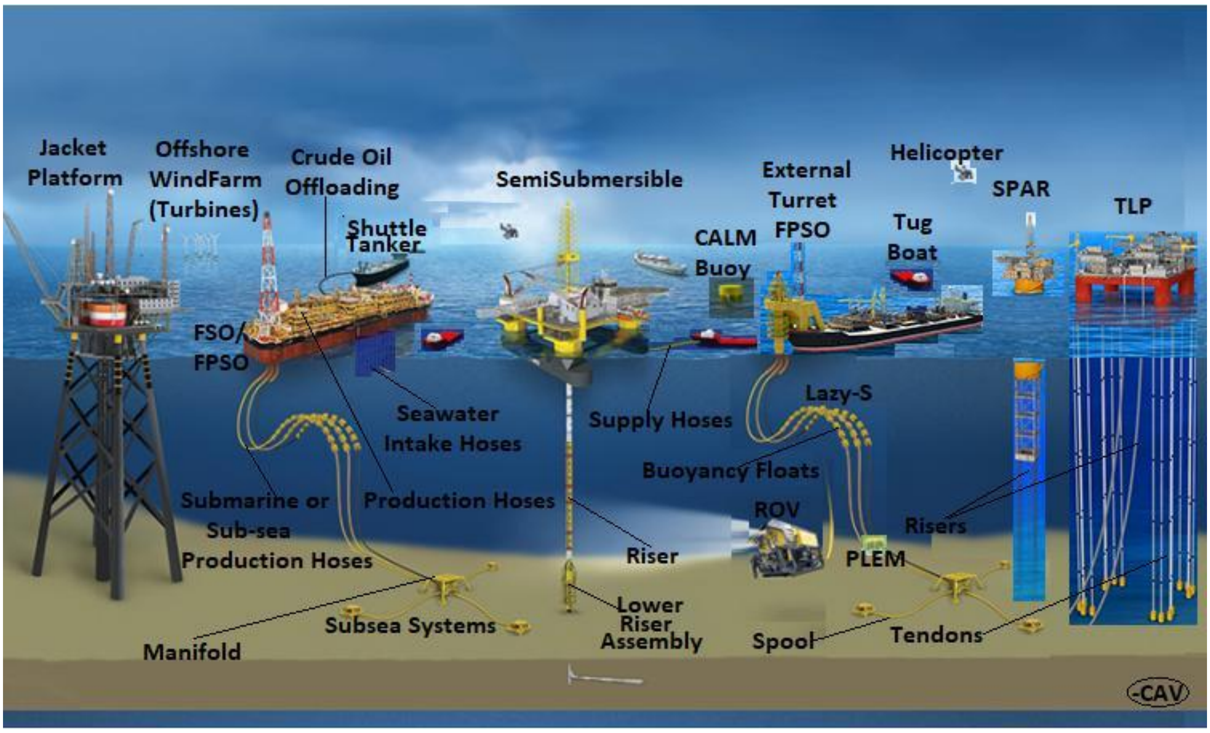


Figure 1 Offshore application of marine bonded hoses showing different offshore platforms and marine hoses

2.0 Developments on Bonded Marine Hose

In this section, the developments of marine hoses are presented.

2.1 Historical Development of Marine Hose

Flexible marine hoses, flexible riser and pipeline technology for offshore oil and gas production still undergo development. Nevertheless, flexible pipes have multi-faceted applicabilities from other sectors before being introduced to the offshore industry. Flexible pipelines were once thought to be maintenance-free and did not need to be inspected on a regular basis. However, recent reports on hose failures, riser failures and flexible pipe failures have shown that some reported cases on these facilities and assets offshore. Thus, the need to improve upon the design, manufacture, service delivery processes and production grades. This includes the hoses, pipes, end-terminations, and accessories, which have to be improved however, recent reports also show that significant improvements have been achieved since their initial introduction. The concept of a flexible armoured maritime pipeline was originally introduced and implemented on a large scale in World War II's PLUTO (PipeLine Under The Ocean) project, which transported petroleum from the United Kingdom to Normandy, France, under the English Channel. High-voltage marine power cable technology was used in the design. Today, more progress on marine bonded hose technologies with historical timelines has been recorded, as presented in Table 1. It shows main highlights in marine hose developments, such as Trelleborg launched the first TRELLINE submarine/floating hose that meets API spec 17K, developed jointly by Trelleborg and SBM Offshore for specific applications, such as OOL (oil offloading lines), deep offshore, flow lines, shallow water and CALM buoy to

FPSO (Trelleborg 2018; Rampi et al. 2006; Mayau et al. 2006; Prischi et al. 2012). Also, earlier in 1983, the world's stiffest 24-inches Special Reinforced Submarine Hose (SRSH) was developed with a bending stiffness of 500 KN-M^2 (51ton-m^2). According to Yokohama (2016), this SRSH is three to four times stiffer than conventional 24-inches hose. This outstanding characteristic contributed to the successful installation of a SALM system for FOSCO at a depth of 45 meters (150ft.) in the Japan Sea.

Figure 2 The extreme size of dredging hoses compared to floating hoses (Courtesy: Antal S. et al. 2012; Adapted with permission of Germa Hornsby of Continental Dunlop Oil & Marine).

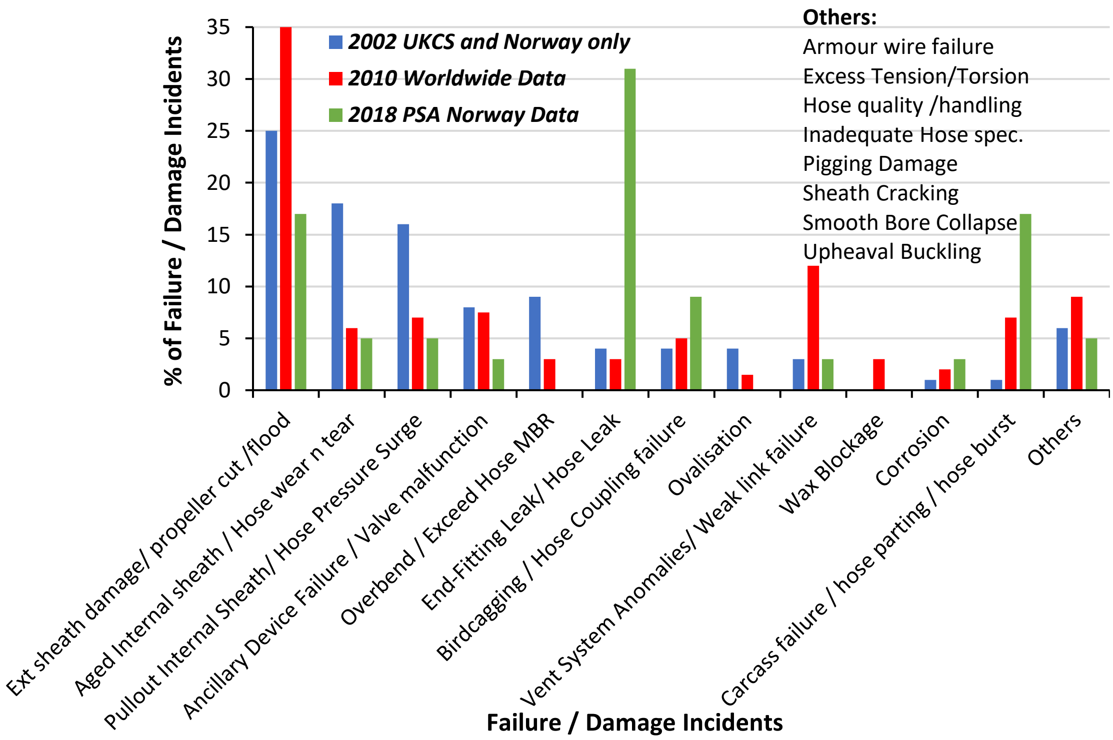


Figure 3 Failure and damage incidents on unbonded flexible pipes using 2002, 2010, 2018 data (Sources: PSA 2018; Muren 2007; Saunders and O'Sullivan, 2007; Drumond et al. 2018; Adapted with permission of PSA Norway & Elsevier Publishers)

Table 1 Historical timeline on the development of marine bonded hose technologies, with founding years of manufacturers

Year	Progress Made, Buoy / Hose Manufacturer & Joint Industry Project (JIP)	Reference
1871	Continental AG was founded as Continental-Caoutchouc und Gutta-Percha Compagnie	Continental (2021, 2014)
1898	Dunlop Rubber Company (formerly Pneumatic Tyre and Booth's Cycle Agency Ltd.) was established. In addition, GoodYear Tire & Rubber Company was founded	Dunlop (2015), GoodYear (2021), NationalArchives (2021)
1905	Trelleborgs Gummifabriks AB (the Rubber Factory Corporation of Trelleborg) founded	Trelleborg (2021, 2018)
1917	The Yokohama Rubber Co., Ltd. was established	Yokohama (2016)
1920s	Continental merger started Continental Gummi-Werke AG	Continental (2021)
1925	Eddelbüttel+Schneider was founded to manufacture hoses and sleeves for dredging and mining. It is now part of Continental ContiTech Group.	ES (2012), DSMA (2019), Richardson S. (2004).
1935	Manuli Rubber Industries was established	ManuliRubber (2021)
1949	Shenyang Rubber Tube Factory was established	VHMarinTech (2021)
1960	Yokohama marketed its first marine hose in 1960. Since then, Yokohama has succeeded in making a number of technological breakthroughs in product development	Yokohama (2016)
1962	Float Sink hose system for SPM - Yokohama's helix free main line hose with air buoyancy.	Yokohama (2016)
1964	The first commercial maritime pipeline, based on marine power cable technology, was built between two Danish islands	Sparks (2018)
1965	Durham Rubber & Belting Corp. was founded	Thomasnet (2021)
1970s	Coflexip used flexible pipe in offshore applications as flowlines, production and export risers	Sparks C.P. (2018)
1972	SOFEC Inc. was established & IFP France invented high pressure-resistant plastic pipes	SOFEC (2021), Sparks (2018)
1975	Trelleborg's first OCIMF qualified nippleless hose with dual carcass called KLELINE.	Trelleborg (2018)
1977	Flexible risers were first used as dynamic risers in Garoupa field, offshore Brazil.	Sparks (2018)
1977	Yokohama's NBR leak free tube lining, processed by spiral wrapping, completely solved the problems of lining quality, eliminating blisters, lining separation and nipple leak.	Yokohama (2016)
1978	Yokohama's Polyurethane cover option to the conventional rubber covered hose. The smooth, hard surface of polyurethane eases handling, and its bright colors are its assets.	Yokohama (2016)
1978	Flexomarine and BLUEWATER were established	Flexomarine (2013), Bluewater (2016)
1980s	IFP developed unbonded flexible pipe using cable industry experience. This led to more Joint Industry Projects (JIPs) on flexible pipes around mid 1980s	PSA (2013)
1981	Manuli Rubber Industries acquired Fluiconnecto Network (formerly Sonatra)	Fluiconnecto (2021)
1983	World's stiffest 24" SRSH (Special Reinforced Submarine Hose) has 51ton-m^2 bending stiffness.	Yokohama (2016)
1984	Super 300 hose - Yokohama's Super 300 hose was developed from total construction analysis by FEM and improved resistance to surge pressure and kinking- high safety margin	Yokohama (2016)
1986	Fluid-Tec Engineering & Trading Pte Ltd.was established	FluidTec (2015)
1987	High aromatic hose - Yokohama's high aromatic hose, suitable for liquids with up to 60% aromatic hydrocarbon content, such as high octane gasoline, was developed.	Yokohama (2016)
1992	Double Carcass hose with Twist Warning System (TWS) - Yokohama style warning system, featuring twist of straight orange stripes on the hose, & warns on failure at primary carcass.	Yokohama (2016)
1994	"Friends of Flexibles" ad-hoc JIP of industry operators, manufacturers and material suppliers after the first flexible pipe end-fitting failure at Veslefrikk, due to inner sheath layer failure.	PSA (2018, 2013)
1998	EMSTEC GmbH was established	EMSTEC (2021, 2016)
1999	Trelleborg launched REELINE the first large-diameter hose designed for reeling specifically.	Trelleborg (2018)
1999	Yokohama's Flashing floating hose having effective built-in flashing light unit developed to increase visibility of hose line position to boats nearby especially during night time.	Yokohama (2016)
2001	Trelleborg developed and introduced the first hose suitable for arctic conditions	Trelleborg (2018)
2004	Double carcass hose with Dual Warning System (DWS) for primary carcass leak detector.	Yokohama (2016)
2005	Yokohama's "Super Stream" Offloading Marine Hose for rough offshore application	Yokohama (2016)
2006	TANIQ investigated IGW technology for offloading hoses and aeronautic hoses	Nooij S. (2006)
2006	Trelleborg launched the first TRELLINE submarine/floating hose that meets API spec 17K.	Trelleborg (2018), Rampi et al. (2006)

2009	Trelleborg launched CRYOLINE LNG hose for remote offshore gas fields export via FLNG	Trelleborg (2018)
2009	Industry standard- OCIMF GMPHOM 2009 was developed. DOM was first to qualify on it.	OCIMF (2009), ContiTech (2014)
2010	Yokohama Reeling Hose developed for FPSO /FSO reels to resist crush and bending loads.	Yokohama (2016)
2011	SBM Offshore's Cryogenic Offshore Offloading and Loading (COOL™) system certified	SBMOffshore (2011)
2011	Trelleborg's first GMPHOM 2009 compliant nipple hose with double carcass, as it increased manufacturing capacity in Brazil for specially designed floating & submarine hoses.	Trelleborg (2012, 2018)
2012	GMPHOM 2009 Hose - Yokohama's Seaflex series got GMPHOM OCIMF 2009 approval.	Yokohama (2016)
2015	Trelleborg developed first TRELLINE submarine lines with 600mm ID that are 2km long.	Trelleborg (2018)
2016	Trelleborg introduced first Seawater Suction hose specified to API 17K designed for FLNG.	Trelleborg (2018)
2017	Manufacturers supplied suite solutions to world's first floating LNG Ship-to-Shore System	Trelleborg (2018)

2.2 Overview on Marine Hose Development

Current state-of-the-art hose designs include Selflote- the first integrally floated oil hose, Saflote- the first double-carcass anti-pollution floating hose and DEEPFLO, which are API 17K-specified hoses designed for deep water operations (ContiTech 2017; Antal et al. 2003; Katona et al. 2009). Limited hose patents have also been presented to show advances on marine hose innovations in patent publications and scholarly articles. For instance, Antal Sandor's patents (Antal et al. 2001, 1988, 1985; Horvath et al. 1970) were supported by some scholarly articles (Antal et al. 2003, 2012a, 2012b; Nagy et al. 1999). In Antal et al. (2003), a numerical design on 6-inches bonded flexible riser using FEA was presented with experimental validation, and he concluded by discussing the steps taken to validate the hose in line with the API 17K standard. However, hoses are rubberised structures as was opined, so one safety apparatus that can be recommended to control hose accidents during offloading operations is the use of pneumatic fenders and other offshore fenders, such as the Inflatable Offshore Fender Barrier Structures -IOFBS (Aboshio 2014; Aboshio et al. 2021, 2013, 2016). These help to reduce the incidents of hose failure as presented in Figure 3, such as during discharge procedure, and it will also protect these hoses from propeller cuts, damage from tug boats or damage from similar heavy equipment offshore. Although hose failure statistics was not reported in this review, it is recommended to undertake sufficient hose pressure tests because most hose failures involve delamination and carcass failure. Based on the available data for unbonded flexible pipes as seen in the extrapolated '2018 data' obtained from PSA (2018) in Figure 3; it can be noticed that leaks are the most recently reported issues on flexibles, at 31%. The findings are similar to those reported in the literature on failure of flexible risers (PSA 2018, 2013; Løtveit S.A. 2009; Muren 2007; Charlesworth et al. 2011; Dahl et al. 2012; O'Brien P., et al. 2012), flexible pipelines (Muren 2007; Drumond et al. 2018; Simonsen A. 2014; Saunders & O'Sullivan 2007, Li et al. 2018a, 2018b) and subsea hose systems (Serene & Chze 2015, Katona et al. 2009, Goff & Kay 2015). Currently, there are still demands to improve the presently available marine hoses. By design, the marine hose is designed to cope with high external pressure loads, due to the elastomeric properties and steel reinforcements inside its layers (Lassen et al. 2010, 2014; Gao et al. 2018, 2021; Zhou et al. 2018). While some researched analytically (Gao P. et al. 2021; Zhou et al. 2018; Knapp et al. 1979) on hose reinforcements, some progress in replacing the steel reinforcement of marine bonded hoses with composite materials were made by Tonatto et al. (2016a, 2016b, 2017, 2019, 2020), by continuing work on earlier models on the same project (Costa A.P.S. 2007; Gonzalez G.M. et al. 2013, 2016). However, the fatigue of the reinforcement strength of marine hoses requires more investigation, as gaps in the research trend exist regarding limited articles on hose fatigue (Lassen et al. 2010, 2014; Prischi et al. 2012; Rampi et al. 2006) and helical reinforcements (Charlesworth et al. 2011; Chor et al. 2015; Knapp 1979; Tonatto et al. 2018). As demonstrated in Figure 4, some procedures for hose fatigue solutions and application for hoses as performed by ContiTech Dunlop Oil & Marine (DOM). In locations where a normal flexible hose has difficulty in reaching, it requires preformed hoses with a smaller radius of curvature, as seen in Figure 4(a-b). Thus, these preformed production lines are useful in such tight corners, tight spaces and challenging connections. According to ContiTech (2018), it can be used for hard pipe replacements, as it does not require hot work, painting and has removable pigging loops. It has a typical reduction of MBR by about 50% and can be customised into an array of varying configurations. A typical list of currently-available hose range is given in Table 2.

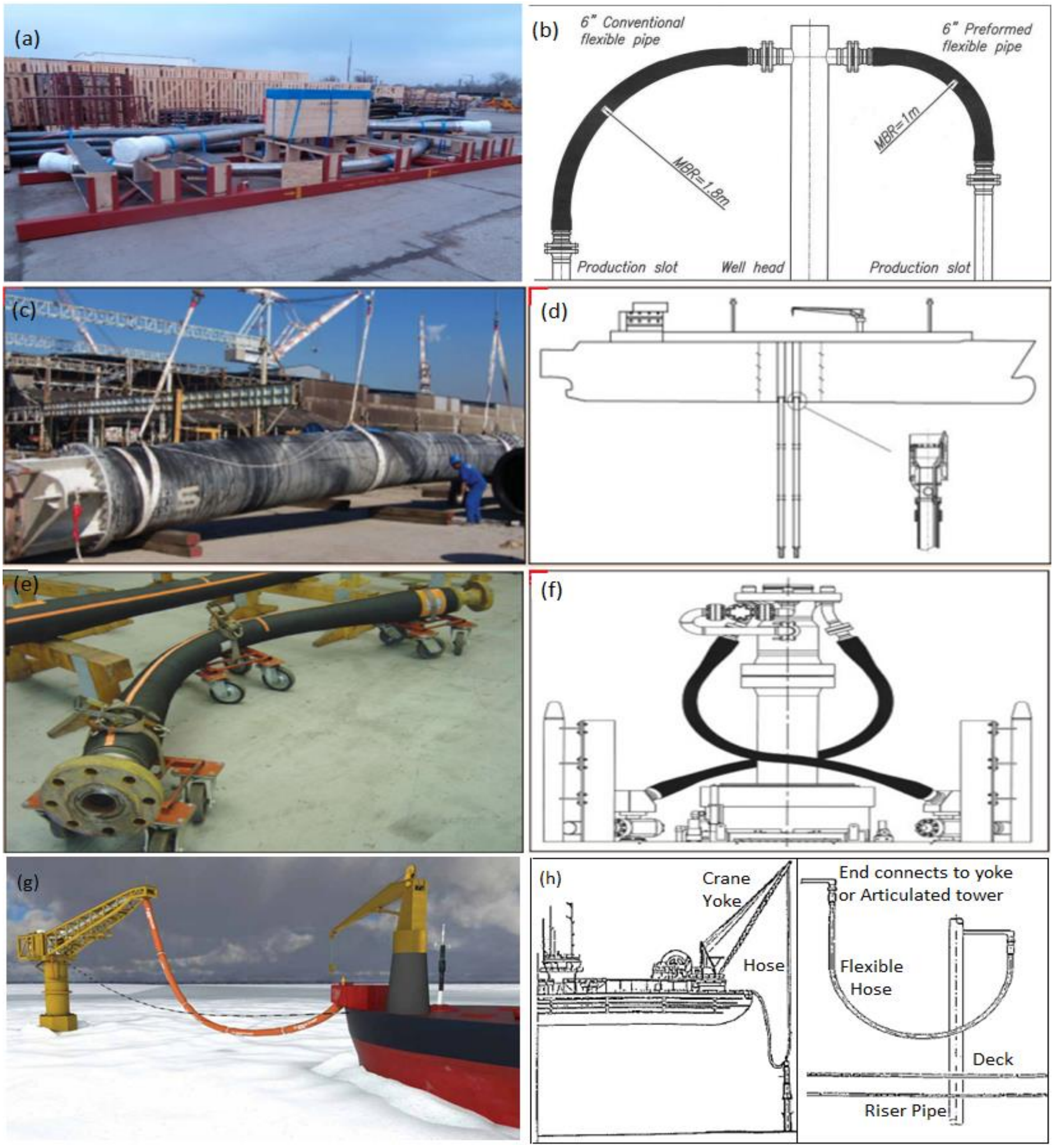


Figure 4 Hose developments by Dunlop ContiTech, showing (a) Preformed production lines (b) Conventional and preformed production jumpers (c) Water uptake line removed from Barracuda Oilfield (Brazil) for inspection, ID > 1000 mm, (d) Schematic drawing of a water intake system, (e) TauroBend preformed 3" (76 mm) 103,4 MPa (15000 psi) bonded Choke and

Kill line, capable of 121 °C operating temperature and more than 36 MPa collapse pressure, (f) Schematic drawing of the top of subsea blow out preventer (g) API 17K range of offshore offloading hoses in challenging arctic sea, (h) pile driving application using a pile harmer and a hose from yoke to articulated tower (Adapted with permission of Germa Hornsby of Continental Dunlop Oil & Marine, Sina Leswal and Diana Boenning, both of Heuthig -parent media house of Kautschuk und Gummi Kunststoffe (KGK) publications, and acknowledgement from Nagy Tibor -the author of the KGK publications; Source: Katona et al. 2009; Nagy et al. 1998; ContiTech, 2018, 2020).

Table 2 Typical list of currently-available hose range (Courtesy: ContiTech, 2018)

Hose Type	**Hose ID**	**Pressure range (psi)**	**Maximum Available Length**	**Applicable Certification**
Production Oil/Has Hose	2”-14”	218 (15 bar) – 7,500	60m (2”-8”); 30m (10”-14”)	API 17K
Choke & Kill Hose	2”-4”	5,000-15,000	60m	AP 16C
Cement Hose	2”-4” 3”	5,000-15,000 20,000	60m	API 7K, FSL 0 Taurus Design
Rotary Hose	2”-6” 5”	5,000-7,500 10,000	60m	API 7K, FSL 1/ FSL 2 Taurus Design

2.3 Hose End-Fitting

The end-fittings of hoses are very essential in the hoseline’s composition. With respect to the load transfer mechanisms, these end fittings could have different designs with flange ends, as shown in Figures 5 and 6. End-fittings constitute a significant aspect of the marine hose that also acts as the connection between different hose sections of the hose-string (Huang & Leonard 1989; O’Donoghue 1989; O’Donoghue & Halliwell 1990; Zhang et al. 2015; Roveri et al. 2002; Continental 2020; Yokohama 2016; Chesterton 2019). The mechanics of end-fittings can be seen in studies including submarine hoses and other types of flexibles have led to more advances on hose technologies.

