DeepRope® manual 2004

THE DIGITAL VERSION

DeepRope®

Polyester & Dyneema® mooring ropes manual 2004

ISO-9001 CERTIFICATED FIRM

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Summary

Rapid developments in the field of synthetic fibres have led to serious alternatives for the traditional wire/chain systems in marine and offshore operations. The most important difference between fibre and wire ropes is the fact that there is extensive experience, both practical and in design, for wire rope in engineering applications. For fibre rope experience is largely empirical and in the marine environment. However based on the material and rope design selected an assessment of the behaviour can be made. For fibre rope the materials have a significant influence on the primary characteristics of the rope, such as elongation, weight for a given strength, fatigue life and abrasion. Secondly the rope construction will also affect those characteristics and determine whether behaviour and use improves or becomes more critical. For example within a limited range elongation can be increased for a rope made from a given fibre. Certain rope designs are sensitive to kinking and others not at all.

In this manual a short overview is given of the materials and rope constructions available for synthetic moorings, additionally attention is given to deepwater mooring systems and the design for deepwater mooring lines. It is written for the use of synthetic lines in offshore operations.

Here the manufacturing of a polyester deepwater mooring line is shown.

Le Lis

Le Lis n.v. manufactures ropes for deepwater offshore applications, known as DeepRope®, and Deltaflex® ropes. The company has been active since 1919. The company is ISO 9001-2000 certified in sales, marketing, research, development and production of yarns, tapes and strapping, marine- and offshore ropes in synthetic high performance fibres. It is located some 30 minutes from the Port of Antwerp and some 50 minutes from Brussels.

Le Lis n.v. is a subsidiary of Bexco n.v.. Other companies in the group are Vermeire n.v. and Bexco Fibres n.v. Vermeire n.v. manufactures ropes for marine and offshore applications. The products for the marine environment range from polypropylene, polyester, bexcoline composites, polyamide (nylon). In offshore applications HMPE (Dyneema®) Aramid ropes and Single Point Mooring hawsers are well known products. The systems comply with OCIMF guidelines. Bexco Fibres n.v. is active in extrusion and strapping. The group has some hundred employees and in 2003 a turnover of € 18 million.

Vryhof Anchors

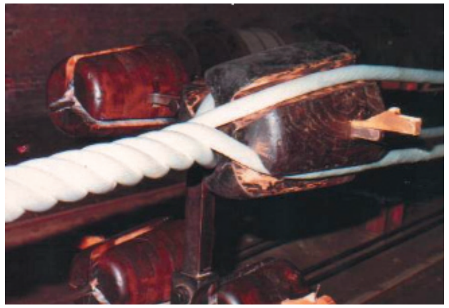
For millennia anchoring was achieved by using a stone and something that looked like a rope. Over the last twenty five years of more recent history Vryhof Anchors b.v. has brought the art to more mature status. The company has grown into a world leader in state-of-the-art engineering and manufacturing of total mooring systems for every kind of floating structure. From the very beginning Vryhof has fully understood that the needs of clients are not to be satisfied by the supply of standard hardware alone, and the exclusive specialisation and dedication to customer's requirements have yielded remarkable results.

The first anchor, STEVIN, was followed by an ongoing series of improvements, the HOOK, STEVMUD, STEVDIG and STEVROCK, each an optimal combination of practical feedback and further research to create ideal anchor designs for specific operating conditions and soil types. In the 80's the specific advantages of the previous anchors were combined into one new high performance anchor: STEVPRIS and its hard soil version STEVSHARK. With the Mk5 version an anchor efficiency of 60 times its own weight is achieved and since the introduction more than 6000 pieces have been sold worldwide.

With oil exploration and maritime activities going into deeper and deeper waters (with generally soft soils) in the 90's, Vryhof introduced the STEVMANTA Vertically Loaded Anchor. This anchor type has been installed successfully in several deepwater mooring projects since then. Besides the above mentioned products, Vryhof Anchors is able to provide a wide range of mooring components as well as a number of engineering services. Of the latter, assistance during installation of anchors and the supply (at a rental base) of the special STEVTENSIONER for tensioning jobs are the most noticeable.

The company is ISO 9001-2000 certified and the above mentioned products can be supplied with certification of all major classification authorities.

The beginning of rope making is hidden in the clouds of history. However already in pre-historic times man knew that parts of certain plants were very strong and suitable for transferring loads and fixing things together. The first ropes were probably three-strand ropes, with the same basic construction as still in use today. Ropes were made by hand and found their primary use in building and ships. For example the Egyptian pyramids could not have been built without ropes.



In the Middle Ages rope makers in Europe were organised in guilds and in every port rope makers could be found. It is also around that time that they started to use rope walks for production. These typically were narrow paths, some hundred meters long. At the beginning of the walk a wheel was placed with a hook that could be rotated. The rope maker would attach some fibres to the hook and someone else would rotate the wheel, thus forming a yarn. This would then be continued until the end of the walk was reached. When sufficient yarns were twisted, they would be laid on the rope walk again, attached to the wheel and then a strand would be formed by twisting the wheel in the opposite direction. This would then be repeated a third time to form a rope. Needless to say this required a lot of craftsmanship.

Around 1700 people started to use horses to make ropes and later steam engines. Towards the end of the century register plates and dyes were introduced and this greatly improved the quality of the ropes. Around the beginning of 1800 the process was further mechanised, gradually removing the need for rope walks.

The next big step in rope making was the introduction of synthetic fibres. This greatly improved the durability of ropes as rotting was no longer an issue. Also choice between different fibres would greatly

affect strength, weight and other characteristics. In the photo the production of a four-strand rope on a traditional rope walk is shown, with a wooden dye to position the strands.

The last big step was the introduction of braiding. In this process the strands are interweaved in a maypole fashion. This gives a rope that is torque free.

Today ropes are combinations of these two basic processes: twisting and braiding. The combination of material and construction choices allows tailoring of the rope characteristics to meet the requirements of challenging applications. Even though synthetic ropes have found their way into space, the main use is still in marine and industrial applications. Choice of materials ranges from polypropylene to aramid or high-modulus polyethylene, the latter two giving ropes with comparable strengths as wire rope. Nowadays natural fibre rope is only a fraction of total rope production.

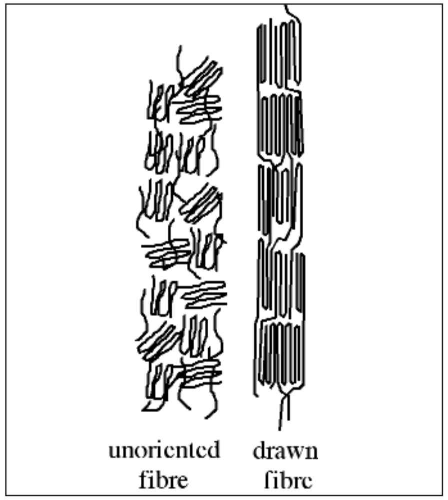
Natural fibres are being used from the earliest times for ropes. They will not be discussed extensively in this manual because they are seldom used in engineered applications. Natural fibre rope is used in historic applications or where environmental issues are critical. For completeness they will be briefly discussed in this chapter. The main focus is on the synthetic fibres.

Natural fibres

In principle ropes can be made from any fibrous material. Examples are Cocos, Cotton. However three types are mainly used: Hemp, Manilla and Sisal.
Hemp (Canabis sativa) originates from Central Asia. The fibres can be extracted through a rotting process or through drying and hackling. Hemp typically is tarred to stop the rotting process. Manilla is the fibre from the leaves of Musa textilis (related to banana). They originate from the Philippines (hence its name). The lighter and thinner a Manilla fibre, the stronger it is. Sisal is also extracted leaves from the Agalve sisalana. It is less strong then Manilla and will absorb water. The water uptake is reduced through treatment with oil.

Synthetic fibres

All synthetic fibres are produced from polymers; that is to say from molecules that repeat more or less ad infinitum. Here the different fibres mainly used in ropes and their primary characteristics are shortly discussed. Basic behaviour of a rope is largely determined by the fibre selected. The rope design can modify characteristics, but can not change fundamental behaviour. For polymeric materials properties (such as strength, stiffness, fatigue) are to a great extend determined by material and processing conditions. Orientation of the material and interaction between molecules inside the fibre determine overall interaction in the fibre, see also sketch and table. Interaction between the various crystalline regions



Fiber properties

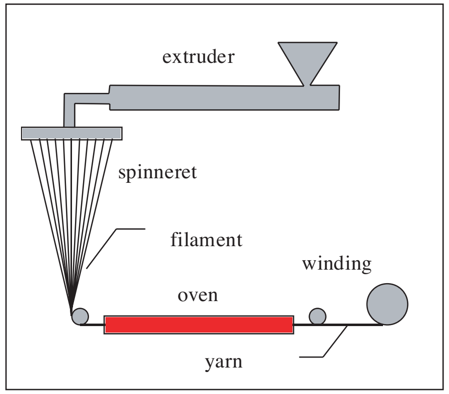
determines how closely the crystalline (or sonic) modulus can be approached and interaction between the molecules determines the movement or slippage which becomes visible as creep in the fibre. Typically the strength and stiffness of a molecule is significantly higher than that of the fibre. Overall strength is determined by how well the material is oriented, the crystal size and how strong the interaction is between the crystalline regions. A good example of this is Dyneema: it is made from polyethylene, a material that normally had a low strength and stiffness. By giving the material a high crystallinity and high orientation the theoretical strength and stiffness is approached where normally the low interaction between molecules prevents this.

Material	Fibre Type	Crystallinity	Sonic modulus N/tex	Fibre modulus N/tex	Density Kg/l	Chain interaction
PET	Diolen 855*	40%	13	6.5	1.38	medium/high (dipolar)
PA6	Enkalon*	50%	7	4.8	1.14	high (H-bridges)
Aramid	Twaron *	95%	67	42	1.44	high (H-bridges)
UHMWPE	Dyneema+	>97%	165	110	0.97	low (van der Waals)

Diolen, Enkalon and Twaron are trademarks of Acordis. Dyneema is a trademark of DSM.

Fibre Materials

Here the different synthetic fibres mainly used in ropes and their primary characteristics are shortly discussed. The rope design can modify characteristics, but can not change fundamental behaviour. Therefore the materials have to be selected first for a given application. For polymeric materials properties (such as strength, stiffness, fatigue) are to a great extend determined by material and processing conditions.
With traditional synthetic fibres, such as nylon (polyamide) and polyester, the polymer is melted and the fibre is formed by squeezing the polymer through a die. This die is rather like a shower head with a large number of small holes. Each thread of plastic going through these holes becomes one filament. Then it solidifies in air or liquid and is drawn. This process of drawing is called spinning and orients the molecules

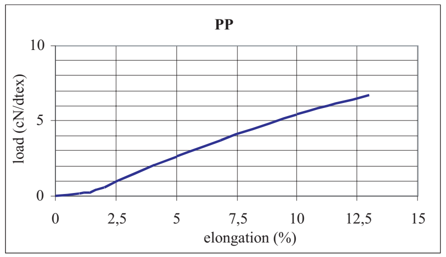


developing high tensile strength; see also sketch. For example the tensile strength of nylon plastic is 30 – 90 N/mm². When drawn into a fibre this same plastic develops 900 N/mm². In the case of the aramids and aromatic polyesters there is no melting point and the fibres have to be spun by chemically dissolving the polymer. This is a much more expensive process.

Secondary Fibre Properties	Abrasion	Creep	Kinking
Aramid HT	poor	low	susceptible
Aramid copolymer	medium	low	susceptible
Aramid SM	poor	low	susceptible
Gel-spun PE	very good	high	resistant
LC polyester	medium	low	susceptible
Steel wire	very good	very low	very resistant
Polypropylene	poor	medium	resistant
Bexcoline Composite	good	low/medium	resistant
Polyester	good	low/medium	resistant
Nylon	good	h. medium	resistant

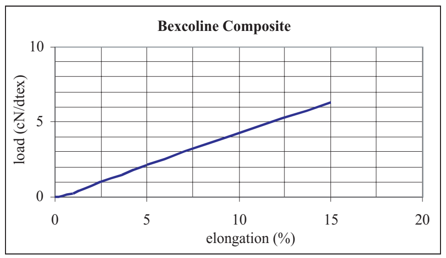
Polypropylene

For ropes polypropylene is most often produced as split film. This means a film is extruded and is split using knifes before drawing. The strength is obtained in this drawing process. Other fibres are mostly produced as multi-filament. Polypropylene is chemically inert, has a low density (it floats), but has a somewhat lower melting point (160°C) and lower strength. Standard PP has a low UV resistance; however with UV stabilisation the resistance can be good.



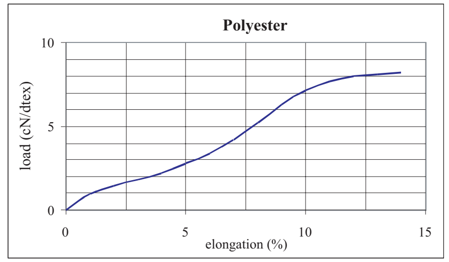
Bexcoline Composite

Bexcoline composite is a mixed or composite fibre based on polyester and our proprietary bexcord yarn. It combines the abrasion resistance and fatigue life of polyester with the lower density of nylon (1.1 –1.14). Because of its lower weight it has excellent handling characteristics. The UV resistance is good. Wet and dry strength is identical. A special marine finish is applied to further increase the wear resistance in a marine environment. This finish has been tested conform ASTM D6611-00 and is water repellent.



