

Recommended Practice for Ancillary Equipment for Flexible Pipes and Subsea Umbilicals

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Introduction

This recommended practice (RP) is the result of a Joint Industry Project to develop a worldwide industry standard for the design, material selection, analysis, testing, manufacture, handling, transportation, installation, and integrity management of flexible pipe ancillary equipment. The objective of this RP is to provide an integrated approach, together with API 17B, API 17J, and API 17L1, to the design of flexible pipe systems. Therefore, it is intended that this RP be used in conjunction with these documents.

The majority of ancillary equipment is custom-built and can be designed and manufactured in a variety of methods. It is not the intent of this RP to discourage novel or new developments in ancillary equipment. On the contrary, it is recognized that a variety of designs and methods are possible. For this reason, some topics are presented in general terms to provide guidance to the user while still leaving open the possibility of using alternative approaches. The reader should be aware that ancillary equipment technology (concepts, design and analysis methodologies and criteria, components manufacturing and testing, operational roles and demands, maintenance and inspection, etc.) is in a state of rapid and continuing evolution. Therefore, potential users need to apply care in their application of the recommendations herein.

Système Internationale (SI) units are identified first when cited in the document. United States Customary (USC) units may be given in brackets after the SI units.

Recommended Practice for Ancillary Equipment for Flexible Pipes and Subsea Umbilicals

1 Scope

This RP provides guidelines for the design, materials selection, analysis, testing, manufacture, handling, transportation, installation, and integrity management of ancillary equipment for flexible pipes and umbilicals. It supplements API 17L1, which specifies minimum requirements for the design, material selection, manufacture, documentation, testing, marking, and packaging of the ancillary equipment.

This RP presents the current best practice for design and procurement of ancillary equipment and gives guidance on the implementation of the specification for standard ancillary products. In addition, this RP presents guidelines on the qualification of prototype products.

The applicability relating to a specific item of ancillary equipment within this RP is stated at the beginning of the section dedicated to that item of ancillary equipment.

This RP applies to the following ancillary equipment:

- bend stiffeners;
- bend restrictors;
- bellmouths;
- buoyancy modules and ballast modules;
- subsea buoys;
- tethers for subsea buoys and tether clamps;
- riser and tether bases;
- clamping devices;
- subsea buoy clamps
- piggy-back clamps;
- repair clamps;
- I/J-tube seals;
- pull-in heads/installation aids;
- connectors;
- load-transfer devices;
- mechanical protection;
- fire protection;
- VIV suppression strakes.

This document may be used for bonded flexible pipe ancillary equipment, though any requirements specific to these applications are not addressed.

Where relevant, the applicability of recommendations to umbilicals is indicated in the applicability section for the ancillary equipment in question.

This RP does not cover ancillary equipment for flexible pipes and umbilicals beyond the connector, with the exception of riser bases and load-transfer devices. Therefore, this document does not cover turret structures or I-tubes and J-tubes, for example. In addition, it does not cover flexible pipe or umbilical storage devices, for example reels.

This RP is intended to cover ancillary equipment made from several material types, including metallic, polymer and composite materials. It may also refer to material types for particular ancillary components that are not commonly used for such components currently but may be adopted in the future.

This RP applies to ancillary equipment used in association with the flexible pipe and umbilical applications listed in API 17B, API 17J, API 17E, and API 17K.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 2F, *Specification for Mooring Chain*

API Specification 9A, *Specification for Wire Rope*

API Recommended Practice 17A, *Design and Operation of Subsea Production Systems—General Requirements and Recommendations*

API Recommended Practice 17B, *Recommended Practice for Flexible Pipe*

API Specification 17J, *Specification for Unbonded Flexible Pipe*

API Specification 17K, *Specification for Bonded Flexible Pipe*

API Specification 17L1, *Specification for Ancillary Equipment for Flexible Pipe and Subsea Umbilicals*

DNVGL-OS-D301 ¹, *Fire Protection*

DNVGL-ST-F201., *Riser Systems*

DNVGL-ST-N001., *Marine Operations and Marine Warranty*

IAPSO ², *Standard Seawater*

3 Terms, Definitions, Abbreviations, and Symbols

3.1 Terms and Definitions

For the purposes of this document, the terms and definitions given in API 17B, API 17J, API 17K, API 17L1 and the following apply, many of which are repeated from API 17L1 for the convenience of the user.

¹ DNVGL - Veritasveien 1, 1363 Oslo, Norway, www.dnvgl.com.

² International Association for the Physical Sciences of the Oceans, <http://iapso.iugg.org>.

3.1.1**anchor base**

Structure used to secure one end of a tether to the seabed.

3.1.2**ancillary component**

Component that is attached to the flexible pipe or umbilical to perform one or more of the following functions:

- a) to control the flexible pipe or umbilical behavior;
- b) to provide a structural transition between the flexible pipe or umbilical and adjacent structures;
- c) to attach other structures to the flexible pipe or umbilical;
- d) to protect or repair the flexible pipe or umbilical;
- e) to provide a seal along the flexible pipe or umbilical length.

3.1.3**ballast module**

Negatively buoyant component of which a number are used at discrete points over a length of flexible pipe or umbilical to provide added weight.

3.1.4**banding**

Device used to secure mechanical protection to the flexible pipe or umbilical.

3.1.5**batch**

Quantity of product made of a unique mixture of one or more polymer components, given as either a percentage of total output, or produced over a short period of time as specified by the manufacturer.

NOTE A short period of time can be for example up to 24 hours, or across shift changes etc., which is based on manufacturing capacity, job length and product line.

3.1.6**bend restrictor**

Mechanical device made of interlocking vertebrae that functions as a mechanical stop and limits the local radius of curvature of the flexible pipe or umbilical to a minimum value.

3.1.7**bend stiffener base**

Face of the interface structure on the support structure side at which the bend stiffener begins.

3.1.8**bend stiffener body**

Polymeric part of a bend stiffener that provides extra stiffness to the flexible pipe or umbilical to prevent it from over-bending or fatigue failure.

3.1.9**bend stiffener cap**

Structural component of some bend stiffener designs comprising a cylindrical metallic shell that fits externally around part of the bend stiffener length adjacent to the bend stiffener base.

3.1.10**bend stiffener tip**

End of the bend stiffener body opposite the base.

NOTE The bend stiffener tip, for a particular bend stiffener configuration, is shown in Figure 48.

3.1.11

bending stress

Portion of primary stress proportional to the distance from the centroid of a cross-section, excluding the effects of discontinuities and stress concentrations.

NOTE Definition taken from API 2RD.

3.1.12

blown foam

Polymer foam containing no microspheres or macrospheres.

3.1.13

bridle

Load-bearing Y-shape structure that forms the transition between a subsea buoy frame and its tethers.

3.1.14

buoyancy element

Part of a buoyancy module or some subsea buoys that gives uplift to the module or buoy.

NOTE The buoyancy element comprises a buoyant material and external skin. It does not include buoyancy tanks.

3.1.15

buoyancy module

Discrete component, consisting of a buoyancy element, and means of securing it to the pipe or umbilical, used to provide net uplift by attaching a series of such components along a length of pipe or umbilical.

3.1.16

buoyancy tank

Part of some subsea buoys that consists of a pressure vessel filled with gas at ambient or higher pressure that gives uplift to the subsea buoy.

3.1.17

Chinese finger

Device used during installation that consists of a meshed structure that grips around the flexible pipe or umbilical outer sheath.

NOTE The mesh is configured such that the higher the load applied to it, the tighter its grip.

3.1.18

clamp body

Part of a clamp that is in surface contact with the pipe or umbilical outer sheath.

3.1.19

clamp inner liner

Part of some clamp bodies consisting of a compliant lining of material in contact with the flexible pipe or umbilical outer sheath that allows for variations in the pipe or umbilical external diameter.

3.1.20

composite

Combination of a polymer material and a reinforcing material that enhances the properties of the polymer.

3.1.21

composite syntactic foam

Composite material consisting of a polymer matrix containing both microspheres and macrospheres.

3.1.22**connector**

Device used to provide a leak-tight structural connection between the end fitting and adjacent piping.

NOTE It does not include flexible pipe-end fittings.

3.1.23**crushing capacity**

Maximum localized radial compressive load that a flexible pipe or umbilical can resist.

3.1.24**loaded locking radius**

Radius of a bend restrictor during lock-up with applied loading.

3.1.25**diver-assisted I/J-tube seal**

I/J-tube seal that requires diver assistance to make-up the seal.

NOTE It can incorporate a clamping device.

3.1.26**diverless I/J-tube seal**

I/J-tube seal that does not require diver assistance.

NOTE The seal is created by pulling it in to an I/J-tube. A clamping device resists the pull-in forces.

3.1.27**dry repair**

Repair of a flexible pipe or umbilical that has been retrieved from the water.

3.1.28**dynamic bend restrictor**

Design scenario where there is intermittent lock-up between bend restrictor elements induced by external forces such as wave and current environmental loads.

3.1.29**end fitting adjacent interface structure**

Bend stiffener interface structure where the end fitting is positioned within the interface structure.

3.1.30**female interface structure**

Bend restrictor interface structure that fits around the adjacent bend restrictor element.

3.1.31**final net buoyancy**

Net buoyancy at the end of the service life.

3.1.32**fire protection**

Layer of material that provides passive fire protection to the flexible pipe or umbilical for a specified duration of time in the event of a fire.

3.1.33**flexible pipe system**

Fluid conveyance system for which the flexible pipe(s) is the primary component, and which includes ancillary components attached directly or indirectly to the pipe.

3.1.34**flexible riser base connection**

Part of a riser base that forms the transition between the flexible pipe end fitting and the riser base structure.

3.1.35**free-locking radius**

Radius of a bend restrictor during lock-up without applied loading. Free-locking radius also referred to as geometric locking radius.

3.1.36**galling**

Gradual removal of material from a surface due to repetitive relative motion with an adjacent surface.

3.1.37**gutter**

Part of a subsea arch that the flexible pipe or umbilical rests on and may be clamped to.

3.1.38**heat distortion temperature**

Temperature at which an applied load causes a test sample to deflect by a specified amount.