Table 3 Main components of a typical loading and discharge marine bonded hose

Component	**Material**	**Function**
Lining	Super Nitrile	Chemical resistance to fluids carried, sweet crude with 40% max aromatic content
Main Reinforcement	Patented Hybrid	Internal pressure resistance, tensile strength and other mechanical attributes
Helical Wires	High Tensile Steel	External pressure resistance, tensile strength, kink resistance
Binding Wires	High Tensile Steel	Mechanical locking of main reinforcement to end fittings
Holding Plies	Patented Hybrid	Cover and extra tensile reinforcement
Cover	Rubber/Fabric	Abrasion resistance, ozone resistant, protection for internal bore components
Flange	Patented Compact	Interconnection of individual hose lengths
Rubber / Metal Bonding System	Proprietary Materials	Chemical bond from fitting to lining / main plies / hose cover
Electrical Properties	Continuous or Discontinuous	As specified by client
Steel Corrosion Protection System	Rubber Moulding; Special Coating systems as required	Corrosion protection of flange and exposed external metal parts
*Specification/Guide: API 17K. Service & Fatigue Analysis: Yes.	Manufacturing Process: Fully Traceable. Hose Product Type: Deepflo Submarine lines. (Source: Katona et al. 2009)	

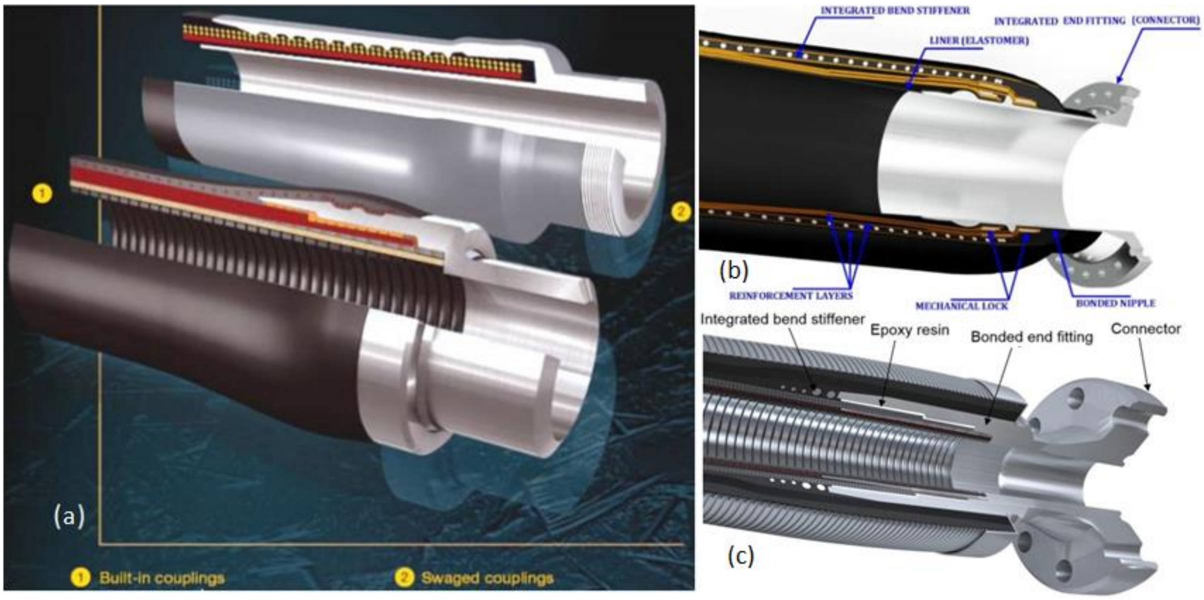


Figure 5 End fitting designs showing (a1) end fitting with built-in coupling, (a2) end-fiting with swaged couplings, (c) parts of normal DOM end fitting and (d) parts of DOM End fitting with built-in coupling (Courtesy: Dunlop ContiTech; Adapted with permission of Germa Hornsby of Continental Dunlop Oil & Marine).

2.4 Hose Layers

Marine hoses are designed to withstand different pressure loads, by using different layers as tabulated in Table 3. In principle, the design capabilities of marine hoses can be customised based on specifications which include inner diameter, outer diameter, length of hose, weight of the hose, colour of hose, tube thickness, working pressure, hose bend radius and the end-fittings. Due to the different hose risers configurations such as the Chinese-lantern configuration, in addition to the aspects of lamination and reinforcements needed on pipelines, risers and hoses, there is the need to have a review on the mechanics of offshore hoses and the hose riser systems. With newer developments in layered pipelines and offshore hoses, the effect of the moment-curvature response, the load response, the D/t ratios of the hoses, the minimum bending radius required, the effect of composite materials and pipeline ovalisation are all important concepts in SURP and have been looked at by different researchers.

Due to the high load requirement of offshore hoses, it is necessary to also carry out numerically investigation. Lassen et al. (2014), presented a finite element model for bonded loading hoses with extreme load capacity assessments and a fatigue life prediction methodology. The bonded loading hoses were subjected to high pressure, tension and bending in a catenary configuration and in repeated reeling under high hose tension. The load effects on the hose during the reeling operations and the fatigue life predictions methodology for both steel components and rubber were emphasized with full scale testing for a 20-inch bonded hose with steel end fittings. Due to the ability of rubber to withstand high deformations, rubberised hoses have been applied in the offshore industry. Different experimental studies on rubber hoses have been carried out on rubber materials (Poisson et al. 2011; Zine et al. 2011) and rubber hoses (Mars & Fatemi, 2005, 2010; Lassen et al. 2010; Szabó et al. 2017).

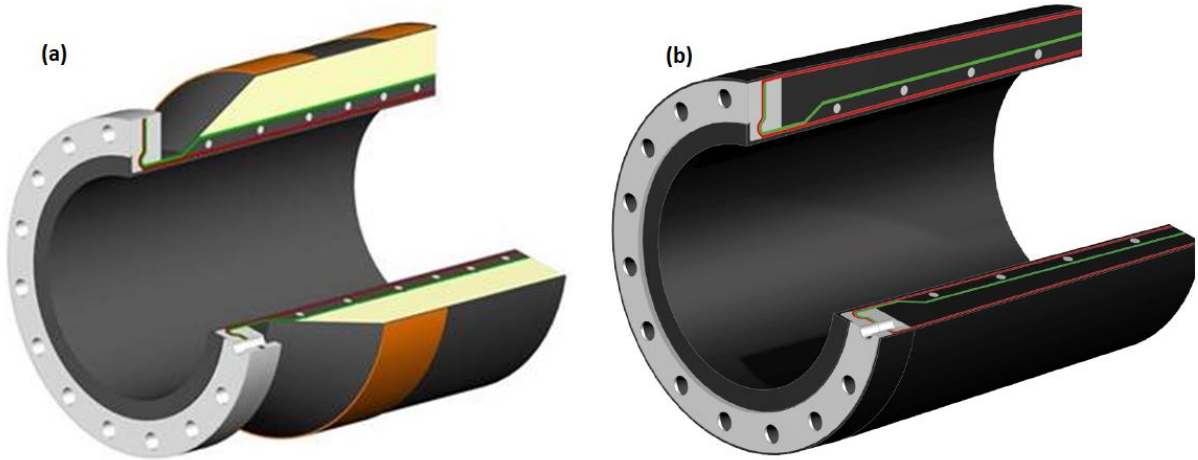


Figure 6 Dual carcass reeling hose ends showing (a) reinforced flange/ bolt indent, and (b) nippleless reinforced flange (Adapted with permission of Jonathan Petit of Trelleborg; Courtesy: Trelleborg)

2.5 Hose Manufacture

There are different types of manufacturing processes that are considered in manufacturing bonded hoses. These are considered based on the choice of the materials of the hose, the best manufacturing practices, manufacturers design concepts, manufacturers patents, industry requirements and market demands (ContiTech 2017, 2020; EMSTEC 2016; HoseCo 2017; Bluewater 2011, 2009b, 2020). Based on the pressure rating and design requirement, the hoses can have a single carcass (SC) or dual carcass (DC), as shown in Figure 7. Currently, different marine bonded hoses have been identified in the market with different product names like Kleeline, Reeline, etc. Also, there are different hose manufacturers (OIL 2014, 2015; Trelleborg 2016, 2014; SBMO 2012; Yokohama 2016; Technip 2006). Some companies that manufacture flexible kill and choke lines, according to API 7K and API 16CE, are given in Table 4. It is noteworthy to add that the users must check the hose products, though, despite being tested and qualified by industry standards (OCIMF 2009; OCIMF 2021, Amaechi 2022). However, the introduction of industry standards helped to reduce the manufacturing defects, such as noted in Table 5. During some tests and numerical investigations conducted, it has been observed that an important issue that has arisen is the reinforcement strength during hose designs (Gao Q. et al. 2018; Gao P. et al. 2021; Zhou et al. 2018; Tonatto et al. 2017, 2018, 2020). The hose reinforcement can be a spring spiral or a helical spring or ring-stiffened reinforcement, as shown in Figure 8. The use of a helical Steel framework embedded throughout the riser section and the addition of a rubberized chord fabric wrapped around the sections, as shown in Figure 8, is an excellent approach for further strengthening the riser construction. This assists the riser in dealing with structural loads imposed on it by either external environmental conditions or internal pipeline pressure.

Table 4 Some manufacturers of API standard marine hoses

Manufacturer / Company	Facility Location	Observation
Coflexip Flexible Products	Duco Inc., UK	Bonded hoses
Contitech Rubber (Former Taurus)	Hungary	Bonded hoses
Contitech Oil & Gas	Grimsby, UK	Bonded hoses
Flexi France	Le Trait, France	Non-bonded hoses
Jingbo Petroleum Machinery Company Ltd	China	Non-bonded hoses
Yokohama Seaflex	Tokyo, Japan	Bonded hoses
Trelleborg	Clermont-Ferrand, France	Bonded hoses

Table 5 Typical hose manufacturing defects with defect rate before 2008 (Courtesy: ContiTech)

Type of defect	**Percentage**
Defect before FAT test	0.33%
Liner	0.06%
Length	0.004%
Jammed on	0.004%
Esthetical	0.2%

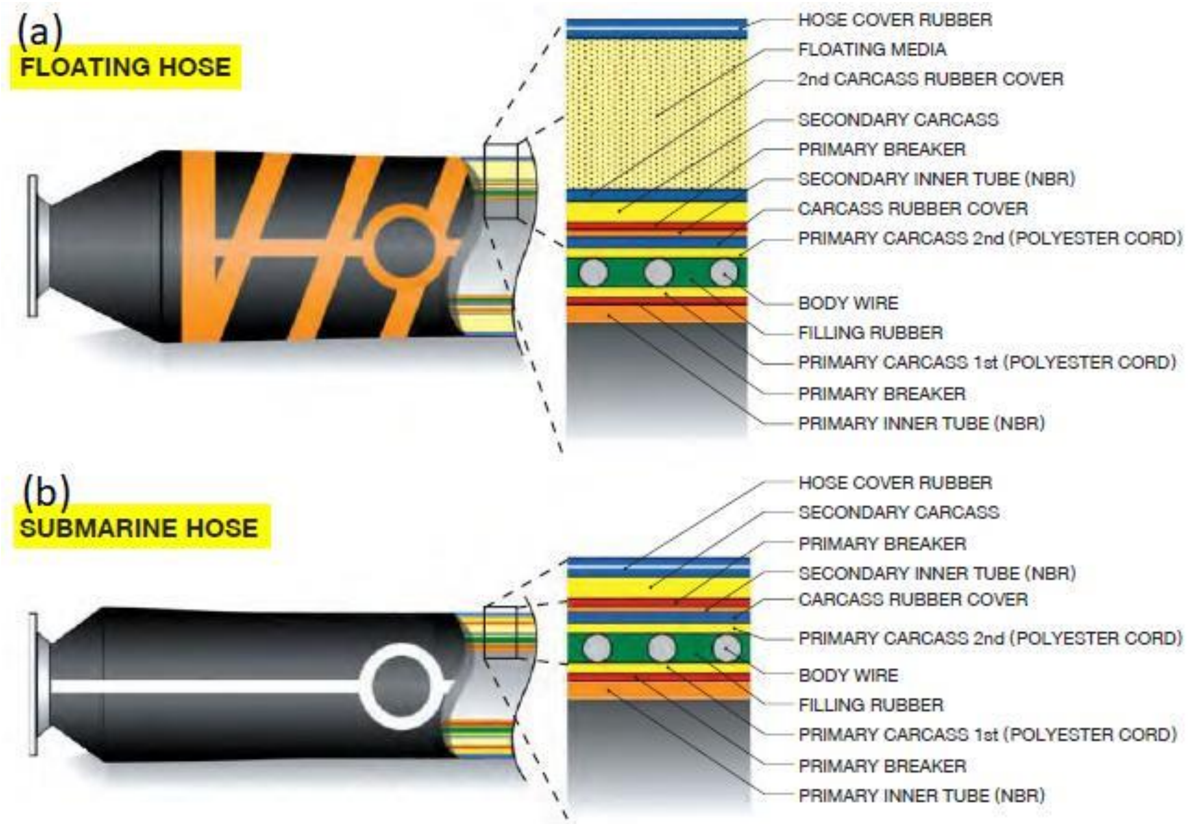


Figure 7 Schematic representation of Floating hose and Submarine Hose (Courtesy: Yokohama)

2.6 Hose Materials

The design of hoses is always carried out with specific considerations on the elastomeric materials. Common elastomer materials for bonded hoses obtained from manufacturers can be seen in Table 6, which is an example of rubber properties matrix for marine hoses (ContiTech 2018; Richardson S. 2004; Mills 2000). As is depicted on Figure 8, the hose can be developed using materials made of rubberised cord fabric. However, the materials used should be fully traceable for prototype hose construction and must comply with the quality control procedures of the Hose Manufacturer (FluidTec 2015; Flexomarine 2013; EMSTEC 2016; Yokohama 2016). Samples of the materials can be tested in the laboratory, using recommended tests in Table 7, specified in OCIMF (2009).

(a) (b)

Figure 8 Hose reinforcement showing (a) hose reinforcement and elastomer materials on a floating hose, and (b) hose layers, ring stiffened reinforcement and armoured layers of dredging hose (Courtesy: Image (a) is Adapted with permission of Elsevier Publishers and Prof. Menglan Duan of Fudan University and China University of Petroleum; {Source: Gao Q. et al. 2018}; Image (b) is by Shandong HOHN Group)

Table 6 Commonly used elastomers in bonded hoses with the rubber properties

Elastomers	**General Properties**									
	Abrasion	**Low Temperature**	**Weather resistance**	**Ozone resistance**	**Heat resistance**	**Oil resistance**	**Fuel resistance**	**Chemical resistance**	**Petroleum fluid resistance**	**Aromatic resistance**
NBR/ Polyvynyl Chloride			++	+		++				
Ethylene propylene rubber (EPR/ EPDM)			++	++	++	-		+		
Styrene Butadiene Rubber (SBR)	++					-	-			
Isoprene rubber (IR)	++	++				-	-			
Natural Rubber (NR)	++	++				-	-			
Chloroprene Rubber (CR)			++	++	++	+	+	+	+	
Nitrile Butadiene Rubber (NBR)	++				+	++	++		++	+
++ Excellent property; + Moderate property; - Poor Property. (Source: *High Performance flexible hose brochure, ContiTech, 2014*).										

Table 7 Material tests recommended by OCIMF 2009 standard

Material	**Property**	**Unit**	**Requirement**	**Test Method**
Lining	Tensile strength	MPa	Only Info	ISO 37
Lining	Elongation at break	%	Only Info	ISO 37
Lining	Hardness	IRHD	Only Info	ISO 48
Lining	Density	gm/mm^3	Only Info	ISO 2781

Lining	Resistance to liquids	%	Not greater than 60	ISO 1817, Method 1. 48hrs at 40ºC, liquid C
Cover	Abrasion resistance	mm^3	250 max	ISO 4649, Method A
Cover	Resistance to ozone	---	No cracks when magnified at x2 view	ISO 1431-1, 72hrs 50 pphms O^3, 10% extension at 40ºC and 65% relative humidity
Lining	Resistance to temperature	ºC	No significant deterioration at -20ºC	Gehman test to ISO 1432
Cover	Resistance to temperature	ºC	No significant deterioration at -29ºC	Gehman test to ISO 1432

2.7 Hose Ancillaries

Hose ancillaries are components that are connected to the hose-string. Among these ancillaries are two important components - the marine breakaway coupling (MBC) and hose end valve (HEV), as shown in Figure 9. The MBC is a device that is installed typically to control flow and discharge under high pressures. It is usually installed unto the hose transfer system at the loading or offshore discharge terminals. The design of MBC helps to prevent oil spills during oil product transfer by parting at pressures lower than the burst capacity of the marine hose, which closes gradually in preventing surges due to critical pressures. In a recent report, KLAW (2021) presented the methods of stress reduction on hose reel transfer systems when wound unto hose reels. Another issue identified is that the hose load also could lead to crushing damage on the marine hose when reeled. One approach considered is to optimise the offloading reel drums (Wilde 2020), tensioner reel (Fantuzi et al. 2019; Chesterton 2020) or to optimise the hose model (Zhou et al 2018; Gao P. 2021; Gao Q. 2018; Cao et al. 2017).

Figure 9 Two hose systems showing reels, reeling hoses, marine breakaway coupling (MBC) and Hose End Valve (HEV).

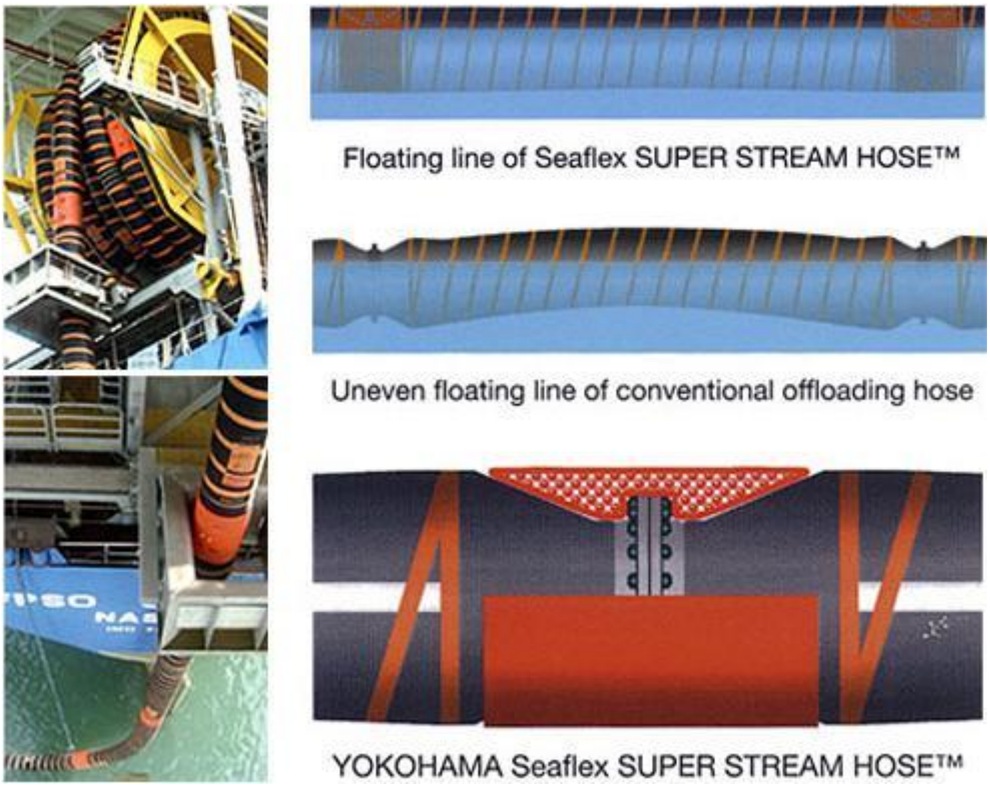


Figure 10 Marine hose showing hose coupling (MBC) on floating and reeling hose (Courtesy: Kenwell & Yokohama).

Certain considerations are factored in during the design of marine bonded hoses. These include: the type of marine hose, usage, operating environment, the transportation, handling, storage, etc (HSE 1999; OCIMF 2021; Amaechi 2022). Recent designs of hoses, such as the Yokohama's Seaflex Super stream (SS) hose shown in Figure 8, has a special carcass designed with tube lining constructed within the hose by combining specially designed float system. Thus, it makes the hose design to be advantageous in optimised reserve buoyancy, extended durability, better performance, less fatigue on both the hose-manifold and the hoses, and makes it an ideal application for reel-winding systems (Kenwell 2021; Lipski 2011; Abelanat 2012). Generally, most marine bonded hoses are flexible, and can be spools around a reeling system or spooled through to systems, such as during reel-laying, as shown in Figure 10. Due to the application of reeling hoses, such as the pipe-laying vessel depicted in Figure 11, it is crucial to control the flow on the hose. Reeling usually involves some torsion and tensions, which induces some strains on the hoses, as depicted in Figure 12.

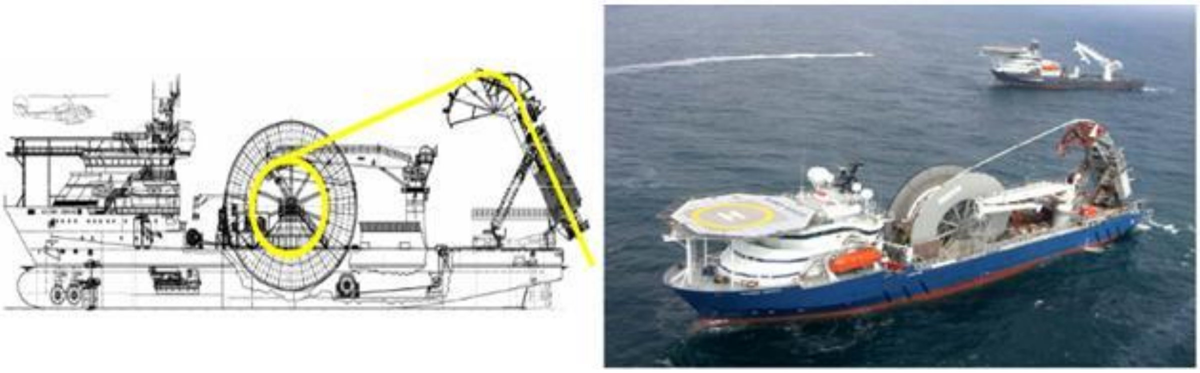
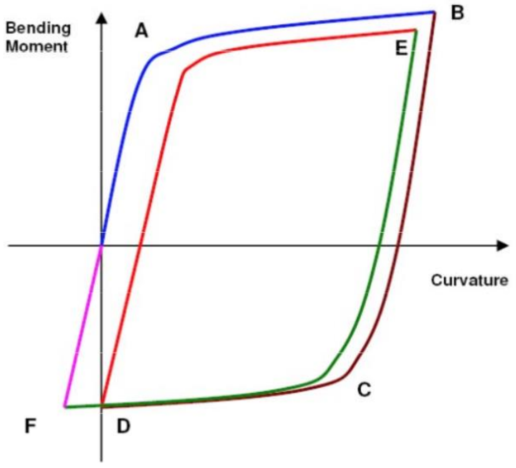


Figure 11 Pipe-laying technique called reel-lay using FPSO-mounted reeling drum and reeling hoses (Courtesy: Subsea7).



Point A: pipeline is plasticized and passing the yield point

Point B: maximum curvature

Point C: reverse plastic deformation

Point D: the pipeline is approximately straight in the span due to the combination of pipe self-weight and applied back tension.

Point E: curvature is always equivalent to the radius of the aligner wheel

Point F: The pipeline is then subjected to a reverse plastic bending in the three-point straightener arrangement.

Figure 12 Bending moment vs curvature for a reeling hose system

3.0 Hose Technologies, Application Benefits and Challenges

In this section, the application benefits and challenges were presented.

3.1 Configuration of Marine Bonded Hoses

There are different configurations of marine hoses, as depicted in Figure 13. These configurations are based on different application requirements, environmental conditions, space utilization and design requirement. By design generally, marine hose structures comprise of different sections, as presented in Figures 5-8. However, the pitfall is that some of these hoses have limited usage due to the short service life of the marine hoses of about 25 years (Amaechi et al., 2019a, 2019b, 2021d, 2021e, 2021f), compared to steel marine risers which have vast applications, as reported in various literature on marine risers (Ali et al. 2020; Bai Y. and Bai Q., 2005; Sagrilo et al. 2000; Young et al. 1978; Aranha and Pinto 2001) or much higher service life. A comprehensive review of these systems have been conducted in various studies but did not detail the configuration requirements (Pham D. et al. 2015; Drumond et al. 2018; Amaechi et al. 2021b, 2021c, 2021d, 2021e, 2021f, 2019a, 2019b). Hence, a review of hose statics and dynamics can be useful in understanding theoretical solutions to the equations of motion of typical marine hose-risers. Amaechi (2022) provided a comprehensive overview of static and dynamic analysis methodologies. Proper computations are required on hose behaviour for different hose-riser configurations, such as the Lazy-S (see Figure 14) and Chinese-lantern configurations (see Figure 15). Some applications with different configurations exist on thermoplastic tubes (Picard et al. 2007; Yu et al. 2015), LNG transfer hoses (Rong-Tai Ho 2008), offloading hoses for CO_2 (Brownsort, 2015), slurry simulation in spooled hoses (Cees van Rhee et al. 2013), seawater intake hoses (Antal et al. 2003, 2012), ship-to-ship transfer hoses (Rong-Tai Ho 2008; Continental 2019), composite risers (Sobrinho et al. 2011; Wang et al., 2016; Amaechi et al. 2017, 2019c, 2019d, 2021a, 2022a), flexible risers (Liu et al. 2013; Ramos 2016; Sousa et al. 2009), and other types of pipelines have led to more advances on this area.