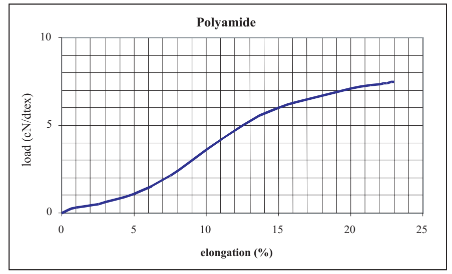
Polyester

Polyester (= Dacron, Terylene, Trevira, Diolen) is a particularly reliable fibre with mechanical properties quite close to those of nylon. The abrasion resistance of polyester is better than that of nylon and so is the tension-tension fatigue performance. Since the cost of both fibres is quite similar polyester should generally be preferred. In favour of nylon is its lower density (1.14 vs 1.38) and higher energy absorption.
Under normal working conditions polyester is not sensitive to hydrolysis. The melting point of polyester is around 260°C. The UV Resistance is good.



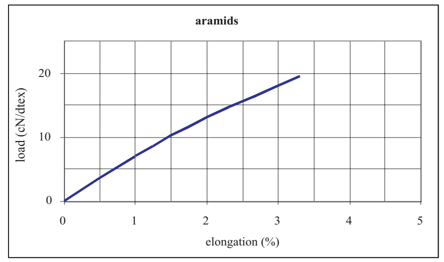
Polyamide

Polyamide or Nylon was the first synthetic fibre discovered. It is available as a fibre as nylon 6 and nylon 6-6. Both types have virtually identical mechanical properties but nylon 6-6 is thermally more stable. In ropes both types are generally equally suitable. Since nylon was the first fibre discovered it is better established than polyester but the fatigue properties of polyester are better than those of nylon. The melting point is 215°C. In normal conditions of use nylon 6 is influenced water; it has a softening effect. The UV resistance is acceptable.



Aramid

Aramid fibres such as Kevlar and Twaron are substantially stronger than nylon. They derive their great strength by substituting the linear chain of (CH2)n with a benzene ring. This also creates chemical and thermal stability. Aramids will not melt but start to carbonize at temperatures above 425° C. The UV stability is medium. Aramids have excellent tension-tension fatigue resistance and exhibit low creep. However the abrasion resistance of these fibres is not good. An aramid co-polymer (Technora) has better bonding between the molecular chains and as expected the abrasion resistance and lifetime in running over pulleys is improved.

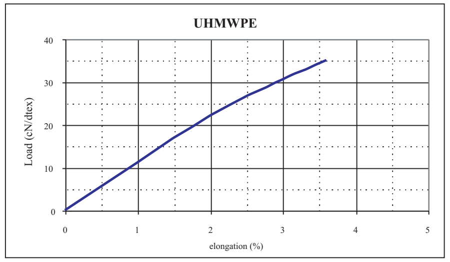


Liquid Crystal Polyester

The hope was that liquid crystal polyesters (= Vectran) would have higher strengths than the aramids with a much improved abrasion performance. The reported results have been mixed, breaking strength and elongation are very similar and abrasion is higher. The actual strengths in ropes are no higher than with aramid and the lifetime in tension-tension fatigue is about equivalent. However it has a good performance in cycling over sheaves.

Gel-Spun Polyethylene

Polyethylene is an amorphous plastic with relatively low tensile strength compared to what would be possible if it was aligned and crystalline. With a ultra-high molecular weight polyethylene and a special process called gel spinning this alignment and cristallinity can be achieved. The polymer is dissolved in a solvent which results in a gel like solution and under these circumstances it is possible to spin a highly drawn fibre. It is commonly known as High Modulus PolyEthylene (= Dyneema, Spectra). The fibre has a very high tensile strength. The fibre density is only 0.97 and consequently the strength to weight ratio is also very high. The fibre has an extremely low coefficient of friction and is extremely resistant to internal and external abrasion. The lifetime in cycling over sheaves is extraordinary. The thermal properties of HMPE are no better than ordinary polyethylene and it melts at around 150° C. HMPE is also prone to cold flow and therefore has a high creep rate.

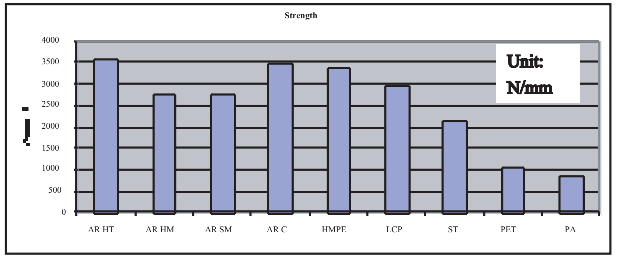


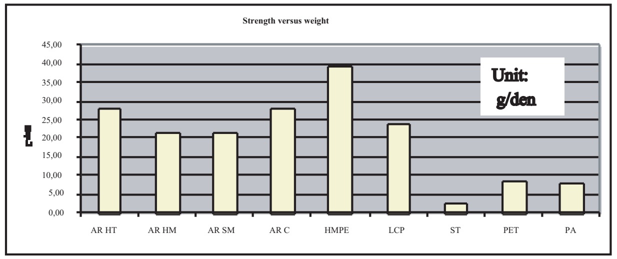
Fibres properties overview

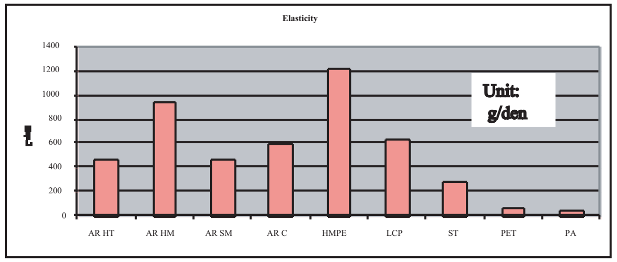
On the next page, the fibre properties are shown in the top table and graphically represented below that.

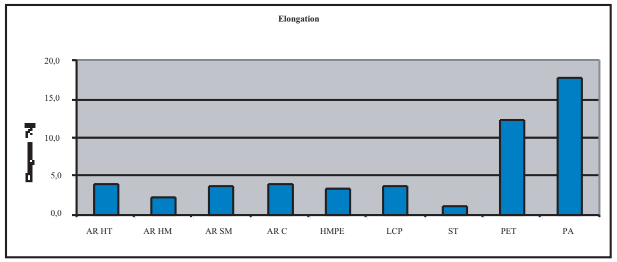
Fiber properties

	Tensile strength N/mm²	Modulus of elasticity N/mm²	Elongation to break (yield) %	Max Use Temperature °C		Melting Point ° C	Density kg/l
				short	continuous		
Aramid HT	3 600	60 000	4.0	200	160	480	1.44
Aramid copolymer	3 500	73 000	4.0	200	160	480	1.39
Aramid SM	2 760	60 000	3.7	200	160	480	1.44
Gel-spun PE	3 300	85 000	3.5	80	60	145	0.97
LC polyester	3 000	80 000	3.8	180	120	330	1.41
Steel wire	2 160	200 000	1.1			1600	7.86
Polypropylene	500	4 200	12	100	70	165	0,91
Bexcoline Composite	650	4 300	15	120	80	165/260	1.14
Polyester	1050	9 000	12.5	180	120	260	1.38
Nylon	850	5 500	18.0	140	80	215	1.14







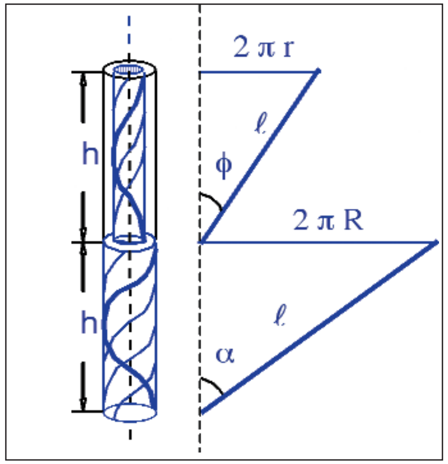


Various techniques are used to convert fibres into ropes. Unlike steel wire, fibres can tolerate substantial twist during manufacture and this allows a wide range of possibilities for a rope construction. Most ropes constructions use twisting during one or more production steps to obtain load sharing, handling stability and other characteristics.

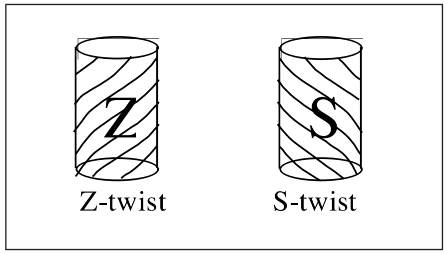
Here the production steps in rope making, their terminology and the constructions possible are shortly discussed. In the next chapter the characteristics of polyester deepwater mooring lines are discussed.

Yarn Assembly

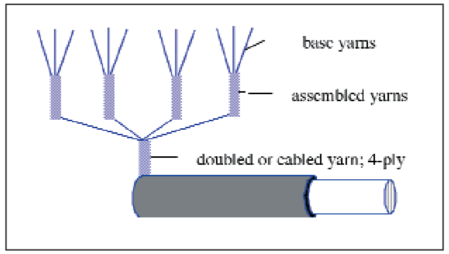
A yarn is made up of a large number of fine filaments. In the case of the high modulus yarns which are highly drawn the filament diameter is around 12 microns. In a yarn there are typically 1000 or more filaments. Yarn diameters are extremely small and they are assembled together by one of several possible processes. The main assembly method is twisting, for this process strength of the assembled yarn is a function of the material, twist level and processing control. Once the twist level is known for which the strength is optimal it can easily be translated to other sizes of yarn. If the twist angle is similar the twist loss will also be similar, see sketch.



Twist direction is expressed as Z (right-hand lay) and S (left-hand lay), see sketch. Normally twist directions are alternated each production step to obtain a stable construction with minimal torque, see sketch. The choice for a singly ply or a double yarn typically is determined by the machinery available and/or the required stability. A doubled yarn requires an extra production step, however it also has more shape stability. This gives the doubled yarn a better wear and abrasion resistance than a single ply. Traditional yarns have high elongation and then twisting this is not a critical operation, assuming good manufacturing and QC practices.



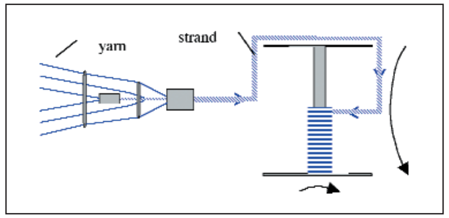
With high modulus yarns it is important that the yarns are twisted with even tensions and that they share load evenly in the resultant construction. This limits the methods that can be used and generally involves more production steps than with traditional ropes.

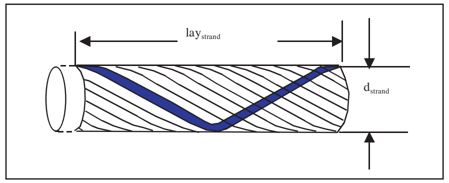


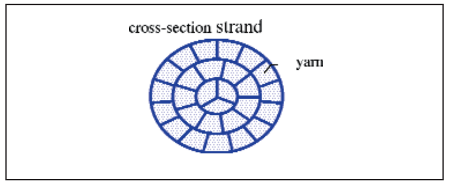
An alternative method for assembling yarns is binding them together in an outer jacket or encapsulating in a resin. Since these jackets have a relatively large cross-sectional area they result in ropes of large diameter and weight. Consequently this technique is rarely used.

Strands

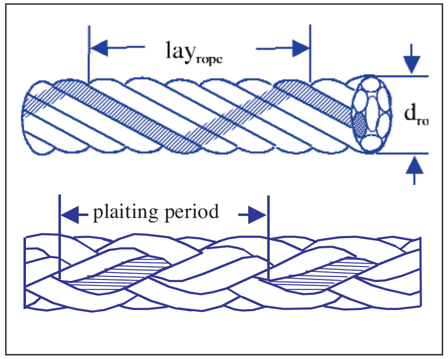
The basic geometry of a strand is similar to that of a yarn, assembled yarns are twisted together to make a strand, this causes length differences between those yarns. The number of layers and the lay length in the strand are the key parameter that determines this. By carefully separating the yarns in layers the variation between yarns in a layer can be further minimised. This is done using dyes, tensioning and separator plates. There are three fundamental methods for making strands; here a two-for-one strander is shown.







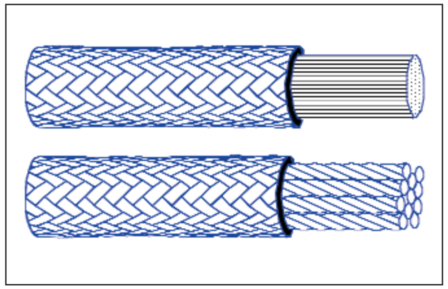
Ropes



Lay length or plaiting period for the rope not only influences strength, but also other characteristics like elongation and shape stability. In a design these characteristics have to be weighed against each other for each application. For the same material a high strength design will have a low elongation and a stable, firm rope will have a lower strength for the same amount of material.