3.1.39**hybrid bend restrictor**

Bend restrictor with a combination of polymer and metallic elements.

3.1.40**hydrogen embrittlement**

Weakening of metallic material due to free hydrogen released by connection to the CP system.

3.1.41**hydrolysis**

Decomposition of a chemical compound by reaction with water.

3.1.42**hydrostatic collapse pressure**

For syntactic foams, the hydrostatic collapse pressure is defined as the pressure relating to a non-recoverable change in the "Pressure vs Time Chart" (or on the Load vs Deflection Chart) which is measurement dependent. For composite syntactic foams, the hydrostatic collapse pressure is defined as the pressure which results in an immediate 5 % buoyancy loss.

3.1.43**I/J-tube seal**

Device that fits around a flexible pipe or umbilical and is used to provide a pressure-tight seal in an I/J-tube to contain corrosion-inhibited fluid within, or prevent gas escaping from topsides.

3.1.44**initial net buoyancy**

Net buoyancy before immersion in seawater.

3.1.45**installation**

Integration of the ancillary equipment into the pipe or umbilical system.

NOTE This term does not refer to installation of the flexible pipe unless specifically stated.

3.1.46**installation contractor**

Party contracted to perform installation of the flexible pipe or umbilical system and/or ancillary equipment.

NOTE Such installation could be in the manufacturer's scope of work.

3.1.47**installation tower**

Tilttable laying ramp, fed by reels or carousels, whose angle to the vertical can be adjusted to suit the installation.

3.1.48**interface structure**

Structure that transfers loads from a bend stiffener or bend restrictor to the adjacent structure.

3.1.49**intermediate bend stiffener**

Bend stiffener located at some point other than the topside connection and the seabed connection, but at some intermediate point along the flexible pipe between these connections.

3.1.50**internal clamp strap**

Part of some buoyancy modules that secures the internal clamp body to the flexible pipe or umbilical.

NOTE The internal clamp strap is positioned within the interior of the buoyancy element.

3.1.51**lifting point**

Connection point on a structure used to interface with lifting equipment.

3.1.52**load-transfer device**

Device that is used to transfer loads from the pipe or umbilical end fitting or bend limiter interface structure to the topsides structures but does not have any pressure-containing capacity.

3.1.53**lock-up**

Locking together of individual bend restrictor elements.

3.1.54**lower catenary**

Length of pipe or umbilical between the riser base and the subsea buoy.

3.1.55**macrosphere**

Ceramic, polymer, or composite spheres greater than 1 mm in diameter that form a structural part of composite syntactic foams.

3.1.56**male interface structure**

Bend restrictor interface structure where the adjacent bend restrictor element fits over the interface structure.

3.1.57**manufacturer**

For the purposes of this RP, the manufacturer of the ancillary equipment.

3.1.58 **membrane stress**

 σ_p

Average stress value across the thickness of a solid section, excluding the effects of discontinuities and stress concentrations.

EXAMPLE — The general primary membrane stress in a pipe loaded in pure tension is the tension divided by the cross-sectional area. σ_p may include global bending as in the case of a simple pipe loaded by a bending moment.

NOTE Definition taken from API 2RD.

3.1.59 **microsphere**

Ceramic, polymer, or composite sphere between 1 μm and 1000 μm in diameter that forms a structural part of syntactic and composite syntactic foams.

3.1.60 **module element**

Part of a buoyancy or ballast module that gives uplift or added weight to the module.

NOTE The module element does not include buoyancy tanks.

3.1.61 **moonpool**

Opening in a platform/vessel that allows access to the water.

3.1.62 **net buoyancy**

Resulting buoyancy after considering all buoyant and nonbuoyant components in a subsea buoy or buoyancy module.

3.1.63 **overboarding chute**

Arch-shaped structure positioned at the edge of a vessel that is used as an installation aid for pipe or umbilical.

3.1.64 **passive fire protection**

Coating, cladding, or free-standing system that provides thermal protection in the event of a fire and that requires no manual, mechanical or other means of initiation, replenishment, or sustenance.

NOTE Definition taken from DNVGL OS-D301.

3.1.65 **permanent ancillary equipment**

Ancillary equipment that is to be used for the entire service life of the pipe or umbilical.

3.1.66 **permanent bend stiffener**

Bend stiffener that is to be used for the entire service life of the flexible pipe or umbilical.

3.1.67 **piggy-back clamp**

Spacer in a piggy-back system that is clamped to the supporting and supported pipe and does not allow relative movement of the supported pipe.

3.1.68**piggy-back guide**

Spacer in a piggy-back system that is clamped to the supporting pipe and allows relative movement of the supported pipe.

3.1.69**prototype test**

Test performed to establish or verify a principal performance characteristic for a particular design, which may be a new or established design.

3.1.70**pull-in head**

Device used during installation to connect the flexible pipe or umbilical end fitting to a pull-in wire, consisting of structure that connects to end-fitting and a connection that interfaces with lifting equipment.

3.1.71**raw materials supplier**

Supplier of raw materials for any of the components of an item of ancillary equipment.

3.1.72**reaction collar**

Bend restrictor interface structure comprising a split-shell configuration that clamps around the pipe or umbilical end fitting.

3.1.73**reaction flange**

Bend restrictor interface structure comprising a split flange arrangement that bolts directly to the support structure over which a bend restrictor element is assembled.

3.1.74**repair clamp**

Clamp that is positioned over a damaged area of pipe as a means to repair such an area.

3.1.75**scouring**

Removal or dissolution of parts of the seabed by bottom currents.

3.1.76**seabed connection**

Connection between riser end fitting and riser base.

3.1.77**secant modulus**

Slope of line drawn through the origin of a stress strain curve and intersecting a point on the stress strain curve corresponding to specified strain.

3.1.78**secondary stress**

Any normal or shear stress that develops as a result of material constraint.

NOTE 1 This type of stress is self-limiting, which means that local yielding can relieve the conditions that cause the stress, and single application of load will not cause failure.

NOTE 2 Definition taken from API 2RD.

3.1.79**service life**

Period of time during which the flexible pipe or umbilical is designed to fulfil all specified performance requirements.

3.1.80**setting time**

Time required for polymer or composite component to reside in mold before being removed.

3.1.81**snatch load**

Sudden load that acts on a slack tether with resulting dynamic amplification up to several times the applied tension.

3.1.82**spacer**

Discrete component of which a number in series are used to piggy-back one or more supported pipes to a supporting pipe over a prescribed length.

3.1.83**splice**

Termination normally formed by looping the rope around a spool or similar attachment means, separating the rope into strands or groups or strands, and then tucking these strands back into the rope structure.

NOTE Definition taken from API 2SM.

3.1.84**static bend restrictor**

Design scenario where bend restrictor is subjected to static loads only, and where there is no or negligible intermittent contact between bend restrictor elements induced by wave and current environmental loads.

3.1.85**subsea buoy frame**

Structural part of a subsea buoy. Includes the gutters, housings for clamps and buoyancy tanks or buoyancy elements and connection points for tether connection hardware.

3.1.86**support structure**

Structure that supports and transfers loads from a pipe or umbilical or bend limiter at either the topside, seabed, or intermediate connection.

3.1.87**supported pipe**

Pipe or umbilical that is attached via a series of piggy-back clamps or guides to a supporting pipe over a prescribed length.

3.1.88**supporting pipe**

Pipe that supports one or more pipes or umbilicals via a series of piggy-back clamps or guides over a prescribed length.

NOTE A supporting pipe can be a flexible pipe.

3.1.89**syntactic foam**

Composite material consisting of a polymer matrix containing microspheres only.

3.1.90**system owner**

Purchaser of pipe system from pipe system provider.

3.1.91**tear strength**

Measure of the force necessary to cause tearing of a sample of material (nicked or un-nicked) under specified conditions.

3.1.92**temporary bend stiffener**

Bend stiffener that is required to satisfy its functional requirements temporarily for flexible pipe or umbilical installation, handling or other activities but not in service.

3.1.93**tether**

Chain or rope used to connect a pipe or a subsea buoy to a tether base, including connecting hardware necessary at each end termination.

3.1.94**tether base**

Structure that secures one or a group of tethers to the seabed, including tether connection points and lifting points.

3.1.95**topside connection**

Connection between flexible pipe or umbilical end fitting and platform.

3.1.96**upper catenary**

Length of riser between the platform and the subsea buoy.

3.1.97**wet repair**

Repair of a flexible pipe in situ.

3.2 Abbreviations and Symbols

For the purposes of this document, the following abbreviations and symbols apply.

C_a	allowable stress factor ($C_a = 0.67$). Note: Taken from API 2RD.
C_f	design case factor. Note: Taken from API 2RD.
D_0	diameter at the bellmouth top end
D_b	diameter at the bellmouth bottom end
E	tensile modulus
F_s	shear force
G	shear modulus
l_b	length of bellmouth, measured along the curved wall
M	bending moment
R_b	minimum allowable bend radius (of a bellmouth)
T	effective tension

ν	Poisson's ratio
α	ratio of minimum (top) to maximum (bottom) curvatures (of a bellmouth)
k_b	curvature at bottom entry (equals y/R_b , where R_b is the radius) (of a bellmouth)
ϕ_b	angle of bottom entry (of a bellmouth)
σ_b	bending stress
σ_p	membrane stress
σ_q	secondary stress
$(\sigma_x)_e$	von Mises component of stress for σ_x . Example: $(\sigma_p)_e$ is the von Mises membrane stress.
AISI	American Iron and Steel Institute
API	American Petroleum Institute
AWS	American Welding Society
BS	standard issued by British Standards Institute
BV	Bureau Veritas
CCTV	closed-circuit television
CEN	Committee on European Normalization
CNC	Computer Numerical Control
CP	corrosion protection
DIN	Deutsches Institut für Normung e.V.
EMMUA	Engineering Equipment and Materials Users Association
EPDM	ethylene propylene diene monomer
FAT	factory acceptance testing
FEA	finite element analysis
FPU	floating production unit
GRE	glass-reinforced epoxy
GRP	glass-reinforced plastic
GVI	general visual inspection
HCP	Hydrostatic Collapse Pressure
HMPE	high modulus polyethylene
IAPSO	<i>International Association for the Physical Sciences of the Oceans</i>
IBL	Instrumented Buoyancy Loss
IVA	independent verification agent
MAOP	maximum allowable operating pressure
MBL	minimum breaking load
MBR	minimum bend radius
MBS	minimum breaking strength
MWL	mean water line
N/A	not applicable

NDE	nondestructive examination
PCD	pitch circle diameter
PD	Published Document
PLEM	pipeline end manifold
PLET	pipeline end termination
ROV	remotely operated vehicle
SBR	styrene butadiene rubber
SWL	safe working load
UKOOA	United Kingdom Offshore Operators Association
UV	ultraviolet
VIV	vortex-induced vibration

4 General Recommendations

4.1 Introduction

All flexible pipe/umbilical ancillary equipment should comply with the general recommendations in Section 4 (General recommendations). Clamping devices (buoyancy module clamps, load transfer devices including clamping elements, subsea buoy clamps, tether clamps, piggyback clamps and guides, repair clamps and I/J-tube seals with clamps) should comply with the general recommendations in Section 11 (General clamping device recommendations). Specific ancillary equipment should comply with the relevant section providing specific requirements.