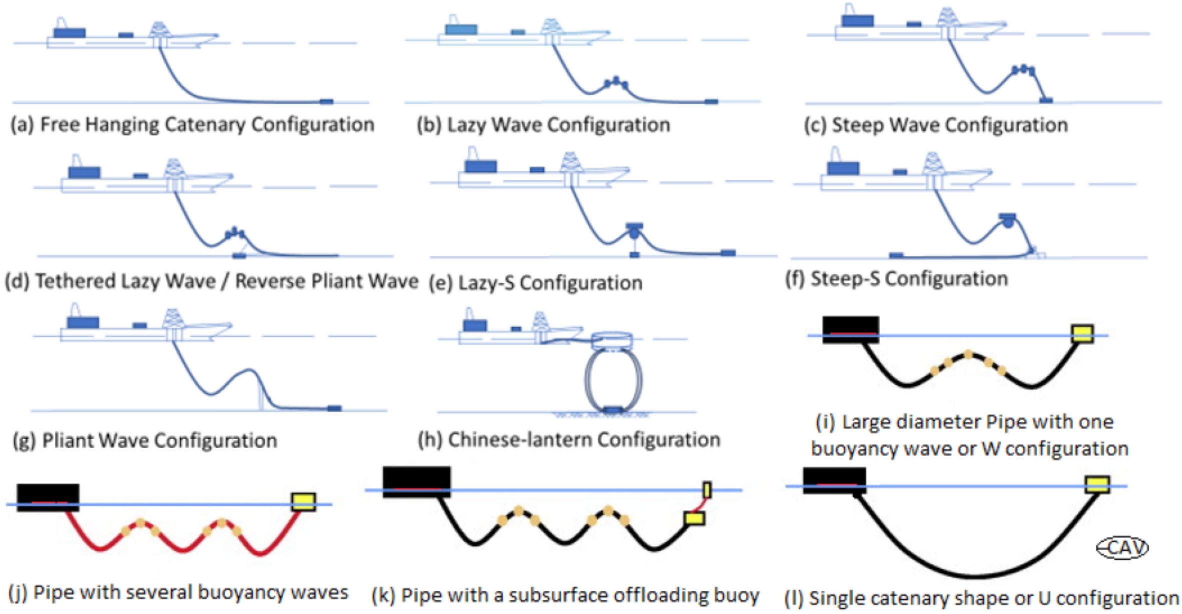


Figure 13 State-of-the-art configurations for marine hoses and marine risers

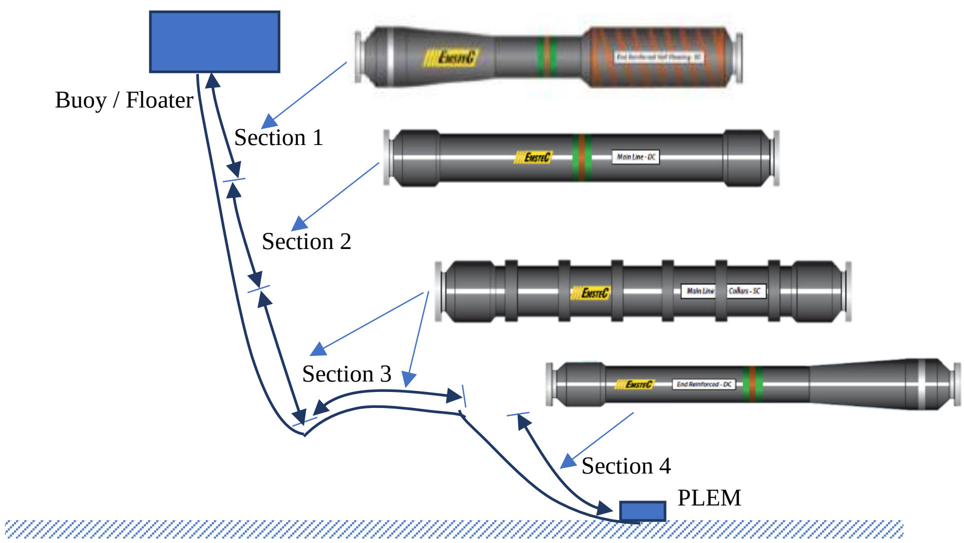


Figure 14 Typical depiction of underwater marine hoses in Lazy-S (Hose Image adapted with permission of EMSTEC, but sketch was designed by Author 1- C.V.A; Hose Courtesy: EMSTEC.)

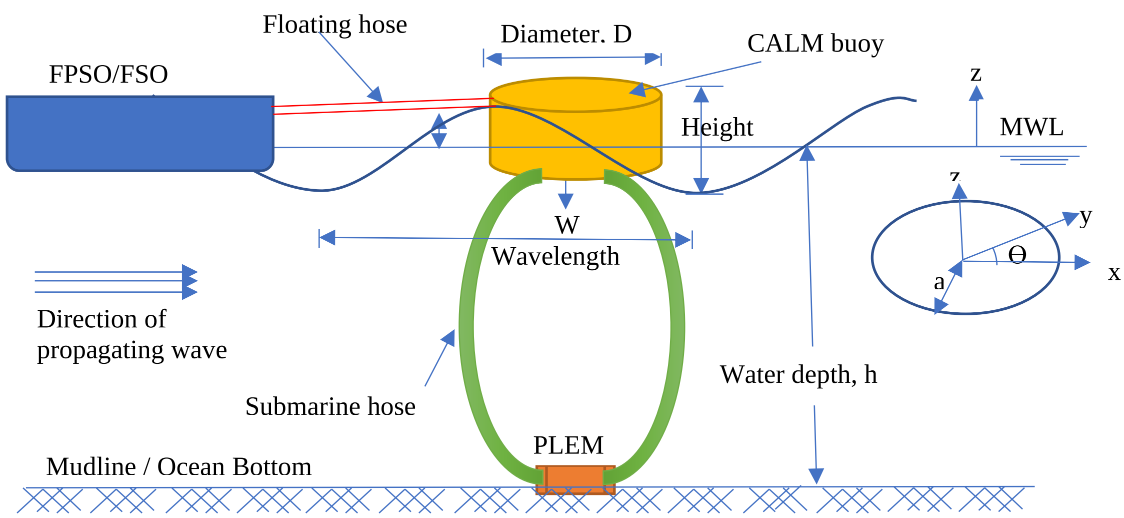


Figure 15 Depiction of waves acting upon floating buoy having marine hoses in Chinese-lantern configuration

3.2 Mechanical Property and Test Methods on Hoses

The mechanical property and test methods on hoses are used in different experimental setups conducted, such as the burst test (Gao Q. et al. 2018; OCIMF 2009; Yokohama 2016). Gao Q. et al. (2018) reported that the structural strength of the hose layers, spring reinforcement, and end fittings as critical components of the hose structure using OCIMF (2009) specified tests. Choi B.L. (2015) reported on optimized design variables for carbon-fiber-reinforced epoxy composite coil springs which had a weight reduction above 55%. Chiu C. et al. (2007) experimentally investigated the mechanical behaviors of helical composite springs. Similar hose spring analysis was carried out numerical on helical spring for high speed valve train and coil collisions (Gu Z. et al. 2020). The study concluded that the FE model can predict the erratic force spikes of the spring at high testing speeds, which cannot be predicted by the conventional analytical model. This is very important in designing hose reinforcements as these offshore hoses are subject to impacts and hose failure modes from high speed boats, tug-boats, offloading FPSOs, and other ancillaries propellers (Amaechi et al. 2021a, 2021b). However, recent reports on inflatable barriers using similar elastomeric hose materials have reinforcements but were not presented in the designs (Aboshio et al. 2021, 2016, 2015).

From the aspect of mechanical property as tabulated in Tables 5, 6, and 8, different experimental studies on rubber hoses have been carried out on rubber materials (Poisson et al. 2011; Zine et al. 2011; Mars and Fatemi 2005; 2010; Lassen et al. 2010; Szabó et al. 2017; Milad et al. 2018). Elastomers have been investigated to have different applications in offshore services (Antal S. et al. 2012, 2003, 1998; Nagy T. et al. 1999; Katona et al. 2009). However, they also react to harsh environmental conditions (Schrittener B. et al. 2016; Balasooriya W. et al. 2018, 2021). Milad et al. (2018) investigated on the hyperelastic material behaviour of a PVC/nitrile elastomer with woven continuous nylon reinforcement composite sheet. It was conducted under loading cases of uniaxial extension and pure shear achieved via wide strip tension testing using a novel advanced non-contact optical strain measurement technique, on an Imetrum system. It was numerically investigated using ABAQUS hyperelastic materials models for modelling the curve fitting (Motulsky and Ransnas 1987; Ogden 1972; Yeoh 1993), similar to other methods (Ruiz and Gonzalez, 2006; Potluri and Thammandra 2007; Pan et al., 2009). In another study, Aboshio A. et al. (2015) investigated the mechanical properties of neoprene coated nylon woven reinforced composites experimentally and used ABAQUS material model in the FEA. Earlier experimental works on offshore hoses involved model and full scale tests. Ziccardi & Robbins (1970) presented selection of hose systems for single point mooring (SPM) systems at Hakozaki and Koshiba terminals in Tokyo Bay, Japan for the U.S military. The next year, Dunlop (1971) specified the first offshore hose manual that prescribed the design of hoses, different hose parameters, such as the minimum bend radius, the end connection for the hoses which led to the current GMPHOM OCIMF (2009), API 17K (2016) and ISO 13628-10 (2006) standards as well as other industry specifications (Bluewater 2020; Trelleborg 2016b; OIL 2020; EMSTEC 2016; Continental 2020). Details on the recommended tests on offshore hoses are presented in Table 4. Specifications, such as the buoy manifold design angle at which it bisects with the Mean Water Level (MWL), when it slopes into the water may be at 15^{o} angle (Brown 1985b; Amaechi et al. 2019b), depend on the design. At that position, unusual stress effect is minimal on the first hose due to bending, kinking or premature hose failure. Typical numerical models of hose applications can be seen in the CALM buoy hose configured in Chinese-lantern (see Figures 16) and ship-to-ship hose configuration (see Figure 17).

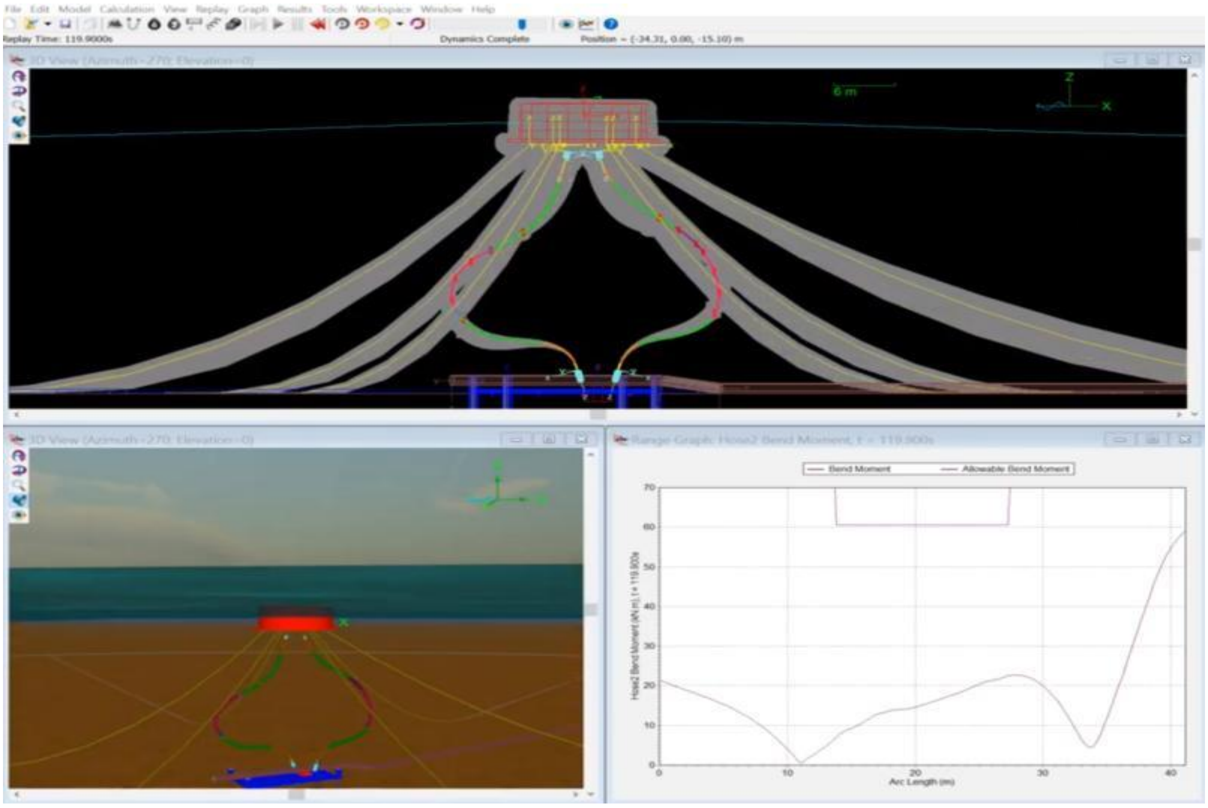


Figure 16 CALM Buoy submarine hoses in Chinese-lantern configurations for SPM showing hose bending moment

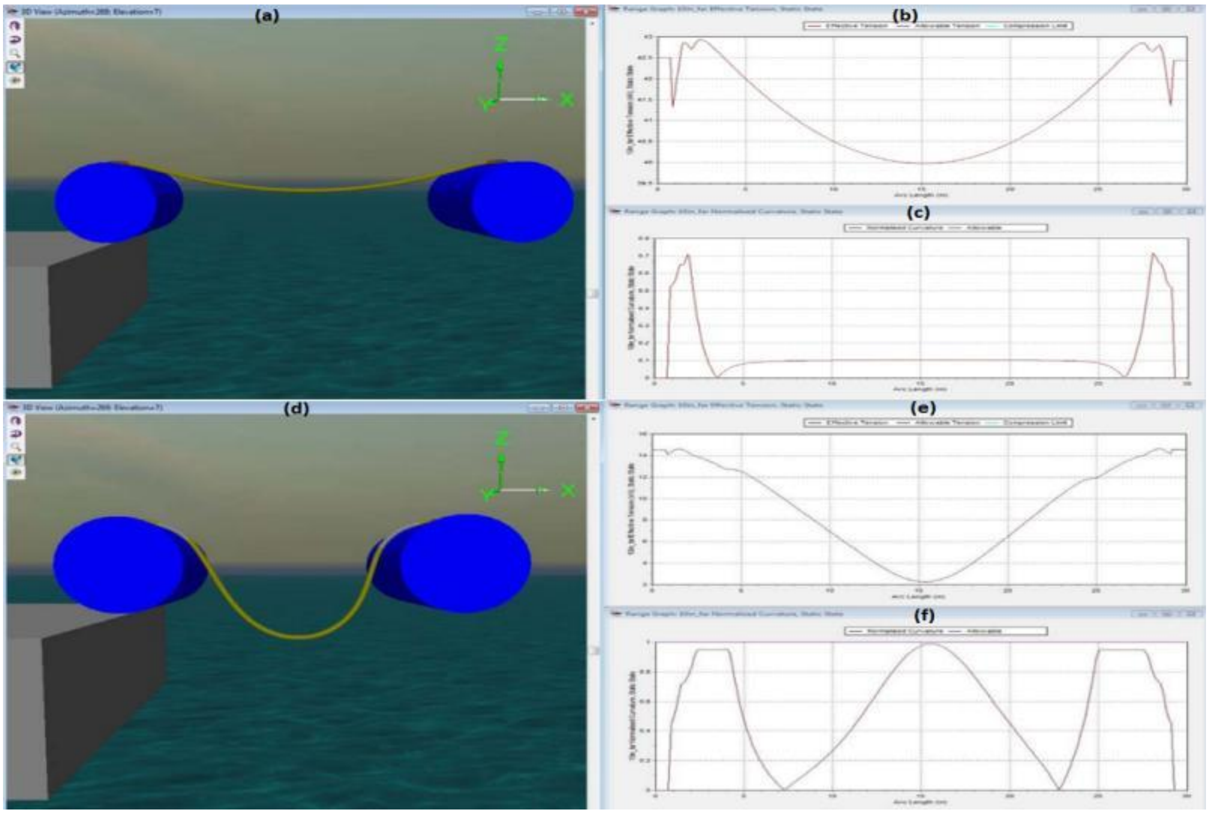


Figure 17 Hose configurations showing (a)near hose config., (b) near hose effective tension, (c) near hose normalized curvature, (d) far hose config., (b) far hose effective tension, (c) far hose normalized curvature

Table 8 Property requirements tests for elastomer and metallic materials according to API (Source: API 17K: 2017)

Materials	**Characteristic**	**Tests**	**Test methods**	**Liner**	**Embedded compound**	**Cover**	**Insulation layer**	**Carcass**	**Reinforcing layers**	**Comments**
Elastomer	Mechanical / physical properties	Tensile strength/ elongation	ASTM D638	X	X	X	X	---	---	Or ISO 37
		Stress relaxation properties	ASTM E328	X	---	X	---	---	---	Swaged end fitting only
		Hardness	ISO 868, ASTM D2583	X	X	X	---	---	---	Or DIN 53505
		Compression set	ASTM D395	X	X	X	X	---	---	Swaged end fitting only
		Hydrostatic pressure resistance	---	---	---	---	X	---	---	Insulation material only
		Abrasion resistance	ISO 4649	X	---	---	---	---	---	Or DIN 53516. Not required for liner and carcass
		Tearing resistance	ASTM D624	X	X	X	---	---	---	Or ISO 34-2
		Void formation	API 17K	X	X	X	---	---	---	---
		Adhesion	ASTM D413 & ISO 4647	X	X	X	X	---	---	Or BS/ISO 36.
		Density		X	X	X	X	---	---	---
	Thermal properties	Coefficient of thermal conductivity	ISO 2781	X	X	X	X	---	---	---
		Brittleness temperature		X	X	X	---	---	---	Or ISO 812.
	Permeation characteristics	Fluid permeability		X	X	X	X	---	---	At design temperature and pressure, minimum to CH_4, CO_2, H_2S and CH_3OH.
		Blistering resistance		X	X	---	---	---	---	At design conditions, gas service pipes only.
	Compatibility and aging	Fluid compatibility		X	X	X	X	---	---	---
		Aging		X	X	X	X	---	---	ISO 188
		Ozone resistance		---	---	X	X	---	---	---
		Swelling		X	---	X	X	---	---	---
		Water absorption		X	---	X	X	---	---	Insulation material only.
Metallic materials (carcass strip, reinforcement cables) and weldments	Chemical properties	Chemical composition	ASTM A751	---	---	---	---	X	X	Or ISO 16120-1
		Chemical resistance	API 17K	---	---	---	---	X	X	---
		Microstructure	API 17K	---	---	---	---	X	X	---
	Strength properties	Erosion resistance	API 17K	---	---	---	---	X	---	Carcass only.
		Fatigue resistance	API 17K	---	---	---	---	---	X	Resistance armour in dynamic applications only.
		SSC (Sour service static) and HIC testing	API 17K	---	---	---	---	---	X	To specified environments; reinforcement armour only.
		Ultimate strength	ISO 6892	---	---	---	---	X	X	For this purpose, it is equivalent to ASTM A370
		Yield strength	ISO 6892	---	---	---	---	X	X	It is equivalent to ASTM A370
		Elongation	ISO 6892	---	---	---	---	X	X	---
		Wear resistance	API 17K	---	---	---	---	---	X	---

Based on the hose response, Brady et al. (1974) conducted a full scale test using 60.96 cm (24 inches) hoses attached to a CALM buoy off Nigeria, to measure the forces on the hose at a monobuoy. The authors concluded that the hose problem was due to mainly due to fatigue and less of high stresses. Thus, the need to estimate the strength of hoses to improve hose performance (Saito et al. 1980; Amaechi C.V. et al. 2019a; Pinkster and Remery 1975). Saito et al. (1980) studied the external forces that cause kinking on marine hoses was carried out. The study reported measurements by researching on a 50.8cm (20 inches) floating hose in Tokyo Bay, and observed that the first-off buoy hose resisted fatigue from axial force acting on it, and also resisted kinking due to proper reinforcement. A summarised list of some model CALM buoy tests carried out in various test facilities is presented in Table 5, showing different test models on CALM buoy were carried out in different test facilities using model scales, such as 1:20 for a 20m diameter buoy at MARIN Wave Tank (Cozijn & Bunnik 2004; Bunnik et al. 2002; Cozijn et al. 2005) and at Lancaster University Wave Tank using scale 1:20 for 10m diameter buoy (Amaechi C.V. et al., 2019a, 2021h, 2021l, Amaechi 2022). The buoy studies included in this review are in Table 9.

Table 9 Model tests on CALM buoy offshore hose systems

CALM Buoy Description	Year	Model test scale	Reference Company
Porto CALM buoy model tests on shallow water	2002, 2004	smaller scale	Single Buoy Moorings Inc.
Erha deepwater CALM buoy large scale model tests	2003	Scale 1:28.75	Single Buoy Moorings (SBM)
Mooring tests on a shallow water CALM buoy	1997	smaller scale	Bluewater,
CALM buoy model test	2002, 2004	Scale 1: 20	MARIN (Cozijn & Bunnik 2004; Bunnik et al. 2002; Cozijn et al. 2005)
Kizomba SPM model tests	2002	Scale 1:60	Single Buoy Moorings Inc.,
CALM buoy large scale model tests,	2001	Scale 1:20	Bluewater Energy Services BV
DOM's CALM buoy model tests	1987	Scale 1:43	DOM, Heriot-Watt University UK, O'Donoghe & Halliwell (O'Donoghe & Halliwell, 1988, O'Donoghe 1987)
Australian North West Shelf CALM	1996	smaller scale	Bluewater,
Bonga SPM model tests	2001	Scale 1:60	Single Buoy Moorings Inc.,
Deep draft export buoy model tests	2002	Scale 1:60	Single Buoy Moorings Inc.,
CALM buoy model tests	1979	Scale 1:15	DOM, Quash & Burgess (Quash & Burgess, 1979)
CALM buoy large scale model tests	2004	Scale 1:20	Bluewater Energy Services BV,
CALM buoy model tests	2019, 2021	Scale 1:20	Lancaster University UK (Amaechi et al. 2019a, 2021h, 2021l, Amaechi 2022)

3.3 Fatigue of Marine Bonded Hoses

In the industry, fatigue calculations for flexible hoses and flexible marine risers have been calculated using different methods like fatigue life estimations, S-N curves and Bending Strength Ratio (BSR) methods (Ellis et al. 2008; Lassen et al. 2010; Chibueze et al. 2016; Rampi et al. 2006). Lassen et al. (2010) carried out a fatigue test and the ultimate strength of steel reinforced rubber loading hose according to API 17B (API 2014). Fatigue test conducted on the rubberised hoses showed complexly high deformations in cyclic motion. Rampi et al. (2006) investigated on the fatigue of Oil offloading Lines (OOL) - a special marine bonded hoses for offloading, as presented in Table 10, and had some good findings with failure, attributed partly to some vibrations from the test bench, as shown in Figure 18. In another investigation summarised in the hose models in Table 11, Lassen et al.

(2014) also presented a fatigue life prediction approach and a FEA for bonded loading hoses with severe loading evaluations, and found that burst pressure affected hose fatigue. Using a catenary design for some repeated reeling under high hose tension, the bonded loading hoses were exposed to severe, bending, tension and pressure. From the investigation, it was observed that reeling has an underlying effect on the hoses, especially the ones close to the helix. Various studies on the fatigue of marine hoses with highlights on their findings are given in Table 11.

Figure 18 Combined bending fatigue + tension using a test bench (Courtesy: Rampi et al. 2006)

Table 10 Fatigue test results on OLL offloading marine bonded hoses (Rampi et al. 2006)

Components	**Damage Prediction**		**Test results**
	Mean	Standard Deviation	
Reinforcement steel cables layers	0.64	4.9	No failure
	0.8	5.9	Failure
Longitudinal steel cables in flange area	1.19	20.8	No failure (2 flanges)
	1.09	19.8	No failure (1 flange)
	1.07 (>2)*	19.1	Failure** (1 flange)
*Figures in brackets gives an estimation of the fatigue damage including vibration contributions, as during the last phase of the tests. **A malfunction of an articulation of the test bench created significant vibrations at the flange connection that failed.			

Table 11 Summary of the reviewed models on marine hoses covering numerical, experimental, fatigue and analytical studies

Description	**Comment**	**Model**	**Ref**
Submarine hoses attached to CALM buoy, using Chinese-lantern config.	LM_FEM (lumped mass, finite element model, 3D, ANSYS AQWA, Orcaflex, panel model, line theory	Numerical model	Amaechi C.V. et al. 2019a, 2021g
Solid-liquid two-phase flow in slurry pipeline using C4D	two-phase flow velocity measurement, deep-mining pipeline	Experimental model	Yang H. et al. 2018
flexible hose in deep ocean mining application	Fluid−solid interaction of resistance loss, FEM, MSC.MARC/MENTAT software	Numerical model	Wang Z. et al. 2012
dynamic analysis of flexible hose connected to deep-ocean mining pipeline	3D FEM, ANSYS, towing water tank test	Experimental & Numerical model	Wang G. et al. 2007
Dynamic modelling methods for flexible pipe	RecurDyn, SSM, FDM_LM, RISA_EP	Experimental & Numerical model	Lee C.H. et al. 2015
Numerical modelling of Swaggering process for end fitting and stress relaxation	FEM, Stress relaxation, Contact pressure, End fitting of hose, MARC	Experimental & Numerical model	Cho and Song (2007)

Investigation on structural behavior of ring-stiffened composite offshore rubber hose under internal pressure	Experimental, ABAQUS, FEM, burst test on prototype hose, steel helix wire	Numerical & Experimental model	Cao Q. et al. (2017, 2018)
High-Pressure Hydraulic Hoses with Steel Wire Braid	Hose deformation on end fitting, hose wire braid reinforcement	Analytical & Numerical model	Rattensperger H. et al. (2003)
Fatigue life assessment of fabric braided composite rubber hose	Complicated large deformation cyclic motion,	Fatigue test	Cho J.R. et al (2015)
Compressive-tensile fatigue behavior of cords / rubber composites	Experimental test and material testing of rubber hose and cord	Fatigue test	Tonatto M.L.P. et al. (2017)
Composite spirals and rings under flexural loading	Material test of composites spirals, MCT model, cohesive zone,	Experimental & Numerical model	Tonatto M.L.P. et al. (2017)
On the Fatigue of Steel Catenary Risers	Numerical study, Orcaflex,	Fatigue test	Chibueze N.O. et al. (2016)
Reinforcement layers in bonded flexible marine hose under internal pressure	theory, parametric study, multilayer composite hose, Mathematica Code	Analytical & Numerical model	Zhou Y. et al. (2018)
Ultimate strength, fatigue durability of steel reinforced rubber loading hose, Load response and finite element modelling	Experimental test and material testing of rubber hose, end fitting steel nipple, FEA, hose reeling, rubber material	Fatigue test, Numerical & Experimental model	Lassen T. et al. (2010, 2014)
12” 30m long flexible hoses, ship-to shore LNG transfer	Numerical study, Orcaflex, FEA, Model test, reinforced rubber hose	Numerical & Experimental model	Szekely G. et al. (2018)
20” LNG Cryoline floating hose, EN1274-2 qualification;	Full scale, fatigue test, burst test, CFD using STAR-CCM+, Hs of 4m	Numerical & Experimental models	Giacosa A. et al. (2016)
Mathematical Model of a Marine Hose-String at a Buoy	Mathematical model, hose in statics and dynamics.	Analytical model	Brown (1985a, 1985b), Brown & Elliot (1988)
vertical bending moments and axial forces in floating hose-strings	Theory of forces on floating hoses Numerical	Analytical & Numerical model	O’Donoghue & Halliwell (1990)
Axial behaviour of 20” bonded flexible marine hose under different loads	Elastomer, REBAR, Steel end fitting, axisymmetric loads	Analytical & Numerical model	Gonzalez G.M. et al. (2016)
20” bonded flexible marine hose under bending loads	Elastomer, REBAR, Steel end fitting, axisymmetric loads, ABAQUS	Numerical model	Gonzalez G.M. et al. (2014)
Improvement of bonded flexible pipes acc. to new API Standard 17K	Prototype test of 6” pipe for burst, collapse and axial tests	Numerical & Experimental models	Antal S., et al. (2003).