Rope constructions are divided in 4 broad categories as listed below:
1. parallel lay
2. stranded (wire rope construction)
3. laid
4. plaited & braided

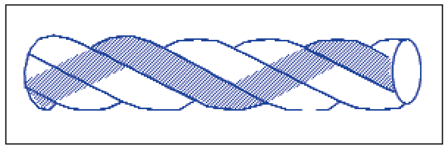
Parallel yarn and parallel strand



Most parallel lay ropes are actually made using parallel yarns and an extruded plastic jacket usually polyethylene. An intermediate step between parallel ropes and wire ropes is the parallel strand rope. In this case the yarns are
twisted to form strands which are flexible and then assembled together under an outer jacket. This has often been braided. These two types of parallel ropes are illustrated here.

Fibre properties are translated into rope with high efficiencies. It will not rotate under load and is insensitive to twisting.

Laid



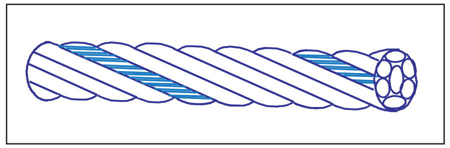
Laid constructions are extremely old and were originally made by hand from natural fibres. The point about them is that they are made with a substantial amount of twist, 30° or more. This gives them structural integrity and they do not need external jackets to hold them together. The most common laid constructions are 3 and 4 strand and an example is shown

below. For a typical design a good fibre strength and fatigue life will translate into acceptable properties in the rope. A laid rope will rotate under load, but the effect on the strength is limited.

The high modulus fibres do not tolerate these high levels of twist in large ropes without catastrophic loss of tenacity. This is due to the fact that these yarns are prone to squeeze breaks and cannot withstand high internal compression. Consequently the use of laid constructions is limited to cords and small ropes. It should be noted that 3 and 4 strand ropes can be made with low helix angles but they then need an external jacket or resin to provide structural integrity. In this form they can be treated as a wire rope.

Stranded or wire rope constructions

In this construction, twisted strands are arranged in one or more concentric rings around a central core strand as in constructing wire rope. The core strand may not be designed to carry load. Common constructions are:
- 6 + 1 (six strands around the core)
- 12 + 6 + 1 (twelve strands around six strands)
- 18 + 12 + 6 + 1

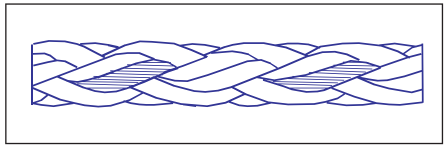


Most wire rope constructions are supplied with a braided polyester or nylon jacket. Extrusions and polyurethane coatings have also been used. A combination of both a braid and an extrusion or coating makes an extremely tough jacket. A six-strand rope is shown here. Also a stranded rope will have a good strength and fatigue translation from the fibre. It will rotate under load with a limited effect on the strength.

Torque balance can be achieved by designing the rope in two concentric layers. The inner layer is stranded in one direction and the outer layer in the opposite direction. The rope is designed so that the torques produced in each layer is equal in magnitude but opposite in direction. The individual strands are often jacketed with a thin cover. This holds the fibre yarns together during production but can also be a factor in providing optimum performance when cycling over pulleys particularly for aramids.

Plaited

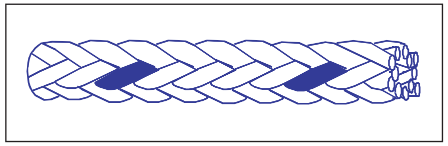
Plaited ropes are sometimes described as square braids. They are produced on a plaiting machine containing eight reels, each containing one strand. Groups of two reels interweave as a pair around the other pairs of reels to produce an eight strands rope of a somewhat square cross section. No twist is taken out of the strand during manufacturing, which is important for large size ropes.



As previously observed the high modulus fibres are unsuitable for high twist constructions and are not common in plaited ropes. However it is possible to produce this construction with low levels of twist without losing all structural integrity.

Braided

Braids can either be solid or circular. Single circular braids are hollow. The braid consists of an equal number of interwoven clockwise and anti-clockwise strands. The braid pattern is normally over 1 under 1 or under 2 over 2. The individual strands are generally made up of 1 or more parallel twisted textile or rope yarns. In many good designs the yarns on the outside of the braid are aligned with the axis of the rope. The rope does not rotate under load, however if twist is introduced the strength will be affected. Here a twelve-strand rope is shown. It is very stable on the winch, because of its round shape



Double braid or braid on braid consists of an outer braid over an inner braid. These are more compact than single braids and are the only realistic braided alternative in large ropes. The comments made about high levels of twist in laid and plaited ropes apply equally to braided ropes and consequently these are not practical alternatives for high modulus fibres unless the helix angles are kept extremely low.

Terminations

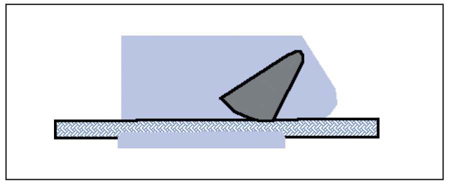
Terminations are normally critical in the rope design. Most of the handling and abrasion occurs on the terminations, load is transferred into the rope. Four types of rope terminations are mostly used:

Knots

Depending on the rope design and the type of knot used the knot strength will vary. For plaited ropes the knot strength typically will vary between 25 and 35% of the new strength. Also the life of rope is significantly reduced by a knot. Because of this knots should be removed at the earliest possible moment.

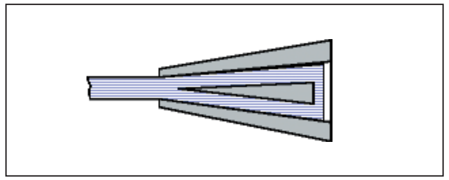
Clamps

Clamps are mostly used in leisure applications. For example in yachting rope special rope designs are used that can withstand the local compression from this termination. Efficiencies are very material and construction specific.



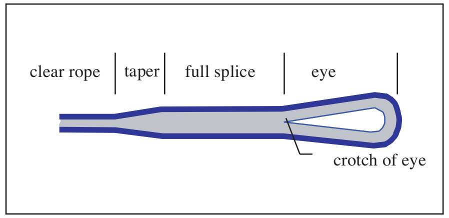
Sockets

Sockets are widely used for wire rope. However for synthetic ropes sockets are seldom used, because they are difficult to inspect and have a negative effect on the fatigue life of the rope. An exception is aramid rope, where sockets are well accepted. Strength efficiencies of 100 % are possible, depending on the diameter, design of the rope and termination.



Splices

This is the most widely used termination for synthetic ropes. For a professional splice the reduction in breaking strength is minimal (10%). Typically the reduction in the fatigue life is also very small. Many different types of thimbles are available for insertion in the eye. They can be optimised for handling, life or other criteria.



Construction and rope properties

The information given her is only a small part of the data that is available. Often it is difficult to determine beforehand what data is needed to estimate the behaviour in the application. Also in answering questions from users, often more questions are generated. To address this efficiently the documentation at Bexco has been structured per product:

Rope construction	Tension-tension	Cycling over sheaves	Strength to dia.	Toughness
Parallel strand ropes	v. good	moderate	high	moderate
Parallel yarn ropes	v. good	poor	excellent	poor
laid 3- and 4-strand	good	high	medium	good
Wire-rope constructions	v. good	excellent	high	good
Torque-balanced	v. good	good	high	moderate
8 plait	good	poor	medium	excellent
12 braid	good	good	medium	excellent
Braid on braid	good	poor	medium	v. high

Comparison of Fibres in Ropes

Here the most widely used materials for ropes in a marine environment are compared, both 8-strand plaited and the parallel-strand design. Bexcoline Composite 099 (BC 099) and Bexcoline Composite 110 (BC 110) are our composite materials, with a density of resp. 0.99 kg/l and 1.1 kg/l.

		HMPELINE		Bexcolon		Bexcord 091		BC 099		BC 110		BexcoFlex		BexcoPET 138	
Diam mm	Circ. "	MBL kN	weight kg/100m	MBL kN	weight kg/100m	MBL kN	weight kg/100m	MBL kN	weight kg/100m	MBL kN	weight kg/100m	MBL kN	weight kg/100m	MBL kN	weight kg/100m
l32	4	883	47,6	224	56,8	181	48,4	162	43,3	196	48,6	300	68,5	179	66,8
36	4,5	1025	60,2	282	72,1	238	58,0	204	52,9	243	60,0	346	79,5	230	84,5
40	5	1218	74,3	347	89,2	295	72,6	296	72,2	336	87,5	417	96,6	280	104
44	5,5	1456	89,9	417	108	351	87,1	358	91,5	400	104	481	112	336	126
48	6	1687	107	490	128	406	102	422	106	465	120	544	128	396	150
52	6,5	1963	126	569	150	480	121	495	126	545	141	627	149	460	176
56	7	2230	146	658	174	535	136	569	145	620	157	709	169	529	204
60	7,5	2541	167	749	199	627	160	647	164	710	183	790	190	603	235
64	8	2845	190	850	227	699	179	736	188	801	206	879	211	681	267
68	8,5	3142	215	954	256	790	204	829	213	901	232	1016	246	763	301
72	9	3481	241	1066	287	880	228	927	237	1001	258	1097	267	850	338
76	9,5	3815	268	1182	320	988	252	1015	261	1101	283	1302	315	941	377
80	10	4189	297	1306	355	1078	286	1137	295	1224	319	1433	348	1037	417
88	11	4927	360	1569	430	1275	358	1363	352	1456	380	1698	415	1243	505
96	12	5649	428	1856	512	1489	430	1618	417	1711	447	1988	489	1467	601

8-strand rope strengths vs diameter and weight.

		HMPELINE		Nylon		Polyester		Bexcord 091	
Diam mm	Circ. "	MBL kN	Weight kg/100m	MBL kN	Weight kg/100m	MBL kN	Weight kg/100m	MBL kN	Weight kg/100m
32	4	737	58	219	64	259	73	201	53
36	4,5	957	73	284	81	338	92	260	66
40	5	1103	88	331	98	394	112	302	81
44	5,5	1398	108	402	117	479	133	378	98
48	6	1692	127	497	140	591	161	463	117
52	6,5	1985	146	591	164	704	188	533	132
56	7	2354	170	709	192	844	222	633	154
60	7,5	2721	194	803	216	956	249	742	177
64	8	3087	225	898	247	1069	284	812	200
68	8,5	3528	253	1040	281	1238	325	935	226
72	9	3969	281	1134	305	1350	353	1051	254
76	9,5	4190	309	1229	340	1463	392	1154	288
80	10	4631	337	1370	375	1631	433	1298	319
88	11	5733	408	1701	455	2025	528	1593	386
96	12	6615	486	1985	545	2363	630	1813	456
104	13	7938	571	2315	627	2756	726	2128	535

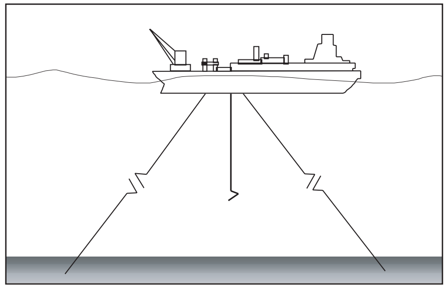
Parallel-strand rope streghts vs diameter and weight.

All Ultraline® ropes have a Bexcoline Composite cover.

Below, two basic systems that are used in deepwater mooring today and the characteristics are discussed.

Taut-leg moorings

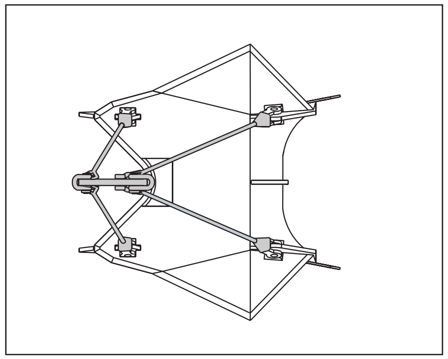
As water depth increases conventional, catenary systems become less and less economical. For permanent systems a cost-effective, synthetic alternative has been developed: Taut Leg Mooring.



In this system each line is strung out directly to the seabed typically at an angle of 45°. As the platform drifts horizontally with wind or current, the lines stretch and this sets up an opposing force. Polyester mooring lines have the right restoring characteristics and thus are the preferred choice for this application. Because of the angle at which the rope arrives at the seabed the anchor will be loaded vertically. Suction piles or special anchors, so-called VLA's have to be used.

Stevmanta VLA

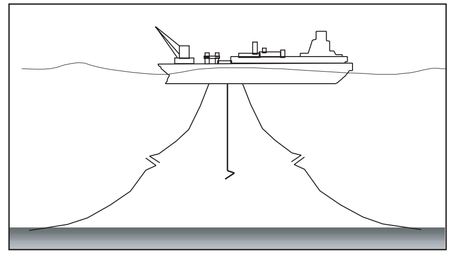
The Stevmanta VLA (Vertically Loaded Anchor) is a new design anchor whereby a traditionally rigid shank has been replaced by a system of wires connected to a plate. The anchor is designed to accept vertical (or normal) loads and is installed as a conventional drag embedment anchor with a horizontal load to the mudline to obtain the deepest penetration possible. By changing the point of pulling at the anchor, vertical (or normal) loading of the fluke is obtained thus mobilising the maximum possible soil resistance. Thus it is ideally suited for taut-leg moorings.



