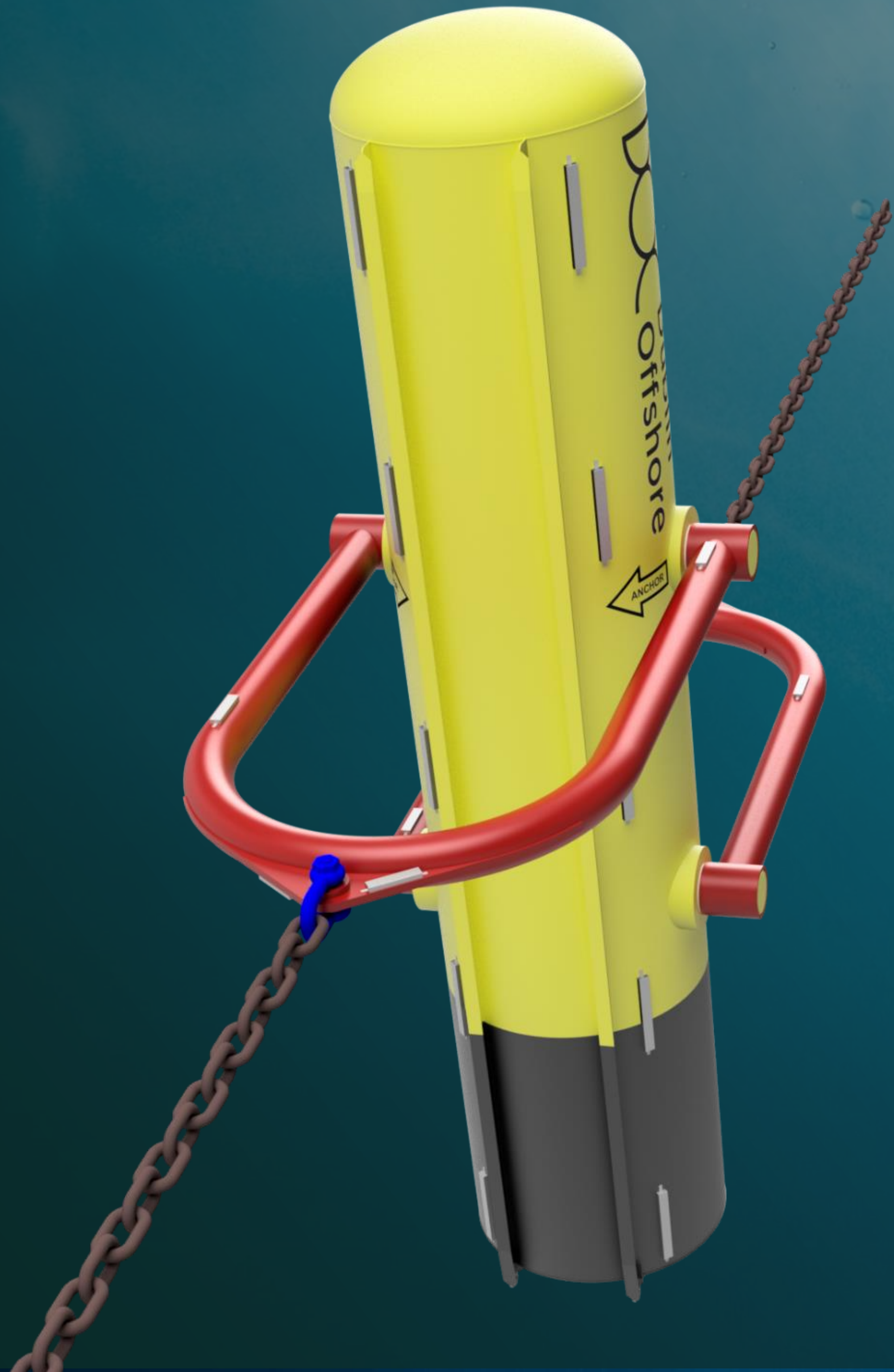
Dublin Offshore

LOAD REDUCTION DEVICE



INTRODUCTION

THE CHALLENGE

With the growth in capacity and quantity of FOW installations, requirements for more efficient and reliable mooring technology are emerging – the Carbon Trust found that 'Mooring installation is a major cost contributor'. It is therefore considered the right time to develop this key enabling technology at the infancy of what will become a multi-billion-euro market in the coming years.

Carbon Trust, 2019

FLOATING WIND

Floating Offshore Wind (FOW) is an emerging technology enabling the further expansion of offshore wind to regions where the water is too deep to fix turbine foundations directly on the seabed. The technology combines tried and tested wind turbine generator technology from fixed-bottom offshore wind with platform architectures widely used in the O&G industry. The floating structures use various designs such as semi-submersible platforms, tension leg platforms, or floating spar-buoy structures to support the turbines. FOW farms have the potential to access stronger and more consistent wind resources in deep ocean areas, expanding the potential locations for renewable energy production and mitigating challenges associated with limited shallow-water sites. As a relatively new technology, floating offshore wind holds promise for scaling up renewable energy capacity and further contributing to the transition towards cleaner energy sources.