3.4 Application of Marine Bonded Hoses

The application of marine bonded hoses have been identified in other areas, as presented in Table 12. It can be seen that these bonded hoses could be manufactured into different sizes and for different pressure ratings, based on the fluid content, environment and operational conditions. There are also smaller marine hoses, industrial hoses and bigger marine hoses. Hose brands include Dunlop hoses, Parker hoses, Trelleborg hoses, Goodyear hoses, etc. (Goodyear 2015; Trelleborg 2014,2016,2018,2020; Contitech 2018). Applications of offshore hoses have also led to advances in different mooring systems used in buoy-to-ship hose installation (Amaechi et al. 2021g, 2021h, 2021i, 2021j, 2021k, 2021l, 2021m). Typical hose installation is shown in Figure 19. Some of these hoses require floating hoses and catenary hoses while the others require submarine hoses. However, marine bonded hoses are generally specified according to pressure ratings, like 15bar, 19bar and 21 bars, and standard hose lengths of 9.1m, 10.7m, and 12.2m. The application of offshore hoses in the industry have been identified in South China Sea, Bohai Sea, offshore Brazil, offshore Australia, and offshore West Africa, among other seas. In this review, the

OOL is the particularly chosen hose product for discussing the advantages and technical applications as summarised in Table 13.

Figure 19 Installation of floating hoses for a CALM buoy in offshore Brazil (Courtesy: BR)

Table 12 Areas of application of marine bonded hoses for transfer, loading and offloading

Hose Type	Applications	
Marine Bonded Hoses	Oil & Petroleum transfer	Abrasive material transfer
	Painting transfer	Air, breathing air transfer
	Steam transfer	Chemical product transfer
	Drain sewer cleaning	Machinery /Vehicle applications
	Food transfer	Welding applications
	Leisure boat applications	Water applications

Table 13 Comparative advantages of Trelline OOL hose from technical and commercial aspects

Technical advantage	**Commercial advantage**
- Sizes could range to the largest available having practical OOL diameters (smaller winch, smaller horizontal pull, smaller hung weight, smaller SPM buoy, less mooring weight, reduced number of OOL lower Booster Pumping requirement, lower influence on SPM design, etc.) - If there is any damage case, the complete OOL does not require to be changed but just the damaged hose section. - Lighter spread of installation as it requires lesser pulling capacity. - Transport can be done via conventional transportation vessels (liners).	- Lower Offloading OPEX cost (e.g. booster pumping system power consumption and maintenance) - Significant reduction in Overall Deepwater SPM terminal CAPEX - Less Distributed Buoyancy - Lower SPM buoy cost - Flexibility in project execution (installation in phases if required, flexible installation spread) - Lower cost on installation - Lower cost for SPM mooring

3.5 Patent on Marine Bonded Hoses

Marine hoses can be classified as a type of flexible risers called bonded flexible risers, as flexible risers can either be bonded or unbonded. Despite their typical capacity ratings of 9 bar and 21 bar, they have a short service life of 5 to 25 years (Amaechi et al., 2019a, 2021a, PSA 2018, 2013, Løtveit S.A. 2009), compared to steel marine risers (Aranha & Pinto 2001;Sagrilo et al. 2000, Young et al. 1978, Bai Y. & Bai Q., 2005, 2010). It is noteworthy to state that the service life of marine hoses (like other marine hoses) depends on usage (Amaechi et al. 2021a,2021b,2021c), the type of layers -single carcass (SC) or dual carcass (DC) type (Amaechi et al. 2021d,2021e,2021f), handling / maintenance (Amaechi et al. 2021g,2021h,2021i), environmental factors (Amaechi et al. 2021j,2021k,2021l), and motion response from vessel (Amaechi et al. 2021m,2021n,2021o,2021p). The development of marine bonded hoses includes different end-fitting design concepts, as in Table 14 and Figure 20. These have led to design patents developed on marine bonded hoses, as presented in Table 15. It shows the progress made in innovating hose technologies in the offshore/ marine industry.

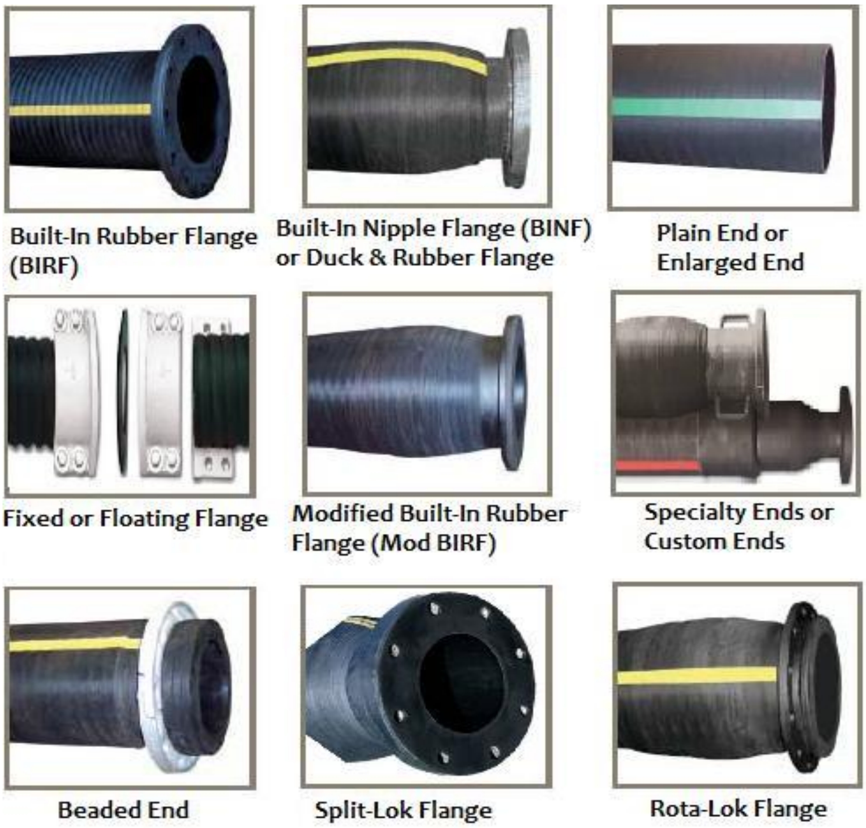


Figure 20 Types of Hose Ends with the Flanges (Source: GoodYear)

Table 14 Description of different offshore hose ends with the flanges

Name of Hose End	Description of Hose End
Built-In Nipple Flange (BINF)	During fabrication, a steel nipple is inserted into the hose and connected to the hose body, giving optimum gripping power and an unrestricted transition area. It could be ANSI fixed or floating flanges, but they're best for high-pressure, heavy-duty applications.
Built-In Rubber Flange (BIRF) or Duck & Rubber Flange	When mated to a matching flange, a full-face rubber flange is created from extended plies of rubber and produces a liquid-tight seal. It's perfect for transporting abrasive materials under low pressure. Fabric plies and hose tubing wrap around the flange's face. The rubber flange and the steel back-up flange are moulded together. It's best for mild to medium-duty abrasive applications that require minimal pressure.
Plain End or Enlarged End	The hose end can be used as a plain hose to fit the pipe's outside diameter, or it can be extended to fit the pipe's outside diameter.

Modified Built-In Rubber Flange (Mod BIRF)	Rubber plies and reinforcements from the hose body stretch via the steel nipple and across the surface of the flange, providing a protective barrier against abrasive or corrosive elements. It will provide an unrestricted full flow transition area. It is recommended for full-vacuum servicing and high-pressures.
Specialty Ends	Hose ends that have been specifically or custom-designed to meet the demands and standards of designers.
Beaded End	Extended rubber plies and reinforcement are used to create a beaded finish. When fastened to a mating flange, split steel back-up rings function as a connecting surface and form a liquid-tight seal.
Split-Lok Flange	The developer can generate assemblies in the field using a two-piece reusable coupling system that is attached externally with compression bolts. This is for material transfer hose with a big bore.
Rota-Lok	A rubber-lined stub end supports a steel floating flange. This is the best choice for abrasive materials and high-pressure applications.
Fixed or Floating Flange	These are drill-bored and ANSI forged steel flanges that are built-in, internally enlarged, or externally swaged.

Table 15 Patents on development of marine hoses and flexible pipes

Patent No.	Reference	Date	Title of Patent
US3,119,415A	Galloway F.M., Kerr R.M., Rittenhouse G.J, Sinnamon R.H.	Jan. 28, 1964	Buoyant hose
US20040012198A1	Arthur Brotzell, Stewart Fowler, Chanthol Tho	Jan. 22, 2004	Composite coiled tubing end connector
US4887	Carter J.W.	1985.	Method and apparatus for longitudinally reinforcing continuously generated plastic pipe.
US5579809A	William A. Millward, John Dabinett	Dec. 3, 1996	Reinforced composite pipe construction
US6042152A	Baldwin D.D., Reigle J.A., Drey M.D.	Mar. 28, 2000	Interface system between a composite pipe and coupling pieces
US5520422A *	Ralph Friedrich, Ming Kuo, Kevin Smyth	1994-10-24	High-pressure fiber reinforced composite pipe joint
US20140216591A1	Joel Aron Witz, David Charles Cox	2009-06-02	Reinforced Hose
US20090159145A1	Aaron K. Amstutz	2007-12-19	Hose with composite layer
US 8,770,234 B2	Joel Aron Witz	Jul. 8, 2014	Hose
US20060249215A1	Bryant, M.J.,	2006.	Anti-collapse system and method of manufacture.
US4470621A	Joseph H. Irvine	Sep. 11, 1984	Flexible tubular connector
US5654499A	Dardanio Manuli	Aug. 5, 1997	Dual carcass flexible hose
US8439603B2	Joel Aron Witz, David Charles Cox	May 14, 2013	Improvements relating to hose
US3769127A	Goldsworthy W., Hardesty E.	30 Oct., 1973.	Method and apparatus for producing filament reinforced tubular products on a continuous basis.
US7523765B2	Quigley P. A., Feechan M., Wideman T. W.	Apr. 28, 2009	Fiber reinforced spoolable pipe
US3817288A	E Ball	June 18, 1974	Hose pipes
EP0672227B1	Richards S. J., Reza A., Zandiyeh K.	Sept. 20, 1995	Hose end fitting and hose assembly
US6264244B1	Isennock C.W., Headrick D. C., Berning S. A.	Jul. 24, 2001	End connector for composite coiled tubing
US 2011/0120636A1	Bailey S.L., Miller A.K.,	2011-05-26	Pultruded Arc-Segmented Pipe.
US3,905,398A	Johansen H. A.; Philippi L.R.; Green E.A.,	Sept. 16, 1975	Composite reinforced hose wherein the reinforcing material is braided aromatic polyamide filaments
US8656961B2	Chen, B.	2014.	Composite flexible pipe and method of manufacture.
US Patent	Williams, J.G.,	1994.	Dimensional stability.
US5908049A	Williams, J.G., Sas-Jaworsky, A.,	1999-06-01	Spoolable composite tubular member with energy conductors.
US5285008	Sas-Jaworsky A. & Williams J.G.	8 Feb., 1994.	Spoolable composite tubular member with integrated conductors.
US20040012198A1	Arthur Brotzell, Stewart Fowler, Chanthol Tho	Jan. 22, 2004	Composite coiled tubing end connector
US5988702	Sas-Jaworsky A.	23 Nov., 1999.	Composite coiled tubing end connector.
US3531143A	Horvath L. Gundisch G., Arvai M., Antal S.	1970-09-29.	Head-formation of flexible hoses, especially for deep-drilling hoses.
US 4,741,794.	Antal S., Smaroglay P., Lantos E.	May 3, 1988.	Equipment for the manufacture of mainly large-diameter flexible hoses having spiralled reinforcement
US Pat. 4,120, 324	Pahl K. H.	1978-10-17	High pressure hose composed of elastomers and embedded reinforcements

US6315002 US Pat. 6, 831, 002	Antal S., Gelencsér S., Nagy T., Seregély Z.	2001-11-13	High pressure flexible hose structure and method of manufacture
US8241453B2	Bétéri G., Füstöst I., Katona T., Lantos E., Nagy T.	2009	Method and apparatus for manufacturing fibre-reinforced hoses

3.6 Hazard & Risk assessment

Due to the need for safety and to ensure quality compliance, companies like DNVGL and Bureau Veritas (BV) can be contracted to conduct a risk assessment in conjunction with the API 17K certification programme, as reported by Rampi et al. (2006). A reliability assessment was conducted as presented in Table 16, which shows a rough comparison of a single unloading line against a multi-line solution. A functional examination of the Trelline remote export line system was used to conduct a HAZID (hazard identification) investigation in the first phase. In a second step, an FMECA (Failure Mode, Effects, and Criticality Analysis) is used to provide a qualitative assessment of the primary hazards. Risks related to process and internal fluid (pig deterioration, internal corrosion, etc.), uncontrolled third-party action (dropped object, ship collisions, etc.), sea water environment (marine growth, external corrosion, etc.), and action from interfaces (CALM buoy / FPSO offset, waves, current, etc.) are then examined. There are different types of failures, as presented in Table 17. Once quality compliance is met, there be any circumstance that should be deemed unsatisfactory (criticality level 3). To manage the highest-ranking risks, recommendations are made and implemented (criticality level 2). In terms of system redundancy in the Trelline project, it was reported that special emphasis was paid to comparing a single OOL to a system with several OOLs, which revealed that the benefit of having many OOLs redundant is not assured (Rampi et al. 2006, Mayau & Rampi 2006). The capacity of a system to provide a component with backup in the event of failure is known as redundancy. In order to ensure full and robust redundancy, in addition to duplicating the modules, the following recommendations are made:

- non-interference: the existence of redundant components should have no effect on the main one's operation.
- Elimination of common modes of failure: all modes of failure should be avoided. This usually means that the components are separated to prevent them from being exposed to the same damaging effects of external threats.
- Diversification: This requirement aims to avoid the time to failure being of the same order of magnitude because all the components are nominally equal.

Table 16 Comparison of offloading line with multi-line solution

Features	**Possible Consequences**	**Impact on Reliability & Availability**
Reduced flow rate / per line	Reduces failure rate	Positive
Two instead of one	Increase probability of impact by external	Negative
	Increase inspection effort	Negative
	Increase probability of presence of a defect	Negative
	Increase probability of damage due to pig run	Slightly negative
Proximity	Interaction between lines	Negative
	Sensitivity to common mode of failure	Neutral
Same type of components	Similar Mean Time to Failure (MTTF)	Neutral or slightly positive

Table 17 Types of Hose Failures Assessed

Type of failure	**Effects**
Hazardous Failure	It includes the generation or creation of detrimental physical effects such as heat flux, and blasts.
Functional Failure	It is due to the lost of function slightly or completely in a system.
Human Management Failure	It is due to poor supervision of the hose-related processes, or poor maintenance of components like hose valves.

3.7 Challenges of Marine Hoses

Presently, marine bonded hose incidents and flexible riser incidents have been recorded and examined in this study (PSA 2018, Svein Are Ltveit 2009, 2018). On hoses for offloading crude crude oil, there have been a few recorded failures in service, as well as some oil spill incidents during hose loading and transfers. The application, on the other hand, is in great demand, and innovative engineering solutions which have been proposed to address these problems. Marine bonded hoses do experience material damage, failure modes and proprietary design issues, as earlier presented. Although, the necessary checks are done, qualified and verified hoses still under failure which have been identified to be mostly (48%) from hose leaks. It has been gathered that hose manufacturers have been very supported in industry reports such as the PSA state of the art on bonded flexible pipes (2008, 2018) and for reviewing the standards such as OCIMF 2009 and API 17K rev3. However, the industry requires more statistics and data as feedback from PSA and ITOPF, among other research firms that gather data on the industry. Table 18 shows some identified issues that affect bonded hoses and might lead to hose failure.

Table 18 Challenge of marine bonded hose failures and some identified causes

Cause of Failure	Highlights
Kinking at or around the fittings	Once the fitting's barb cuts through the hose tube, the product being transported can escape into the reinforcement, causing the cover to bubble or blister within a few feet of the end.
Surging or excessive working pressure	Usually a huge burst at the outside of a bend with shredded reinforcement.
Bending a hose past its minimum bend radius	Kinking, crushing, or pushing a hose to bend beyond its minimum bend radius are all examples of this (measured from the inside edge of the hose, not the centerline). This is very prevalent on high-pressure or vacuum pipes.
Tube or cover that is incompatible with fluids or the environment	This causes discoloration, swelling, sponginess, or the hose carcass to break down. Always rotate material handling hoses to maintain even wear of the hose tube.
Poor craftsmanship or lack or support personnel from hose manufacturer during installation	Hose and fittings are built of a unique blend of diverse materials using sophisticated production procedures - flaws or deviations bigger than permissible tolerances can be caused by human error, inconsistent machinery, or poor product quality or raw materials. Ends blowing off assemblies can be caused by poor coupling techniques or the “mixing and matching” of mismatched hose, couplings, or clamps.
Misapplication	Using a hose, fitting, or clamp for a purpose it was not designed for is one of the most common causes of failure.
Temperature Exposure	As the temperature rises, so does the pressure rating. Excessively hot or cold temperatures will cause discoloration, cracking, or hardening, as well as the accumulation of static electricity if the hose wire is not correctly grounded.
Hose-line length is too short	Too short a length prevents the hose from expanding and contracting in response to variations in pressure or temperature, putting unnecessary strain on the fittings and hose reinforcement.
Defective hose or improperly fitted or selected clamp	Failure from a defective hose, such as pin holes, blow-outs, or tube and cover separation, often occurs in the first few hours of service. The connection can be ejected from the end of the hose

	due to improperly installed or chosen clamps. Always double-check the manufacturer's recommendations using STAMPED data.
Short service life or age-long hose usage	Hose is a flexible component that will degrade over time, as it has material mechanics dependent on different factors. Depending on the composition, application, and environment, the shelf or service life will range from 1 to 20+ years. At low pressures, older hoses grow discoloured, stiff, or burst.
Transfer of contaminated media	Foreign particles or residue in the fluid or air might flow through the tube, breaking it down or prematurely wearing it out. Always clean hoses before putting them in the field to avoid cross-contamination.
Hose carcass damage from the outside	Kinks, crushed parts, and cover damage that exposes reinforcement will gradually break down the reinforcement, resulting in hose failure.
Twisting hose during installation or service	Twisting a hose instead of bending it normally will shorten its life. When putting a hose in a permanent installation, it is estimated that a 7% twist can shorten hose life by 90%.
Vessel motion during loading or discharge	During a loading or discharge operation, the vessel is weathervaned or dynamically positioned to avoid oil spills and hose failure or early disconnections. Sometimes, tug boats are used to keep the vessel in position or it will be moored in response to the weather condition.

3.8 Current Research Gaps & Future Trends

One research gap is the synergy between academia and the industry, to ensure better research outputs and knowledge exchange on the technology. However, the industry identifies it as a risk with sharing trade secrets, unless NDAs (Non-Disclosure Agreements) are signed. On the other hand, the industry can extend invitations to the academia during their annual seminars, product exhibitions and trainings. It is noteworthy to state that this review is not sponsored by any hose manufacturer, and no input was directly or indirectly given on their products. One key challenge is that industry is not open to share data with academia. On this project as handled in Lancaster University UK, some contacts were made to the industry manufacturers during this review but no response was received, except permissions to use images. Also, their materials were not tested directly on this review, so it was based on performance reports, the available hose brochures and scholarly publications available. A report by PSA (2018) presented some views by two industry manufacturers on marine bonded hoses -Trelleborg and ContiTech /Dunlop Oil & Marine. According to Trelleborg, their hoses for oil product transfers -*REELINE, KLELINE and TREELINE* have proved to be sustainable and effective, from a material point of view. However, they keep researching its designs with test data, and operational experience. Considering their long track record in the industry for the key players in hose manufacturing, there were no gaps identified, such as in the stability of the material used for hose fabrication. Each hose manufacture has a unique design, and mostly patented designs with proprietary materials used in manufacturing the hoses. An example is the uique arrangement of end terminations on Trelleborg products, having compact flange that may include integrated Bending Stiffener when required, as shown in Figure 6. These end-fittings and flanges have passed through rigorous full-scale fatigue tests to predict the behaviour of the end terminations. This happens to be the region that can develop a combination of tension with high bending loads at the domain of the compact flanges. In addition, it has a gasket that is built in, to prevent failure with high sealing performance recorded for over 10 years (PSA 2018). One method which is used is to accurately control the pre-tension by torqueing and thus, be able to ascertain any pre-tension during from the composite array of the flanges. Trelleborg also claims never to have reported any bolting failure from their hose products.

Another issue that could help is sharing information within the industry between hose manufacturers and users. However, it also has risks, due to industry conflicts of interests, trade secret issues, risk of proprietary information and risking manufacturers reputations. Despite that, it would be helpful that there are exchange of information, not necessary trade secret of design knowledge on the useful art, but on best practices. The industry will appreciate always having reliable marine hose products that will have longer service life and good failure indication systems. This will in-turn provide improved reliability, more accurate information on the hose service life as well as extensions for different product ranges of the bonded hoses. On the other hand, manufacturers have contrasting views with industry users on some issues. There are still some issues with manufacturer and industry operators unifying on some test limits, such as reducing the test criteria with GMPHOM guideline (OCIMF 2009) for torsion test on marine hoses from 2 deg./m to 1 deg/m. However, hose manufacturers like ContiTech/Dunlop Oil&Marine (PSA 2018) feel that it would be a backward step, which would affect the quality of the hose and can affect the integrity of hose-lines on the offshore structure, when deployed. Thus, having a unifying standard on marine bonded hoses that is globally accepted is still an issue in the industry, but hopefully these issues will be collated and an updated version of the OCIMF (2009) standard or an ISO, EN, BS, NIS, DNVGL, NORSOK, API, or ABS standard on marine bonded hoses will be elaborated and published, in the nearest future.

4.0 Conclusion

The development of marine bonded hoses is progressing globally, as has been reviewed herein. The excellent resource potential of marine hoses globally can proffer good incentives for competitive advantages, increased synergies, more collaborations, funding supports, further researches and developments on hose technology and related areas for floating offshore structures (FOS), such as shuttle tankers, turret buoys and CALM buoys. It is noteworthy to state that efficient utilisation of marine hoses in the industry, is usually achieved when suppliers or hose manufacturers provide installation support personnels to ensure the delivery is safe. In this review, the related industry recommendations and standards are examined and evaluated critically. This aids in the identification and provision of the most pertinent verification and validation requirements for the design and manufacture of bonded flexible rubber hoses. This can be employed in a SWIR application if the special requirements of these bonded flexible rubber hoses are taken into account. In addition to transporting untreated seawater, the weights caused by self-weight, vessel motion, and external pressures must be accommodated.

The main highlights of this review are as follows:

- *Overview on offshore industry, sustainable fluid transfer and hose end-fittings.*
- *Historical development, hose design, and manufacturing of bonded marine hoses.*
- *Review on mechanics, hose performance, and assessment of CALM buoy hose systems.*
- *Marine hose configurations, hose modelling, deployment and collaborative synergies.*
- *Application methods for fluid transfer and hose-related sustainable technologies.*

This review avows that the design and manufacture of bonded flexible rubber hoses are governed by some industry regulations and recommendations. While some of these industry rules and recommendations may be implemented, the design and manufacture of bonded flexible rubber hoses for a SWIR application is not particularly covered. It is suggested that it be included in the scope of any future document evaluated or a new SWIR-specific document. As a result of the review, the paper defines the most important criteria and proposes a technique for verifying and validating the design and fabrication of a flexible hose in a SWIR application. Despite the fact that this work presents a set of verification and validation criteria for the design and manufacture of bonded flexible rubber hoses, it does not go into detail about any particular hose type, such as SWIR applications on FPSO vessels. It should also be highlighted that other stakeholders are now considering these technologies for similar purposes. This applies to new Floating Liquefied Natural Gas (FLNG) boats as well as special cylindrical vessels. Although marine bonded hoses have great potentials, the performance reports from scaled tests, and experiments indicate the need for further developments. Competitiveness between hose manufacturer facilities, key performance index (KPI) and product sales competitions between manufacturers has been key indicators that has also driven sales of marine hoses in the industry. Novel devices have been developed to ensure hose monitoring offshore which has also helped in ensuring hose safety, and reduce the recorded incidents of hose failures. Sensitization is another issue which would help to create synergy between hose users and hose manufacturers. An example is attending industry seminars such as OTC Conferences, ASME/OMAE Conferences, SubseaUK Conferences, Orcaflex User Group meetings and Dunlop Oil&Marine Annual Seminars. This could also help to publicise useful information and share data on user-related information, such as marine hose sales by regions. Lastly, funding researches on marine bonded hoses is another aspect that has affected development of the technology, as very few industry facilities, institutions and research institutes were recorded to have research works on marine bonded hoses or related, such as CALM buoys) -either is small scale or full scale.