As a VLA is deeply embedded and always loaded in a direction normal to the fluke, the load can be applied in any direction. Consequently the anchor is ideal for taut-leg mooring systems, where generally the load angle varies from 25 to 45 degrees. The angle adjuster changes the mode of the anchor from pull-in mode to vertical (or normal) mode.
For more details consult the Vryhof anchor manual.

Inert Catenary mooring

For temporary systems either a polyester taut-leg or a catenary mooring with Dyneema insert lines are a cost-effective alternative for dynamically positioned rigs. The choice between these two alternatives is driven by cost of the mooring versus operational limitations.



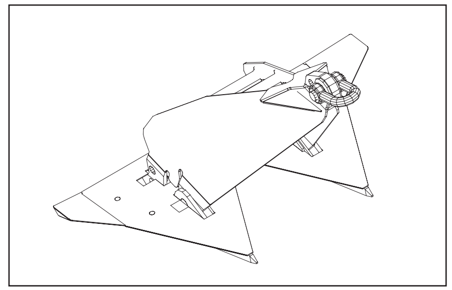
A DeepRope® Dyneema® insert will transfer mooring forces without changing the catenary. In shallow waters, an all chains system works well but as the water depth increases the weight of the chain becomes excessive and it tends to hang directly down from the rig. By inserting a Dyneema® line the mooring stiffness increases, without a weight penalty. Thus no modifications to the riser system are necessary when going to deeper water. Depending on the exact design it is even possible to improve the restoring characteristics. This will extend the weather window for drilling time. As the DeepRope® Dyneema® lines are neutrally buoyant they can be pre-installed with only a small surface buoy, thus reducing hook-up time. Depending on the soil conditions and anchor design used a small up-lift may be allowable at the anchor point. This will simplify installation considerably.

Stevpris Mk5

The Stevpris/Stevshark anchor exists since 1980 and supersedes older Vryhof models like Stevin, Stevmud and Hook. The development of the anchor was based on two philosophies;

a) Reduce resistance to the anchor during penetration and consequently deep embedment to obtain a high holding capacity.

b) Enlarge flukes as much as possible to mobilise a maximum of soil resistance.



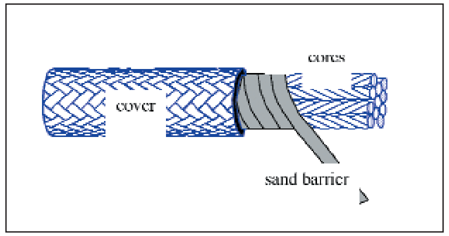
This resulted in an anchor with wide flukes. To reduce the bending moment in the flukes, the shank was made out of two parts, widely spaced at the flukes and joining each other at the anchor shackle.

Application of synthetics in deepwater mooring

The V-shape of the shank added another advantage to the anchor, soil resistance is not only mobilised in the cable pulling direction, but also perpendicular to the large surfaces of the shank. The soil is compressed in forward and sideways direction. The shank mobilises more soil resistance and adds a downward directed load component to the anchor, improving the penetration. Thus this anchor has a very high ratio of ultimate holding capacity (UHC) versus anchor weight and a very quick and deep penetration, i.e. a very short drag length. The deep penetration of the Stevpris anchor makes it very suitable to resist uplift forces that might occur in deep water. The latest models, the Stevpris Mk5 and Stevshark Mk5, are the improved versions of the Stevpris, and have been installed all over the world since 1990.

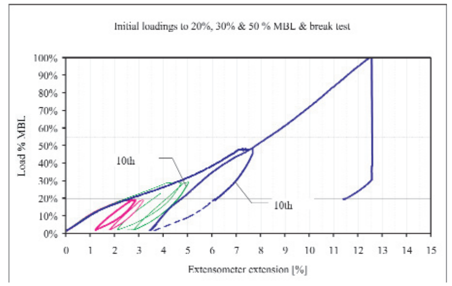
For more details on this anchor and its design please consult the Vryhof anchor manual.

Deeprope® polyester lines



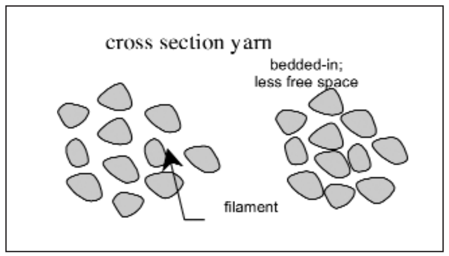
The DeepRope® line for mooring applications is a so-called parallel core construction. It consists of three parts, namely core elements, sand and mud barrier and the cover (see figure). However the general characteristics, like elongation, elasticity and fatigue are determined by the polyester fibre and the three-strand core. In the next chapter the specification of the rope will be discussed.

Static loading



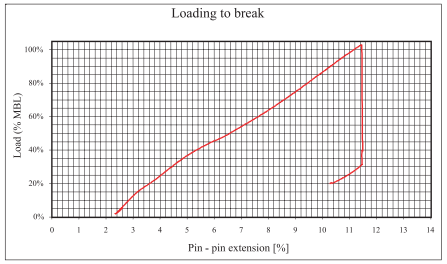
Elongation of ropes typically is non-linear, furthermore it is a parameter describing different mechanisms, such as elongation from initial load or that from the fibre itself or elongation from the rope itself versus that from the splices. These different causes for the same phenomenon can lead to confusion and thus errors. Here we try to differentiate and clarify when what type of elongation can be expected in the use of a Deepwater mooring rope.

The constructional or initial elongation under load is a function of the rope construction and manufacturing conditions. It is non-reversible and occurs on a first loading (see graph), manufacturing conditions, construction and splicing all play a role. Typically there will be more free space in a braided rope than in a laid rope. The underlying cause is the free-space between filaments in a yarn. This free-space is reduced when the fibres start bedding in (see sketch). This causes a reduction in diameter of the yarns while the length of the filaments does not chance. Because of the helical structure this results in an overall lengthening. This lengthening is a function of the rope construction (3-strand laid, 8-strand braided, etc.) and initial free-space between the filaments.



For a given rope the amount of constructional elongation found in the field is mainly determined by the maximum load level achieved. This is clearly visible in the above graph.

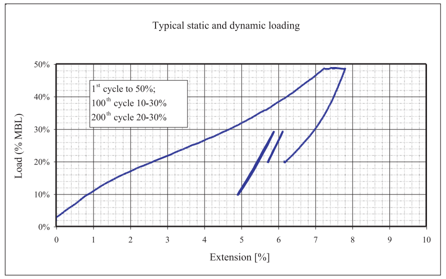
The elongation to break is measured from pin to pin, here the terminations (= splice) is included with the measurement. This typically gives a slightly lower elongation (0.1-0.3%) than when measured mid-span with an extensiometer. This can be expected as splices are included in this measurement. In the splice elongation will be lower.

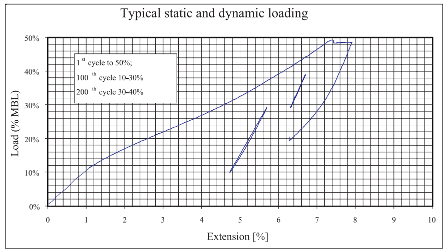


An average test result is slightly higher than the Minimum Breaking Load.

Dynamic Loading

Under dynamic loading conditions polyester quickly stiffens and shows a lower elongation. This effect has been extensively studied. For example in Deepwater Fibre Moorings, an Engineers Design Guide (OPL publication) tests are published on polyester fibres and ropes (for the ropes Acordis Diolen is mostly used). The dynamic stiffness of polyester ropes is determined to a great extent by the mean load and load amplitude, the frequency has a minor negligible influence over the frequency ranges normal for offshore mooring systems (6-600 sec). For a well designed rope with only minor imbalances the stiffness stabilises within a hundred cycles.



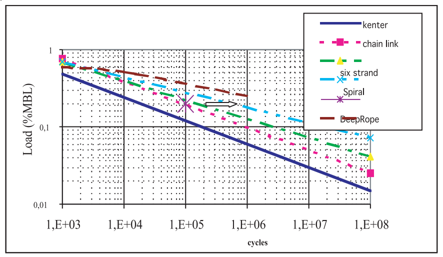


More additional data are available, here only an overview is given.

Fatigue

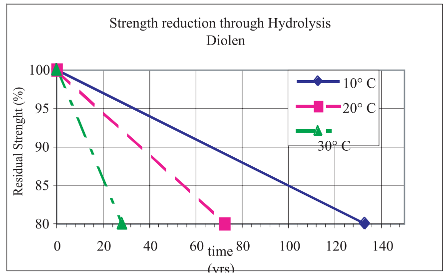
Based on Deepwater Fibre Moorings, an Engineers Design Guide (OPL publication) the fatigue life of polyester is superior to that of other mooring components below load ranges of 60 % of the MBL.

The Best-Fit curve is taken from Engineers Design Guide.



Hydrolysis

For polyester, water will penetrate into the material when it is submerged over long periods. More specifically it penetrates into the amorphous zones, where it causes a slight swelling. Strength reduction through hydrolysis can be characterised from fibre data as this mechanisms works on the fibre level.

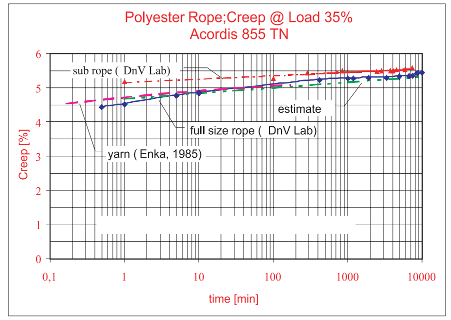


Based on tests conducted by Acordis and extrapolation a conservative estimate of the strength reduction can be made, see graph.

For a Deepwater mooring line at a temperature of 20° C the strength reduction will be some 6% of the MBL after 20 years.

Creep

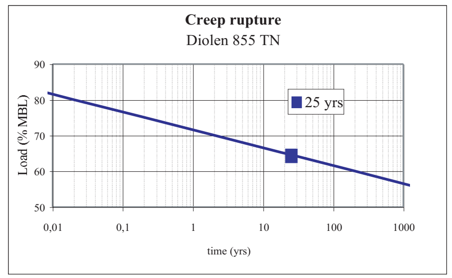
The creep behaviour of polyester rope can be accurately predicted from fibre data, see curve.
Initially there is a small difference between yarn and rope. This is probably caused by construction effects.



First elongation under constant load for the rope is best estimated from the initial load elongation curve. After a short time (10 minutes), the creep of individual yarns in the rope has stabilised and differences in length from rope making do not have a significant effect on the lengthening or creep.

Creep Rupture

The time-dependent elongation of polyester can be separated in several categories. There is an effective and instantaneous extension, this extension is measured under a single loading. Secondly there is a time-dependent, recoverable extension. This shows as a hysteresis loop in cyclic loading. Thirdly there is the non-recoverable elongation which occurs under long continuous load. Given enough time the yarns will fail under high continuous loads and this phenomenon is known as stress rupture.



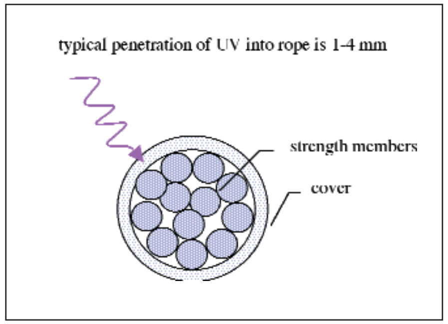
In the Engineers Design Guide a conservative estimate is given for creep rupture, see curve.

Because of the non-linear behaviour of polyester estimates below 60% of the MBL are too conservative. However even with these numbers it can be concluded that under normal conditions creep rupture is not a critical factor for the life of the mooring line.

For a Deepwater mooring line the time to rupture at a continuous load of 60% of the MBL is some 160 years.

Resistance against UV

Typical penetration depth of UV light into a material is 1-4mm, depending on the colour of the yarn.



The polyester fibres used for the DeepRope® mooring lines have an excellent intrinsic UV stability. Based on tests the cover yarns will have some 80% of their original strength after one year of direct exposure in Europe (worst case is Australia were this will be 80% after half a year).

As the cover for Deeprope® mooring lines is some 7 mm thick the inner strength members will not be exposed to direct sunlight under normal conditions. Thus no strength degradation is foreseen.

To what extent the seawater filters the UV light is not evaluated.

Effect of particle ingress

There is a relative high risk of sand and mud getting in the rope if it accidentally is dropped on the seabed during installation. Alone these particles have little to no effect; however in combination with cyclic loading particles will abrade the fibres. This will affect the strength and can considerably shorten the life of the rope as fibres abrasion progresses.

To prevent this particle ingress a filter material has been wrapped between the cover and the inner cores, see sketch. This was necessary, because the mud particles are so fine that only in depth filtration will prevent them from getting into the inner strength members. Also the stability of the filter system is higher. In the test this also showed. The polyester cover filters out most of the sand. The filter stops the sand that did get through the cover. The mud passed through the cover and is stopped by the filter.