Multiple FOW demonstration projects are in operation globally and therefore FOW is now focussed on driving cost reduction; delivering cost-effective technical solutions to compete with fixed-bottom offshore wind and to enable roll out of FOW at a commercial scale.

INNOVATION

Dublin Offshore (DO) have developed a Load Reduction Device (LRD) for permanent moorings targeting the FOW market. By reducing mooring line loads, reducing the risk of failure and reducing mooring CAPEX Dublin Offshore's novel mooring technology can support accelerated delivery of FOW deployment at scale globally.

The Dublin Offshore team have developed the LRD technology (YouTube Explainer Video), a patented mooring component that changes a mooring system response to environmental forces. The LRD allows the structure to move in a controlled compliant response to wave induced motions. The result is substantial design load reduction for the entire mooring system and the FOW platform, which directly translates into meaningful cost and risk reduction for the customer.

This design manual provides guidance and support to mooring designers on the efficient design and optimisation of LRD-integrated mooring systems.

LRD TECHNOLOGY

REDUCED MOORING LOADS

REDUCED FATIGUE DAMAGE

STORM PROTECTION

TAILORED RESPONSE

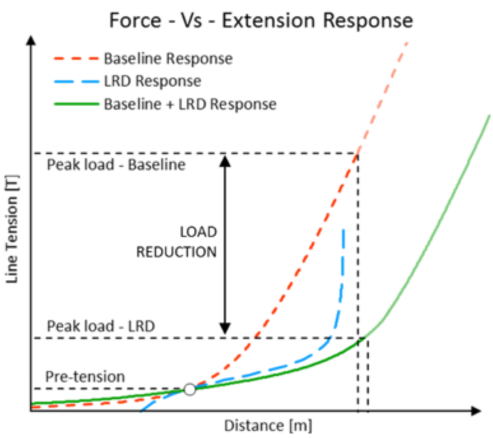
REDUCED CAPEX

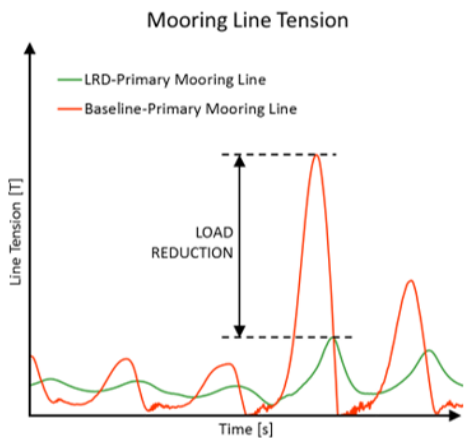
>25 YEAR DESIGN LIFE

LOAD REDUCTION DEVICE (LRD)

The LRD is a subsea component of an offshore mooring system. It is fully scalable and tuneable to deliver the customer's specific mooring response requirement. The LRD is manufactured using basic materials such as steel and concrete which have a demonstrated track record in the marine environment. The LRD has received a Statement of Feasibility which determined the technology can be designed within existing codes and standards, and does not require any qualification.

HOW IT WORKS





The LRD comprises a buoyant end and a weighted end with two attachment arms to connect the device within the mooring line. In the nominal position the device maintains a vertical orientation and subsequently rotates in response to movement of the floating platform. Rotation of the device provides extension of the mooring line overall length, and the combination of weight and buoyancy creates a restoring force to return the device to the nominal vertical position. The result is a bespoke non-linear mooring response.

REDUCED RISK

LONG TERM PERFORMANCE

BESPOKE RESPONSE

LOW TECHNICAL NOVELTY

ESTABLISHED MARINE MATERIALS

ROBUST & SIMPLE DESIGN

LRD BENEFITS

The primary goal of the LRD is to reduce the overall risk profile and cost of energy on FOW projects however there are some additional environmental and design benefits which can be considered important by the customer. The LRD can be integrated into a wide range of site conditions, platforms and mooring systems which can result in CAPEX reductions in the mooring system in excess of 50%. The LRD benefits across cost, environmental and design performance are summarised as follows:

Cost

- CAPEX and LCOE reduction
- Cost Optimised mooring system
- Risk reduction
- Reduced logistics with moorings BOM
- Increased local content
- Removal of supply bottlenecks

Environment

- Reduced anchor footprint
- Removal of chain thrashing and seabed impact
- Noise reduction
- Reduced site boundaries and permitting requirements
- Improved stakeholder engagement

Design

- Increased use of synthetic rope
- Reduced design driving loads
- Remove line replacement operations
- Bespoke mooring response
- No novel materials
- Full life maintenance free mooring system

By using a simple gravity-based mechanism constructed from well-established and mature materials (steel & concrete) the LRD based mooring will deliver high performance over the full life of the mooring system. The certification process is based on extensive engagement with DNV and is fully defined within existing codes and standards. Early engagement in the FOW project allows for the maximum benefits to be made, such as:

- Mooring system optimisation such as move from a catenary to an inclined taut
- Reduced footprint and minimised seabed interference
- Reduced mooring line quantity
- Smaller chain and anchor
- Removal of chain, clump weights & buoyancy modules from the system
- Smaller installation vessels
- Platform mass reduction
- Increased Mean Time Between Failure & improved Annual Energy Production.