Data Availability Statement

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

Authorship Contribution Statement

Conceptualization, C.V.A., F.W., C.A.O., J.Y.; methodology, C.V.A., F.W., C.A.O., J.Y.; software, C.V.A., F.W., I.A.J., A.A., C.A.O., J.Y.; validation, C.V.A., F.W., I.A.J., A.A., C.A.O., J.Y.; formal analysis, C.V.A., F.W., J.Y.; investigation, C.V.A., F.W., I.A.J., A.A., C.A.O., J.Y.; resources, C.V.A., F.W., I.A.J., A.A., C.A.O., J.Y.; data curation, C.V.A., F.W., J.Y.; writing—original draft preparation, C.V.A.; writing—review and editing, C.V.A., F.W., I.A.J., A.A., C.A.O., J.Y.; visualization, C.V.A., F.W., I.A.J., A.A., C.A.O., J.Y.; supervision, F.W., J.Y.; project administration, C.V.A., F.W., J.Y.; funding acquisition, C.V.A., F.W., J.Y.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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References

Abelanet, M. (2012). Installation of electrical heat trace flowline by reel lay. Presented on 22nd Feb 2012. Subsea 7 Presentation, UK. Available at: https://www.yumpu.com/en/document/view/26877695/mechanical-lined-pipe-installation-by-reel-lay-subsea-uk (Accessed on 2nd December, 2021).

Aboshio A., Ye J. (2016). Numerical study of the dynamic response of Inflatable Offshore Fender Barrier Structures using the Coupled Eulerian – Lagrangian discretization technique. Ocean Engineering, Vol. 112, pp.265-276. https://doi.org/10.1016/j.oceaneng.2015.12.020

Aboshio, A, Uche, AO, Akagwu, P & Ye, J (2021), 'Reliability-based design assessment of offshore inflatable barrier structures made of fibre-reinforced composites', Ocean Engineering, vol. 233, 109016. https://doi.org/10.1016/j.oceaneng.2021.109016

Aboshio A, Green S, Ye J. (2014). Dynamic response of Inflatable Offshore Fender Barrier Structures under Impact Loading. Paper 148, Proceedings of the Fourteenth International Conference on Civil, Structural and Environmental Engineering Computing, B.H.V. Topping and P. Iványi, (Editors), Civil-Comp Press, Stirlingshire, Scotland. https://doi.org/10.4203/ccp.102.148

Aboshio A, Green S, Ye J. (2014). New constitutive model for anisotropic hyperelastic biased woven fibre reinforced composite. Plastics, Rubber and Composites, 43(7):225–34. https://doi.org/10.1179/1743289814Y.0000000097

Aboshio A, Green S, Ye J. (2015). Experimental investigation of the mechanical properties of neoprene coated nylon woven reinforced composites. Composite Structures, Volume 120, February 2015, Pages 386-393 https://doi.org/10.1016/j.compstruct.2014.10.015

Aboshio, A. (2014). Dynamic Study of Inflatable Offshore Barrier Structures under Impact and Environmental Loadings (Ph.D. thesis) Engineering Department, Lancaster University, United Kingdom.

ABS (2020). *Rules for building and classing - single point moorings*, American Bureau of Shipping. Available at: https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/offshore/8-single-point-moorings/spm-rules-july20.pdf

ABS (2017). *Rules for building and classing – subsea riser systems*, American Bureau of Shipping. Available at: https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/offshore/123_guide_building_and_classing_subsea_riser_systems_2017/Riser_Guide_e-Mar18.pdf

Ahlstone A. (1973). Light weight marine riser pipe. Patent 3768842 A, USA, 30 October 1973.

Alfagomma, 2016. *Industrial hose & fittings*, Vimercate, Italy: Alphagomma SpA

Ali A., M. Hosseini, B.B. Sahari (2010). A review of constitutive models for rubber-like materials, American Journal of Engineering and Applied Sciences, Volume 3 (1) 232–239. DOI**:** https://doi.org/10.3844/ajeassp.2010.232.239

Ali M.O.A., Ja'e I.A., Hwa M.G.Z. (2020). Effects of water depth, mooring line diameter and hydrodynamic coefficients on the behaviour of deepwater FPSOs. Ain Shams Engineering Journal, Volume 11, Issue 3, Pages 727-739, ISSN 2090-4479, https://doi.org/10.1016/j.asej.2019.12.001.

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

Amaechi, C. V., Ye, J., Hou, X., & Wang, F.-C. (2019b). Sensitivity Studies on Offshore Submarine Hoses on CALM Buoy with Comparisons for Chinese-Lantern and Lazy-S Configuration OMAE2019-96755. *38th International Conference on Ocean, Offshore and Arctic Engineering, Glasgow, Scotland, June 9–14, 2019*. https://doi.org/OMAE2019-96755

Amaechi, C.V. & Ye J. (2017). *A numerical modeling approach of composite risers for deep waters*. ICCS20 20th International Conference on Composite Structures; 2017-09-04 | conference-paper; ISBN 9788893850414., Paris, France

Amaechi, C.V., Gillett, N., Odijie, A. C., Hou, X., & Ye, J. (2019c). Composite risers for deep waters using a numerical modelling approach. *Composite Structures*, Volume *210*. https://doi.org/10.1016/j.compstruct.2018.11.057

Amaechi, C.V., Gillett, N., Odijie, A.C., Wang, F., Hou X., Ye J. (2019d) *Local and Global Design of Composite Risers on Truss SPAR Platform in Deep waters.* In: MECHCOMP2019 5th International Conference on Mechanics of Composites, 2019-07-012019-07-04, Instituto Superior Técnico, Lisbon, Portugal. Available at: https://eprints.lancs.ac.uk/id/eprint/136431 (Accessed on 2nd December, 2021).

Amaechi, C.V., Gillet N., & Ye, J. (2022a). Tailoring the local design of deep water composite risers to minimise structural weight. *Journal of Composite Science. 2022, (under review)*.

Amaechi C.V., Ye J. 2021a. Local tailored design of deep water composite risers subjected to burst, collapse and tension loads. *Ocean Engineering* 2021. (accepted, in-print).

Amaechi C.V. 2021b. A review of state-of-the-art and meta-science analysis on composite risers for deep seas. Ocean Engineering 2021. (under review).

Amaechi C.V. 2021c. Development of composite risers for offshore applications with review on design and mechanics. Ships and Offshore Structures. 2021. (under review).

Amaechi C.V., Chesterton C., Butler H.O., Wang F., Ye J. 2021d. An Overview on Bonded Marine Hoses for sustainable fluid transfer and (un)loading operations via Floating Offshore Structures (FOS). *J. Mar. Sci. Eng. 2021, 9(11)*. https://doi.org/10.3390/jmse9111236.

Amaechi C.V., Chesterton C., Butler H.O., Wang F., Ye J. 2021e. Review on the design and mechanics of bonded marine hoses for Catenary Anchor Leg Mooring (CALM) buoys. *Ocean Engineering Vol. 242, 110062*. https://doi.org/10.1016/j.oceaneng.2021.110062.

Amaechi C.V., Wang F., & Ye, J. 2021f. Mathematical Modelling of Bonded Marine Hoses for Single Point Mooring (SPM) Systems, with Catenary Anchor Leg Mooring (CALM) Buoy application - A Review. *J. Mar. Sci. Eng.* ***2021****, 9(11), 1179; https://doi.org/10.3390/jmse9111179*

Amaechi, C.V., Wang F., & Ye, J. 2021g. Numerical Assessment on the Dynamic Behaviour of Submarine Hoses Attached to CALM Buoy Configured as Lazy-S Under Water Waves. *J. Mar. Sci. Eng. 2021, 9(10), 1130; https://doi.org/10.3390/jmse9101130*

Amaechi C.V., Wang F., Ye J. 2021h. Investigation on Hydrodynamic Characteristics, Wave-Current Interaction and Sensitivity Analysis of Submarine Hoses Attached to a CALM Buoy. *J. Mar. Sci. Eng. 2021, 9*. (under review).

Amaechi C.V., Wang F., & Ye, J. 2021i. Numerical studies on CALM buoy motion responses and the effect of buoy geometry cum skirt dimensions with its hydrodynamic waves-current interactions. *Ocean Engineering* 2021. (accepted, in-print).

Amaechi C.V., Chesterton C., Butler H.O., Gu Z., Odijie C.A., Wang F., Hou X., Ye J. 2021j. Finite element modelling on the mechanical behaviour of Marine Bonded Composite Hose (MBCH) under burst and collapse. *J. Mar. Sci. Eng. 2021*, 2021 (Under review)

Amaechi C.V., Wang F., & Ye, J. 2021k. Understanding the fluid-structure interaction from wave diffraction forces on CALM buoys: Numerical and analytical solutions. *Ships and Offshore Structures. https://doi.org/10.1080/17445302.2021.2005361*.

Amaechi C.V., Wang F., Ye J. 2021l. Experimental study on motion characterization of CALM buoy hose system with CFD investigation on vortex effect. *J. Mar. Sci. Eng.* 2021, 9. (under review).

Amaechi C.V., Wang F., Ye J. 2021m. Numerical assessment of marine hose load response during reeling and free-hanging operations under ocean waves. *Marine Structures* 2021. (under review).

Amaechi C.V. 2022. Novel design, hydrodynamics and mechanics of marine hoses in oil/gas applications. *PhD Thesis (in view).* Engineering Department, Lancaster University, Lancaster, UK.

Ambrose (1979). Flexible hose lines. Patent 4153079, USA, 1979-05-08.

Anderson J. J., Nance D. A. and Mickelson C. S. (1998). Composite cylinder termination formed using snap ring. Patent 5813467 A, USA, 29 September 1998.

Andrick et al. (1997). Symmetrical gasket for a pipe joint. Patent 5687976, USA, 1997-11-18.

ANSYS, 2016a. *ANSYS Aqwa Theory Manual, Release 17.2*, Canonsburg, USA: ANSYS Inc.

ANSYS, 2016b. *ANSYS Aqwa User's Manual, Release 17.2*, Canonsburg, USA: ANSYS Inc.

Antal et al. (2001). High pressure flexible hose structure and method of manufacture. Patent 6315002, USA, 2001-11-13

Antal S., Tibor Nagy T., and Boros A. (2003). Improvement of bonded flexible pipes acc. to new API Standard 17K. Offshore Technology Conference, 5-8 May, Houston, Texas, USA. Paper No. OTC-15167-MS. DOI: https://doi.org/10.4043/15167-MS

Antal S., Nagy T., Boros A.: IRC 2003, Nürnberg, June 30. to July 3., 2003.

Antal S., Imre D., Gyula B., Katona T. (2012). Finite element analysis of seawater intake hoses. SIMDAY 2012, Budapest.

Antal S., Gelencser S., Nagy T., Seregely Z. (1998). Problems of improving flexible pipes (Hoses) designed for the delivery of high pressure gas and gaseous oil. Kautschuk und Gummi Kunststoffe 51(1):51-57. Available at: https://www.kgk-rubberpoint.de/en/hefte/

API (2020). API list of manufactures for flexible hoses. Available at: www.api.org

API (2014). API 17J: Specification for Unbonded Flexible Pipe. Fourth Edition. American Petroleum Institute, USA.

API (2017). API 17K: Specification for Bonded Flexible Pipe. Third Edition. American Petroleum Institute, USA

API (2015). API Spec. 7K. Specification for Drilling and Well Service Equipment. Sixth Edition, American Petroleum Institute, USA.

API (2014). API RP 17B. Recommended Practice for flexible pipe. Fifth Edition, American Petroleum Institute, USA.

ARPM, 2015. *Hose Handbook; IP-2* Ninth., Shadeland Station Way, Indianapolis: Association for Rubber Products Manufacturers.

Asano et al. (1986). Hydraulic brake hose. Patent 4617213, USA, 1986-10-14.

ASTM D412-16, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers-Tension, ASTM International, West Conshohocken, PA, 2016.

ASTM D885 / D885M-10A (2014) e1, Standard Test Methods for Tire Cords, Tire Cord Fabrics, and Industrial Filament Yarns Made from Manufactured Organic-Base Fibers, ASTM International, West Conshohocken, PA, 2014.

ASTM E111-04. Standard test method for young's modulus, tangent modulus, and chord modulus. West Conshohocken, PA: ASTM

International; 2004.
Avery A. and Martin S. (2003). Reinforced thermoplastic pipe: Innovative technology for onshore field developments. In: Proceedings of the 22nd international conference on offshore mechanics & arctic engineering. *Volume 3: Materials Technology; Ocean Engineering; Polar and Arctic Sciences and Technology*. Cancun, Mexico, June 8-13, 2003, pp. 787-794. https://doi.org/10.1115/OMAE2003-37041
Bai Yong and Bai Qiang (2005). Subsea pipelines and risers. First Ed. Elsevier, Oxford, UK.
Bai, Y., Bai, Q. (2012). Subsea Engineering Handbook. Gulf Professional Publishers (Elsevier), Waltham.
Balasooriya W., Schrittener B., Pinter G., Schwarz T., (2018). A fracture mechanical approach to identify the behavior of elastomers in hostile environments. German Rubber Conference (Deutsche Kautschuk-Tagung) 2 - 5 July 2018, Nürnberg, Germany. DOI: 10.13140/RG.2.2.32431.87206
Balasooriya W., Clute C., Schrittener B., Pinter G. (2021). A Review on Applicability, Limitations, and Improvements of Polymeric Materials in High-Pressure Hydrogen Gas Atmospheres. Polymer Reviews. Polymer Reviews. DOI: 10.1080/15583724.2021.1897997
Baldwin DD, Reigle JA and Drey MD. Interface system between composite tubing and end fittings. Patent 6042152 A, USA, 28 March 2000.
Barbero E.J. (2010). Introduction to composite materials design. Boca Raton: CRC Press.
Barnard (1938). Hose end structure. Patent 2122126, USA, 1938-06-28.
Bastien, S.P. et al., 2009. Ocean Wave Energy Harvesting Buoy for Sensors. , pp.3718–3725.
Bernitsas, M.M. & Kokkinis, T., 1983. Buckling of Risers in Tension due to Internal Pressure: Nonmovable Boundaries. *Journal of Energy Resources Technology*, 105(September 1983), pp.277–281.
Berteaux, H.O., 1976. *Buoy engineering*, New York, USA: John Wiley and Sons.
Berteaux, H.O., Goldsmith, R.A. & Schott III, W.E., 1977. *Heave and Roll response of free floating bodies of cylindrical shape*, Massachusetts, USA.
Blanchard C. J., Anastasio F. L. (2016). Floating systems and method for storing produced fluids recovered from oil and gas wells. US5885028A, USA, 10 December, 2016.
Bluewater, 2011. *Bluewater Turret Buoy- Technical Description*, Amsterdam, The Netherlands: Bluewater Energy Services.
Bluewater (2020). Comprehensive Experience Overview: Oceans of knowledge. Bluewater, pp. 1-15. Available at: https://www.bluewater.com/wp-content/uploads/2020/05/Experience-Overview-May-2020.pdf Retrieved on 30th July, 2020.
Bluewater, 2009a. *Buoyed Up: The future of tanker loading/offloading operations*, Amsterdam, The Netherlands: Bluewater Energy Services. Available at: https://www.bluewater.com/wp-content/uploads/2013/04/CALM-Buoy-brochure-English.pdf Retrieved on 30th July, 2020.
Bluewater, 2009b. *Conventional Buoy Mooring Systems*, Amsterdam, The Netherlands: Bluewater Energy Services.
Bluewater, 2016. *Turret Buoy*, Amsterdam, The Netherlands: Bluewater Energy Services.
Boatman L. T. (2003). Flowline termination buoy with counterweight for a single point mooring and fluid transfer system. US6558215B1, USA, 06 May 2003.
Boccotti, P., 2015. *Wave Mechanics and Wave Loads on Marine Structures*, USA: Elsevier B.V.
Boccotti, P., 2000. *Wave Mechanics for Ocean Engineering*, Amsterdam, The Netherlands: Elsevier B.V.
Bok-Lok Choi, Byoung-Ho Choi (2015). Numerical method for optimizing design variables of carbon-fiber-reinforced epoxy composite coil springs. Composites Part B: Engineering, Volume 82, pp. 42-49. https://doi.org/10.1016/j.compositesb.2015.08.005
Brady, I., Williams, S. & Golby, P., 1974. A study of the Forces Acting on Hoses at a Monobuoy Due to Environmental Conditions. In *Offshore Technology Conference Proceeding -OTC 2136*. Dallas, Texas, USA: OnePetro, pp. 1–10.
Braud J., Brown PA. and O'Nion G. (1998). Submerged CALM buoy. US5816183A, USA, 06 October, 1998.
Bree, J., Halliwell, A.R. & Tom O'Donoghue, 1989. Snaking of floating marine oil hose attached to SPM buoy. *Journal of Engineering Mechanics*, 115(2), pp.265–284.
Bridgestone, 2017. *Hydraulic hose: couplings, accessories and equipment*, Bensheim, Germany: Bridgestone Company.
Bridgestone, J., 1976. *Study of causes of kinking in floating hoses at Petrobras/Tefran terminal. Report No. 6YMT-0011*, Japan.
Briggs (1990). Graduated friction anchor. Patent 4950001, USA, 1990-08-21.
Brown, M.J., 1985a. Mathematical Model of a Marine Hose-String at a Buoy- Part 1 - Static Problem. In P. Dyke, A. O. Moscardini, & E. H. Robson, eds. *Offshore and Coastal Modelling*. England: Springer, pp. 251–277.
Brown, M.J., 1985b. Mathematical Model of a Marine Hose-String at a Buoy- Part 2 - Dynamic Problem. In P. Dyke, A. O. Moscardini, & E. H. Robson, eds. *Offshore and Coastal Modelling*. England: Springer, pp. 279–301.
Brown, M.J. & Elliott, L., 1988. Two-dimensional dynamic analysis of a floating hose string. *Applied Ocean Research*, 10(1), pp.20–34.
Brown P. A. and Poldervaart L. (1996) Fluid transfer system for an offshore moored floating unit. US5505560A, USA, 09 April, 1996.
BS 903-5:2004 Physical testing of rubber. Guide to the application of rubber testing to finite element analysis. (2004) BSI, London.
BSI (2008). BS EN 1474-2: 2008. European Standard 1474: Installation and equipment for liquefied natural gas – Design and testing of marine transfer systems. Part 2: Design and testing of transfer hoses. British Standards Institution.
Busch R. A. (1987). Spar buoy fluid transfer system. US4648848A, USA, 10 March, 1987.
Camozzato, G., Poirier, N., Hiller, D., Acheritobehere, A., Xavier, M., Romeu, N. B., Seize E., Silva, A. L. (2015). Execution Challenges for a First of its Kind Project in Santos Basin Brazil. Offshore Technology Conference, 04-07 May, Houston, Texas, USA. DOI: https://doi.org/10.4043/25843-MS
Cao, P., Xiang, S., He, J., Kibbee, S., & Bian, S. (2015). Advancing Cold Water Intake Riser Design through Model Test. Offshore Technology Conference, 04-07 May, Houston, Texas, USA. DOI: https://doi.org/10.4043/25917-MS
Cao Q. et al. 2017. Analysis of multi-layered fiber-wound offshore rubber hose under internal pressure. ICCS17 Conference, Paris, France.
Carpenter, E.B. et al., 1994. Behaviour of a moored Discus Buoy in an Ochi-Hubble Wave Spectrum -OMAE1994. In *Offshore Technology Conference Proceeding*. ASME, pp. 347–354.
Carter J. W. (1985). Method and apparatus for longitudinally reinforcing continuously generated plastic pipe. Patent 4887, Editor, USA, 1985.
Castelbaum et al. (1984). Flexible hose having an end connection fitting. Patent 4477108, USA, 1984-10-16.
Cees van Rhee, Edwin Munts, Jochem van den Bosch, Rick Lotman, John Heeren (2013). New Developments in the Simulation of Slurry Behaviour in Spooled Hoses for Offshore Mining Applications. Offshore Technology Conference, 6-9 May, Houston, Texas, USA. Paper Number OTC-24082-MS, DOI: https://doi.org/10.4043/24082-MS
Chakrabarti, S.K., 2001. *Hydrodynamics of offshore structures* Reprint., Southampton, UK: WIT Press.
Chakrabarti, S.K., 1994. *Offshore Structure Modeling -Advanced Series on Ocean Engineering -Volume 9*, Singapore: World Scientific.
Chakrabarti, S.K., 2002. *The Theory and Practice of Hydrodynamics and Vibration -Advanced Series on Ocean Engineering -Volume 20*, Singapore: World Scientific.
Chakrabarti, S.K., (2005). Handbook of Offshore Engineering. Elsevier, UK.
Chakrabarti, S.K., Frampton, R.E., (1982). Review of riser analysis techniques. Appl. Ocean Res. 4 (2), 73–90. https://doi.org/10.1016/S0141-1187(82)80002-3
Charlesworth, D., D'All, B., Zimmerlin, C., Remita, E., Langhelle, N., & Ting W. (2011). "Operational Experience of the Fatigue Performance

of a Flexible Riser with a Flooded Annulus." Paper OTC 22398 presented at the OTC Brasil, Rio de Janeiro, Brazil, October 2011. doi: https://doi.org/10.4043/22398-MS

Chen Y., Seemann R., Krause D., Tay T.E., Tan V.B.C. (2016). Prototyping and testing of composite riser joints for deepwater application. Journal of Reinforced Plastics and Composites, Vol. 35, Issue 2, 95-110. DOI: 10.1177/0731684415607392

Chesterton C. (2020). A global and local analysis of offshore composite material reeling pipeline hose, with FPSO mounted reel drum. BEng Dissertation. Lancaster University, Engineering Department.

Chevalier et al. (1974). Couplings of reduced size and capable of transmitting high mechanical stresses between an armoured flexible member and a rigid element. Patent 3799587, USA, 1974-03-26.

Chibueze, N.O., Ossia, C.V. & Okoli, J.U., (2016). On the Fatigue of Steel Catenary Risers. *Strojniški vestnik - Journal of Mechanical Engineering*, 62(12), pp.751–756. https://doi.org/10.5545/sv-jme.2015.3060

Chiu C., Hwan C., Tsai H., Lee W., (2007). An experimental investigation into the mechanical behaviors of helical composite springs, Compos. Struct. Vol. 77 331–340. https://doi.org/10.1016/j.compstruct.2005.07.022

Cho J.R. and Yoon Y.H. (2016). Large deformation analysis of anisotropic rubber hose along cyclic path by homogenization and path interpolation methods. Journal of Mechanical Science and Technology 30 (2), pp. 789-795. DOI 10.1007/s12206-016-0134-5

Cho J.R., Song J.I. (2007). Swaging process of power steering hose: Its finite element analysis considering the stress relaxation. Journal of Materials Processing Technology, Volumes 187–188, 12 June 2007, Pages 497-501. https://doi.org/10.1016/j.jmatprotec.2006.11.113

Cho J.R., Yoon Y.H., Seo C.W., Kim Y.G. (2015). Fatigue life assessment of fabric braided composite rubber hose in complicated large deformation cyclic motion. Finite Elements in Analysis and Design, Volume 100, August 2015, Pages 65-76 https://doi.org/10.1016/j.finel.2015.03.002

Cho, J. R., Song, J. I., Noh, K. T. and Jeon, D. H. (2005). Nonlinear finite element analysis of swaging process for automobile power steering hose. J. Materials Processing Technology 170, 1−2, 50−57. https://doi.org/10.1016/j.jmatprotec.2005.04.077

Chung J S, White A K, Loden W A. (1981). Nonlinear transient motion of deep ocean mining pipe[J]. Journal of Energy Resources Technology, 103(3): 2−10.

Chung J. S., Cheng B. R., Huttelmaier H. P. (1994). Three-dimensional coupled responses of a vertical deep-ocean pipe: Part I. Excitation at pipe ends and external torsion[J]. International Journal of Offshore and Polar Engineering, 4(4): 320−330.

Chung J. S., Cheng B. R., Huttelmaier H. P. (1994). Three-dimensional coupled responses of a vertical deep-ocean pipe: Part II. Excitation at pipe top and external torsion[J]. International Journal of Offshore and Polar Engineering, 4(4): 331−339.

Chung J. S., Felippa C. A. (1981). Nonlinear static analysis of deep ocean mining pipe — Part II: Numerical studies[J]. Journal of Energy Resources Technology, 103(3): 16−25.

Cristescu, N. (1964). *Rapid motions of extensible strings. Journal of the Mechanics and Physics of Solids, 12(5), 269–278. DOI:10.1016/0022-5096(64)90025-0.*

Continental (2021). Welcome to Contnental (History 1871). Continental Corporation. Available at: www.continental.com/en/ (Accessed on 2nd November, 2021).

ContiTech, 2017. Marine Hoses - Offshore Fluid Transfer. *Contitech Oil & Gas*. Available at: http://www.contitech-oil-gas.com/pages/marine-hoses/marine-hoses_en.html [Accessed September 30, 2017].

ContiTech (2018). 2H Offshore Lunch & Learn - API 17K Production Hoses. Dunlop Oil & Marine - ContiTech. Available at: https://aosoffshore.com/wp-content/uploads/2020/02/Contitech-API-17K-production-hose.pdf Retrieved on: 7th August 2021

ContiTech (2019). Dunlop Oil & Marine - ContiTech Marine Hose Brochure. Available at: https://aosoffshore.com/wp-content/uploads/2020/02/ContiTech_Marine-Brochure.pdf Retrieved on: 9th April 2020

ContiTech (2020). Dunlop Oil & Marine - ContiTech Offshore Product Catalogue: GMPHOM 2009 Hoses Brochure. Available at: https://www.jst-group.com/wp-content/uploads/2020/01/Brochure-Dunlop-Oil-and-Marine-GMPHOM.pdf Retrieved on: 9th April 2021

ContiTech (2014). Hose Data Tables: GMPHOM 2009 hoses. Continental ContiTech and Dunlop Oil & Marine, Grimsby, UK.