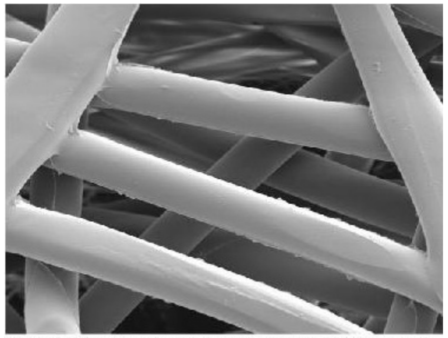


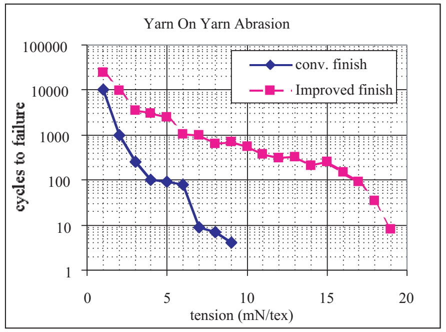
Figure 10. Filter material, inside layer No. 2. The image is 220 µm wide.

Axial Compression fatigue

This can occur when a rope experiences an excessive number of cycles at low tension or when it goes slack. Under these conditions the repeated sharp kinking will have an adverse effect. Based on the data for polyester from the Engineers Design Guide a safe limit is 100 000 cycles (severe strength loss starts to occur above 1 000 000 cycles).
Thus under normal installation and operational conditions axial compression fatigue will not occur.

Marine Finish

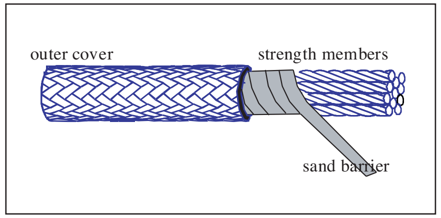
Nylon was one of the first fibres used for single point mooring hawsers. Here it was found that under normal conditions of use cycling caused movement between fibres. This movement caused abrasion, giving an unacceptable reduction in strength of the rope.



Marine Finish has first been developed for nylon to improve the abrasion resistance between yarns. It is tested conform ASTMD 6611-00. With the introduction of other materials in marine applications finishes also have been developed to improve the material's internal abrasion resistance. Here a typical curve is shown for a polyester yarn. Even though polyester is not sensitive to hydrolysis, a marine finish is standard for fibres used in permanent mooring systems. With the marine finish the life of the fibre is significantly improved under higher loads (e.g. in storm conditions).

Construction

The DeepRope® line for mooring applications is a so-called parallel core construction. This construction consists of three parts, namely the core elements, sand and mud barrier and the cover (see figure).



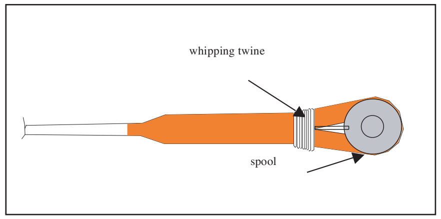
The core elements are three-strand ropes that are oriented parallel to the longitudinal axis of the rope. The three-strand core design is used because of its strength efficiency and splice ability.

Depending on the installation procedure there may be a potential risk that the rope is dropped on the seabed. Although this in itself has no effect on the rope it is possible that seabed particles may diffuse into the rope. These particles will have a deteriorating effect on the strength over the life of the rope due to their abrasive nature. To avoid this a filter material is inserted between the cover and the core. Initially operators required the filter to stop particles of 20 µm or bigger and a filter was approved for that purpose. However requirements have gone down to particles of 5 µm. For this a new filter material has been approved that exceeds the requirements and filters down to 2 µm.

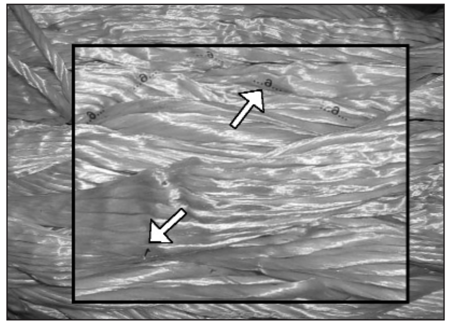
Typically the cover will be some seven millimetres thick. A standard marking will be included in the cover. For special applications alternative materials and different thickness are also possible.
Here the manufacturing process of DeepRope® is shown.

Terminations

The DeepRope® Polyester line has a splice plus round thimble as standard termination. The splice procedure used here has been specially developed for these applications. Operators and certifying authorities have raised a concern for the parallel-strand design: by random splicing of the sub-ropes the consequence of a single core damage can have catastrophic conse-



quence on the rope strength. If that core is spliced into another core, then this second core may slip as a result of the damage to the first core. Thus this second core also no longer bears load. This way slippage may migrate through the rope causing imbalances between the subropes, resulting in a severe reduction in overall rope strength. This problem is overcome by splicing every single sub-rope back into itself. Now the rope is more damage tolerant; if a subrope is damaged, then only that part is affected. Damage assessment can focus on that section, overall integrity is not affected.



For DeepRope® mooring lines every subrope is spliced into itself, making the design more damage tolerant, for this purpose every sub-rope has a special marker tape allowing easy identification (see photo). Also the technique has been developed to splice with minimal tools. This allows splicing on site, requiring only a few tools and a clean, dry workspace. With the more accurate splicing technique variation has reduced, giving a higher reproducibility in strength and stiffness when the ropes are used.

To further improve the life of the splice the eye and the splice are protected using DeltaWeb plus a 2-component polyurethane.

Detailed installation procedures for mounting the thimble in the eye are available on request.

Shipment & Storage

Typically the DeepRope® Polyester are shipped on a reel. Only short lengths are shipped in a box.

Deeprope® features

Material	Polyester
Construction	Load-bearing cores with a protective cover of polyester
Colour of Rope	White with marker yarns
Specific Gravity	1,38
Melting Point	251° C
Abrasion Resistance	Excellent
U.V. resistance	Excellent
Temperature resistance	Workable in sub-zero temperatures
Chemical resistance	Good
Water absorption/ Fibres	< 0,05%
Water uptake	± 30 %
Dry & wet conditions	Resistant to corrosion and seawater; can be stowed wet

DeepRope® Polyester strength table

Material: Acordis Polyester 855TN
Minimum Breaking Load in spliced condition
Total weight is in air:
Submerged weight is in seawater (_ = 1,05 kg/l)
conform ISO (@1- 2% MBL)
conform PetroBras spec. (@20% MBL)

Diam	MBL		Total weight [kg/m]		Submerged weight		Stiffness [kN]		
mm	tf	kN	@2% MBL	@20%MBL	@2%MBL	@20%MBL	EA[1]	EA[2]	EA[3]
113	380	3723	8,80	8,24	2,11	3723	7,19E+04	8,43E+04	1,10E+05
117	414	4061	9,49	8,88	2,27	4061	7,84E+04	9,20E+04	1,20E+05
126	467	4738	10,9	10,2	2,60	4738	9,15E+04	1,07E+05	1,40E+05
130	518	5077	11,5	10,8	2,76	5077	9,80E+04	1,15E+05	1,50E+05
133	552	5415	12,2	11,4	2,92	5415	1,05E+05	1,23E+05	1,60E+05
137	587	5754	12,9	12,0	3,08	5754	1,11E+05	1,30E+05	1,70E+05
141	621	6092	13,6	12,7	3,24	6092	1,18E+05	1,38E+05	1,80E+05
144	656	6430	14,2	13,3	3,40	6430	1,24E+05	1,46E+05	1,90E+05
147	690	6769	14,9	13,9	3,56	6769	1,31E+05	1,53E+05	2,00E+05
151	725	7107	15,6	14,5	3,72	7107	1,37E+05	1,61E+05	2,10E+05
154	759	7446	16,2	15,1	3,88	7446	1,44E+05	1,69E+05	2,20E+05
157	794	7784	16,9	15,8	4,04	7784	1,50E+05	1,76E+05	2,30E+05
160	828	8123	17,5	16,4	4,19	8123	1,57E+05	1,84E+05	2,40E+05
163	863	8461	18,2	17,0	4,35	8461	1,63E+05	1,92E+05	2,49E+05
166	897	8800	18,9	17,6	4,51	8800	1,70E+05	1,99E+05	2,59E+05
169	932	9138	19,5	18,2	4,67	9138	1,76E+05	2,07E+05	2,69E+05
172	966	9476	20,2	18,8	4,82	9476	1,83E+05	2,15E+05	2,79E+05
175	1001	9815	20,8	19,4	4,98	9815	1,89E+05	2,22E+05	2,89E+05
177	1035	10153	21,5	20,0	5,13	10153	1,96E+05	2,30E+05	2,99E+05
180	1070	10492	22,1	20,6	5,29	10492	2,03E+05	2,38E+05	3,09E+05
183	1104	10830	22,8	21,2	5,45	10830	2,09E+05	2,45E+05	3,19E+05
185	1139	11169	23,4	21,8	5,60	11169	2,16E+05	2,53E+05	3,29E+05
188	1173	11507	24,1	22,4	5,76	11507	2,22E+05	2,61E+05	3,39E+05
190	1208	11846	24,7	23,0	5,91	11846	2,29E+05	2,68E+05	3,49E+05
193	1242	12184	25,4	23,6	6,07	12184	2,35E+05	2,76E+05	3,59E+05
195	1277	12522	26,0	24,2	6,22	12522	2,42E+05	2,84E+05	3,69E+05
198	1311	12861	26,7	24,8	6,38	12861	2,48E+05	2,91E+05	3,79E+05
200	1346	13199	27,3	25,4	6,53	13199	2,55E+05	2,99E+05	3,89E+05
203	1380	13538	28,0	26,0	6,69	13538	2,61E+05	3,07E+05	3,99E+05
205	1415	13876	28,6	26,6	6,84	13876	2,68E+05	3,14E+05	4,09E+05
207	1449	14215	29,2	27,2	6,99	14215	2,74E+05	3,22E+05	4,19E+05
210	1484	14553	29,9	27,8	7,15	14553	2,81E+05	3,29E+05	4,29E+05
212	1518	14892	30,5	28,4	7,30	14892	2,87E+05	3,37E+05	4,39E+05
214	1553	15230	31,2	29,0	7,45	15230	2,94E+05	3,45E+05	4,49E+05
221	1656	16245	33,1	30,8	7,91	16245	3,14E+05	3,68E+05	4,79E+05
227	1760	17261	35,0	32,6	8,37	17261	3,33E+05	3,91E+05	5,09E+05
233	1863	18276	36,9	34,4	8,83	18276	3,53E+05	4,14E+05	5,39E+05
239	1967	1929	38,8	36,1	9,29	1929	3,72E+05	4,37E+05	5,69E+05
245	2070	20307	40,7	37,9	9,74	20307	3,92E+05	4,60E+05	5,99E+05

Dynamic Modulus based on type approval tests for BV and PetroBras: [1] cycling between 10-30% MBL, [2] cycling between 20-30% MBL, [3] cycling between 40-50% MBL

Deeprope® polyester lines

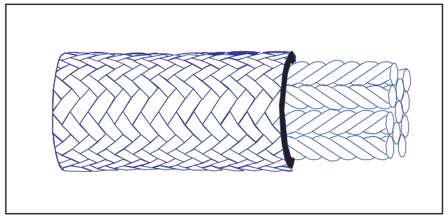
DeepRope® Polyester strength table (ASTM)

Material: Acordis Polyester 855TN
Minimum Breaking Load in spliced condition
Total weight is in air:
Submerged weight is in seawater (_ = 1,05 kg/l)
conform ISO (@1- 2% MBL)
conform PetroBras spec. (@20% MBL)