Fully Certifiable System

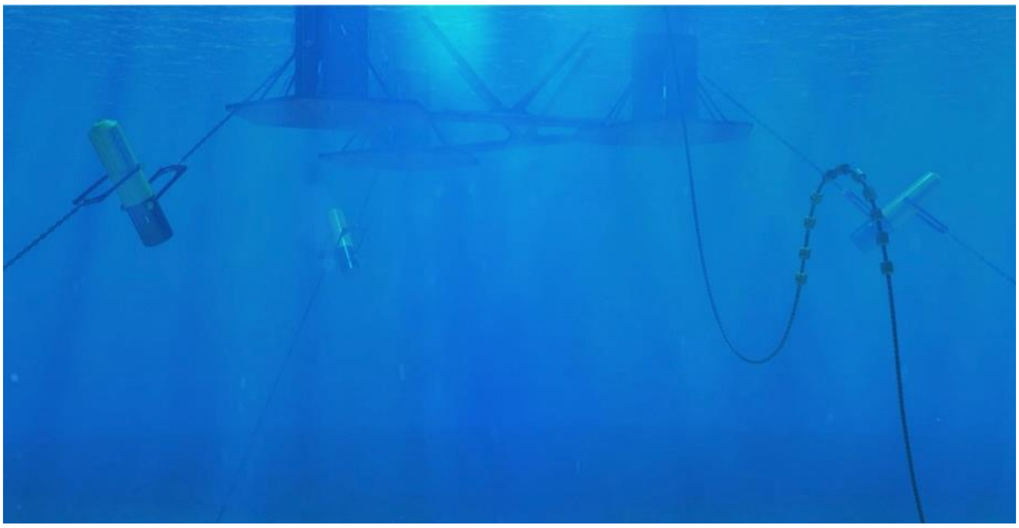
Simplified Bill of Materials

LOCALISED SUPPLY CHAIN

LIFE CYCLE TECHNICAL SUPPORT

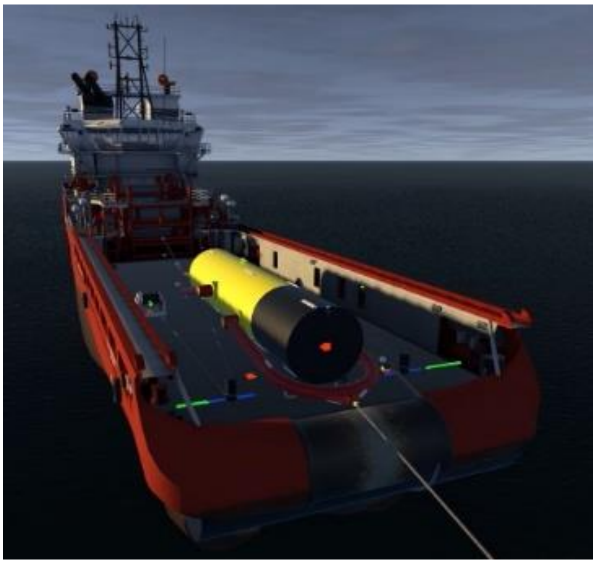
LRD INTEGRATION

- LRDs are compatible with all platforms, mooring configurations, chain & rope and anchor types.
- Integration of the LRD can deliver cost reduction not just by reducing loads but by enabling full system optimisation. The compliance delivered provides design choices for the mooring designer enabling the use of low-cost, certified mooring equipment and addressing potential supply chain bottlenecks for heavy mooring equipment.
- Cost reduction should consider optimisation of the full system Bill of Materials versus the baseline station-keeping system (i.e. reduction in line qty, overall line length, anchor qty and spacing).



MARINE OPERATIONS

- Installation of the LRD utilises the same Anchor Handler Tugs that are used for mooring and floater installation. Specialist vessels or equipment are not required.
- The LRD is over boarded from the deck via the stern roller in an operation that is commonly used for anchors.
- Inclusion of the LRD can result in the reduction of marine operations / installation cost for the mooring system due to the reduced equipment size and as a result of the significant quantity of chain and rope removed during the optimisation phase.