Coppens A., Poldervaart L. (1984). Mooring system. 25 December, 1984.

Craig, Ian. "Review of Bonded Rubber Flexible Hose Design Codes and Guidelines in Relation to Sea Water Intake Risers on FPSO Vessels." Paper presented at the Offshore Technology Conference Asia, Kuala Lumpur, Malaysia, March 2016. doi: https://doi.org/10.4043/26648-MS

Cruz, I., Claro, C., Gouveia, J., Lemos, L., Câmara, M., Pereira, L., Mair J.A., de Paula M. T. R. and Escudero, C. C. (2015). The New Technology Enablers Developed and Deployed on a Live Project. Offshore Technology Conference, 04-07 May, Houston, Texas, USA. DOI: https://doi.org/10.4043/25832-MS

Cruz, I., Claro, C., Sahonero, D., Otani, L., & Pagot, J. (2015). The Buoy Supporting Risers (BSR) System: A Novel Riser Solution for Ultra-Deep Water Subsea Developments in Harsh Environments. Offshore Technology Conference, OTC Brasil, 27-29 October, Rio de Janeiro, Brazil. DOI: https://doi.org/10.4043/26330-MS

Cruz, I., Hepner, G., Karunakaran, D., Claro, C., Nicoletti, F., Fontaine, E., Hesar M,, de Paula M. T. R. and Trovoado, L. C. (2015). The Buoy Supporting Risers (BSR) System: Engineering a Solution for Ultra-Deep Water Subsea Developments in Harsh Environments. Offshore Technology Conference, 04-07 May, Houston, Texas, USA. DOI: https://doi.org/10.4043/25865-MS

Cunff, C. Le et al., 2007. Derivation of CALM Buoy coupled motion RAOs in Frequency Domain and Experimental Validation. *International Journal of Offshore and Polar Engineering*, (2007-JSC-594), pp.1–8.

Dahl, C. S., Andersen, B., Asp M., and Mikael G. (2012). "Developments in Managing Flexible Risers and Pipelines, A Suppliers Perspective." Paper OTC 21844. Presented at the Offshore Technology Conference, Houston, Texas, USA, May 2011. doi: https://doi.org/10.4043/21844-MS

Danyi Antal, Domonkos Imre, Bétéri Gyula, Katona Tamás (2012). Finite Element Analysis of seawater intake hoses. Continental ContiTech. Simday 2012, Budapest. Available at: https://docplayer.net/3495153-Finite-element-analysis-of-seawater-intake-hoses.html Retrieved on: 24th January, 2020

Dareing D.W. (2012). Mechanics of drillstrings and marine risers. First Edition. ASME Press, New York, USA. DOI**:** https://doi.org/10.1115/1.859995

Davidson, J. & Ringwood, J. V, 2017. Mathematical Modelling of Mooring Systems for Wave Energy Converters — A Review. *Energies*, 10(666).

De Baan J. and van Heijst W. J. (1991). Disconnectable mooring system for deep water. US5044297A, USA, 03 September, 1991.

De Baan J. and van Heijst W. J. (1994). Offshore tanker loading system. US5275510A, USA, 04 January 1994.

De Baan J., 2007. Off-shore mooring and fluid transfer system. Patent US7179144B2, USA. 2007-02-20.

De Sousa, J. R. M., Lima, E. C. P., Ellwanger, G. B., and Papaleo, A., 2001, "Local Mechanical Behavior of Flexible Pipes Subjected to Installation Loads," Proceedings of the 20th International Conference on Offshore Mechanics and Arctic Engineering.

Dean, R.G. & Dalrymple, R.A., 1991. *Water wave mechanics for engineers and scientists - Advanced Series on Ocean Engineering, Volume 2*, Singapore: World Scientific.

DNV, (2014). *DNV-OS-C201 Structural Design of Offshore Units (WSD Method) -Offshore Standard*, Norway: Det Norske Veritas.
DNV (2007). DNV-OS-F101 Offshore Standard. Submarine pipeline systems. Det Norske Veritas, Norway.
DNV (2010). DNV-OS-F201 Dynamic Risers: offshore standard. Det Norske Veritas, Oslo.
DNVGL (2015). DNVGL-OS-E403. Flexible hoses - Rules and standards. Available at: https://rules.dnv.com/docs/pdf/DNV/CP/2015-12/DNVGL-CP-0183.pdf
Doyle, S., & Aggidis, G. A. (2019). Development of Multi-Oscillating Water Columns as Wave Energy Converters. *Renewable and Sustainable Energy Reviews*, *107*, pp. 75-86. https://doi.org/10.1016/j.rser.2019.02.021
Drumond G.P., Pasqualino I.P., Pinheiro B.C., Segen F.E. (2018). Pipelines, risers and umbilicals failures: A literature review. Ocean Engineering, Volume 148, 15 January 2018, Pages 412-425 https://doi.org/10.1016/j.oceaneng.2017.11.035
DSMA (2019). Continental / ContiTech: Eddelbüttel + Schneider GmbH . Deep Sea Mining Alliance (DSMA), Hamburg, Germany. Available at: https://www.deepsea-mining-alliance.com/en-gb/continental
Duggal, A. & Ryu, S., 2005. The dynamics of deepwater offloading buoys. In *WIT Transactions on The Built Environment*. WIT Press.
Dunlop (2015). Dunlop History- Where it all began. Dunlop Europe. Available at: www.dunlop.eu/dunlop_be/_header/about_us/history/ (Accessed on 2nd November, 2021).
Dunlop (1971). *Dunlop Offshore hose manual*, Grimsby, England: Dunlop Oil and Marine Division.
Eisenzimmer (1982). Hose coupling. Patent 4353581, USA, 1982-10-12.
Ellis, S. E., Wadsworth, T. M., Lee, K., Gerdes, M., & Altizer, S. (2008). Connection Fatigue Index (CFI): An Engineered Solution for Connection Selection and a Replacement for BSR. Society of Petroleum Engineers, IADC/SPE Drilling Conference, 4-6 March, Orlando, Florida, USA. DOI: https://doi.org/10.2118/112105-MS
EMSTEC, 2016. *EMSTEC Loading & Discharge Hoses for Offshore Moorings*, Rosengarten: EMSTEC. Available at: https://www.emstec.net/fileadmin/files/product/downloads/EMSTEC_Loading_and_Discharge_HOM_2009__5th_Edition-open-file_10.pdf
EMSTEC (2021). EMSTEC -About us. Available at: www.emstec.net/about/ (Accessed on 2nd November, 2021).
Entwistle, K. M. (1981). "The behaviour of braided hydraulic hose reinforced with steel wires," International Journal of Mechanical Sciences, Vol. 23, No. 4, pp. 229-241. https://doi.org/10.1016/0020-7403(81)90048-5
Eriksson, M., Isberg, J. & Leijon, M., 2006. Theory and Experiment on an Elastically Moored Cylindrical Buoy. , 31(4), pp.959–963.
Fantuzzi N., Borgia F., Formenti M., Righini R. (2019). Mechanical optimization of an innovative overboarding chute for floating umbilical systems. Ocean Engineering, Volume 180, 15 May 2019, Pages 144-161. https://doi.org/10.1016/j.oceaneng.2019.04.004
Frederico Eggers, José Humberto S. Almeida Jr., Cristiano B. Azevedo, Sandro C. Amico (2019). Mechanical response of filament wound composite rings under tension and compression. Polymer Testing, Volume 78, 105951 https://doi.org/10.1016/j.polymertesting.2019.105951
Feiler et al. (1950). Coupling assembly for rotary drill hose. Patent 2506494, USA, 1950-05-02.
Felippa C. A., Chung J. S. (1981). Nonlinear static analysis of deep ocean mining pipe—Part I: Modeling and formulation[J]. Journal of Energy Resources Technology, 103(3): 11−15.
Fernando, S. U., Sheldrake, T., Tan, Z., and Clements, R., 2004, "The Stress Analysis and Residual Stress Evaluation of Pressure Armour Layers in Flexible Pipes Using 3D Finite Element Models," Proceedings of the 23rd International Conference on Offshore Mechanics and Arctic Engineering, 2004. https://doi.org/10.1115/OMAE2004-51200
Fisher et al. (1999). Gasket assembly with elastomer expansion area. Patent 5947533, USA,1999-09-07.
Flexomarine (2013). Product Catalogue—Hoses for Offshore Loading and Discharge Operations. Available at: www.flexomarine.com.br
FluidTec, 2015. *Anflex Industrial hose*, Singapore: Fluid-Tec Engineering & Trading. Available at: https://fluid-tec.net (Accessed on 2nd November, 2021).
Fluiconnecto (2021). Fluiconnecto-Our History. Available at: www.fluiconnecto.com/about-us/history (Accessed on 2nd November, 2021).
Flory J. F. (1976). Combined catenary and single anchor leg mooring system. US3979785A, USA, 14 September 1976.
Francesca Brindle (2016). Trelleborg launches new seawater intake hoses for FLNG. Available at: https://www.hydrocarbonengineering.com/product-news/22032016/trelleborg-launches-new-seawater-intake-hoses-for-flng-applications-2835/ Retrieved on 19th July, 2020.
Friedrich R., Kuo M. and Smyth K. (1998). High-pressure fiber reinforced composite pipe joint. Patent 5785092 A, USA, 28 July 1998.
Gallagher W. P. (1995). Marine riser. Patent 5474132 A, USA, 12 December 1995.
Gao Q., Zhang P., Duan M., Yang X., Shi W., An C., Li Z. (2018). Investigation on structural behavior of ring-stiffened composite offshore rubber hose under internal pressure. *Applied Ocean Research*, 79 (1), 7-19. https://doi.org/10.1016/j.apor.2018.07.007
Giacosa A., Mauriès B., Lagarrigue V. 2016. Joining forces to unlock LNG tandem offloading using 20" LNG floating hoses: An example of industrial collaboration. Presented at the Offshore Technology Conference, Houston, 2-5 May 2016. OTC-27132-MS.
Giorgi, G. et al., 2016. Nonlinear Hydrodynamic Models for Heaving Buoy Wave Energy Converters. AWTEC Asian Wave and Tidal Energy Conference, Singapore. Available at: http://www.eeng.nuim.ie/jringwood/Respubs/C264AWTm.pdf. Retrieved on 26th June, 2020.
Goddard (1998). Pipe coupler. Patent 5765880, USA, 1998-06-16.
Goff R. & Kay J. (2015). Investigations into the immediate and underlying causes of failures of offshore riser emergency shutdown valves. Prepared by the Health and Safety Laboratory for the Health and Safety Executive 2015. Research Report RR1072, HSE Books. Available at: https://www.hse.gov.uk/research/rrpdf/rr1072.pdf
Goldsworthy W. and Hardesty E. (1973). Method and apparatus for producing filament reinforced tubular products on a continuous basis. Patent 3769127 A, USA, 30 October 1973.
Gong S., Xu P., Bao S., Zhong W., He N., Yan H. (2014). Numerical modelling on dynamic behaviour of deepwater S-lay pipeline. Ocean Engineering, Volume 88, 15 September 2014, Pages 393-408. DOI: https://doi.org/10.1016/j.oceaneng.2014.07.016
Gonzalez, G.M., de Sousa, J.R.M. & Sagrilo, L.V.S. (2016) A study on the axial behavior of bonded flexible marine hoses. Marine Systems & Ocean Technology, 11:31–43. DOI: 10.1007/s40868-016-0015-x
Goodall (1940). Rotary hose coupling construction. Patent 2220785, USA, 1940-11-05.
GoodYear (2015). Parker Hose. Good year Rubber Products. Avaialable at: https://www.goodyearrubberproducts.com/top-100-products/Parker-Hose/Parker-Hose.asp Accessed on 8th September, 2021.
GoodYear (2021). GoodYear's Beginnings. Available at: www.corporate.goodyear.com/us/en/about/history/beginnings.html (Accessed on 2nd November, 2021).
Gouveia, J. et al., (2015). Steel Catenary Risers (SCRs): From Design to Installation of the First Reeled CRA Lined Pipes. Part I - Risers Design. OTC-25839-MS. In *Offshore Technology Conference Proceeding*. Houston, Texas, USA: OnePetro. **https://doi.org/10.4043/25839-MS**
Gouveia, J., Sriskandarajah, T., Karunakaran, D., Manso, D., Chiodo, M., Maneschy, R., Pedrosa J. and Cruz, I. (2015). The Buoy Supporting Risers (BSR) System: Steel Catenary Risers (SCRs) From Design to Installation of the First Reel CRA Lined Pipes. Offshore Technology Conference, OTC Brasil, 27-29 October, Rio de Janeiro, Brazil. DOI: https://doi.org/10.4043/26332-MS

Graber, H.C. et al., 2000. ASIS —A New Air–Sea Interaction Spar Buoy: Design and Performance at Sea. *Journal of Atmospheric and Oceanic Technology*, pp.708–720.

Graham, H., 1982. *Newcastle model hose tests*, Grimsby, England.

Grepaly, Istvan et al. (2005). High-pressure hose with adhesively bonded hose coupling which can be post-assembled. United States Patent 6938932, USA, 9th June, 2005.

Han S. R., Choi J. H. and Kwak J. S. (2012). New metal fitting geometry and optimization of the swaging parameters for an automobile power steering hose. International Journal of Automotive Technology, Vol. 13, No. 4, pp. 637−644. DOI: 10.1007/s12239−012−0062−z

Harkleroad W. I. (1969). Basic Principles of Hose Design. *Rubber Chemistry and Technology* 42 (3): 666–674. **https://doi.org/10.5254/1.3539247**

Hayes G. and Lemond J. (2013), Reducing noise in hydraulic systems. Parker Hannifin Corporation. Available at: https://pdfs.semanticscholar.org/4632/3432ab9d101393f6ae7beea7e01f86f09d0f.pdf

Hiller, D., Karunakaran, D., Cruz, I., & Tadeu, M. (2015). Developing an Innovative Deepwater Riser System: From Concept to the Full Production of Buoy Supporting Risers (BSR). Offshore Technology Conference, 04-07 May, Houston, Texas, USA. DOI: https://doi.org/10.4043/25850-MS

Haid, L. et al., 2013. Simulation-Length Requirements in the Loads Analysis of Offshore Floating Wind Turbines Preprint. In *32nd International Conference on Ocean, Offshore and Arctic Engineering*. Nantes, France: ASME.

Hampton J. E. (1991). Mooring system. US5065687A, USA, 19 November, 1991.

Hasselmann, K. et al., 1973. Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP). *Ergänzungsheft zur Deutsche Hydrographische Zeitschrift; Ergänzungsheft; Reihe A*, 12(8 0).

Hattori et al. (1989). Corrugated plastic pipe coupling. Patent 4871198, USA. 1989-10-03.

Hefler et al. (1992). Flexible coupling device for use in an engine manifold system. Patent 5159811, USA, 1992-11-03.

Holthuijsen, L.H., 2007. *Waves in oceanic and coastal waters* 1st ed., New York, USA: Cambridge University Press.

Hong S. and Hong S. W. (1994). A three-dimensional dynamic analysis of towed system, Part 1. A Mathematical Formulation, Journal of Ocean Engineering and Technology, 8 (1), pp. 16-22. Available at: https://www.koreascience.or.kr/article/JAKO199411920577005.pdf

Hong K.S. and Shah U. H. (2018). Vortex-induced vibrations and control of marine risers: A review. Ocean Engineering 152 (2018) 300–315. https://doi.org/10.1016/j.oceaneng.2018.01.086

Horvath et al. (1970). Head-formation of flexible hoses, especially for deep-drilling hoses. Patent 3531143, USA, 1970-09-29.

Horvath et al. (1977). Coupling for reinforced flexible hoses. Patent 4000920, USA, 1977-01-04.

HoseCo, 2017. *HoseCo Oil, Gas & Marine solutions*, Canning Vale, Australia: HoseCo Oil.

Huang, T.S. & Leonard, J.W., 1989. *Lateral Stability of a flexible submarine hoseline*, Port Hueneme, California, USA.

Humphreys G. (2006). Composite marine riser. Patent 7144048A1, USA, 25 December 2006.

Hursa A, Rolich T, RažićSE (2009). Determining pseudo Poisson's ratio of woven fabric with a digital image correlation method. Textile Research Journal; 79(17): 1588–1598. https://doi.org/10.1177%2F0040517509104316.

Irvine H. Max, 1981. Cable Structures. Mit Press, Cambridge, Massachusett, USA.

IMCA (2001). Failure of cable socks (chinese fingers) on subsea rigging. IMCA SF 12/01 Report. Available at: https://www.imca-int.com/alert/136/failure-of-cable-socks-chinese-fingers-on-subsea-rigging/

ISO (2006). ISO 13628-10: Petroleum and natural gas industries-Design and operation of subsea production systems-Part 10: Specification for bonded flexible pipe.

ISO (1991). ISO 1436: Rubber Hose and Hose Assemblies-Wire-Reinforced Hydraulic Type-Specification, International Standard.

ISO (1997). ISO 8032: Rubber and Plastics Hose Assemblies Flexing Combined Hydraulic Impulse Test Half-Omega Test," International Standard.

Jae-Won Oh, Chang-Ho Lee, Sup Hong, Dae-Sung Bae, Hui-Je Cho, Hyung-Woo Kim (2014). A study of the kinematic characteristic of a coupling device between the buffer system and the flexible pipe of a deep-seabed mining system. International Journal of Naval Architecture and Ocean Engineering**,** Volume 6, Issue 3, September 2014, Pages 652-669. https://doi.org/10.2478/IJNAOE-2013-0203

Jansen M.B. (1985). Fixed turret subsea hydrocarbon production terminal. US4301840A, USA, 24 November, 1981.

Jean-Loup Isnard, Patrick Ducousso, Rene Perratone (1999). Vessel with a disconnectable riser supporting buoy. US5941746A, USA, 24 August, 1999.

Jean-Louis Poisson, Florian Lacroix, Stephane Meo, Gaëlle Berton, Naranayaswami Ranganathan (2011). Biaxial fatigue behavior of a polychloroprene rubber. International Journal of Fatigue, Volume 33, Issue 8, August 2011, pp. 1151-1157 https://doi.org/10.1016/j.ijfatigue.2011.01.014

Jiang, D., Ma, L., et al., 2017. Design and analysis of a wave-piercing buoy. In *Automotive, Mechanical and Electrical Engineering*. CRC Press, pp. 69–73. Available at: https://doi.org/10.1201/9781315210445-16.

Jiang, D., Zhang, J., et al., 2017. Effect of heave plate on wave piercing buoy. In *Automotive, Mechanical and Electrical Engineering*. CRC Press, pp. 367–370.

Jiang, D., Li, W., et al., 2017. The strength analysis of the wave piercing buoy. In *AIP Conference Proceedings*.

Johansson et al. (1991). Method of joining tubes having a corrugated wall of plastic material. Patent 5053097, USA, 1991-10-01.

Jonathan Petit (2016). Trelleborg seawater intake hoses meet unique demands of FLNG applications. Available at: https://news.cision.com/trelleborg/r/trelleborg-seawater-intake-hoses-meet-unique-demands-of-flng-applications,c9939506 and https://mb.cision.com/Main/584/9939506/491456.pdf Retrieved on 19th July, 2020.

Jones R. M. (1998). Mechanics of composite materials. 2nd Edition. CSC Press, Boca Raton, USA. https://doi.org/10.1201/9781498711067

Jorge, P. et al. (2014). Design and analysis of buoy geometries for a wave energy converter. Int J Energy Environ Eng (2014) 5:91, DOI 10.1007/s40095-014-0091-7

Joubert P. and Falcimaigne J. (1989). Device for preventing a flexible line from twisting. US4820217A, USA, 11 April, 1989.

Joubert P., Loupias M., Durando P. (1981). Device for transferring a fluid through a liquid body by means of a flexible pipe. US4263004A, USA, 21 April, 1981.

Kaiser (1960). Fitting for a large-diameter rubber or plastic hose subjected to high loads Patent 2940778, USA, 1960-06-14.

Kalogirou, A. & Bokhove, O., 2016. Mathematical and numerical modelling of wave impact on wave-energy buoys; OMAE2016-54937. In *International Conference on Ocean, Offshore and Arctic Engineering*. Busan, South Korea: ASME, pp. 1–8.

Kang, Y. et al., 2014. Coupled analysis of FPSO and CALM buoy offloading system in West Africa. In *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE2014-23118*. California, USA: ASME.

Katayama, T. & Hashimoto, K., 2015. Development of a Motion Stabilizer for a Shallow-Sea-Area Spar Buoy in Wind , Tidal Current and Waves. , 2(3), pp.182–192.

Katona T., Nagy T., Zandiyeh A.R.K., Prinz M. , Boros A. (2009). High performance flexible lines for the Oil industry. Presented at the IRC 2009, in Nuremberg, Germany, June 29- July 02, 2009. Published on: Kautschuk und Gummi Kunststoffe KGK, Issue November

2009. pages 589-592. Available at: https://www.kgk-rubberpoint.de/wp-content/uploads/migrated/paid_content/artikel/910.pdf
Kenwell (2021). Seaflex Offshore Laoding & Discharge Hoses - Super Stream Hose. Available at: http://www.kenwell.com.sg/products/seaflex_offshore_loading_&_discharge_hoses/super_stream_hose Accessed on: 19th July, 2021.
Kim, J. et al., 2015. Design of the dual-buoy wave energy converter based on actual wave data of East Sea. *International Journal of Naval Architecture and Ocean Engineering*, 7(4), pp.739–749. Available at: http://dx.doi.org/10.1515/ijnaoe-2015-0052.
Kim, Sung-Soo, Yun, Hong-seon, Lee, Chang-Ho, Kim, Hyung-Woo, and Hong, Sup. "Efficient Analysis of a Deep-Seabed Integrated Mining System Using a Subsystem Synthesis Method." *Proceedings of the ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. *Volume 6: 11th International Conference on Multibody Systems, Nonlinear Dynamics, and Control*. Boston, Massachusetts, USA. August 2–5, 2015. V006T10A014. ASME. https://doi.org/10.1115/DETC2015-46700
Kim, B. T. and Kim, H. J. (2003). A study on the deformation characteristics of a high-pressure hose with respect to the swaging strokes. J. Korea Society for Power System Engineering 17, 4, 37−42. Kim,
Kim, B. T. and Kim, H. J. (2003). Nonlinear finite element analysis for the swaging of a high-pressure hose. J. Korea Society for Power System Engineering 7, 2, 44− 50.
KLAW (2021). Reducing stress on Hose Reel transfer systems when using Marine Breakaway Couplings. KLAW Whitepaper. Available at: https://www.klawproducts.com/klaw/reports-and-papers/reducing-stress-hose-reels/
Knapp R.H. (1979). Derivation of a new stiffness matrix for helically armoured cables considering tension and torsion. International Journal for Numerical Methods in Engineering, Vol. 14, 515-529.
Krismer, S. Hydraulic hose failures caused by corrosion of the reinforcing strands. *Practical Failure Analysis* **3,** 33–39 (2003). https://doi.org/10.1007/BF02717420
Kunio Hasegawa, Yinsheng Li, Kazuya Osakabe (2014). Collapse loads for circumferentially through-wall cracked pipes subjected to combined torsion and bending moments. Engineering Fracture Mechanics, Volume 123, June 2014, Pages 77-85 https://doi.org/10.1016/j.engfracmech.2013.12.013
Kurt (2021). Marine Hydraulics: Marine Hose Products. Kurt Hydraulics. Available at: www.kurthydraulics.com/industry-solutions/marine/ (Accessed on 2nd November, 2021).
Kwak, S. B. and Choi, N. S. (2009). Micro-damage formation of a rubber hose assembly for automotive hydraulic brakes under a durability test. Engineering Failure Analysis 16, 4, 1262−1269
Kwak, S. B. and Choi, N. S. (2009). Micro-damage formation of a rubber hose assembly for automotive hydraulic brakes under a durability test. Engineering Failure Analysis 16, 4, 1262−1269.
Kwong A.H.M and Edge K.A. (1998). A method to reduce noise in hydraulic systems by optimizing pipe clamp locations. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, Vol 212, Issue 4. https://doi.org/10.1243%2F0959651981539451
Kuiper, G.L., Metrikine, A.V. and J.A. Battjes, A New Time-domain Drag Description and its Influence on the Dynamic Behavior of a Cantilever Pipe Conveying Fluid. Journal of Fluids and Structures 23 (2007) 429–445.
Lagarrigue V., Hermary J., Mauriès B. 2014. Qualification Of A Cryogenic Floating Flexible Hose Enabling Safe And Reliable Offshore LNG Transfer For Tandem FLNG Offloading Systems. Presented at the Offshore Technology Conference, Houston, 5-8 May 2014. Paper No. OTC-25413-MS. DOI: 10.4043/25413-MS.
Lagarrigue V. & Landriere N. (2017). Trelleborg Survey report 2017; in: Louise Smyth (2017). Trelleborg, France. Available at: https://www.engineerlive.com/content/fluid-dynamics
Langkjaer (2002). Assembly of an end-fitting and a flexible pipe. Patent 6412825, USA, 2002-07-02.
Lassen, T., Eide, A. L., & Meling, T. S. (2010). Ultimate Strength and Fatigue Durability of Steel Reinforced Rubber Loading Hoses. Proceedings of 29th International Conference on Ocean, Offshore and Arctic Engineering: *Volume 5, Parts A and B.* DOI:10.1115/omae2010-20236
Lassen T., Lem A.I., Imingen G. (2014). Load Response and Finite Element Modelling of Bonded Loading Hoses. Proceedings of ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering**,** June 8–13, 2014, San Francisco, California, USA. Volume 6A, Paper No: OMAE2014-23545, V06AT04A034; pp. 1-17, https://doi.org/10.1115/OMAE2014-23545
Lebon, L. & Remery, J., 2002. Bonga: Oil Off-loading System using Flexible Pipe. In *Offshore Technology Conference Proceeding -OTC 14307*. Houston, Texas, USA: OnePetro, pp. 1–12.
Lee C.H. et al. (2015). A Study of Dynamic Analysis for Deep-seabed Integrated Mining System using Subsystem Synthesis Method. ECCOMAS Thematic Conference on Multibody Dynamics June 29 - July 2, 2015, Barcelona, Catalonia, Spain. Available at: http://congress.cimne.com/multibody2015/admin/files/fileabstract/a211.pdf
Lee, C., Hong, S., Kim, H. *et al.* (2015). A comparative study on effective dynamic modeling methods for flexible pipe. Journal of Mechanical Science and Technology 29 (7), pp. 2721-2727. DOI: https://doi.org/10.1007/s12206-015-0520-4
Lee G. C. et al. (2011). A Study of the Life Characteristic of Hydraulic Hose Assembly by Adopting Temperature-Nonthermal Acceleration Model. Journal of Applied Reliability, Volume 11 Issue 3, Pages 235-244. Available at: https://www.koreascience.or.kr/article/JAKO201136151483093.pdf
Lee, G. C., Kim, H. E., Park, J. W., Jin, H. L., Lee, Y. S. and Kim, J. H. (2011). An experimental study and finite element analysis for finding leakage path in high pressure hose assembly. International Journal of Precision Engineering and Manufacturing Vol. 12, No. 3, pp. 537-542. DOI: 10.1007/s12541-011-0067-y
Longmore D.K. and Schlesinger A. (1991). Transmission of Vibration and Pressure Fluctuations Through Hydraulic Hoses. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering. Volume 205, Issue 2, pp. 97-104. https://doi.org/10.1243/PIME_PROC_1991_205_319_02
Løtveit S. A. (2009). PSA Norway State of the art Bonded Flexible Pipes: 5662 PSA Norway. 4Subsea AS, Asker, Norway. Report Number 2008-4SUB-0189, Revision 2.0. Available at: https://www.ptil.no/contentassets/cc69bb9245ca41dfab2e3e635f22f58b/report-on-bonded-flexible-pipes2009.pdf Retrieved on 21st December, 2021.
Løtveit S.A. (2018). State of the art Bonded Flexible Pipes 2018: 1255 PSA Norway- Bonded flexibles. 4Subsea AS, Asker, Norway. Report Number 26583U-1161480945-354, Revision 2.0. Available at: https://www.4subsea.com/wp-content/uploads/2019/01/PSA-Norway-State-of-the-art-Bonded-Flexible-Pipes-2018_4Subsea.pdf Retrieved on 21st December, 2021.
Lenci, S., Callegari, M. (2005). Simple analytical models for the J-lay problem. *Acta Mechanica* **178,** 23–39. DOI: https://doi.org/10.1007/s00707-005-0239-x
Li X., Jiang X. and Hopman H. (2018). A review on predicting critical collapse pressure of flexible risers for ultra-deep oil and gas production. Applied Ocean Research 80 (2018), 1-10. https://doi.org/10.1016/j.apor.2018.08.013
Li X., Jiang X. and Hopman H. (2018). Prediction of the critical collapse pressure of ultra-deep water flexible risers - a literature review. FME Transactions, Vol 46 (3), 306-312. https://doi.org/10.5937/fmet1803306L
Li Yuanwen, Liu Shaojun, Hu Xiaozhou. (2018). Research on rotating speed's influence on performance of Deep-Sea lifting motor pump

based on DEM-CFD. *Marine Georesources & Geotechnology* 38:6, pages 744-752. https://doi.org/10.1080/1064119X.2018.1514550