Diam	MBL		Total weight [lb/ft]		Submerged weight		Stiffness [kips]		
inch	tf	kips	@2% MBL	@20%MBL	@2%MBL	@20%MBL	EA[1]	EA[2]	EA[3]
4,45	380	837	5,92	5,54	1,41	1,32	1,62E+04	1,89E+04	2,47E+04
4,62	414	913	6,38	5,97	1,53	1,43	1,76E+04	2,07E+04	2,69E+04
4,95	467	1030	7,30	6,82	1,74	1,63	2,06E+04	2,41E+04	3,14E+04
5,10	518	1141	7,75	7,25	1,85	1,73	2,20E+04	2,58E+04	3,36E+04
5,25	552	1217	8,21	7,67	1,96	1,83	2,35E+04	2,76E+04	3,59E+04
5,40	587	1293	8,66	8,09	2,07	1,93	2,50E+04	2,93E+04	3,81E+04
5,54	621	1369	9,11	8,51	2,18	2,03	2,64E+04	3,10E+04	4,04E+04
5,67	656	1445	9,56	8,92	2,29	2,13	2,79E+04	3,27E+04	4,26E+04
5,80	690	1521	10,01	9,34	2,39	2,23	2,94E+04	3,44E+04	4,49E+04
5,93	725	1597	10,45	9,76	2,50	2,33	3,08E+04	3,62E+04	4,71E+04
6,06	759	1673	10,90	10,17	2,61	2,43	3,23E+04	3,79E+04	4,93E+04
6,18	794	1749	11,34	10,58	2,71	2,53	3,38E+04	3,96E+04	5,16E+04
6,31	828	1825	11,79	11,00	2,82	2,63	3,52E+04	4,13E+04	5,38E+04
6,42	863	1901	12,23	11,41	2,92	2,73	3,67E+04	4,31E+04	5,61E+04
6,54	897	1978	12,67	11,82	3,03	2,83	3,82E+04	4,48E+04	5,83E+04
6,65	932	2054	13,11	12,23	3,14	2,92	3,96E+04	4,65E+04	6,06E+04
6,77	966	2130	13,55	12,64	3,24	3,02	4,11E+04	4,82E+04	6,28E+04
6,88	1001	2206	13,99	13,05	3,35	3,12	4,26E+04	4,99E+04	6,50E+04
6,98	1035	2282	14,43	13,45	3,45	3,22	4,41E+04	5,17E+04	6,73E+04
7,09	1070	2358	14,87	13,86	3,56	3,31	4,55E+04	5,34E+04	6,95E+04
7,19	1104	2434	15,30	14,27	3,66	3,41	4,70E+04	5,51E+04	7,18E+04
7,30	1139	2510	15,74	14,67	3,76	3,51	4,85E+04	5,68E+04	7,40E+04
7,40	1173	2586	16,18	15,08	3,87	3,61	4,99E+04	5,85E+04	7,62E+04
7,50	1208	2662	16,61	15,48	3,97	3,70	5,14E+04	6,03E+04	7,85E+04
7,60	1242	2738	17,05	15,89	4,08	3,80	5,29E+04	6,20E+04	8,07E+04
7,69	1277	2814	17,48	16,29	4,18	3,90	5,43E+04	6,37E+04	8,30E+04
7,79	1311	2890	17,92	16,69	4,28	3,99	5,58E+04	6,54E+04	8,52E+04
7,88	1346	2966	18,35	17,10	4,39	4,09	5,73E+04	6,72E+04	8,75E+04
7,98	1380	3042	18,79	17,50	4,49	4,18	5,87E+04	6,89E+04	8,97E+04
8,07	1415	3118	19,22	17,90	4,60	4,28	6,02E+04	7,06E+04	9,19E+04
8,16	1449	3194	19,65	18,30	4,70	4,38	6,17E+04	7,23E+04	9,42E+04
8,25	1484	3271	20,08	18,71	4,80	4,47	6,31E+04	7,40E+04	9,64E+04
8,34	1518	3347	20,51	19,11	4,91	4,57	6,46E+04	7,58E+04	9,87E+04
8,43	1553	3423	20,95	19,51	5,01	4,66	6,61E+04	7,75E+04	1,01E+05
8,68	1656	3651	22,24	20,71	5,32	4,95	7,05E+04	8,27E+04	1,08E+05
8,93	1760	3879	23,53	21,90	5,63	5,24	7,49E+04	8,78E+04	1,14E+05
9,18	1863	4107	24,81	23,10	5,93	5,52	7,93E+04	9,30E+04	1,21E+05
9,41	1967	4335	26,10	24,29	6,24	5,81	8,37E+04	9,82E+04	1,28E+05
9,64	2070	4563	27,38	25,48	6,55	6,09	8,81E+04	1,03E+05	1,35E+05

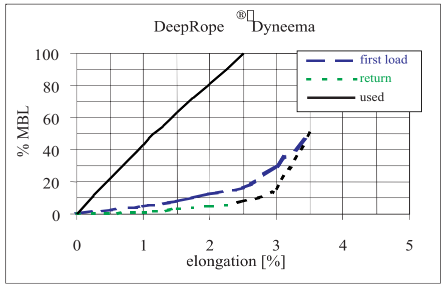
Modulus based on type approval tests for BV and PetroBras: [1] cycling between 10-30% MBL, [2] cycling between 20-30% MBL, [3] cycling between 40-50% MBL

The DeepRope® Dyneema® line for mooring applications is also a parallel core construction. It consists of two parts, namely core elements and the cover (see figure). Unlike for polyester lines, here a different cover is used, namely based on our Bexcoline Composite fibre. Also here the Dyneema fibre and the three-strand core determine the general characteristics, like elongation, elasticity and fatigue.
In the next chapter the specification of the rope will be discussed.



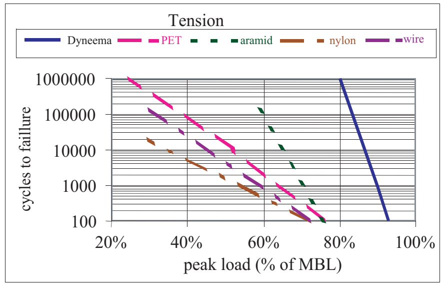
Load-elongation

DeepRope® Dyneema ropes in new condition typically have a higher elongation than when they are used. Here the elongation is shown when the rope is loaded a first time (3-4% elongation @ 50% MBL) and the elongation when the rope is broken in (after 10 cycles to 50% MBL, conform ISO).



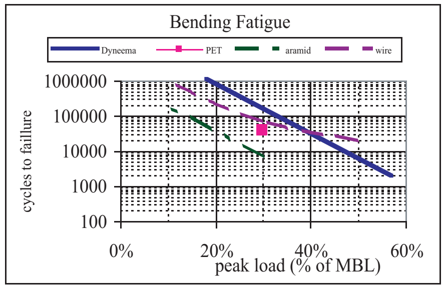
Tension-Tension fatigue

The fatigue resistance of Dyneema is excellent, as shown in this figure. Especially at high loads (i.e. shock loading) the number of cycles to failure is reasonable to good. This makes DeepRope® Dyneema® ropes very suitable for dynamic applications. Also because of the low fibre to fibre friction little to no internal abrasion occurs. Thus under fatigue loading the breaking strength does not deteriorate until the rope is close to failure.



Bending-Bending fatigue

The figure shows the results of tests carried out at Stuttgart University on Dyneema ropes, wire ropes and Aramid ropes. From these tests it can be seen that the bending fatigue of Dyneema is as good as, or better than, steel wire rope.
The standard DeepRope® line design normally will have a lower bending fatigue, although local bending will not have a strong effect. If the bending fatigue is critical modified designs are recommended.



Creep

Creep is defined as the non-recoverable plastic deformation of the fibre. In ropes creep has two important effects. Firstly, as individual fibres creep under tension loads will equalise between the different yarns, thereby optimising rope strength. Secondly, as discussed below creep can be used to estimate the safe working life of a rope. Because creep is strongly influenced by load and temperature, high, continuous loads should be considered for a first estimate of the creep behaviour. Special grades for mooring lines are available, that have a lower creep.
For a detailed estimate consult our technical staff.

Wear and tear

Dyneema® has very high abrasion resistance compared with other synthetic fibres, as can be seen in this table. Both the cut resistance and the wet abrasion resistance are excellent, which makes Dyneema® very suitable for marine applications. However, any synthetic fibre in direct contact with unpolished or corroded steel can be damaged. Thus it is recommended that smooth, clean contact points should be used. A non-load bearing nylon jacket braid has been used to provide additional abrasion protection for the strength member cores.

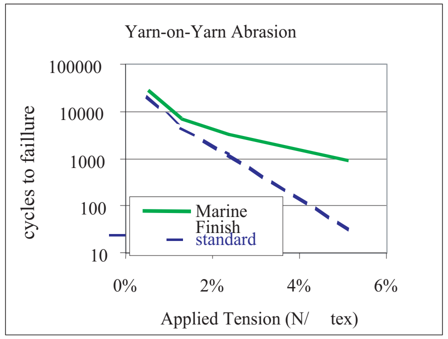
Yarn type	Cut resistance	Abrasion resistance	
		Dry	Wet
Dyneema	+++	++	+++
Bexcoline Comp.	++	++	+++
Polyester	++	++	++
Nylon	++	+++	+
PP	+	+	0
Aramid	+++	+	-

UV Resistance

The UV Resistance of Dyneema is excellent and normally no special protection against UV is necessary. As discussed with the UV Resistance for the DeepRope® Polyester (page 25), here the cover also provides additional protection.

Bexcoline Composite Fibre

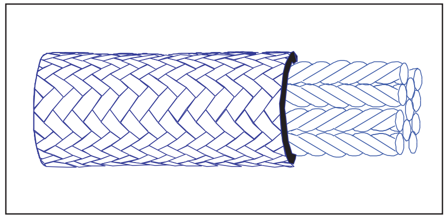
Bexcoline is a composite fibre with polyester as strength member, with excellent fatigue characteristics and abrasion resistance. The fatigue life is comparable to pure polyester, but the weight for a given strength is comparable to that of nylon. The behaviour of the rope is not influenced by water, thus wet and dry strength are identical. Because of material and its life cycle under normal use its most important application is a cost-effective solution for SPM Hawsers.



Here the Bexcoline Compostite fibre is used for the cover. It has a lower friction than polyester, thus less friction is generated on bollards and capstans. Also the cover is less likely to catch. Also the abrasion in the YOY test (ASTM 6611-00) is comparable. For this design a Marine Finish is applied to further improve the abrasion resistance.

Construction

The DeepRope® line for mooring applications is a so-called parallel core construction. This construction consists of two parts, namely the core elements and the cover (see figure).



The core elements are three-strand ropes that are oriented parallel to the longitudinal axis of the rope. The cover is a Bexcoline Composite braid that provides dimensional stability to the rope structure and protects the cores from external damage. It is treated with a Marine Finish to further enhance the life of the cover under abrasion loads. The cover braid does not contribute to the strength of the rope. The three-strand core design is used because of the good stretch characteristics and excellent splice strength efficiency exhibited by this type of core design.

Deeprope® Dyneema® lines

Because of it's low weight and small diameter a DeepRope® Dyneema® line can be transported without special measures. In most cases length is dictated by the use and not by shipping limitations.

Terminations

The DeepRope® Dyneema® line typically has a splice plus thimble as termination. The splice procedure used here has been especially developed for these applications. Operators and certifying authorities have raised a concern for the parallel-strand design: by random splicing of the sub-ropes the consequence of a single core damage can have catastrophic consequence on the rope strength. If that core is spliced into another core, then this second core may slip as a result of the damage to the first core. Thus this second core also no longer bears load. This way slippage may migrate through the rope causing imbalances between the subropes, resulting in a severe reduction in overall rope strength and all as a result of a single core failing. This problem is overcome by splicing every single sub-rope back into itself. Now the rope is more damage tolerant; if a subrope is damaged, then only that part is affected. Damage assessment can focus on that section, overall integrity need not be considered.

For DeepRope® mooring lines every subrope is spliced into itself, making the design more damage tolerant. Also the technique has been developed to splice with minimal tools. This allows splicing on site, requiring only a few tools and a clean, dry workspace. With the more accurate splicing technique variation has reduced, giving a higher reproducibility when the ropes are tested. The main difference between a polyester and Dyneema® splice it the low friction of the Dyneema® fibre. To compensate for this, special coatings in the splice and more tucks are used.

To further improve the life of the splice the eye and the splice are protected using DeltaWeb® plus a 2-component polyurethane.

The end termination may also consist of a standard removable spool (as for the polyester). However, because handling is very important for this type of mooring line typically an alternate termination is used, such as:
• Tubular thimble for use with a standard shackle
• K2B Thimble for use with standard Kenter Shackle

Shipment & Storage

Typically the DeepRope® Dyneema® lines are shipped on a reel, see also page 41. Only short lengths are shipped in a box

Deeprope® features

Material	High Modulus PolyEthylene
Construction	load-bearing cores with a protective cover of composite yarn (other covers on request)
Colour of Rope	White (other colours on request)
Specific Gravity	0,975 floating
Melting Point	145° C
Abrasion Resistance	Excellent
U.V. resistance	Good
Temperature resistance	Medium
Chemical resistance	Excellent
Water absorption/ Fibres	< 0,05%
Water uptake	n.a.
Dry & wet conditions	Strength & fatigue do not change in water
Range of use	Off-shore installation, mooring

DeepRope® Dyneema® mooring line; Strength table

Dia	Min Break Load		Weight	Stiffness	
mm	tf	kN	kg/m	EA [tf]	EA [kN]
81	372	3649	3,30	2,07E+04	2,03E+05
87	447	4379	3,83	2,48E+04	2,43E+05
93	521	5108	4,34	2,89E+04	2,84E+05
98	596	5838	4,85	3,31E+04	3,24E+05
103	670	6568	5,35	3,72E+04	3,65E+05
108	745	7298	5,85	4,13E+04	4,05E+05
113	819	8027	6,34	4,55E+04	4,46E+05
117	894	8757	6,83	4,96E+04	4,87E+05
121	968	9487	7,32	5,37E+04	5,27E+05
125	1043	10217	7,80	5,79E+04	5,68E+05
129	1117	10946	8,28	6,20E+04	6,08E+05
133	1191	11676	8,76	6,61E+04	6,49E+05
137	1266	12406	9,24	7,03E+04	6,89E+05
140	1340	13136	9,72	7,44E+04	7,30E+05
144	1415	13865	10,2	7,85E+04	7,70E+05
147	1489	14595	10,7	8,27E+04	8,11E+05
150	1564	15325	11,1	8,68E+04	8,51E+05
154	1638	16055	11,6	9,09E+04	8,92E+05
157	1713	16784	12,1	9,51E+04	9,32E+05
160	1787	17514	12,5	9,92E+04	9,73E+05
163	1862	18244	13,0	1,03E+05	1,01E+06
166	1936	18974	13,5	1,07E+05	1,05E+06
169	2011	19703	13,9	1,12E+05	1,09E+06
171	2085	20433	14,4	1,16E+05	1,14E+06
174	2159	21163	14,9	1,20E+05	1,18E+06
177	2234	21893	15,3	1,24E+05	1,22E+06
180	2308	22622	15,8	1,28E+05	1,26E+06
182	2383	23352	16,3	1,32E+05	1,30E+06
185	2457	24082	16,7	1,36E+05	1,34E+06
187	2532	24812	17,2	1,41E+05	1,38E+06