LRD SELECTION

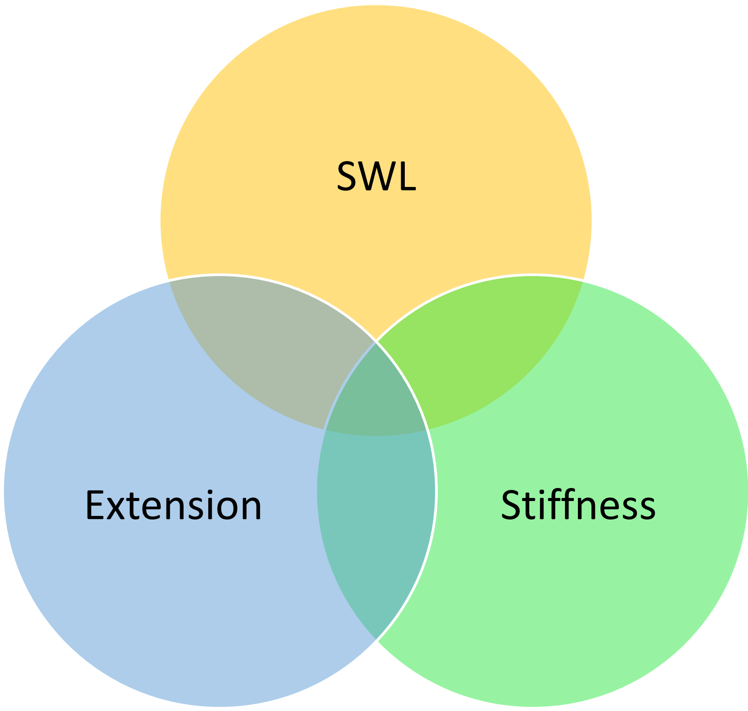
LRD CHARACTERISTICS

The LRD enables mooring system optimisation by introducing engineered compliance to the system such as by allowing reduced weight of catenary and reduced mooring radius in comparison with traditional mooring architectures.

The performance of the LRD is characterised by three design parameters:

- Safe Working Load (SWL). The SWL is the normal operating limit for the LRD in service. It corresponds to the upper end of the extension range in the low stiffness phase (Phase 2) before the LRD reaches maximum rotation and is pulled taut. This load magnitude can be considered a target to be reached in the Ultimate Limit State load cases such as for a 50 year return period seastate.
- LRD Extension Length. The LRD extension length is determined by the LRD geometry and the position of the axes connecting the arms to the main body. Increased extension length results in reduced mooring line peak load. The LRD extension length is defined as the extension delivered by the LRD within the low stiffness operating phase (Phase 2) of the stiffness curve.
- LRD Stiffness. The LRD stiffness is defined as the average stiffness within the low stiffness operating phase of the stiffness response curve. Typically low stiffness supports reduced peak loads however this must be balanced against the required extension length to ensure compatibility with platform excursion requirements.

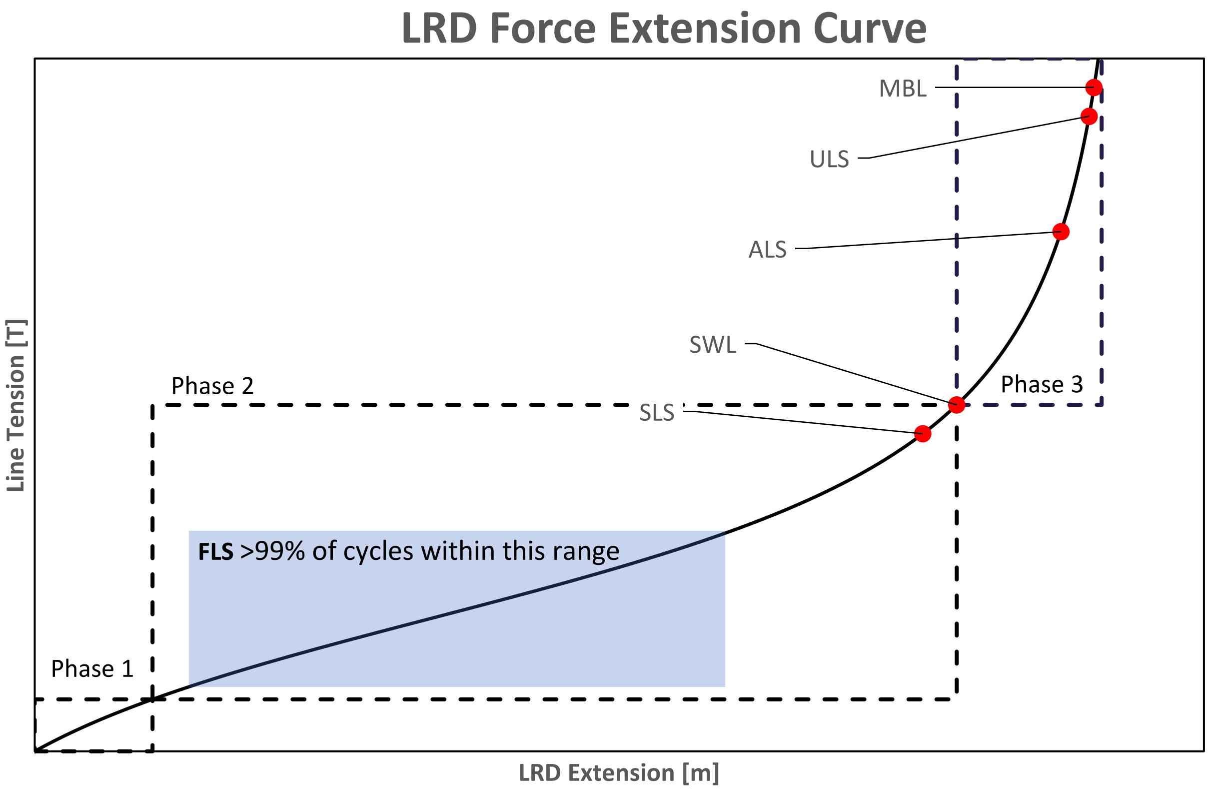
These three LRD characteristics are inter-related and therefore it is the role of the mooring designer to identify the sweet spot between SWL, stiffness and extension that meets the specific project requirements.