This section identifies the sections of this RP and of API 17L1 to be consulted for relevant issues. In addition, this section gives a description of all the ancillary equipment addressed by this RP. This section also covers general guidelines and recommendations for ancillary equipment.

All aspects of ancillary equipment technology, from functional definition to installation, are addressed in either this RP or in API 17L1. Some issues are addressed in both documents. The various stages in the procurement and use of ancillary equipment are defined in Figure 1, which also specifies the sections of this RP and of API 17L1 to be referenced for each of the individual stages in the process.

Ancillary equipment manufacturers should make data available to operators, purchasers, and their selected verification contractors to enable independent design analysis verification.

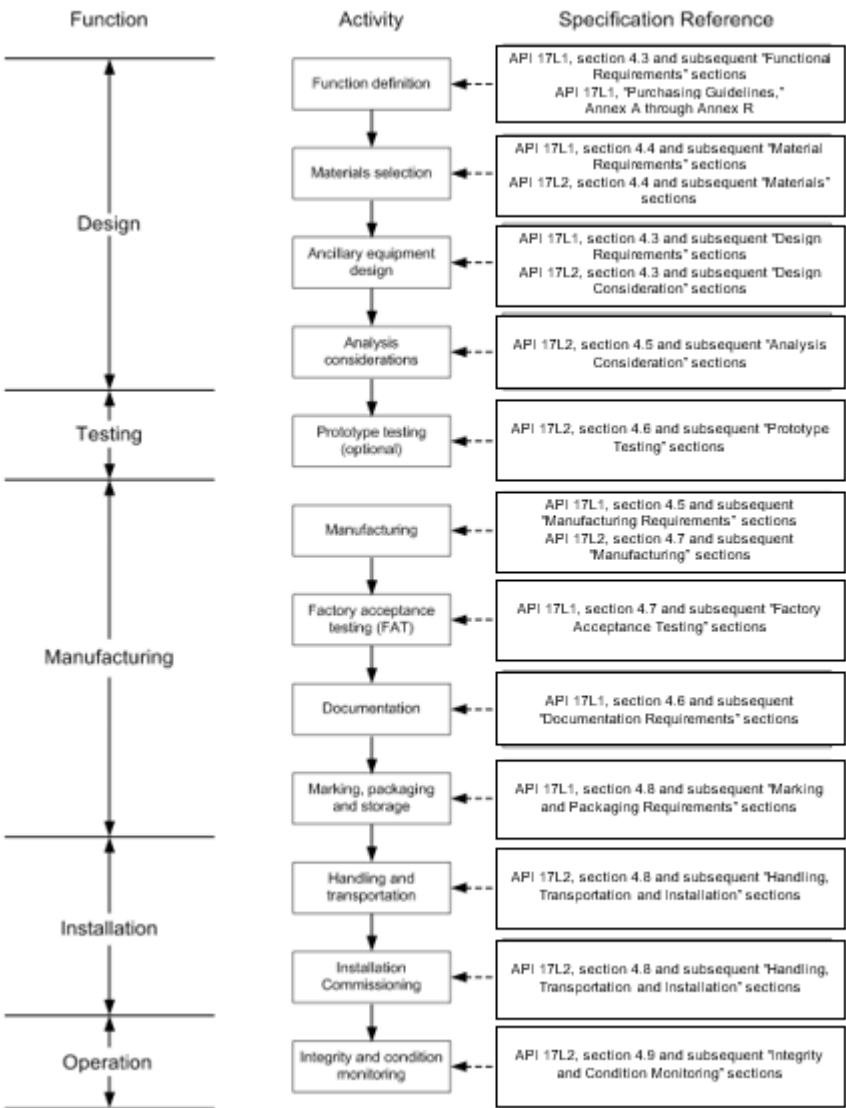
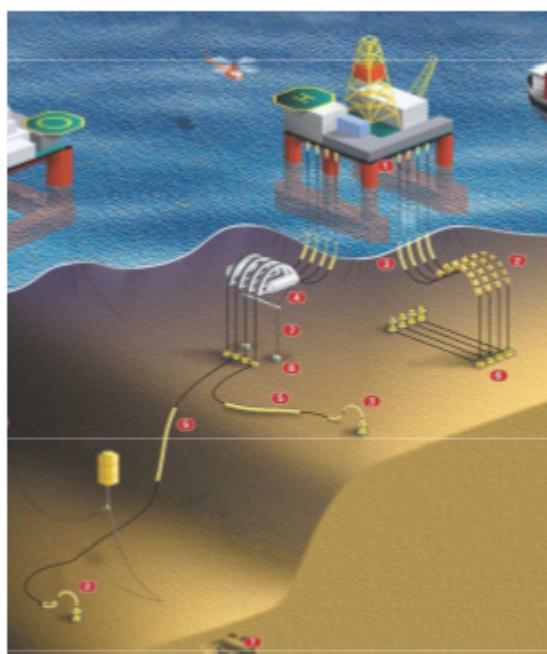


Figure 1—Ancillary Equipment Overview

4.2 Ancillary Equipment Description

4.2.1 Global Position in Flexible Pipe or Umbilical System

Figure 2 shows the position of selected ancillary equipment in the global flexible pipe or umbilical system, i.e. typical global positions of bend stiffeners, buoyancy modules, bend restrictors, subsea buoys, abrasion and impact protection, riser bases, subsea buoy tethers and subsea buoy tether bases.



Key		
1 bend stiffener	4 subsea buoy	7 subsea buoy tether
2 buoyancy modules	5 abrasion and impact protection	8 subsea buoy tether base
3 bend restrictor	6 riser base	

Figure 2—Global View of Selected Ancillary Equipment

4.2.2 Bend Stiffeners

Bend stiffeners are used to protect the flexible pipe/umbilicals from overbending to beyond allowable limits and increase their fatigue performance by reducing curvature variations on fatigue critical components. Bend stiffeners are often used to provide protection to the flexible pipe or umbilical in dynamic applications. Bend stiffeners may also be used in static applications, such as providing protection during installation. They may be attached to the flexible pipe either at the topside connection, or at any intermediate connection, or at the seabed connection. They typically consist of a conical section of polymer material with a cylindrical bore that slides over the flexible pipe or umbilical. Examples of typical bend stiffener configurations are shown in Figure 3 and Figure 4. The bend stiffener is attached to the adjacent structures by means of a metallic interface structure, as shown in Figure 3 and Figure 4, that is embedded in the polymer and is typically bolted into position. Bend stiffeners with a fiber-reinforced conical section are also being proposed.



Figure 3—Bend Stiffener—Truncated Cone Shape

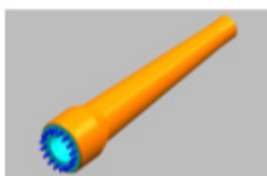


Figure 4—Bend Stiffener—Cylindrical and Truncated Cone Shape

4.2.3 Bend Restrictors

Bend restrictors are designed to prevent bending of flexible pipes/umbilicals beyond predefined threshold values. Bend restrictors are used to support a flexible pipe or umbilical where there is a possibility of damaging the pipe structure because of over-bending. They are primarily used for static applications. Typical applications are pipe support over free spans (where there is the possibility of damaging the pipe structure because of over-bending), wellhead connections, pipeline end termination (PLET) connections, J-tube exits, rigid pipe crossovers, and over a subsea buoy (as can be seen in Figure 20). A J-tube exit application is illustrated in Figure 5. Bend restrictors also may be used to prevent over-bending during installation (as shown in Figure 6 for a PLET connection).

Unlike bend stiffeners, bend restrictors only provide protection once the flexible pipe or umbilical has achieved a particular bend radius. The bend restrictor normally consists of interlocking elements that fit around the pipe. An example of an element configuration is illustrated in Figure 7. These elements do not restrict the pipe from bending until a specified bend radius is reached, at which stage they lock. A typical polymer bend restrictor is shown in Figure 8. The locking of the restrictor prevents further bending of the pipe, and additional loads are carried by the bend restrictor. Loads are transferred to the adjacent structure by means of an interface structure that is attached to the endmost element. Bend restrictor elements can comprise polymer half-shells that are bolted together as shown in Figure 9, or sections of metallic pipe or machined metallic components. Bend restrictors manufactured from standard pipe are more suited to situations in which the bend restrictor is assembled onto the flexible pipe onshore. Machined or molded bend restrictor elements featuring a split configuration in the form of half-shells are more suited to assembly onto the flexible pipe or umbilical offshore.