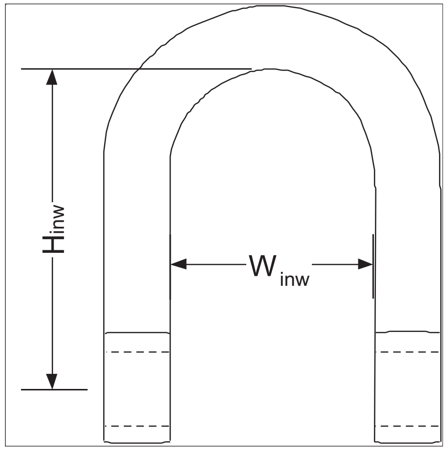
All measurements conform ISO

Dyneema® DeepRope® Strength table (ASTM)

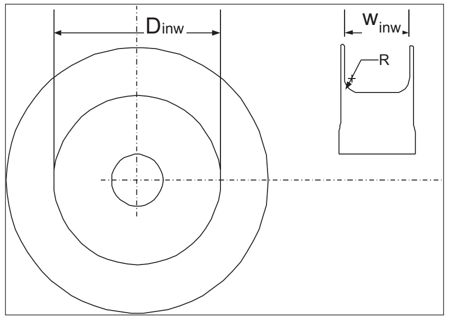
Dia	Min Break Load		Weight	Stiffness	
inch	tf	kips	[lb/ft]	EA [tf]	EA [kips]
3,17	372	821	2,22	2,07E+04	4,56E+04
3,42	447	985	2,57	2,48E+04	5,47E+04
3,65	521	1149	2,92	2,89E+04	6,38E+04
3,86	596	1313	3,26	3,31E+04	7,29E+04
4,07	670	1477	3,59	3,72E+04	8,20E+04
4,26	745	1642	3,93	4,13E+04	9,11E+04
4,44	819	1806	4,26	4,55E+04	1,00E+05
4,61	894	1970	4,59	4,96E+04	1,09E+05
4,77	968	2134	4,92	5,37E+04	1,18E+05
4,93	1043	2298	5,24	5,79E+04	1,28E+05
5,09	1117	2462	5,56	6,20E+04	1,37E+05
5,24	1191	2627	5,89	6,61E+04	1,46E+05
5,38	1266	2791	6,21	7,03E+04	1,55E+05
5,52	1340	2955	6,53	7,44E+04	1,64E+05
5,66	1415	3119	6,85	7,85E+04	1,73E+05
5,79	1489	3283	7,16	8,27E+04	1,82E+05
5,92	1564	3447	7,48	8,68E+04	1,91E+05
6,05	1638	3612	7,80	9,09E+04	2,00E+05
6,17	1713	3776	8,11	9,51E+04	2,10E+05
6,29	1787	3940	8,43	9,92E+04	2,19E+05
6,41	1862	4104	8,74	1,03E+05	2,28E+05
6,52	1936	4268	9,05	1,07E+05	2,37E+05
6,64	2011	4432	9,37	1,12E+05	2,46E+05
6,75	2085	4597	9,68	1,16E+05	2,55E+05
6,86	2159	4761	9,99	1,20E+05	2,64E+05
6,97	2234	4925	10,3	1,24E+05	2,73E+05
7,07	2308	5089	10,6	1,28E+05	2,82E+05
7,18	2383	5253	10,9	1,32E+05	2,92E+05
7,28	2457	5417	11,2	1,36E+05	3,01E+05
7	2532	5582	11,5	1,41E+05	3,10E+05

Standard terminations

The DeepRope® line has a splice plus a round thimble as standard termination. To further improve the life of the splice the eye and the splice are protected using DeltaWeb plus a 2-component polyurethane.



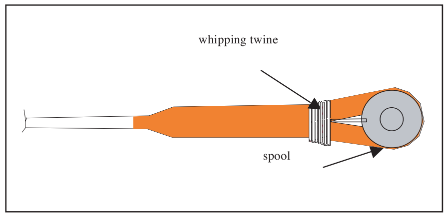
The removable spools should be inserted in the eye during installation. The two legs of the eye should be compressed together with the whipping twine to hold the spool in place (see figure). In addition, the spool should be secured in place with a twine which passes through a special hole in the flange of the spool and around the line.



Here the termination design is given for polyester ropes. Alternative terminations are also available both for polyester and Dyneema®, see also page 38.

Alternative Terminations

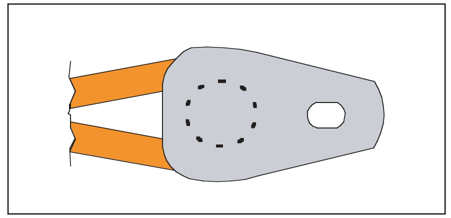
The standard termination for DeepRope® Polyester mooring lines has been optimised for maximum life. The round thimble gives an optimal contact pressure on the rope in the eye. If installed correctly, there are no sharp edges for the rope to chafe against. However it is also a relative heavy design.



Many alternative thimble designs are available that are easier to handle or better lock the rope in position. Here a short overview is given of possible eye terminations. The splice itself is identical; all subropes are spliced back into themselves.

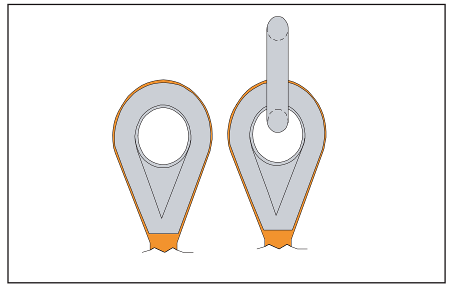
GN Thimble

This thimble is an improvement of the standard thimble plus shackle from the previous paragraph. It has the same basic geometry on the rope side, however now a pin can be inserted for easy connection to a link. This simplifies handling considerably.



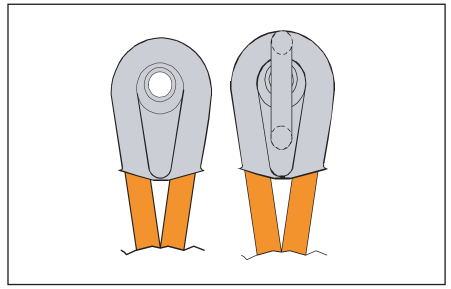
K2B Thimble with or without link

This shackle is mostly used for direct connection to a Standard or Kenter shackle. Basically the rope is laid in a U-groove, that has been bent. The K2B allows for quick and easy connections. It gives no protection if the rope is dragged over the deck of a vessel.



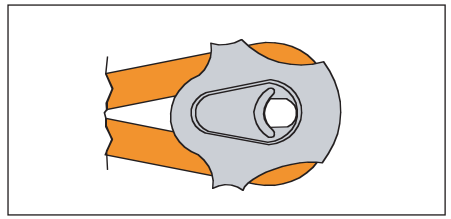
Tubular Thimble with or without link

This thimble is widely used for SPM Hawsers. Here the rope is put in a bent tube. It gives excellent protection and can be easily connected to a shackle.



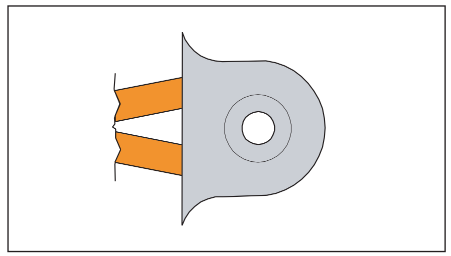
Cast Thimble

This thimble is used for SPM Hawsers. It is very durable and gives excellent protection. Also it allows inspection of the eye. It can be easily connected to a shackle.



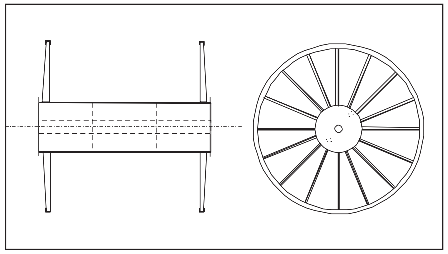
Bell mouth thimble

This thimble allows changing out the rope, whilst keeping the thimble. For SPM Hawsers this termination is typically used if it can be exchanged easily.

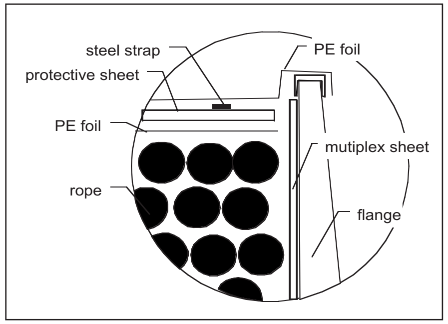


See termination table on page 50.

Reels
DeepRope mooring lines are spooled on steel reels. See sketch.



Packaging
The mooring line is connected to the reel using a small synthetic forerunner. As a first protection a polyethylene foil is wrapped around the rope. Then a protective sheet with a high compressive strength is wrapped around the rope. Lastly a second PE foil is wrapped around the rope onto the flange; this keeps the rope safe from dirt or rain. See also sketch and photos.



Shipping
Only trained and experienced personnel should handle the steel reels. A special lifting beam is provided with the reels, with the Safe Working Load (SWL) indicated on the beam.

The reel should be connected to the beam with special wires and a shackle, matching the SWL. See side view and photos.

The SWL should not be exceeded, or the wires rigged differently than indicated here. Before lifting the rigging should be inspected to ensure that wires can not slip loose. Lifting should be done controlled; the reel should never be dropped. The (un)loading surface should be even, otherwise the reel may roll once the beam is lowered. Any motion should be blocked using kegs or similar devices. The reel should not be restrained manually.

Storage
Storage of the ropes should be done with the utmost care. A Deeprope line should be stored in closed packaging. Well-protected ropes will not lose strength during storage. Unprotected rope parts may be affected by exposure to direct sunlight as this causes U.V. degradation.

Unprotected ropes can lose strength in outer cover fibres caused by U.V. degradation. Under normal conditions of use this will not influence the performance of the rope. However, it may affect the abrasion resistance of the cover.
A visual inspection of the splice and the cover is always recommended when retrieving the rope from storage. When in doubt BEXCOropes should be contacted.

Temperature
A Polyester Deeprope should not be exposed to extreme heat the storage temperature should be less than 80°C continuously or peak temperatures of 100°C over a period of 5 years.

A Dyneema Deeprope should not be exposed to extreme heat the storage temperature should be less than 40°C continuously or peak temperatures of 60°C over a period of 5 years.

Chemicals
Seawater chemicals and pollutants in normal concentrations are not known to adversely affect Deeprope lines, both Polyester and Dyneema. Bases and solvents may have a mild effect.

Note: Never store base chemicals or solvents close to the DeepRope line. Base chemicals and solvents can degrade the rope.

Biological attack
No effects are known to be significant on synthetic DeepRope lines.

Moisture
No effect on Deeprope lines in function of time.

Thimble and shackle table (Polyester)

Rope	Rope	Thimble				Shackle		
dia mm	MBL tf	Dtot mm	Dinw mm	wtot mm	winw mm	W tot mm	Winw mm	Hinw mm
113	367	441	283	191	141	403	201	541
117	400	456	293	196	146	416	206	556
126	467	491	315	208	158	443	218	591
130	500	507	325	213	163	455	223	607
133	533	519	333	216	166	464	226	619
137	567	534	343	221	171	476	231	634
141	600	550	353	226	176	488	236	650
144	633	562	360	230	180	498	240	662
147	667	573	368	234	184	507	244	673
151	700	589	378	239	189	519	249	689
154	733	601	385	243	193	528	253	701
157	767	612	393	246	196	537	256	712
160	800	624	400	250	200	546	260	724
163	833	636	408	254	204	555	264	736
166	867	647	415	258	208	564	268	747
169	900	659	423	261	211	574	271	759
172	933	671	430	265	215	583	275	771
175	967	683	438	269	219	592	279	783
177	1000	690	443	271	221	598	281	790
180	1033	702	450	275	225	607	285	802
183	1067	714	458	279	229	616	289	814
185	1100	722	463	281	231	622	291	822
188	1133	733	470	285	235	631	295	833
190	1167	741	475	288	238	637	298	841
193	1200	753	483	291	241	646	301	853
195	1233	761	488	294	244	653	304	861
198	1267	772	495	298	248	662	308	872
200	1300	780	500	300	250	668	310	880
203	1333	792	508	304	254	677	314	892
205	1367	800	513	306	256	683	316	900

Reel design and dimensions

Flange Diameter Core diameter (cm) Inner width (cm)	350 102 150	350 102 200	350 102 250	350 102 300	350 102 350	350 102 400	350 102 450	350 102 480
Weight incl. PES Rope (mt)	10,4	13,3	16,1	19,0	21,9	24,7	27,5	29,1

Rope dia (mm)	m rope/reel							
113	931	1.241	1.552	1.862	2.172	2.483	2.793	2.979
117	868	1.158	1.447	1.737	2.026	2.316	2.605	2.779
126	749	998	1.248	1.498	1.747	1.997	2.246	2.396
130	703	938	1.172	1.407	1.641	1.876	2.110	2.251
133	672	896	1.120	1.344	1.568	1.792	2.016	2.151
137	633	845	1.056	1.267	1.478	1.689	1.900	2.027
141	598	797	997	1.196	1.395	1.595	1.794	1.913
144	573	764	956	1.147	1.338	1.529	1.720	1.835
147	550	734	917	1.100	1.284	1.467	1.650	1.760
151	521	695	869	1.043	1.217	1.390	1.564	1.668
154	501	668	835	1.003	1.170	1.337	1.504	1.604
157	482	643	804	965	1.125	1.286	1.447	1.543
160	464	619	774	929	1.084	1.238	1.393	1.486
163	447	597	746	895	1.044	1.193	1.342	1.432
166	431	575	719	863	1.007	1.150	1.294	1.381
169	416	555	694	832	971	1.110	1.249	1.332
175	388	518	647	776	906	1.035	1.165	1.242
180	367	489	612	734	856	978	1.101	1.174
185	347	463	579	695	810	926	1.042	1.112
190	329	439	549	659	768	878	988	1.054
195	313	417	521	625	729	834	938	1.000
200	297	396	495	594	693	793	892	951
205	283	377	471	566	660	754	849	905
210	270	359	449	539	629	719	809	863
214	260	346	433	519	606	692	779	831
221	243	325	406	487	568	649	730	779
227	231	308	385	461	538	615	692	738
233	219	292	365	438	511	584	657	701
239	208	277	347	416	486	555	624	666
245	198	264	330	396	462	528	594	634

There are various reel designs available, depending on the installation requirements. Here a typical design and its dimensions are shown. For other designs please contact our staff.