NON-LINEAR STIFFNESS RESPONSE CURVE

The LRD delivers a non-linear stiffness response curve with three distinct phases:

- Phase 1 is relatively stiff and is designed to ensure minimum rotation of the LRD and minimum line extension below pretension and normal operating mean tensions.
- Phase 2 delivers a low stiffness to minimise dynamic loading and to reduce fatigue cycle amplitudes. The LRD will spend all of its normal working life operating in this phase. The operating conditions for fatigue assessment are a subset of the phase 2 operating range.
- Phase 3 is only relevant in accidental or out of design conditions. It delivers a stiff response as the LRD approaches full rotation. Note the LRD is designed to ensure a smooth transition between each phase. This is critical to prevent shock loading to the system and to enable optimisation of both peak and fatigue loads.

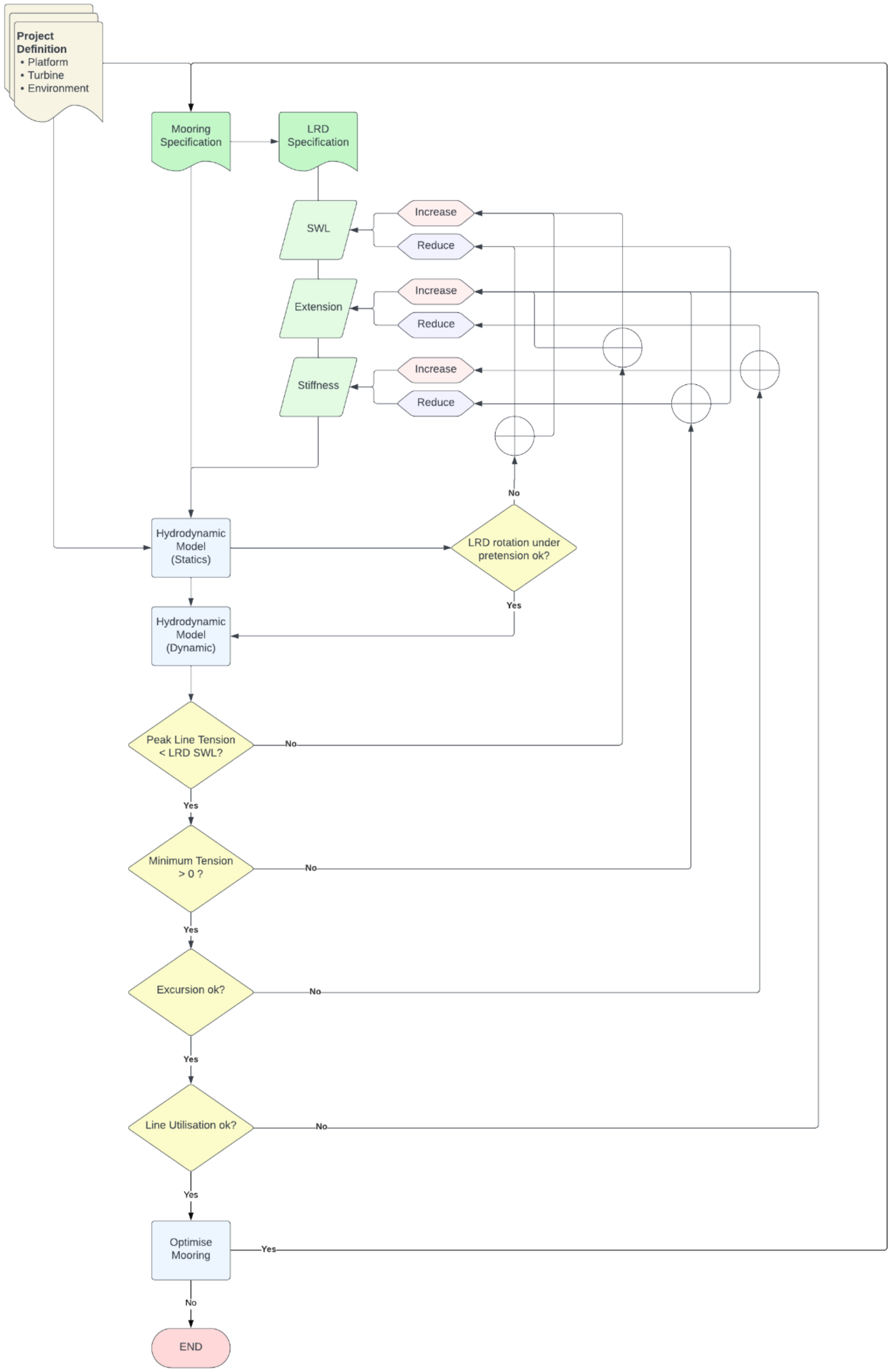


The LRD presents a number of design levers to modify the stiffness response curve. As can be seen in the figure above, increasing the SWL for the same extension results in an increased stiffness, however to deliver a higher SWL with the same extension requires a larger LRD to deliver the restoring moment. Similarly a reduced SWL with the same extension value can be delivered using a smaller LRD.

By modifying the distance between the two LRD axes, an otherwise constant geometry can deliver a range of low extension - high stiffness - high SWL configuration or a high extension - low stiffness - low SWL configuration and everything in between. In this way the LRD can be easily customised to meet the project requirements.

LRD MOORING DESIGN

DESIGN PROCESS



REQUIRED INPUTS

The required inputs for LRD-integrated mooring design are similar to the requirements for conventional moorings. The following table provides a non-exhaustive list of design inputs for FOW mooring analysis.

Component	Description
FOW Platform description	A detailed description of the FOW platform geometry is required to support mooring analysis and this is no different for LRD-integrated systems. The platform description should include platform type, mass, displacement, draft, fairlead positions, centre of gravity, inertia and RAOs. The platform description should be accompanied by a hydrodynamic model, such as a diffraction model or from a series of Morison's elements. Tank validated platform models should be used wherever possible.
Turbine description	Detailed turbine specification is required for detailed mooring analysis. At a minimum, WTG geometry, RNA mass, hub height, and tower geometry and mass should be known. Some simplification can be considered for the purposes of concept feasibility assessment whereby simplified WTG thrust is considered for peak operating and parked cases but for detailed design, the WTG thrust curve, turbine controller should be included.
Mooring Architecture	If the project has specific requirements of the mooring architecture for technical, commercial or environmental reasons they should be identified at the outset to minimise wasted effort. The project may require redundancy of mooring lines, to minimise chain thrashing on the seabed, use of shared anchors, or the use of specific material types in support of local content. Similarly a pretensioning approach should be established to ensure the design is within practical vessel or equipment limits.