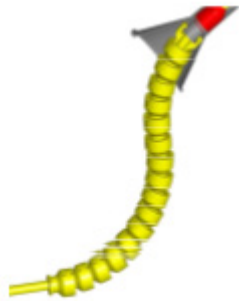


Figure 5—Example of Bend Restrictor for J-tube Exit Application

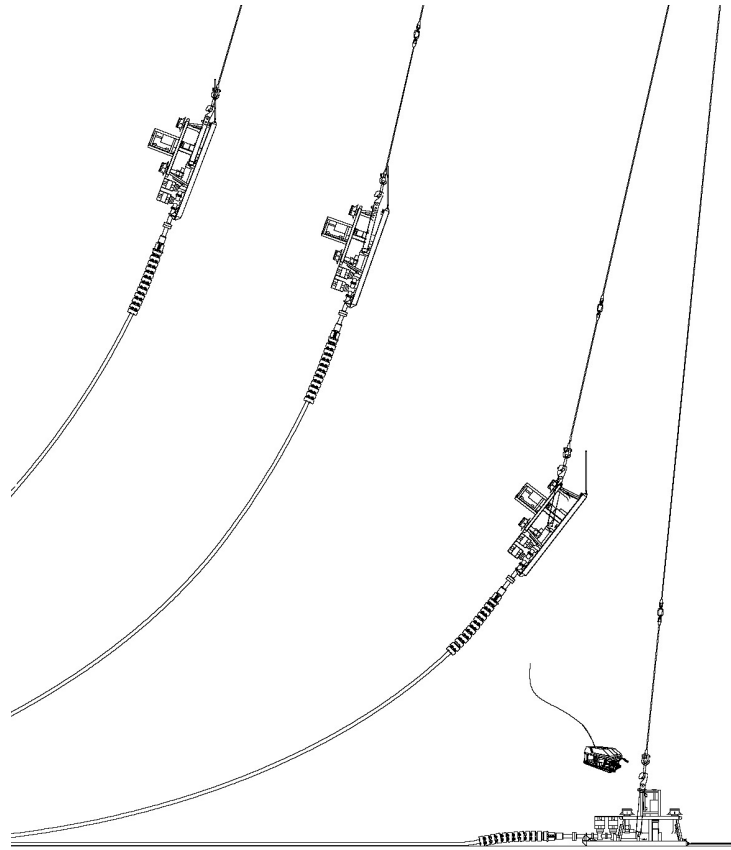


Figure 6—Example of Bend Restrictor Application

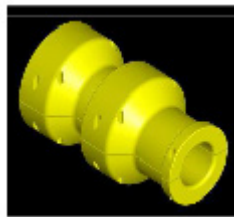


Figure 7—Example of Bend Restrictor Element Configuration



Figure 8—Bend Restrictor

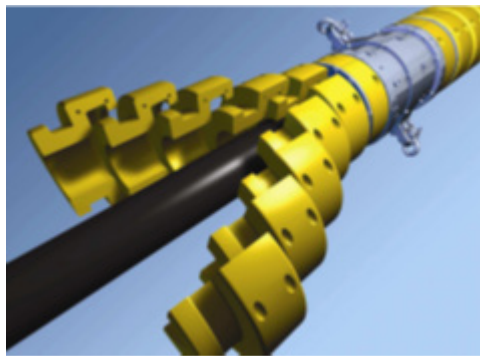


Figure 9—Bend Restrictor (Exploded View) Showing Interlocking Elements

4.2.4 Bellmouths

Like bend stiffeners and bend restrictors, the bellmouth protects the flexible pipe or umbilical from bending to levels beyond its allowable minimum bend radius (MBR). A bellmouth comprises a hollow tube that flares out into a bell-shaped profile at its end, as shown in Figure 10. The pipe exits the bellmouth from this end, and the bell-shaped profile prevents the pipe bending beyond a certain radius within its angular range. The profile may not be axisymmetric due to space restrictions and may not have a cylindrical exit. Bellmouths may be of metallic or composite construction. A metallic bellmouth has the advantage of having a much higher temperature resistance than polymer or composite bend limiters. In a metallic bellmouth, the interior surface of the bellmouth is typically covered in a polymer layer to avoid pipe or umbilical wear. The disadvantage of a bellmouth compared with a bend stiffener can be the possibly prohibitive physical space required to accommodate the bellmouth. Also, where the vessel motions are quite high, the clashing of the pipe with the interior of the bellmouth can be excessive.

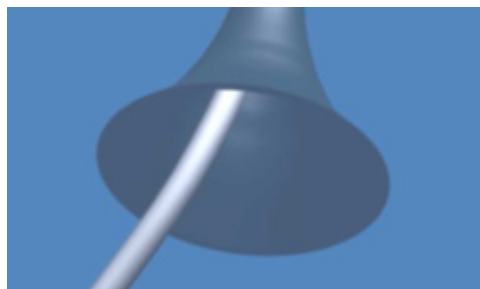


Figure 10—Bellmouth with Cylindrical Exit

4.2.5 Buoyancy Modules

Buoyancy modules are used to achieve the wave-shape riser configurations [lazy (Figure 11), steep (Figure 12), pliant (Figure 21) and W-waves (Figure 13)]. Several modules spaced at intervals along the riser are required to achieve a wave configuration. The buoyancy modules are typically composed of two components: an internal clamp and a syntactic or composite syntactic foam buoyancy element, as shown in Figure 14 a). A close-up of an example of an internal clamp is shown in Figure 14 b). A polymer external skin provides impact and abrasion resistance. The internal clamp is attached to the pipe or umbilical, and the buoyancy element fits around the clamp by means of recesses molded into the interior of the buoyancy element. An internal clamp strap is used to fasten the internal clamp onto the pipe or umbilical. The internal clamp strap may be manufactured from titanium or aramid fiber-based composite. The buoyancy elements may be manufactured in two halves that are fastened together around the clamp by means of bolts or an external strapping arrangement. Alternatively, designs are provided as a unitary hinged module that latches around the internal clamp and is secured with a single locking pin, as shown in Figure 14 c). The internal clamp could be an integral part of the buoyancy module as shown in Figure 14 d). Buoyancy modules are mostly cylindrical in shape, but installation or other constraints may dictate a rectangular shape. Figure 15 shows an example of cylindrical buoyancy modules attached to a riser via twin external straps. Some bonded flexible pipes have integral elastomer collars at intervals along the pipe to facilitate the attachment of ancillary devices. These collars are generally built and cured with the pipe.

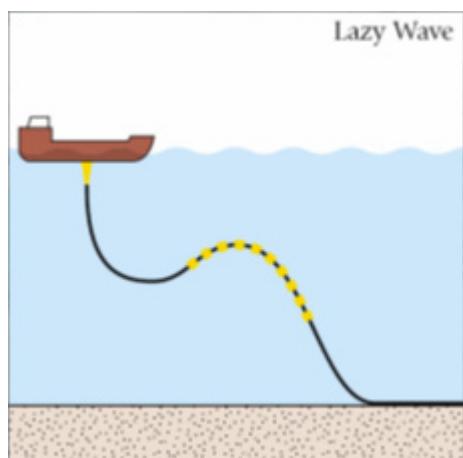
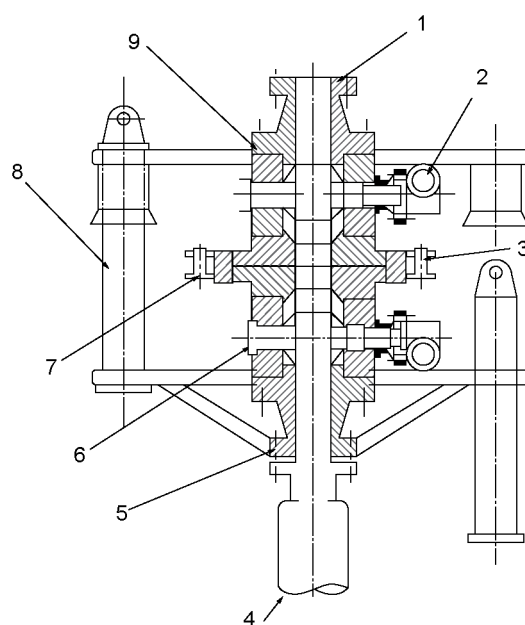


Figure 11—Lazy Wave Flexible Riser Configuration



Key

- | | |
|----------------------------------|-----------------------------|
| 1 hard piping interface flange | 6 lower ball valve |
| 2 ball valve actuator | 7 emergency release coupler |
| 3 piping seals | 8 support structure |
| 4 flexible pipe interface flange | 9 upper ball valve |
| 5 riser interface flange | |

Figure 12—Steep Wave Flexible Riser Configuration

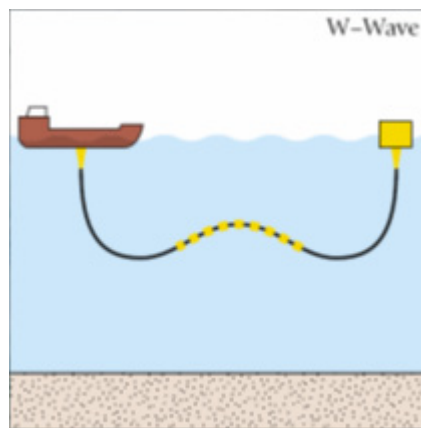


Figure 13—W-wave Flexible Riser Configuration

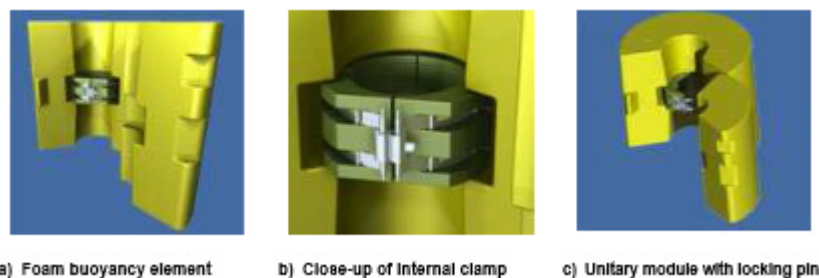


Figure 14—Example of Hinged Buoyancy Module Configuration

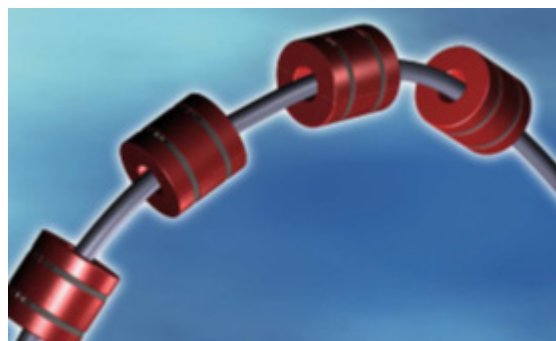


Figure 15—Buoyancy Modules with External Straps

4.2.6 Ballast Modules

In certain circumstances it is desirable to increase the weight of a flexible pipe or umbilical in certain areas, to improve its behavior. To achieve this, ballast modules, which are effectively the opposite of buoyancy modules, are attached to the pipe.