Li Yuanwen, Liu Shaojun, Hu Xiaozhou. (2019). Research on reflux in deep-sea mining pump based on DEM-CFD. *Marine Georesources & Geotechnology* 38:6, pages 744-752. https://doi.org/10.1080/1064119X.2019.1632995

Li, Y., S. J. Liu, and L. Li. 2007. Dynamic Analysis of Deep-Ocean Mining Pipe System by Discrete Element Method. China Ocean Engineering 21 (1): 175–185.

Li, F. S., and Kyriakides, S., 1991, "On the Response and Stability of Two Concentric, Contacting Rings Under External Pressure," Int. J. Solids Struct., 27(1), pp. 1-14. https://doi.org/10.1016/0020-7683(91)90141-2

Lighthill, J., 1986. Fundamentals concerning wave loading on offshore structures. *J . Fluid Mechanics*, 173(1), pp.667–681.

Lighthill, J., 1979. waves and hydrodynamic loading. In *Proc. 2nd. Int. Conf. Behavior of Offshore Structures (BOSS '79)*. London, pp. 1–40.

Lipski, W. (2011). Mechanical Lined Pipe - Installation by Reel-Lay. Subsea 7 Presentation, UK. Available at: https://www.yumpu.com/en/document/view/26877695/mechanical-lined-pipe-installation-by-reel-lay-subsea-uk (Accessed on 2nd November, 2021).

Liu, Y., Huang, H., Gao, H., & Wu, X. (2013). *Modeling and boundary control of a flexible marine riser coupled with internal fluid dynamics*. *11*(61203060), 316–323. https://doi.org/10.1007/s11768-013-1245-5

Lu, J., Frank, M. A., Tan, Z., and Sheldrake, T., 2008, "Bent Collapse of an Unbonded Rough Bore Flexible Pipe," Proceedings of the 27th International Conference on Offshore Mechanics and Arctic Engineering. Paper No: OMAE2008-57063, pp. 27-31; https://doi.org/10.1115/OMAE2008-57063

Maclachlan (1940). Hose and coupling structure. Patent 2219047, USA, 1940-10-22.

Maneschy, R. et al., (2015). Steel Catenary Risers (SCRs): From Design to Installation of the First Reeled CRA Lined Pipes. Part II - Fabrication and Installation. OTC-25857-MS. In *Offshore Technology Conference Proceeding*. Houston, Texas, USA: OnePetro. https://doi.org/10.4043/25857-MS

Manouchehr, S. (2012). A discussion of practical aspects of reeled flowline installation. Proceedings of the ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering, OMAE2012, July 1-6, 2012, Rio de Janeiro, Brazil. Paper No. OMAE2012-83649.

ManuliRubber (2021). Manuli Rubber Industries (MRI)- Mission and Overview. Manuli Rubber, Italy Available at: www.manulirubber.com (Accessed on 2nd November, 2021).

Mars W. and Fatemi A. (2001). "Experimental Investigation of Multiaxial Fatigue in Rubber", 6th International Conference on Biaxial/Multiaxial Fatigue and Fracture, Lisboa.

Mars, W. V., & Fatemi, A. (2004). Observations of the Constitutive Response and Characterization of Filled Natural Rubber Under Monotonic and Cyclic Multiaxial Stress States. *Journal of Engineering Materials and Technology, 126(1), 19-28*. Transactions of the ASME. DOI:10.1115/1.1631432

Mars, W. V., & Fatemi, A. (2005). Multiaxial fatigue of rubber: Part II: experimental observations and life predictions. Fatigue & Fracture of Engineering Materials & Structures, Volume 28, Issue 6, pp. 523-538. https://doi.org/10.1111/j.1460-2695.2005.00895.x

Mars, W. V., & Fatemi, A. (2005). Multiaxial fatigue of rubber: Part I: equivalence criteria and theoretical aspects. Fatigue & Fracture of Engineering Materials & Structures, Volume 28, Issue 6, pp. 523-538. https://doi.org/10.1111/j.1460-2695.2005.00891.x

Martins, C. A., Pesce, C. P., and Aranha, J. A. P., 2003, "Structural Behavior of Flexible Pipe Carcass During Launching," ASME Paper No. OMAE2003- 37053.

Maslin, E., 2014. Unmanned buoy concepts grow. *Offshore Engineer*, 1(05). Available at: http://www.oedigital.com/component/k2/item/5621-unmanned-buoy-concepts-grow.

Mauriès B. 2014. Development of an LNG Tandem Offloading System Using Floating Cryogenic Hoses - Breaking the Boundaries of LNG Transfer in Open Seas. Presented at the Offshore Technology Conference, 5-8 May 2014, Houston, USA. Paper No. OTC-25342-MS. **https://doi.org/10.4043/25342-MS**

Mayau D.; Rampi L. (2006). Trelline— a New Flexible Deepwater Offloading Line (OLL). Paper presented at the The Sixteenth International Offshore and Polar Engineering Conference, San Francisco, California, USA, May 2006. Paper Number: ISOPE-I-06-127. Published: May 28 2006

McCormick, M.E., 2010. *Ocean Engineering Mechanics with applications*, New York, USA: Cambridge University Press.

Milad, M., Green, S., Ye, J., (2018). Mechanical properties of reinforced composite materials under uniaxial and planar tension loading regimes measured using a non-contact optical method, Composite Structures, Vol. 202, pp. 1145-1154. DOI: https://doi.org/10.1016/j.compstruct.2018.05.070

Miller, J. and Chermak, M. A. (1997). Wire braid angle response characteristics in hydraulic hose. SAE Technical Paper 972706, SAE Trans. 106, 2, 107−126 https://doi.org/10.4271/972706

Mills D. (2000). Using rubber hose to enhance your pneumatic conveying process. Powder and Bulk Engineering, Issue 3, March 2000. Pages 79-97. Available at: https://www.powderbulk.com/wp-content/uploads/pdf/pbe_20000301_79.pdf

Minguez, M., Clergue, S., Van Kessel, J., Bessière, L., Pattedoie, S., Renaud, M., Skledar M., Lange F., Miller E., Masterton, S. (2020). Water Intake Riser WIR – from Design to Installation, an Example of Complex Structure Requiring Multi-Disciplinary Approach. Offshore Technology Conference, 04-07 May, Houston, Texas, USA. DOI: https://doi.org/10.4043/30708-MS

Morgan G. and Lilly H. (1974). Transfer system for suboceanic oil production. US3834432A, USA, 10 September, 1974.

Morison, J.R. et al., 1950. The Force Exerted by Surface Waves on Piles. *Petroleum Transactions, AIME*, 189, pp.149–154.

Motulsky HJ, Ransnas LA. Fitting curves to data using nonlinear regression: a practical and nonmathematical review. FASEB J 1987;1(5):365–74.

MSCSoftware (2021). Marc- Advanced Nonlinear Simulation Software. MSC Software, USA. Available at www.mscsoftware.com

Muller (1941). Hose and coupling structure. Patent 2234350, USA, 1941-03-11.

Muller (1949). Hose coupling. Patent 2473441, USA, 1949-06-14.

Mungall J. C. H., Garrett D. L., and Alexander C. H. (1997). Marine steel catenary riser system. US5639187A, USA, 17 June, 1997.

Muren J. (2007). Failure modes, inspection, testing and monitoring. PSA Norway Report. Report Number D5996-RPT01-REV02. Available at: https://www.ptil.no/contentassets/a4c8365164094826a24499ef9f22742b/p5996rpt01rev02cseaflex_janmuren.pdf (Accessed on 2nd November, 2021).

Murphy et al. (1979). Hose coupling. Patent 4143892, USA, 1979-03-13.

Mustoe G. G., Hettelmaier H. P., Chung J. S. (1992). Assessment of dynamic coupled bending-axial effects for two-dimensional deep-ocean pipes by the discrete element method[J]. International Journal of Offshore and Polar Engineering, 2(4): 289−296.

Nagy T., Antal S., Boros A., Sergely Z.I. (1999). High pressure hoses for the offshore oil industry. 'Hochdruckschläuche in der Offshore Ölindustrie'. Presented at the DKG-Fachlagung '98, in Fulda, Germany, 30 Jun-1 July 1999. Published on: Kautschuk und Gummi Kunststoffe 52(7):482-485 [In German Language]. Available at: https://www.researchgate.net/publication/291532602_High_pressure_hoses_for_the_offshore_oil_industry (Accessed on 2nd November, 2021).

Nakane (1935). Flexible hose. Patent 1994587, USA, 1935-03-19.

Nandakumar B. N., Hooper A., Hvide H. J. (2002). Cantenary anchor leg mooring buoy. US5651709A, USA, 20 June, 2002.

NationalArchives (2021). Dunlop Ruber Company Limited. The National Archives, Vol. 74, London Metropolitan Archives: City of London. Available at: www.discovery,.nationalarchives.gov.uk/details/r/ea550246-a341-4f78-9f52-cba3aa5bd69b (Accessed on 2nd November, 2021).

Neto A.G., C.A. Martins, E.R. Malta, R.L. Tanaka, C.A.F. Godinho, (2017). Simplified Finite Element Models to Study the Wet Collapse of Straight and Curved Flexible Pipes, *ASME* J. Offshore Mech. Arct. Eng. 139 (6): 061701, pp. 1-9.

Neto A.G., C.A. Martins, E.R. Malta, R.L. Tanaka, C.A.F. Godinho, (2016). Simplified Finite Element Models to Study the Dry Collapse of Straight and Curved Flexible Pipes, *ASME J. Offshore Mech. Arct. Eng.* 138 (2), p.021701

Neto A.G., C.A. Martins (2014). Flexible pipes: influence of the pressure armor in the wet collapse resistance, J. Offshore Mech. Arct. Eng. 136 031401-1-8. **Paper No:** OMAE-11-1085 https://doi.org/10.1115/1.4027476

Neto, A.G., and Martins, C. A., 2010, "Burst Prediction of Flexible Pipes," Proceedings of the 29th International Conference on Offshore Mechanics and Arctic Engineering, 2010.

Neto, A.G., and Martins, C. A., 2012, "A Comparative Wet Collapse Buckling Study for the Carcass Layer of Flexible Pipes," ASME J. Offshore Mech. Arct. Eng., 134(3), p. 031701

Neto, A.G., Martins, C. A., Pesce, C. P., Meirelles, C. O. C., Malta, E. R., Barbosa Neto, T. F., and Godinho, C. A. F., (2013). "Prediction of Burst in Flexible Pipes," ASME J. Offshore Mech. Arct. Eng., 135 (011401), pp. 1-9.

Newman, J.N., 1963. *The motions of a spar buoy in regular waves, Report No. 1499*, Virginia, USA.

Nooij, S., 2006. *Feasibility of IGW technology in offloading hoses*. Delft University of Technology.

O'Brien P., et al. (2012). "Outcomes from the SureFlex Joint Industry Project—An International Initiative on Flexible Pipe Integrity Assurance". Paper No. OTC 21524. Presented at: *Offshore Technology Conferenc*e, Houston, USA.

O'Donoghe, T. & Halliwell, A.R., 1988. Floating Hose-Strings Attached to a CALM Buoy. In *Offshore Technology Conference Proceeding - OTC 5717*. Houston, Texas, USA: OnePetro, pp. 313–320

O'Donoghue, T. (1987). The dynamic behaviour of a surface hose attached to a CALM buoy . PhD Thesis. *Heriot-Watt University, Edinburgh. Offshore Engineering Department*, UK, pp. 1-197.

O'Donoghue, T., & Halliwell, A. R. (1990). Vertical bending moments and axial forces in a floating marine hose-string. *Engineering Structures*, *12*(4), 124–133.

O'Sullivan, M., 2003. Predicting interactive effects of CALM buoys with deepwater offloading systems. *Offshore Magazine*, 63(1).

O'Sullivan, M., 2002. West of Africa CALM Buoy Offloading Systems. *MCS Kenny Offshore Article*. Available at: http://www.mcskenny.com/downloads/Software - Offshore Article.pdf.

Obokata, J., 1987. On the basic design of single point mooring (1st Report)-Applications of the Dynamic Stability Analysis to the Primary Planning of the System. *Journal of the Society of Naval Architects of Japan*, 1987(161), pp.183–195.

Obokata, J. & Nakajima, T., 1988. On the basic design of single point mooring system (2nd report) - Estimation of the Mooring Force. *Journal of the Society of Naval Architects of Japan*, 1988(163), pp.252–260.

OCIMF, 2009. *Guide to Manufacturing and Purchasing Hoses for Offshore Moorings (GMPHOM)*. 5th Edition. Oil Companies International Marine Forum, Witherby Seamanship International Ltd, Livingstone, UK. Available at: https://www.ocimf.org/publications-advocacy/publications/books/guide-to-manufacturing-and-purchasing-hoses-for-offshore-moorings-gmphom

OCIMF, *Guideline for the Handing, Storage, Inspection and Testing of the Hose*, 2nd Ed. London, UK: Witherby & Co. Ltd, 1995.

OCIMF, *Single Point Mooring Maintenance and Operations Guide (SMOG)*. London, UK: Witherby & Co. Ltd, 1995.

Odijie, A.C., 2016. Design of Paired Column Semisubmersible Hull. PhD Thesis Lancaster University, Lancaster, UK Available at: https://doi.org/10.17635/lancaster/thesis/39.

Odijie, A.C., Wang, F. & Ye, J., 2017a. A review of floating semisubmersible hull systems: column stabilized unit. Ocean Eng., 144(October 2016), pp.191–202. Available at: https://doi.org/10.1016/j.oceaneng.2017.08.020.

Odijie, A.C., Quayle, S. & Ye, J., 2017b. Wave induced stress profile on a paired column semisubmersible hull formation for column reinforcement. Eng. Struct., 143(April), pp.77–90. Available at: https://doi.org/10.1016/j.engstruct.2017.04.013.

Oh J.W. et al. (2015). A study of integration framework for co-simulation with optimization design and multi-body dynamics. ECCOMAS Thematic Conference on Multibody Dynamics June 29 - July 2, 2015, Barcelona, Catalonia, Spain. Available at: http://congress.cimne.com/multibody2015/admin/files/fileabstract/a145.pdf

Oh, J.-W., C.-H. Lee, S. Hong, D.-S. Bae, H.-J. Cho, and H.-W. Kim. 2014. A study of the Kinematic Characteristic of a Coupling Device Between the Buffer System and the Flexible Pipe of a Deep-Seabed Mining System. International Journal of Naval Architecture and Ocean Engineering 6 (3): 652–669. doi:10.2478/IJNAOE-2013-0203

OIL, 2014. *Floating & submarine hoses (EMSTEC)- OIL hoses brochure*, Dudley, UK: Offspring International Limited.

OIL, 2015. *Mooring and Offloading Systems*, Dudley, UK: Offspring International Limited.

OIL (2020). OIL Offloading Hoses Brochure. Offspring International Limited. Dudley, UK. Available at: https://www.offspringinternational.com/wp-content/uploads/2020/06/OIL-Offloading-Hoses-Brochure-2020-W.pdf

Oliveira, M.C., 2003. Ultradeepwater Monobuoys, OMAE2003-37103. In *International Conference on Offshore Mechanics & Arctic Engineering*. Cancun, Mexico: ASME, pp. 1–10.

Olufsen A., Nordsve NT., and Karunakaran D. (1997). Riser. WO1997006341A1, USA, 20 February, 1997.

Orcina Ltd, (2014). *OrcaFlex Manual, Version 9.8a*, Ulverton, Cumbria, UK.

Orcina (2019). OrcaFlex version 10.3d. Software Technical Specification. Orcina Ltd, Ulverston, Cumbria.

Orcina Ltd (2020). Orcina Orcaflex, Retrieved from: http://www.orcina.com/SoftwareProducts/OrcaFlex/index.php , Accessed on 2019-12-22.

Orcina (2020). *Vessel theory: RAOs and phases.* Available at: https://www.orcina.com/webhelp/OrcaFlex10.3d *Accessed 21st Mar. 2020*

Orcina, 2019. OrcaFlex Version 10.3d Documentation, Orcina Ltd, Ulverston, Cumbria, UK. Available at: https://www.orcina.com/SoftwareProducts/OrcaFlex/Documentation/index.php.

Padua M. M., Goulart M. P., Mastrangelo C. F., Loureiro R. R., Castro G. A. V., João L. V., Maddalena M. A. (2020). A Journey of Floating Production Systems in Brazil. Offshore Technology Conference, 4-7 May, Houston, Texas, USA. DOI: https://doi.org/10.4043/30554-MS

Païdoussis, M.P., 2014. *Fluid-Structure Interactions: Slender Structures and Axial Flow* 2nd Ed., Oxford, UK: Elsevier Ltd.

Panicker N. N., Gentry L. L., Moss H. H. (1984). Marine compliant riser system. 03 January, 1984.

Pan B, Qian K, Xie H, Asundi A. Two-dimensional digital image correlation for in-plane displacement and strain measurement: a review. Meas Sci Technol 2009;20(6):6–20.

Papusha, A.N., 2015. *Beam Theory for Subsea Pipelines: Analysis and Practical Applications*, Wiley-Scrivener.

Patel M.H. and Seyed F.B. (1995). Review of flexible riser modelling and analysis techniques. Engineering Structures, Vol. 17, No. 4, pp. 293-304, 1995 https://doi.org/10.1016/0141-0296(95)00027-5

Paumier, L., Averbuch, D., and Felix-Henry, A., 2009, "Flexible Pipe Curved Collapse Resistance Calculation," ASME Paper No. OMAE2009-79117 https://doi.org/10.1115/OMAE2009-79117

Pavlou G. D. (2013). Composite materials in piping applications. DEStech Publications Inc., Lancaster, Pennsylvania, USA. ISBN: 978-1-60595-0297

Pesce C.P., Martins C.A., A.G. Neto, et al., Crushing and wet collapse of flowline carcasses: a theoretical-experimental approach, ASME 2010 29th International Conference on Ocean, Offshore and Arctic Engineering, (2010), pp. 521–529.

Peter Brownsort (2015). Offshore offloading of CO_2: Review of single point mooring types and suitability. Scottish Carbon Capture & Storage (SCCS). Available at: https://era.ed.ac.uk/bitstream/handle/1842/15712/SCCS-CO2-EOR-JIP-Offshore-offloading.pdf?sequence=1&isAllowed=y

Pham D.C., Sridhar N., Qian X., Sobey A.J., Achintha M., Shenoi A. (2016). A review on design, manufacture and mechanics of composite risers. Ocean Engineering Vol. 112(2016)82–96. http://dx.doi.org/10.1016/j.oceaneng.2015.12.004.

Picard, D., Hudson, W., Bouquier, L., Dupupet, G., & Zivanovic, I. (2007). Composite Carbon Thermoplastic Tubes for Deepwater Applications, OTC 19111. *Offshore Technology Conference*, 1–9.

Piccoli D.E. (1976). Hose Design for Unusual Hose Applications. Journal of elastomers & plastics. Vol. 8, Issue 4. https://doi.org/10.1177/009524437600800404

Pierce R. H. (1987). Composite marine riser system. Patent 4634314 A, USA, 6 January 1987.

Pierson, W.J. & Moskowitz, L., 1964. A Proposed Spectral Form for Fully Developed Wind Seas Based on the Similarity Theory of S . A . Kitaigorodskii. *Journal of Geographical Research*, 69(24), pp.5181–5190.

Pinkster, J.A. & Remery, G.F.M., 1975. The role of Model Tests in the design of Single Point Mooring Terminals. In *Offshore Technology Conference Proceeding -OTC 2212*. Dallas, Texas, USA: OnePetro, pp. 679–702.

Policelli F. J. (1989). End connectors for filament wound tubes. Patent 4813715 A, USA, 21 March 1989.

Policelli F. J. (1993). Filament wound threaded tube connection. Patent 5233737 A, USA, 10 August 1993.

Potluri P, Thammandra VS. Influence of uniaxial and biaxial tension on meso-scale geometry and strain fields in a woven composite. Compos Struct2007;77(3):405–18.

Prischi N., Mazuet F., Frichou A., and Lagarrigue V. (2012). "SS-Offshore Offloading Systems and Operations Bonded Flexible Oil Offloading Lines, A Cost Effective Alternative to Traditional Oil Offloading Lines." Paper presented at the Offshore Technology Conference, Houston, Texas, USA, April 2012. DOI: https://doi.org/10.4043/23617-MS

Quash, J.E. & Burgess, S., 1979. Improving underbuoy hose system design using relaxed storm design criteria. In *Offshore Technology Conference Proceeding*. pp. 1827–1836.

Quigley P. A., Nolet S. C. and Williams J. G. (2000) Composite spoolable tube. Patent 6016845, USA, 25 January 2000.

Ramos, R. (2016). *A Consistent Analytical Model to Predict the Structural Behavior of Flexible Risers Subjected to*. *126*(May 2004), 141–146. https://doi.org/10.1115/1.1710869.

Raheem, S.E.A., 2013. Nonlinear response of fixed jacket offshore platform under structural and wave loads. , 2(1), pp.111–126.

Rahman, M., 1981. Non-linear wave loads on large circular cylinders: a perturbation technique. *Advances in Water Resources*, 4(1), pp.9–19.

Rahman, M., 1984. Second order wave interaction with large structures.pdf. In T. B. M. C. Rogers, ed. *Wave Phenomena: Modern Theory and Applications*. Holland: Elsevier B.V., pp. 49–69.

Rampi, L., Lavagna, P., and D. Mayau. (2006). "TRELLINE? A Cost-Effective Alternative for Oil Offloading Lines (OOLs)." Paper presented at the Offshore Technology Conference, Houston, Texas, USA, May 2006. DOI: https://doi.org/10.4043/18065-MS

Rattensperger H., Eberhardsteiner J., Mang H.A. (2003) Numerical Investigation of High-Pressure Hydraulic Hoses with Steel Wire Braid. In: Miehe C. (eds) IUTAM Symposium on Computational Mechanics of Solid Materials at Large Strains. Solid Mechanics and Its Applications, vol 108. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-0297-3_37

Remery G. F. M. (1981). Device for conveying a medium from means provided in a fixed position on a bottom below the water surface to a buoy body. US4279543A, USA, 21 July, 1981.