Anchor constraints	Anchor specification has a significant bearing on the mooring design choices available. Key considerations include limitations on anchor radius, and whether the selected anchor can support vertical loading at anchor, or not. Drag Embedment Anchors, for example, have limited vertical load capacity and may require substantial weight of chain to ensure the anchor is laterally loaded.
Environmental conditions	Site specific metocean conditions are required to inform mooring design. The methodologies required to determine the appropriate statistical description of water depth, current, wave, and wind loading are well described in standards. Design Load Cases such as are described by IEC should be combined with load factors for specific limit states such as are described by DNV.
Vessel constraints	The mooring designer should consider if specific vessels or vessel class has been selected for mooring installation and offshore operations. Key inputs include the limiting crane capacity at marshalling site, vessel deck capacity, bollard pull and stern roller loading limits.
Class inputs	Project certification requirements should be included in mooring design development. Key inputs include definition of the level of redundancy required in the mooring design, definition of ALS or damage cases for consideration in design and the definition of consequence class, load and resistance factors to be adopted.

DESIGN DRIVERS

The LRD mooring design is progressed to balance optimisation across multiple project design drivers. Design should include feedback from HAZID activities, input from marine contractors, and the project cost-modelling. A number of considerations for LRD-integrated mooring design are set out below:

- Optimise line properties to align with standard sizes available within the O&G industry – i.e. deliver supply chain friendly Bill of Materials.
    - Aim for the use of rope line diameters <170mm, which supports deployment using existing vessel winches and standard spools.
    - Where possible use chain sizes <120mm diameter, which allows standard AHV chain gypsy inserts to be used and avoid requirements for larger vessels or upgrades to readily available vessels.
- Lower riser line, including chain and polyester sections, to be of greater length than the water depth to allow hook up to the platform and LRD on deck of the vessel.
- Maintain individual component mass < 250T to allow loadout with standard cranes and support ease of deployment. Maintain component geometry within achievable bounds for offshore handling.
- Consider only certified and readily certifiable components and materials within the system.
- Consider inclusion of interface sections of chain at the anchor and fairlead to support protection of synthetic sections and ease of connection.
- Deliver comparable or improved station keeping performance relative to the baseline mooring system.
- Reduce MBL of components throughout where achievable.
- Reduce mooring footprint where achievable and desirable to the project.
- Identify opportunities for efficient system design through control of platform orientation – i.e. opportunity to align single primary line with predominant wave direction to support deployment of a single LRD only on the primary line.