4.2.7 Subsea Buoys

Subsea buoy systems are used to achieve S-shaped riser configurations, including lazy (Figure 16), steep (Figure 17) and reverse configurations (note that in the reverse configuration the lower catenary of the riser passes back underneath the buoy). The objective of the subsea buoy is to provide up thrust, longitudinal fixture and guidance to the supported risers. The subsea buoy typically consists of buoyancy tanks or elements, supported by a metallic structure, over which lie individual gutters for each pipe. Buoyancy may be provided in the form of buoyancy tanks or solid buoyancy elements. Buoyancy tanks may be constructed from metallic or composite materials and may be pressurized with an inert gas. Buoyancy elements are made from blown or syntactic foam. The risers may be held in place on the gutters by means of clamps. The subsea buoy system is held in

place by a tether base to which it is connected by tethers (lazy-S) or by flexible risers (steep-S). The S-shaped riser configuration can alternatively be achieved by using a fixed support instead of a floating buoy. The main disadvantage of this system is the reduction in compliancy of the riser system.

An example of a subsea buoy with buoyancy elements is given in Figure 18, showing the arch-shaped gutters on top of the subsea buoy, buoyancy elements and chain tethers. Examples of a subsea buoy with buoyancy tanks are shown in Figure 19 and Figure 20. Figure 19 shows the tether base on the seabed and an intermediate V-shaped connection, known as a bridle, that connects the tethers to the main subsea buoy structure. Figure 20 shows three clamps on top of the subsea buoy, as well as the gutters.

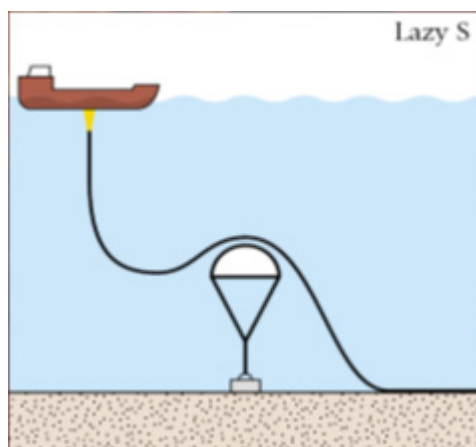


Figure 16—Lazy-S Flexible Riser Configuration

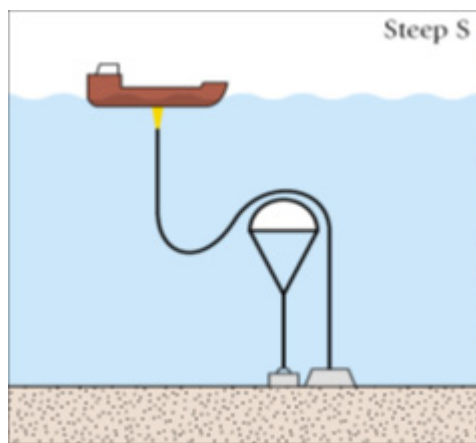


Figure 17—Steep-S Flexible Riser Configuration

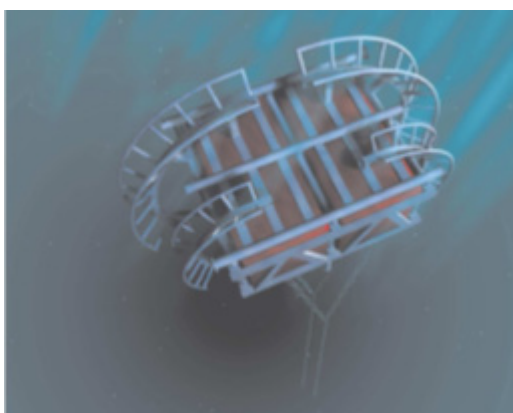


Figure 18—Subsea Buoy with Buoyancy Elements

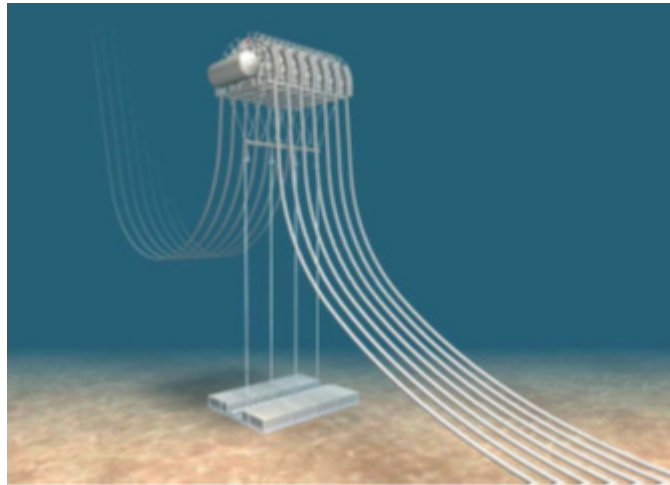


Figure 19—Subsea Buoy with Buoyancy Tanks, Showing Bridle



Figure 20—Subsea Buoy with Buoyancy Tanks, Showing Gutters

4.2.8 Tethers

Tethers are used to hold subsea buoys in place or to secure the riser to the seabed in certain riser configurations, such as a tethered lazy wave configuration. Tethers can be made from chain, wire rope or synthetic fiber. Applications of tethers are shown in Figure 18, Figure 19, and Figure 21.

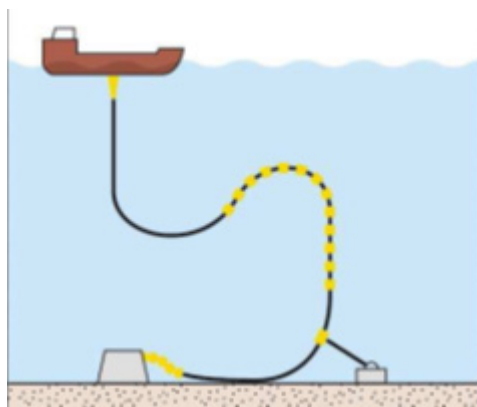


Figure 21—Pliant Wave Configuration with Tether Clamp Restraining Riser Motion at Touchdown

4.2.9 Riser Bases

Riser bases are used to connect flexible risers to flowlines and may also be required to support subsea buoy/arch systems (e.g. steep-S configurations). The riser base can be either a gravity structure, a piled structure, or a suction/anchor pad. Selection of gravity-based or piled structure depends on applied loads and soil conditions. As an alternative, the flexible pipe can be connected directly to a PLET, a manifold or a pipeline end manifold (PLEM), in which case the PLET, manifold or PLEM acts as the riser base. Examples of riser base structures are shown in Figure 22 and Figure 23.

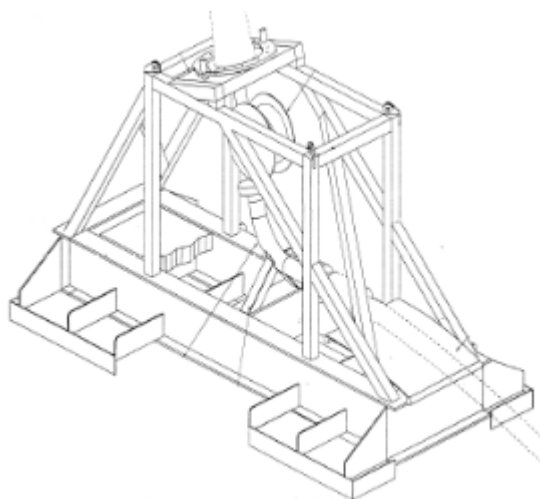


Figure 22—Example of Riser Base

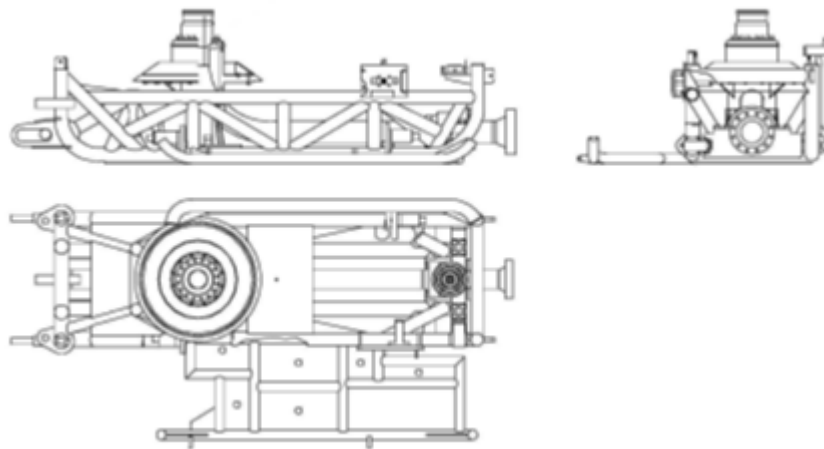


Figure 23—Example of Riser Base/PLET ^[43]

4.2.10 Tether Bases

Tether bases are used to anchor subsea buoy systems (e.g. a lazy-S configuration) or to secure riser tethers to the seabed in certain configurations such as in pliant wave configurations. An example of a tether base for a subsea buoy system is shown in Figure 19. The tether base is shown positioned on the seabed connected to the tethers.