RenewablesUK (2021). Wind energy statistics. Available at: https://www.renewableuk.com/page/UKWEDhome Accessed on: 9th May, 2021.

Rey, V. & Calve, O. Le, 2003. Experimental survey of the hydrodynamic performance of a small spar buoy. , 24(2002), pp.309–320.

Ricbourg, C. et al., 2006. Numerical and Experimental Investigations on Deepwater CALM Buoys Hydrodynamics Loads. In *Offshore Technology Conference Proceeding -OTC 18254 -PP*. Houston, Texas, USA: OnePetro, pp. 1–8.

Richardson S. (2004). Big bore rubber hoses for marine and offshore applications. (2004). *World Dredging, Mining and Construction, 40*(8), August 2004, Pages 16. ISSN: 1045-0343

Rong-Tai Ho (2008). Engineering Considerations for Offshore FSRU LNG Receiving Terminals. Offshore Technology Conference (OTC), 5-8 May, Houston, Texas, USA. Paper OTC 19439. DOI: https://doi.org/10.4043/19439-MS

Roveri, F. E., Volnei, Luís Sagrilo, S., & Cicilia, F. B. (2002). A Case Study on the Evaluation of Floating Hose Forces in a C.A.L.M. System. *Internation Offshore and Polar Engineering Conference*, *3*, 190–197.

Rudnick, B.P., 1967. Motion of a Large Spar Buoy in Sea Waves '. *Journal of Ship Research*, pp.257–267.

Ruiz MJG, Gonzalez LYS. Comparison of hyperelastic material models in the analysis of fabrics. Int J Cloth Sci Technol 2006;18:314–25.

Rychlik, I., 1987. A new definition of the rainflow cycle counting method. *Int. J. Fatigue 9*, 2(2), pp.119–121.

Ryu, S. et al., 2006. Prediction of Deepwater Oil Offloading Buoy Response and Experimental Validation. *International Journal of Offshore and Polar Engineering*, 16(3), pp.1–7.

SAE (2001), "Test and Test Procedures for SAE100R Series Hydraulic Hose and Hose Assemblies SAE J343," SAE Standard REV Jul 2001.

SAE(2008), "Hydraulic Hose," SAE J517. Society of Automotive Engineers

Saito, H. et al., 1980. Actual measurement of external forces on marine hoses for SPM. In *Offshore Technology Conference Proceeding -OTC 3803*. Houston, Texas, USA: OnePetro, pp. 89–97.

Salama M. M. and Mercier J. A. (1987). Aramid composite well riser for deep water offshore structures. Patent 0244048A2, USA, 4 November 1987.

Salama M. M. and Spencer B. E. (2010). Method of manufacturing composite riser. Patent 7662251B2, USA, 16 February 2010.

Sa´nchez, S. H. A., and Salas, C. C., 2006, "Risers Stability under External Pressure, Axial Compression and Bending Moment Considering the Welded as Geometrical Imperfection," Proceedings of the 25th International Conference on Offshore Mechanics and Arctic Engineering, 2006.

Sanders J. V. (1982). A three-dimensional dynamic analysis of a towed system. Ocean Engineering, Volume 9, Issue 5, pp. 483-499. https://doi.org/10.1016/0029-8018(82)90038-5

Sandip Patil et al (2020). The effect of thermostatic test environment on the flexural fatigue performance of hydraulic hose assemblies. IOP Conference Series: Materials Science and Engineering, Volume 804, Issue 012001. International Symposium on Fusion of Science and Technology (ISFT 2020) 6-10 January 2020, New Delhi, India. https://doi.org/10.1088/1757-899X/804/1/012001

Sao, K., Member, S.K. & Numata, T., 1987. Basic Equation and SALM Buoy Motion - Analysis Method for Single Point Mooring (Report 1). *Journal of the Society of Naval Architects of Japan*, 1987(182), pp.257–266.

Sarpkaya, T., 2014. *Wave forces on offshore structures* 1st ed., New York, USA: Cambridge University Press.

Sas-Jaworsky A. (1999). Composite coiled tubing end connector. Patent 5988702, USA, 23 November 1999.

Sas-Jaworsky A. and Williams J. G. (1994). Spoolable composite tubular member with integrated conductors. Patent 5285008, USA, 8 February 1994.

Saunders C., O'Sullivan T. (2007). Integrity management and life extension of flexible pipe. In: Offshore Europe, Society of Petroleum Engineers (SPE). Paper presented at the SPE Offshore Europe Oil and Gas Conference and Exhibition, Aberdeen, Scotland, U.K., September 4-7, 2007. doi: https://doi.org/10.2118/108982-MS

SBMO, 2012. *SBMO CALM Brochure*, Amsterdam, The Netherlands: SBM Offshore. Aailable at: https://www.sbmoffshore.com/wp-content/uploads/2013/09/SBMO-CALM_Original_2048.pdf

SBMOffshore (2011). SBM Offshore's COOLTM LNG Marine Transfer Hose System externally certified for first application in the industry. Press release- SBM Offshore N.V., 22nd March , 2011. Available at: https://www.sbmoffshore.com/wp-content/uploads/2013/05/PressRelease-20110322_Original_541.pdf

Schirtzinger J.F. (1969). Apparatus for loading and unloading offshore vessels. US3466680A, USA, 16 September, 1969.

Schrittener B., Pinter G., Schwarz T., Zalan Kadar, Nagy T. (2016). Rapid Gas Decompression Performance of elastomers – A study of influencing testing parameters. 21st European Conference on Fracture, ECF21, 20-24 June 2016, Catania, Italy. Procedia Structural Integrity 2:1746-1754. DOI: 10.1016/j.prostr.2016.06.220

Schram, J. W., & Reyle, S. P. (1968). *A Three-Dimensional Dynamic Analysis of a Towed System. Journal of Hydronautics, 2(4), 213–220.* DOI:10.2514/3.62793

Selvadurai A. (2006). Deflections of a rubber membrane. J Mech Phys Solids;54(6):1093–119.

Serene C.Y., & Chze L.P. (2015). Subsea Condition Monitoring: Does Effective Diagnosis Increase Availability? Journal of Petroleum Technology (JPT). Published on November 30, 2015. Available at: https://jpt.spe.org/subsea-condition-monitoring-does-effective-diagnosis-increase-availability

Seyed, F.B. & Patel, M.H., 1992. Mathematics of Flexible Risers Including Pressure and Internal Flow Effects. *Marine Structures*, 5(2-3), pp.121–150.

Shabana, A. A., and Yakoub, R. Y. (2001). "Three Dimensional Absolute Nodal Coordinate Formulation for Beam Elements: Theory." ASME. Journal of Mechanical Design. December 2001; 123(4): 606–613. https://doi.org/10.1115/1.1410100

Sherry Xiang, Peimin Cao, Richard Erwin and Steven Kibbee, OTEC Cold Water Pipe Global Dynamic Design For Ship-Shaped Vessels. OMAE2013-10927, Nantes, France, 2013.

Shotbolt K. (1988). Flexible riser system. US4793737A, USA, 27 December, 1988.

Simmons P. (1993). Composite threaded pipe connectors and method. Patent 5233737 A, USA, 10 August 1993.

Simonsen A. (2014). Inspection and monitoring techniques for unbonded flexible risers and pipelines. Masters Thesis, University of Stavanger, Norway.

Smyth L. (2017). Fluid dynamics. Lagarrigue & Landriere (2017). Engineer Live Magazine. Published on 1st Aug. 2017. Available at: https://www.engineerlive.com/content/fluid-dynamics

Sobrinho, L. L., Bastian, F. L., Materiais, E. De, Cariri, C., Janeiro, R. De, & Janeiro, R. De. (2011). *Composite tubes for riser application in deep water † †*. 1–17.

SOFEC (2021). About SOFEC mooring solutions & Fluid Transfer systems. Available at: www.sofec.com/about-sofec/ (Accessed on 2nd November, 2021).

SolentUniversity (2021). Offshore oil and gas renewables. Solent University, Southampton, UK. Available at: https://maritime.solent.ac.uk/maritime-industry/offshore-renewable Accessed on 30th August, 2021.

Song H. and Estep J. W. (2006). Spoolable composite coiled tubing connector. Patent 7059881 B2, USA, 13 July 2006.

Sorensen, R.M., 2006. *Basic Coastal Engineering* 3rd ed., New York, USA: Springer.

Sorensen, R.M., 1993. *Basic Wave Mechanics: For Coastal and Ocean Engineers*, John Wiley and Sons.

Sousa, J. R. M. De, Magluta, C., Roitman, N., Ellwanger, G. B., Lima, E. C. P., & Papaleo, A. (2009). On the response of flexible risers to loads imposed by hydraulic collars. *Applied Ocean Research*, *31*(3), 157–170. https://doi.org/10.1016/j.apor.2009.07.005.

Sparks, C.P. (2007). Fundamentals of Marine Riser Mechancis: Basic principles and simplified analyses. FIrst Edition. *PennWell Corporation, Tulsa, Oklahoma, USA.*

Stanton, P., 2014. Dynamic Risers for Floating Production Systems API Standard 2RD Second Edition , September 2013.

Starita, Joseph M. (2005). Corrugated plastic pipe sections having flanged ends and structurally tight joints thereof. United States Patent 6938933, USA. 09/06/2005.

Stearns, T. de B., 1975. *Computer simulation of underbuoy hoses*. California State University, Northridge, USA; Thesis.

Sun, Liping, Zhang, Xu, Kang, Youwei, and Chai, Shuhong (2015). "Motion Response Analysis of FPSO's CALM Buoy Offloading System." *Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering*. *Volume 11: Prof. Robert F. Beck Honoring Symposium on Marine Hydrodynamics*. St. John's, Newfoundland, Canada. May 31–June 5, 2015. V011T12A008. ASME., https://doi.org/10.1115/OMAE2015-41725

SureFlex, et al. (2010). "State of the Art Report on Flexible Pipe Integrity and Guidance Note on Monitoring Methods and Integrity Assurance for Unbonded Flexible Pipes. Joint Industry Project - SureFlex, WGIM, MCS Kenny. Publisher: Oil and Gas UK. Available at www.oilandgasuk.co.uk, publications code: OP010.

Sweeney, T.E., (1977). *The concept of an unmanned transatlantic sailing buoy (NOAA's Ark), AMS Report No. 1358*, New Jersey, USA.

Szabó, G., Váradi, K. and Felhős, D. (2017) Finite Element Model of a Filament-Wound Composite Tube Subjected to Uniaxial Tension. *Modern Mechanical Engineering*, **7**, 91-112. DOI: 10.4236/mme.2017.74007

Szekely Gergely and Peixoto Eduardo (2018). Flexible Hose Technology Benefits for Ship-to-Shore High Pressure Natural Gas Transfer. Offshore Technology Conference, 30 April - 3 May, Houston, Texas, USA. Paper OTC-28893-MS. DOI: https://doi.org/10.4043/28893-MS

Szekely, G., Peixoto, E., Czovek, Z., & Mezo, T. (2017). Managed Pressure Drilling Flexible Mud Return Line Advances. Society of Petroleum Engineers, IADC/SPE Managed Pressure Drilling & Underbalanced Operations Conference & Exhibition, 28-29 March, Rio de Janeiro, Brazil. DOI: https://doi.org/10.2118/185280-MS

Tang M.G., Lu Q.Z., Yan J., Yue Q.J. (2016). Buckling collapse study for the carcass layer of flexible pipes using a strain energy equivalence method, Ocean Engineering, Vol. 111 (2016) 209–217. http://dx.doi.org/10.1016/j.oceaneng.2015.10.057

Technip, 2006. *Coflexip® Flexible Steel Pipes for Drilling and Service Applications: User' s Guide*, Paris, France: Technip.

Terashima et al. (1996). Reinforced rubber hose, Patent 5526848, USA, 1996-06-18.

ThomasNet (2021). Durham Rubber & Belting Corp.- Company Profile. Available at: www.thomasnet.com/profile/00120500 (Accessed on 2nd November, 2021).

Timoshenko, S. P., and Gere, J. M., 1961, Theory of Elastic Stability, McGraw Hill International Book Company, Inc., New York, USA.

Toh W., Tan L.B., Jaiman R.K., Tay T.E., Tan V.B.C. (2018). A comprehensive study on composite risers: material solution, local end fitting

design and local design. Marine Structures 61 (2018), 155-169. https://doi.org/10.1016/j.marstruc.2018.05.005
Tonatto, M. L., Tita, V., & Amico, S. C. (2020). Composite spirals and rings under flexural loading: Experimental and numerical analysis. *Journal of Composite Materials*, *54*(20), 2697–2705. https://doi.org/10.1177/0021998320902504
Tonatto, M. L., Tita, V., Forte M. M. C. & Amico, S. C. (2018). Multi-scale analyses of a floating marine hose with hybrid polyaramid/polyamide reinforcement cords. Marine Structures, Volume 60, Pages 279-292 https://doi.org/10.1016/j.marstruc.2018.04.005
Tonatto, MLP, Roese, PB, Tita, V, et al. (2019). Offloading marine hoses: computational and experimental analyses. In book: Marine Composites, pp. 389–416. DOI: 10.1016/B978-0-08-102264-1.00014-5
Tonatto, M. L., Tita, V., Araujo R. T., Forte M. M. C., & Amico, S. C. (2017). Parametric analysis of an offloading hose under internal pressure via computational modelling. Marine Structures, Volume 51, Issue 2017, Pages 174-187 https://doi.org/10.1016/j.marstruc.2016.10.008
Tonatto, M. L., Forte M. M. C., Tita, V., & Amico, S. C. (2016). Progressive damage modeling of spiral and ring composite structures for offloading hoses. Materials & Design, Volume 108, Issue 2016, Pages 374-382. https://doi.org/10.1016/j.matdes.2016.06.124
Tonatto, M. L., Forte M. M. C. & Amico, S. C. (2016). Compressive-tensile fatigue behavior of cords/rubber composites. Polymer Testing, Volume 61, August 2017, Pages 185-190 https://doi.org/10.1016/j.polymertesting.2017.05.024
Trelleborg (2021). History- The Trelleborg Story. Trelleborg AB. Available at: www.trelleborg.com/en/about-us/history (Accessed on 2nd November, 2021).
Trelleborg (2012). Reeline hoses Catalogue 2012. Available at: http://www2.trelleborg.com/Global/WorldOfTrelleborg/Fluid%20handling/REELINE_catalogue.pdf (Accessed on 2nd November, 2021).
Trelleborg (2014). Trelline hoses Catalogue 2012. Available at: http://www2.trelleborg.com/Global/WorldOfTrelleborg/Fluid%20handling/TRELLINE%20Catalogue.pdf or http://www.irpc.com.co/docs/TRELLEBORG/TRELLEBORG%20TRELLINE%20HOSES%202012.pdf (Accessed on 2nd November, 2021).
Trelleborg (2016). *Oil & Gas Solutions: Oil & Gas Hoses for enhanced fluid transfer solutions*, Clemont-Ferrand, France: Trelleborg.
Trelleborg (2018). *Oil & Marine Hoses: Innovation and Safety for Oil & Gas Transfer Systems*. Trelleborg Brochure, Pages 1-30. Clemont-Ferrand, France: Trelleborg.
Trelleborg (2020). Hose Design. Available at: https://www.trelleborg.com/en/fluidhandling/products--and--solutions/oil--and--marine/hose--design (Accessed on 2nd November, 2021).
Tschoepe, E.C. & Wolfe, G.K., 1981. SPM Hose Test Program. In *Offshore Technology Conference Proceeding - OTC 4015*. Houston, Texas, USA: OnePetro, pp. 71–80.
Urdshals K. A. B., Hvide J. H. and Hooper A. G. (1994). Single point mooring system employing a submerged buoy and a vessel mounted fluid swivel. US5288253A, USA, 22 February, 1994.
van Diemen, J., et al., 2015. BSR Installation: Displacing 10,000t of Water to Install 2,500t of Steel Buoy at 250m Below Sea Level. Paper OTC-25887-MS presented at the Offshore Technology Conference, Houston, 4 – 7 May
VHMarineTech (2021). VH MarineTech- About Us. Available at: www.marine-flaotinghoses.com/about/ (Accessed on 2nd November, 2021).
Wang F., Lang Y., Li J., Luo Y. (2019). Innovations in a submarine piggyback pipeline project in the East China Sea. Proceedings of the Institution of Civil Engineers -Civil Engineering, Vol. 172 (2): 69-75. https://doi.org/10.1680/jcien.18.00010
Wang Gang, Liu Shao-jun (2005). Dynamic analysis on 3-D motions of deep-ocean mining pipe system for 1000-m sea trial [C]// Proceedings of the Sixth ISOPE Ocean Mining Symposium. Changsha, China, pp. 81−87.
Wang Zhi, Rao Qiu-hua, Liu Shao-jun (2009). Interaction of fluid-solid coupled flexible hose and mining machine in deep-ocean mining system [C]// Proceedings of the Eighth ISOPE Ocean Mining Symposium. Chennai, India, pp. 263−269.
Wang Zhi, RAO Qiu-hua, Liu Shao-jun (2011). Analysis of seabed-mining machine-flexible hose coupling in deep sea mining [C]// Proceedings of the Ninth ISOPE Ocean Mining Symposium. Maui, Hawaii, USA, pp. 143−148.
Wang, G., Liu, S. & Li, L. (2007). FEM modeling for 3D dynamic analysis of deep-ocean mining pipeline and its experimental verification. *J. Cent. South Univ. Technol.* **14,** 808–813. https://doi.org/10.1007/s11771-007-0154-5
Wang, Y., H. Tuo, L. Li, Y. Zhao, H. Qin, and C. An. (2018). Dynamic Simulation of Installation of the Subsea Cluster Manifold by Drilling Pipe in Deep Water Based on Orcaflex. Journal of Petroleum Science and Engineering 163: 67–78. doi:10.1016/j.petrol.2017.12.049.
Wang, Z., Q.-H. Rao, and S.-J. Liu (2012). Fluid-Solid Interaction of Resistance Loss of Flexible Hose in Deep Ocean Mining. Journal of Central South University 19 (11), pp. 3188–3193. doi:10.1007/s11771- 012-1394-6.
Wang, Y., 2015. Design of a cylindrical buoy for a wave energy converter. *Ocean Engineering*, 108, pp.350–355. Available at: http://dx.doi.org/10.1016/j.oceaneng.2015.08.012.
Wang, C., Shankar, K., Ashraf, M. A., Morozov, E. V, & Ray, T. (2016). Surrogate-assisted optimisation design of composite riser. *Journal of Materials: Design and Applications*, *230*(1), 18–34. https://doi.org/10.1177/1464420714539304
Wichers, I.J., 2013. *Guide to Single Point Moorings*, Houston, USA: WMooring Inc.
Wilde (2016) Structural analysis of new offloading reel design for FPSO vessels. Wilde Analysis & ContiTech Bettie. Available at: https://wildeanalysis.co.uk/resource/structural-analysis-new-offloading-reel-design-fpso-vessels/
Wilson, J.F., 2003. *Dynamics of offshore structures* 2nd ed., New Jersey, USA: John Wiley and Sons.
WindEurope (2021). Wind Energy Today. Available at: https://windeurope.org/ Accessed on: 31st August, 2021.
Winzen et al. (1999). Connection between a building component and a pipe-shaped line element. Patent 5865475, USA, 1999-02-02.
Witz, A.J., Cox, D.C., Hall, G.A., Ridolfi M.V., Wort A.J., & Smith R.J.A. (2011). Hose end fitting. Patent US8079619B2, USA.
Witz, A.J. & Cox, D.C., 2013. Improvements relating to hose. Patent US20100183371A1, USA.
Wu X., Ge F., Hong Y. (2012). A review of recent studies on vortex-induced vibrations of long slender cylinders. Journal of Fluids and Structures, Volume 28, January 2012, Pages 292-308 https://doi.org/10.1016/j.jfluidstructs.2011.11.010
Xiangqian, Z.H.U. & Wan-suk, Y.O.O., 2016. Numerical Modeling of a Spherical Buoy Moored by a Cable in Three Dimensions. , 29, pp.588–597.
Yamada K. (1987). Submarine conduit connection apparatus. GB2153332B, UK, 04 March, 1987.
Yang Ning, Chen Guang-guo, Tang Da-sheng. Behavior of single particle and group particles in vertical lifting pipe in china [C]// Proceedings of the Ninth ISOPE Ocean Mining Symposium. Maui, Hawaii, USA, 2011: 153−157.
Yang, H., and S. Liu. 2018. Measuring Method of Solid-Liquid Two-Phase Flow in Slurry Pipeline for Deep-Sea Mining. Thalassas: An International Journal of Marine Sciences 34 (2): 459–469. doi:10.1007/s41208-018-0093-y.
Ye, J., 2016. *Structural and Stress Analysis: Theories, tutorials and examples* Second., New York, USA: CRC Press.
Yeoh OH (1993). Some forms of the strain energy function for rubber. *Rubber Chemistry and Technology* 66 (5): 754–771. https://doi.org/10.5254/1.3538343
Yingying Wang, Haohu Tuo, Liwei Li, Yu Zhao, Hua Qin, Chen An (2018). Dynamic simulation of installation of the subsea cluster manifold

by drilling pipe in deep water based on OrcaFlex. Journal of Petroleum Science and Engineering, Volume 163, April 2018, Pages 67-78 https://doi.org/10.1016/j.petrol.2017.12.049

Yokohama, 2016. *Seaflex Yokohama Offshore loading & discharge hose*, Hiratsuka City, Japan: The Yokohama Rubber Co. Ltd. Available at: https://www.y-yokohama.com/global/product/mb/pdf/resource/seaflex.pdf Accessed on: 31st August, 2021.

Yoon C H, Park Y C, Park J. Solid-liquid flow experiment with real and artificial manganese nodules in flexible hoses [J]. International Journal of Offshore and Polar Engineering, 2009, 19(1): 77−79.

Young, R.A., Brogren, E.E. & Chakrabarti, S.K., 1980. Behavior Of Loading Hose Models In Laboratory Waves And Currents. In *Offshore Technology Conference Proceeding, OTC-3842-MS*. Houston, Texas, USA, pp. 421–428

Yu Dai, Xuyang Li, Wanwu Yin, Zhonghua Huang & Ya Xie (2019): Dynamics analysis of deep-sea mining pipeline system considering both internal and external flow, Marine Georesources & Geotechnology, DOI: 10.1080/1064119X.2019.1708517

Yu Dai, Xuyang Li, Wanwu Yin, Zhonghua Huang & Ya Xie (2019) Dynamics analysis of deep-sea mining pipeline system considering both internal and external flow, Marine Georesources & Geotechnology, DOI: 10.1080/1064119X.2019.1708517

Yu, K., Morozova, E. V, Ashrafa, M. A., & Shankar, K. (2015). Numerical analysis of the mechanical behaviour of reinforced thermoplastic pipes under combined external pressure and bending. *Composite Structures, Vol. 131*, 453–461.

Yu, K., Morozova, E. V, Ashrafa, M. A., & Shankar, K. (2017). A review of the design and analysis of reinforced thermoplastic pipes for offshore applications. Journal of Reinforced Plastics and Composites 2017, Vol. 36(20) 1514–1530 https://doi.org/10.1177/0731684417713666

Yun H.S., Kim S.S., Lee C.H., Kim H.W. (2015). A Study on the Efficient Flexible Multibody Dynamics Modeling of Deep Seabed Integrated Mining System with Subsystem Synthesis Method. Trans. Korean Soc. Mech. Eng. A, Vol. 39, No. 12, pp. 1213 -1220. DOI http://dx.doi.org/10.3795/KSME-A.2015.39.12.1213

Zeidler et al. (1993). Pipe coupling. Patent 5257834, USA, 1993-11-02.

Zewen Gu, Xiaonan Hou, Elspeth Keating, Jianqiao Ye (2020). Non-linear finite element model for dynamic analysis of high-speed valve train and coil collisions. International Journal of Mechanical Sciences, Volume 173, 1 May 2020, 105476. https://doi.org/10.1016/j.ijmecsci.2020.105476

Zhang, S., Chen, C., Zhang, Q., Zhang, D., & Zhang, F. (2015). Wave Loads Computation for Offshore Floating Hose Based on Partially Immersed Cylinder Model of Improved Morison Formula. *The Open Petroleum Engineering Journal*, *8*, 130–137.

Zhu, X. & Suk, W., 2016. Dynamic analysis of a fl oating spherical buoy fastened by mooring cables. *Ocean Engineering*, 121, pp.462–471. Available at: http://dx.doi.org/10.1016/j.oceaneng.2016.06.009.

Zhou, Y., Duan, M., Ma, J., & Sun, G. (2018). Theoretical analysis of reinforcement layers in bonded flexible marine hose under internal pressure. Engineering Structures, 168, 384-398. https://doi.org/10.1016/j.engstruct.2018.04.061

Ziccardi, J.J. & Robbins, H.J., 1970. Selection of Hose Systems for SPM Tanker Terminals. In *Offshore Technology Conference Proceeding -OTC 1152*. Dallas, Texas, USA: OnePetro, pp. 83–94.

Zine A., N.Benseddiq N., Naït M. Abdelaziz (2011). Rubber fatigue life under multiaxial loading: Numerical and experimental investigations. International Journal of Fatigue, Volume 33, Issue 10, pp. 1360-1368 https://doi.org/10.1016/j.ijfatigue.2011.05.005

Zhang D., Shi J., Si Y., Li T. (2019). Multi-grating triboelectric nanogenerator for harvesting low-frequency ocean wave energy. Nano Energy. Vol. 61, pp. 132-140. https://doi.org/10.1016/j.nanoen.2019.04.046