USE STANDARD LINE SIZES

MINIMISE SYSTEM WEIGHT

SELECT CERTIFIED MATERIALS

CONSIDER CHAIN AT INTERFACES

ESTABLISHED MARINE MATERIALS

KEY PERFORMANCE INDICATORS

The KPIs for the mooring system include a combination of mooring line, RNA and anchor considerations. The following list is not intended to be exhaustive and is provided for guidance only.

KPI	Description
Peak Tension	The peak tension is a combination of the mean and dynamic loading on the system. It is typical design driving for the mooring line specification.
Mean Tension	The mean tension is the average line tension across a design load case. It is a combination of low frequency loading such as mean wind speed, current, and mooring line pretension.
Minimum Tension	The minimum line tension provides an indication of slack on the lines, which should generally be avoided. Some rope types may have minimum tension requirements to prevent damage to the wire or fibres strands.
Utilisation Check	The Utilisation Check (UC) is a comparison of the design load to the design resistance. A UC value of less than 1 indicates the design has an acceptable level of safety, i.e. $\frac{Characteristic\ Load\ x\ Load\ Factor}{Characteristic\ Resistance\ x\ Resistance\ Factor} < 1$
Platform Excursion	Platform excursion is a critical design input parameter for dynamic cable design and therefore strict limits are generally applied to the mooring system in advance of dynamic cable design. Reduced platform excursion can reduce the strain on the dynamic cables and should result in fewer outages across the project lifetime.
Anchor Load	Anchor loading is a design driver for the anchor design. Each of the peak load, maximum vertical load, maximum horizontal load and cyclic loading are important for anchor design and selection and should be reported.
Tower Tilt	Tower tilt and RNA acceleration are important KPIs as turbine OEMs may impose strict limits for operating and parked conditions.
RNA acceleration	
Fatigue life	Fatigue is one of the most common failure mechanisms for long term mooring systems. Therefore the fatigue life of the mooring system and each of the constituent parts is a critical performance indicator.
Thrash zone length	Relevant only to catenary and semi-taut mooring systems, the thrash zone length quantifies the length of line disturbing the seabed. It may be an important KPI for environmental impact.
Chain diameter, grade and mass	The specification of chain and rope diameter, length and material or grade has both direct and indirect impacts on the system cost. Direct impacts include the procurement cost which is non-linear with respect to chain or rope size, with threshold sizes for individual suppliers and specific regions above which supply chain challenges exist. Indirect costs include handling onshore and the associated vessel requirements for XL chain and rope.
Rope type, diameter and length	
Mooring System Cost	With significant cost reduction required in FOW to compete with other renewable and traditional energy sources, the mooring system can contribute to establishing commercial feasibility of FOW. Chain and rope suppliers can provide detailed costing for mooring equipment. Please contact DOT for LRD unit pricing.

NUMERICAL ANALYSIS

LRD STIFFNESS RESPONSE CURVE SPECIFICATION

LRD GEOMETRY DEFINITION

SYSTEM ARCHITECTURE

ENVIRONMENTAL LOADING

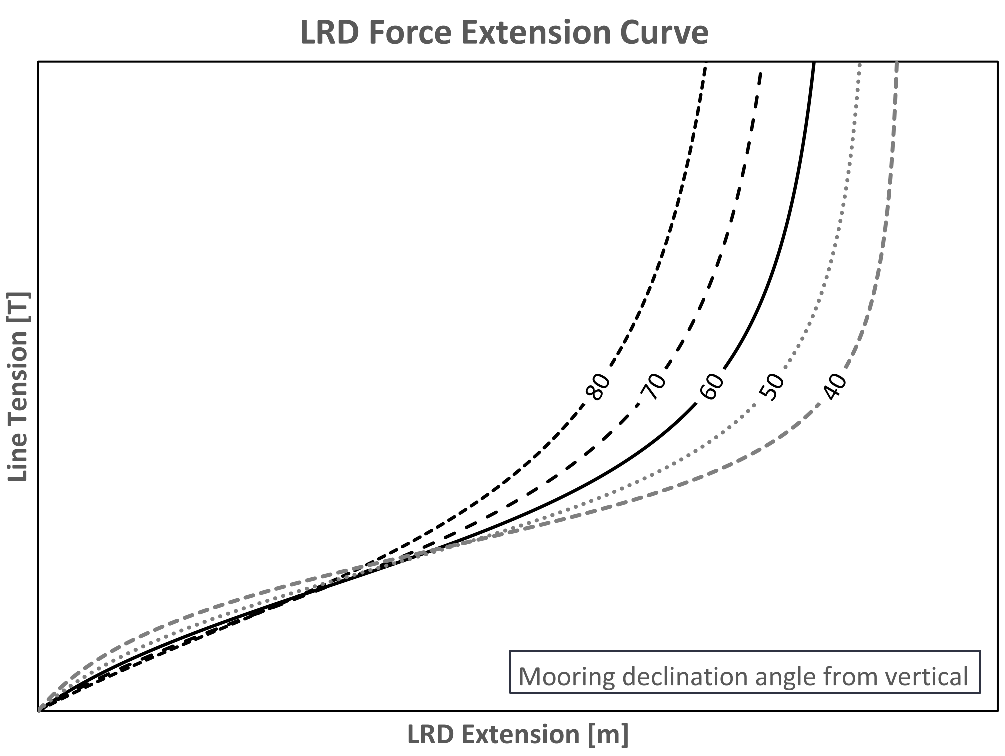
NUMERICAL SIMULATION

NON-LINEAR LINE ELEMENT

The performance of the LRD can be assessed in most leading dynamic analysis software packages by directly modelling the LRD as a body with the mechanical and hydrodynamic properties associated with the selected LRD geometry.