4.2.11 Subsea Buoy Clamps

Subsea buoy clamps are used to secure flexible pipes or umbilicals to subsea buoys. They typically consist of a split steel assembly that is bolted onto the pipe. The clamp bore may include a polymer inner liner material to accommodate expansion and contraction of the flexible pipe, including creep of the outer sheath. Figure 24 shows an example of a subsea buoy clamp configuration having a polymer inner liner between the clamp body and the pipe. The small circular attachments on the clamp are corrosion protection (CP) anodes, and the central circular plate on the clamp is used to locate the clamp within the subsea buoy. Figure 20 shows the clamp deployed on the subsea buoy.

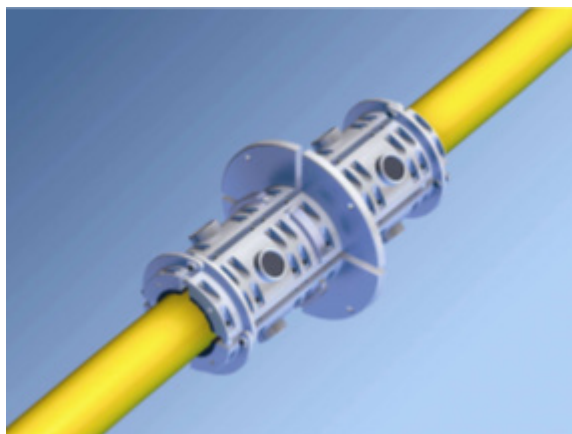


Figure 24—Example of Subsea Buoy Clamp

4.2.12 Tether Clamps

Tether clamps are used to attach tethers directly to a pipe, as shown in a global view of the pipe in Figure 21. The clamp fits around the circumference of the pipe and provides a connection to which the tether is fitted. Sometimes it is necessary to provide bend-limiting devices at either edge of the clamp since the pipe may experience over-bending about these edges. Figure 25 depicts, in close-up view, an example of a tether clamp.

arrangement showing the connection of the tether, via a shackle, to the clamp. It also shows a swivel ring that allows the tether connection to rotate with respect to the clamp.



Figure 25—Close-up View of Tether Clamp

4.2.13 Piggy-back Clamps and Guides

Piggy-back clamps or guides are used at regular intervals along a pipe length to “piggy-back” other lines such as umbilicals or flexible pipes. They may consist of a split polymer assembly, with cylindrical recesses for the supporting pipe and the supported pipe that is bolted onto the supporting pipe. Alternatively, they can comprise a polymer spacer with a cylindrical recess, as shown in Figure 26 and Figure 27. This accommodates the supported pipe and is itself strapped onto the supporting pipe. Strap materials include carbon steel, stainless steel, super-duplex, titanium, and aramid fiber-based composite.

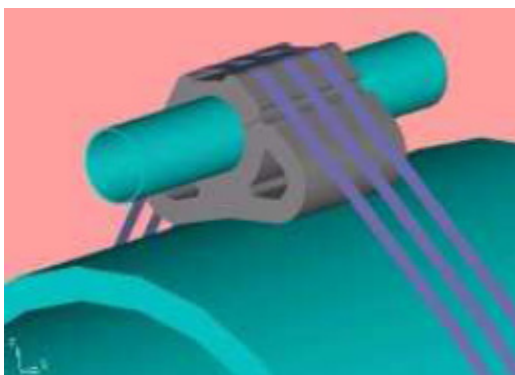


Figure 26—Example 1 of Piggy-back Spacer

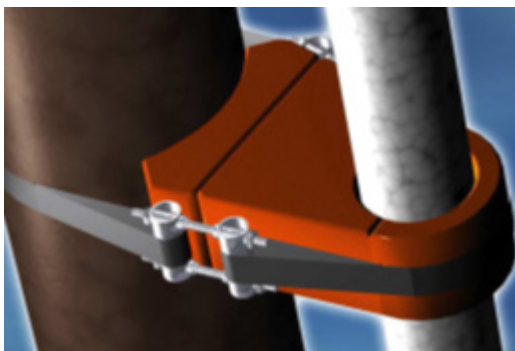
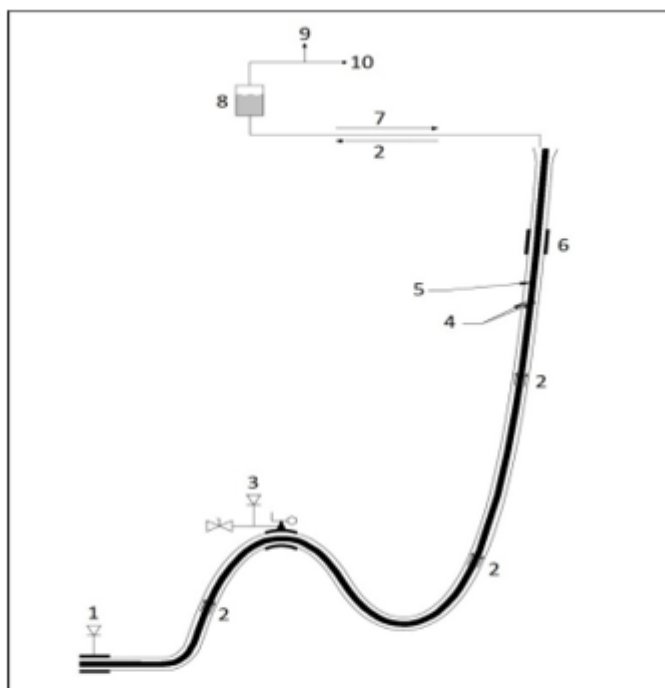


Figure 27—Example 2 of Piggy-back Spacer

4.2.14 Repair Clamps

Repair clamps are used on areas of the flexible pipe where damage has been caused. An example of a repair clamp application is shown in Figure 28. As shown in the figure, the clamp may be required to vent off gases from the flexible pipe annulus. Several configurations are available. A light-weight clamp, such as that shown in Figure 29, can be tensioned, and sealed by a remotely operated vehicle (ROV) onto relatively small areas of damage. Alternatively, a larger clamp design, such as that shown in Figure 30, can be employed for areas of damage that are longer and of greater circumference. The seal is created by tensioning of the attached bolts by an ROV.



Key

- | | |
|--|--------------------------------|
| 1 gas relief valve (opens at $\Delta P = 3$ bar) | 6 clamp |
| 2 permeated gas | 7 inhibitor fluid |
| 3 hog bend: clamp with venting arrangement | 8 header tank (head = 1.7 bar) |
| 4 pipe annulus | 9 to flare |
| 5 pipe bore | 10 to gas sampling |

Figure 28—Example of Repair Clamp Application ^[40]



Figure 29—Light-weight Repair Clamp ^[35]

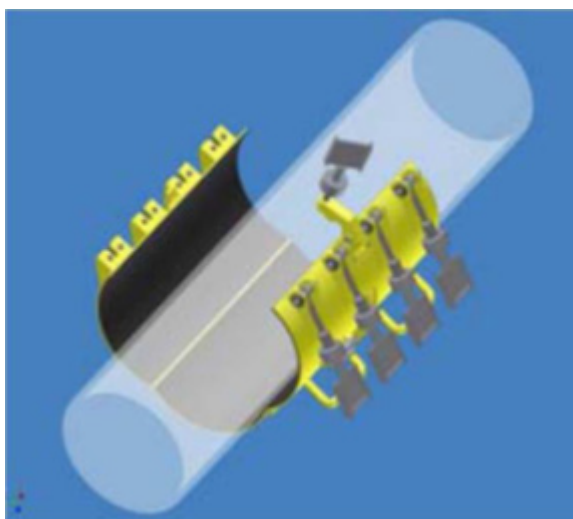


Figure 30—Large Repair Clamp Design ^[35]

4.2.15 I/J-tube Seals

The internal surfaces of an I-tube or J-tube are often difficult to protect against corrosion by traditional means, such as coatings or CP systems. Corrosion rates will diminish with distance from the end of the I/J tube as dissolved oxygen in the seawater is depleted. The tube may also be greased and/or a corrosion inhibited fluid may be used in the I/J tube. The function of the I/J tube seal is to prevent or reduce the exchange of fresh oxygenated seawater with oxygen depleted seawater in the tube and/or to help contain corrosion inhibitors within the I/J tube. There are two types of I/J-tube seal: diverless and diver-assisted. The diverless I/J-tube seal, as shown in Figure 31 and Figure 32, is designed to be pulled into the I/J-tube. The seal is provided by a series of sealing elements, which are shown in Figure 31. The sealing elements are held in position on the pipe by a clamping device that resists the pull-in forces. The diver-assisted I/J-tube seal, as shown in Figure 33, requires assembly by a diver and may also sometimes incorporate a clamp.



Figure 31—Diverless J-tube Seal

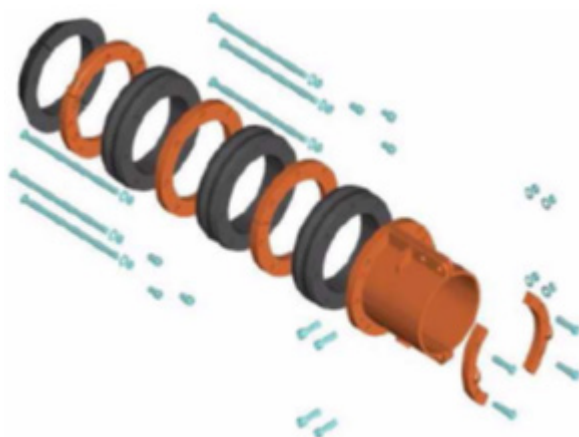


Figure 32—Diverless J-tube Seal (Exploded View)

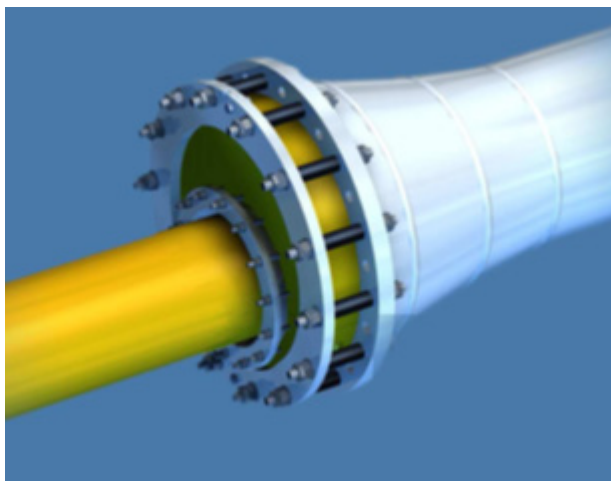


Figure 33—Diver-assisted J-tube Seal

4.2.16 Pull-in Heads

Pull-in heads typically consist of a flanged structure that bolts directly onto the flexible pipe or umbilical end fitting, as shown in Figure 34. A pad-eye is usually welded to the other end and is used to connect to a pull-in wire. Some pull-in heads may incorporate vents to facilitate pressure testing. They are generally a nonstandard item, since they need to be dimensionally compatible with the particular end fitting being used. Thus, they are seldom re-used.

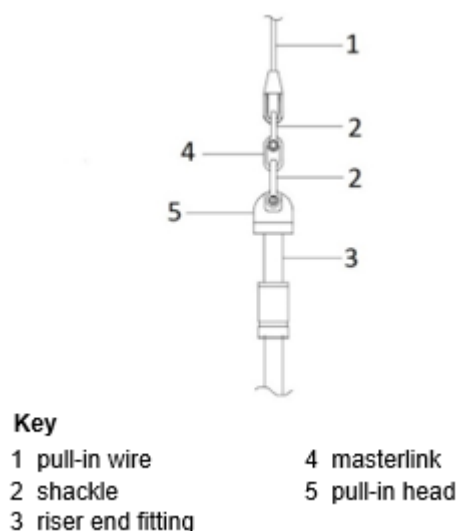


Figure 34—Example of Pull-in Head Configuration ^[32]

4.2.17 Chinese Fingers

Chinese fingers are typically used when transfer of tension is required from lifting devices to the flexible pipe or umbilical. The Chinese finger typically consists of a cylindrical mesh of wire rope that wraps around a portion of the pipe length and is connected to lifting equipment. An example of such a configuration is shown in Figure 35. The Chinese finger is designed such that the grip on the pipe increases with increased tension applied to the Chinese finger. The Chinese finger is designed to impart load onto a pipe principally in an axial direction.

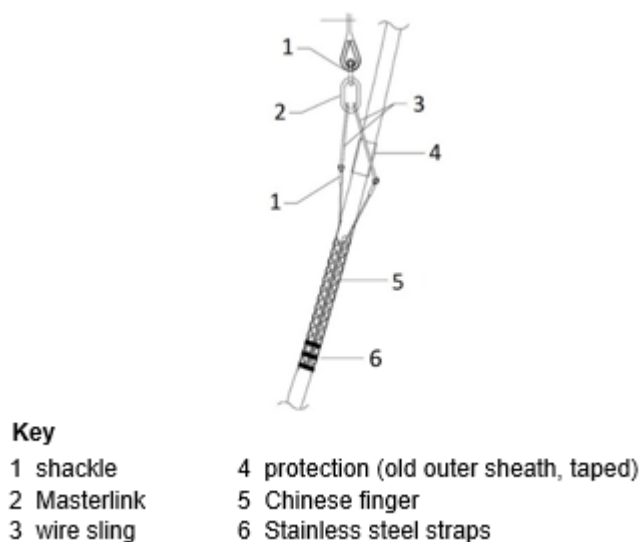


Figure 35—Example of Chinese Finger Configuration ^[32]

4.2.18 Connectors

Connectors are used to connect the flexible pipe-end fittings on both sides of the flexible pipe to the adjacent piping, providing a both pressure-containing and structural connection. They may consist of a simple flanged arrangement that bolts to the end fitting, a clamped hub, or may be of a more complicated design that allows the connector to lock in place after it has been pulled in. Swivel flanges, as shown in Figure 36, are a particular type of connector that offers the advantage of relative rotation between the connector and the vessel to aid installation operations.

Flexible pipe may be supplied and tested with temporary connectors which are cut off to enable welding directly to flowline pipe.

Quick-disconnect and quick-connect-disconnect systems may be used as connectors where emergency release is an operational requirement for dynamic riser applications. Figure 37 illustrates an example of a quick-disconnect system.

The main features of emergency release systems are typically as follows:

- a) isolation ball valve in upper and lower halves of the structure;
- b) ability to disconnect under full design loads and internal pressure;
- c) minimal dimensions and mass for structure;
- d) full bore throughout to allow for pigging;
- e) pressure-tight connection with face-to-face type primary seals, to avoid damage to seals during disconnect/reconnect and dynamic loading;
- f) ball valves to be interlocked with release mechanism, to ensure closure on disconnection (may not be required for all applications);
- g) simplified support structure (guidepost funnels), to allow easy and safe reconnection;
- h) capability to periodically test release mechanism without releasing the riser or breaking primary seals (or, if this is not feasible, an alternative test procedure which includes retesting of primary seals after reconnection).

See API 17A for more detailed descriptions of connectors.

NOTE The description of quick-connect and disconnect systems in this section and Figure 37 has been transferred directly from API 17B.

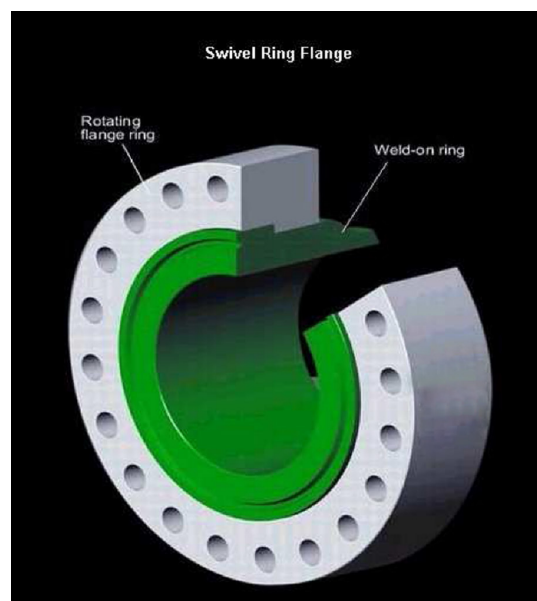
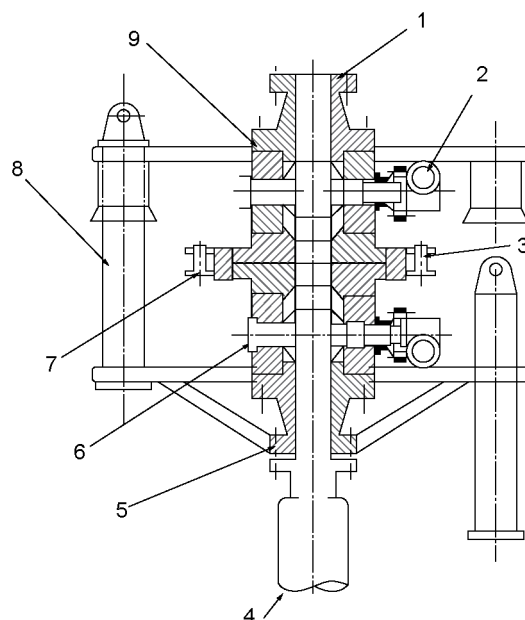


Figure 36—Swivel Flange



Key

- | | |
|----------------------------------|-----------------------------|
| 1 hard piping interface flange | 6 lower ball valve |
| 2 ball valve actuator | 7 emergency release coupler |
| 3 piping seals | 8 support structure |
| 4 flexible pipe interface flange | 9 upper ball valve |
| 5 riser interface flange | |

Figure 37—Example of a Quick-disconnect System

4.2.19 Load-transfer Devices

Load-transfer devices provide an arrangement for transferring the loads from the flexible pipe or umbilical to the topside connection. The load-transfer device may incorporate collars, clamps, or flanges, and may interface with the flexible pipe end fitting or the bend stiffener interface structure. The load-transfer device can be pulled in through the I/J-tube of a vessel whereby a male assembly locks into a female receptacle in the I/J-tube.

Examples of different load-transfer device configurations and corresponding illustrative figures are listed as follows:

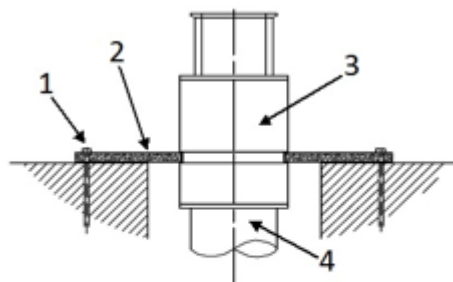
- a) collar that interfaces with the flexible pipe end fitting—Figure 38;
- b) clamp and collar that interfaces with the flexible pipe end fitting and a deck turret—Figure 39;
- c) clamp and collar that interfaces with the flexible pipe end fitting, bend stiffener interface structure and deck supports—Figure 40;
- d) moment-transfer flange that interfaces with the bend stiffener interface structure—Figure 41;
- e) pull-in load-transfer device—Figure 42.

The top connection of a flexible riser can be hung off the support structure (such as a platform, tanker, or semi-sub) either externally or internally.

EXAMPLE 1—The riser can be connected to topsides piping at pontoon level or hung off at upper deck level in an external connection.

EXAMPLE 2—The riser is typically pulled through an I/J-tube and hung off at the top of the I/J-tube in an internal connection (Figure 38 or Figure 39).

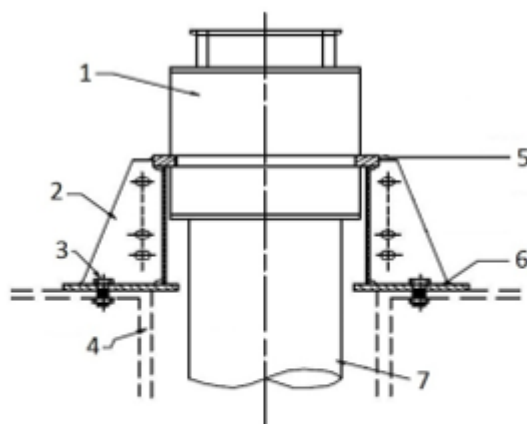
The loading on the two hang-off structures is very different, with the internal connection subject only to axial loads, while the external connection experiences axial, bending, and shear loads.