In order to further simplify LRD integration and mooring analysis the LRD can be represented in the mooring analysis software as a line element with a non-linear stiffness response corresponding to the LRD quasi-static performance. It should be noted that the quasi-static stiffness curve of the LRD is a function of the mooring line declination so care should be taken to ensure the appropriate curve is selected.

Characteristic (Inputs)
LRD Nominal Length (zero extension, Arm padeyes centre to centre)
Stiffness Response Curve
Mooring Line Declination
LRD SWL



Further details on non-linear, quasi-static stiffness response for specific LRD geometries are available from DOT, on request.

LRD SPECIFICATION

LRD GEOMETRY DEFINITION

SYSTEM ARCHITECTURE

ENVIRONMENTAL LOADING

NUMERICAL SIMULATION

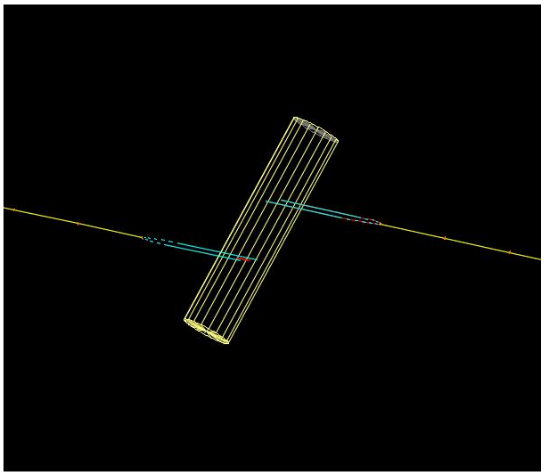
LRD MODELLING (6DOF ELEMENT)

The LRD is modelled as a 6 Degrees of Freedom (6DOF) Buoy, such as in Orcaflex, with the mechanical and hydrodynamic properties associated with the selected LRD geometry. The following components are considered in the analysis.

Component	Function
Main Body	Provides buoyancy, ballast and mooring attachment points
Arms	Connect mooring line to LRD Main Body
Bearings	Ensure free rotation of main body in response to mooring line loads

The combined mechanical properties of the main body structure, buoyancy and ballast are modelled within a single buoy element. The analysis of the LRD includes hydrodynamic forces acting on the component due to both the motion of the LRD, and environmental loading.

Characteristic (Inputs)
Diameter
Length
LRD Mass
COG position
Mass Moments of Inertia (x, y and z)
Vertical offset between hinges
Lateral offset between hinges
Hydrodynamic drag and Inertia coefficients



The LRD is modelled within the mooring system as an integrated hydrodynamically coupled component. The LRD component is modelled with the following inputs and notes:

1. All primary structural components are included with representative mass, buoyancy and geometry
2. Arm length is specified for the required clearance around the LRD body
3. Mooring design is undertaken in time-domain analysis for site specific Metocean conditions.

Further details on specific LRD COG, mass moments of inertia, and hydrodynamic coefficients are available from DOT, on request.

WANT TO KNOW MORE?

WANT TO KNOW MORE? GET IN TOUCH

This lrd technology design manual assumes a working knowledge of LRDs / FOW but please get in touch for our whitepaper, case studies or access to explanatory videos. Read our frequently asked questions at:
www.dublinoffshore.ie/faqs

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INTRODUCTION WORKSHOP

- Dublin Offshore welcome the opportunity for an introductory workshop where we can introduce you to our company, technology and projects. Key outcomes of this workshop are an understanding of customer mooring challenges and a high level understanding of scope for future collaboration.

CONCEPT DESIGN

- The impact of the LRD on the project requires careful consideration as the unit impacts the design, installation, financing, insurance, and operation of the farm. Upon request and following the introductory workshop, we can propose a feasibility study to develop client specific project use case for the LRD which can provide better definition of mooring system benefits including costs.

LRD DELIVERY MODEL

- Our delivery model is to work with developers to optimise their mooring systems with the integration of the LRD at the concept phase of the project through early feasibility studies. This concept can be brought through detailed engineering by the mooring designer.
- Dublin Offshore will take responsibility for the design, procurement and delivery of the certified LRD to an agreed handover location with the installation contractor.
- The LRD is fabricated from standard structural steel and concrete ballast delivered to industry-standard tolerances and specification (e.g. DNV-OS-C401). Existing offshore / marine steel fabricators are well placed using existing capabilities – and local supply chain is prioritised.


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