Key

- | | |
|----------------|-----------------|
| 1 bolts | 3 end fitting |
| 2 split collar | 4 flexible pipe |

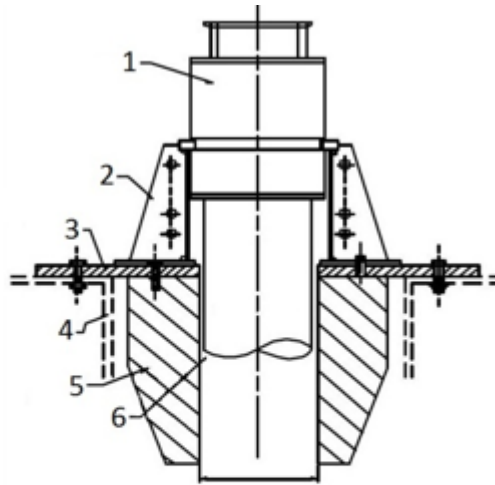
Figure 38—Load-transfer Device with Collar



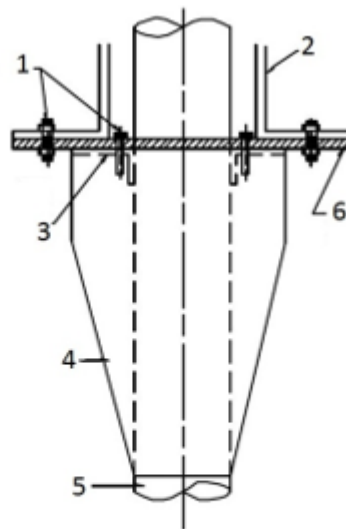
Key

- | | |
|---------------|-----------------|
| 1 end fitting | 5 collar |
| 2 clamp | 6 flange |
| 3 bolts | 7 flexible pipe |
| 4 deck turret | |

Figure 39—Load-transfer Device with Clamp and Collar, Deck Turret

**Key**

- | | |
|--------------------------|------------------|
| 1 end fitting | 4 deck supports |
| 2 collar | 5 bend stiffener |
| 3 moment transfer flange | 6 flexible pipe |

Figure 40—Load-transfer Device with Clamp and Collar, Deck Supports**Key**

- | | |
|--------------------------------------|--------------------------|
| 1 bolts | 4 bend stiffener |
| 2 I-tube | 5 flexible pipe |
| 3 bend stiffener interface structure | 6 moment transfer flange |

Figure 41—Load-transfer Device with Moment-transfer Flange

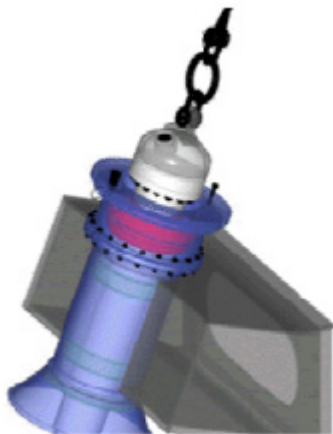


Figure 42—Pull-in Load-transfer Device

4.2.20 Mechanical Protection

4.2.20.1 Abrasion and Impact Protection

It is often desirable to protect the flexible pipe or umbilical from abrasion and impact loads, for example in the touchdown region where the pipe can make intermittent contact with the seabed in dynamic applications. This is particularly true if the seabed conditions are harsh, for example due to presence of coral. Abrasion and impact protection can also be used at the surface to protect pipes from clashing at the hang-off location. Abrasion and impact protection provide the necessary protection to the pipe in these circumstances. It can consist of polymer half-shells or lengths that have a single longitudinal split. Figure 43 shows typical positions of the abrasion protection in the global flexible pipe system, while Figure 44 shows an example of abrasion and impact protection close-up. It can also be supplied spirally cut in which case it is wrapped around the flexible pipe.

This mechanical protection is held in position by banding. Banding can be manufactured from metallic or polymer materials, the latter offering the advantage of a lighter-weight system. In some products the banding is positioned within the abrasion and impact protection, to protect it from abrasion and impact loads. Some abrasion and impact protection products can also provide added weight to the flexible pipe, which is advantageous in cases where additional stability near the touchdown region is required. The added weight is typically achieved by the use of high-density polymers or by incorporation of metal inserts into the abrasion and impact protection.

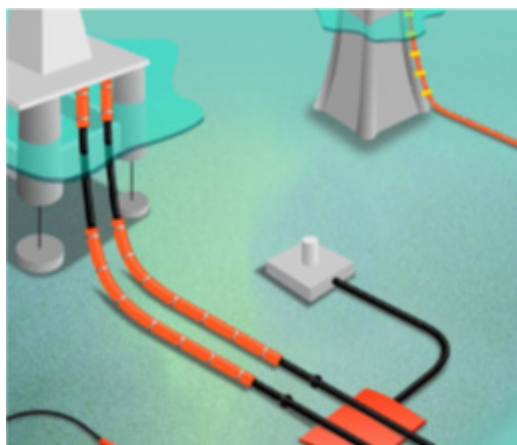


Figure 43—Global View of Flexible Pipe or Umbilical Mechanical Protection



Figure 44—Example of Flexible Pipe Abrasion and Impact Protection

4.2.20.2 Blanket Protection

Blanket protection is a polymer blanket that is used to provide protection to the flexible pipes on the seabed at pipeline or cable crossings, as shown close up in Figure 45. It can also be used to provide stability to the flexible pipe. Its mass may be increased for this purpose by incorporating infill of high density material. It may be installed by ROV.

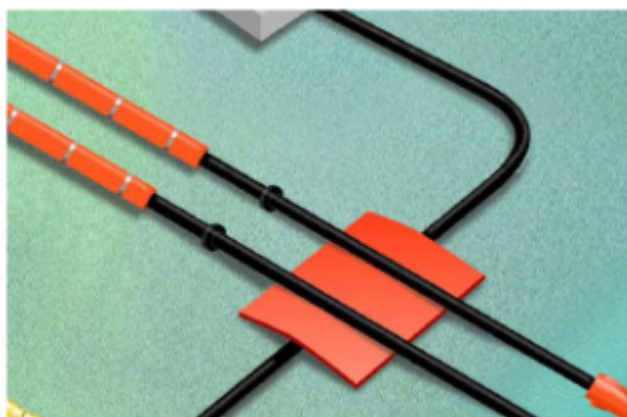


Figure 45—Example of Flexible Pipe Blanket Protection

4.2.21 Fire Protection

Fire protection is used to protect the surface of the flexible pipe or umbilical system from any fires that could potentially break out at topside level. The fire protection may be applied to the flexible pipe, topside end fittings, and any surface ancillary equipment such as bend stiffeners. Figure 46 shows an example of a fire-protection coating configuration for protection of the pipe, end fitting and hang-off structures. Figure 47 shows an example of a fire-protection coating configuration for protection of a bend stiffener and hang-off structures. Ultimately, the fire protection can only protect for a specified amount of time; enough to perform remedial action to prevent production fluid from getting drawn into the fire or adverse damage being caused to the pipe system. Fire protection can be applied in the form of an external coating or a tape that is wrapped around the pipe outer sheath. Alternatively, fire protection can be provided by incorporating dedicated fire-resistant layers within the conventional flexible pipe cross-section make-up.

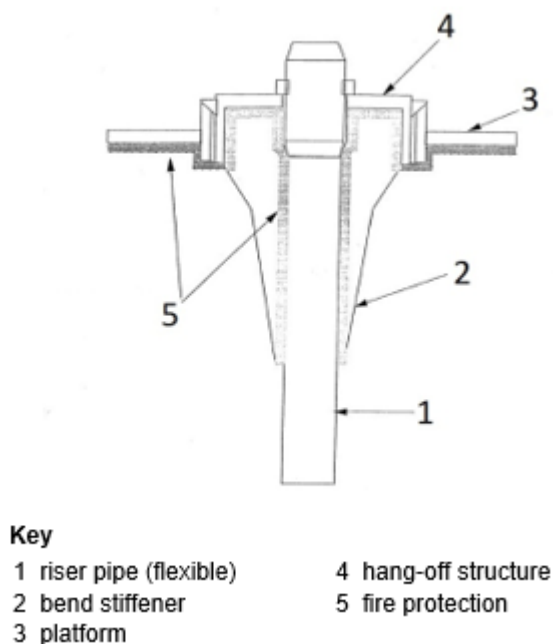


Figure 46—Example of Fire Protection Configuration for Flexible Pipe and Hang-off Structures

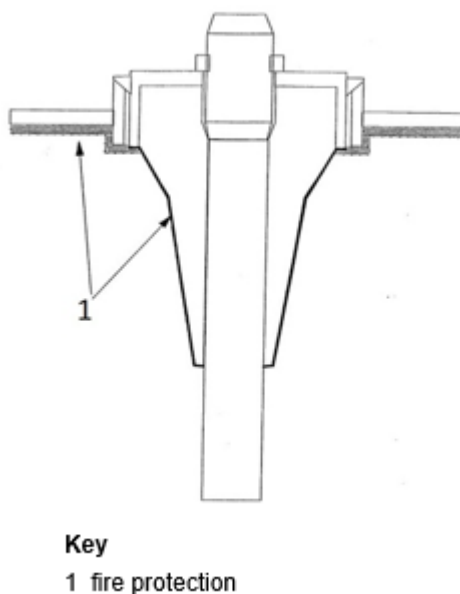


Figure 47—Example of Fire Protection Configuration for Bend Stiffener and Topside Structures

4.2.22 VIV Strakes

Vortex induced vibration (VIV) on a steel pipe, umbilical or flexible pipe (commonly referred to in this document as line) may contribute to the fatigue damage of the line over the service life and the installation, and therefore it can be desirable to reduce the VIV exerted on the line. One way of reducing the VIV magnitude is the installation of VIV strakes onto the line. They can consist of one or more shells with protruding vanes in a helical pattern wrapping around the line which disrupt the current and mitigate most of the VIV oscillations.