OSCAR (Optical SCanning Apparatus for Rope)

Deepwater mooring Ropes are intended to be in service for long periods, up to twenty-five years. Over such a period all kinds of unforeseen events, like overloading, particle ingress, combination of fatigue and abrasion damage and others can influence ropes properties. To date no practical Non-Destructive Test techniques (NDT) have been developed for polyester lines. Visual inspection of the rope, for example with a ROV, will only show external damage. However, ropes can fail from various causes that can not be detected in a visual inspection of the exterior of the rope. To monitor property changes of the mooring system test legs must be inserted and removed at specific intervals for testing. This is expensive and time-consuming.

In the OSCAR project a first NDT method has been developed for ropes. It works by measuring local changes in tensile properties for a long length of rope. The basis for this NDT method is the assumption that a change in rope properties will be accompanied by a change in modulus. Consequently local strain will vary along the length of a rope. If this local strain distribution can be measured, it is possible to identify the location of local modulus changes.

Brillouin

Strain may be determined continuously along the length of a single mode optical fibre by utilising the strain dependence of the Brillouin gain coefficient. This method allows local strain measurements over long ranges of optical fibre.

A special transducer cable has been developed incorporating multiple optical fibres for strain sensing. The mechanical design of the cable ensures that it will follow the elongation of the rope with strain being transferred to the optical fibre in a controlled man-

ner. By using multiple optical fibres two things are achieved. Firstly the system has built-in redundancy, ensuring that even if one of the optical fibres is damaged signal can still be measured. Secondly the fibres can be configured to have a different gain, optimising measurements over a wide range of elongations.

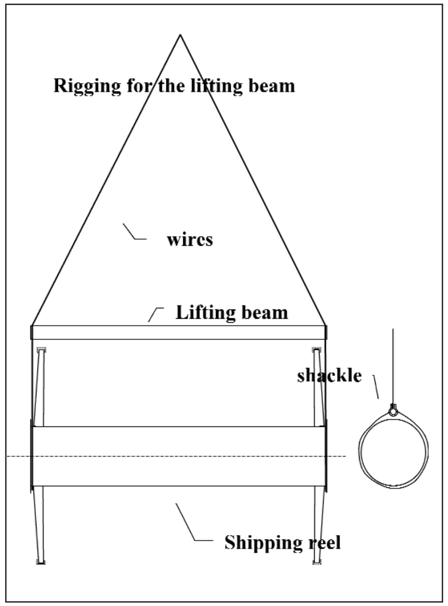
Results

A scaled-down polyester DeepWater mooring line with variable strength along its length has been monitored by a purpose designed, built-in optical fibre strain transducer incorporating standard, unmodified optical fibre. Brillouin analysis of the transducer signal has been used to unambiguously identify the weaker and stronger zones of the rope in a blind test, by determination of local fibre strain. Resolution of the technique used was around 2 metres, but this can be improved with next generation equipment. In the graph the strain of three different fibres is shown, each with a different gain. A, B, C represent the fibres of different gain all simultaneously measured. In each of the readings A, B and C from the three fibres, the valley between the two adjacent peaks clearly identifies the location of low strain, and this corresponds very well with the location of local strengthening.

The partners in the OSCAR project

- Selantic
- TTI
- BexcoRopes
- University of Strathclyde
- BPP Technical Services Ltd.

Synthetic ropes are fundamentally different from steel wire ropes in many aspects. In the following sections the main influences on the installation of these lines are discussed.



Transport

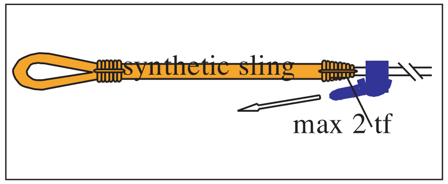
Transportation of the ropes should be done with the utmost care. General recommendations for storage should be adhered also during transport (see page 40). The reels should not be allowed to shift position during transport. Depending on the weight of the reel plus rope either slings or a lifting beam should be used, see sketch.

Installation

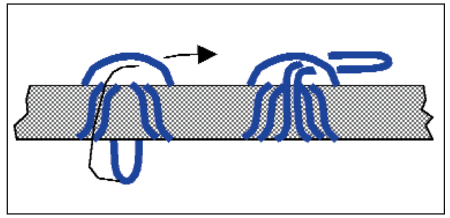
Here the main influences on the installation of these lines are discussed. These are by no means complete, detailed installation procedures can only be made in co-operation with the installation crew.

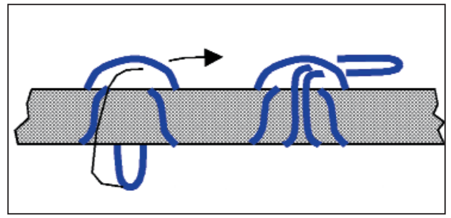
It is recommended that the lines are installed from a winch. To prevent burying of the ropes on the winch they should always be spooled with a minimum tension. As a guideline the spooling tension should be equal to or higher than the weight of the hardware on the bottom end of the mooring line. This is especially important when the ropes are new, because they will still have their constructional elongation. Thus it is recommended to use a bollard or capstan to tension the rope as it is spooled.

Synthetic stoppers should be utilised if the spools have to be inserted during the rope installation process. These stoppers should only be used to secure the rope while disconnecting from the winch and during insertion of the spool, see also sketch. The lashing at the foot of the splice has been strengthened to take normal installation loads and the sling should be mounted behind it as shown here. Other connections (shackles, chain) should only be attached to the spools. After this the stopper should be removed.

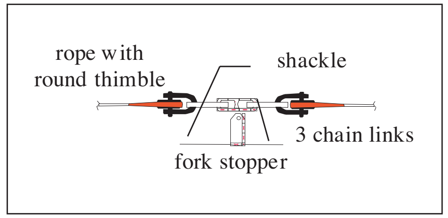


The cover is designed to withstand normal handling but not the heavy shearing forces that could result from using a stopper chain. Thus stopper chain or other types of choking devices should not be used.





This also applies to the use of the forkstopper. Typically a few chain links are used between the Polyester and the rest of the system, these links are meant to stop the line. The stopper should not be used on the line itself.



Do not drag the rope along the deck. If this is unavoidable ensure that the rope passes clear of sharp edges or rough surfaces to prevent snagging or tearing of the cover braid. The rope should not come into contact with any abrasive surfaces such as welds, rust, etc. All potential contact surfaces on the vessel should be checked prior to the installation process to ensure that there are no areas that may damage the rope. All rolling surfaces should be free-turning and smooth. If damage to the cover occurs, it should be repaired as described elsewhere in this manual prior to proceeding with the installation.

When deploying each section over the stern, the eyes of the rope should be kept in the horizontal plane to avoid damaging the rope and spool on the stern roller. The fleet angle between the installation winch and the stern of the vessel should be kept to a minimum to avoid side contact between the rope and the flanges of the winch. Otherwise the rope is liable to chafe against the sides.

Typically the terminations for DeepRope® Polyester lines are roll thimbles. These are shipped separately and mounted during installation. They are fixed to the splice by a seizing; a separate installation procedure is available. For Dyneema® alternate terminations are used (e.g. K2B).

Safe Working Load

Temporary systems

The fatigue life of both Polyester and Dyneema® is better than that of wire ropes under normal loading conditions. Depending on the certification rules a comparable safety factor can be used as for the other mooring components.

Permanent systems

Because of the excellent fatigue life of Polyester, (compared to wire under normal loading conditions) a comparable or slightly higher safety factor is used for polyester than for the other mooring components. This is dependent on the certification rules. Here a limited, quick comparison is made.

Norm	S.F.	Condition
API RP2SM	1.67	Intact dynamic
ABS	1.82	Max intact tension
BV	2	API rules +20%
DNV	1.82	Posmoor

Bending radius

These ropes can be bent over relative small sheaves or guides under low tensions (less than 5% of the MBL). For the main part the minimum bend radius is equal to one and a half (1,5) times the rope diameter (or three times the rope radius). This does not apply to the terminations.
For the terminations the size of the round spool and the stiffness of the protective cover (impregnated with the orange, 2-component polyurethane) limit the minimum bending radius. Here the typical bending radius is six (6) times the rope diameter.
These measures will reduce the risk of installation damage, thus ensuring a very long service life.

Installation of the Deeprope® line

Abrasion resistance

The cover of this rope has not been designed to withstand excessive external abrasion, caused by burrs and grooves in older fairleads. Thus it is recommended to use smooth, clean fairleads, bitts, etc. during installation. If abrasion does occur initially the cover becomes fuzzy and if measures are not taken immediately the fibres in the cover will fail. This exposes the inner cores and they, in turn, will also start to abrade. As a result the breaking strength will reduce. Upon request special epoxy coatings are available to smoothen damaged fairleads for synthetics.

Temperature resistance

The melting temperature of Polyester is ± 250°C, although, under prolonged exposure, the mechanical properties start to change above 100°C. It is important to keep a Polyester rope away from any heat source like an open fire, exhaust pipes, welding, etc. Do not store these ropes in the vicinity of a boiler or heater or against bulkheads or on decks which may reach high temperatures.

The melting temperature of HMPE (Dyneema®) is ± 150°C, although, under prolonged exposure, the mechanical properties start to change above 70°C. It is important to keep a Dyneema® rope away from any heat source like an open fire, exhaust pipes, welding, etc. Do not store these ropes in the vicinity of a boiler or heater or against bulkheads or on decks which may reach high temperatures.

The decision to discard, repair or continue using a Polyester rope can never be taken on the grounds of exact standards. For correct use of the criteria given here general knowledge of, and experience with, fibre ropes in general and Polyester ropes in particular is essential. In case of doubt the rope manufacturer should be consulted. Here only a rough guide on damage and its assessment is given.

Damage to the mooring line is most likely to occur during installation or maintenance of the mooring system. For permanent mooring lines damage can not be accepted as the consequences on the safe working life over a period of twenty years are difficult to asses. Here one needs to decide whether a rope should be replaced immediately or if the replacement can be scheduled.

For temporary moorings, for example drilling, some damage can be accepted as repair or replacement can be done off location. As a guideline the Residual Breaking Strength of the damaged rope should not be less than 75 % of the New Breaking Strength. However this should be agreed by all parties concerned. As previously mentioned, the cover braid of the mooring rope does not contribute to the rope's strength. Therefore, any damage that is confined solely to the cover will not cause a reduction in strength; however, the cover does play an important role in the overall integrity of the rope. Therefore, any damage to the cover should be addressed as quickly as possible. Even if damage appears to be limited to the cover the rope should be inspected thoroughly to ensure that the core strength members have not been affected.
To date an damage JIP is underway to establish an industry acceptable standard for damage assessment of deepwater mooring systems. Bexco is participating in this JIP. Co-ordination is done by DnV. The methodology presented there is an acceptable alternative.

Inspection

The lifetime of a rope is strongly influenced by its construction, the environment it is used in and the type of application. The inspection interval is dependent on the type of application.

The DeepRope® design uses a special splice, with the essential characteristic that individual sub-ropes are spliced back into themselves. As a consequence damage is only limited to the affected sub rope(s).

The residual breaking strength of the rope should be quantified using the procedures described below to obtain a clear view of the strength decay and lifetime.

Discard criteria

The following factors may warrant removing a rope from service:
- wear and abrasion
- friction burns
- creep
- crushing/pinching
- local damage

If local damage is observed then a length of 50 times the diameter before and after that position should be closely inspected and all reductions in strength should be added together.

Wear and Abrasion

Wear and abrasion are the most common causes of rope failure. Rough surfaces, sharp edges, burrs, rust and dirt can cause serious damage to a rope. Winches, pulleys, chocks, bitts, etc. should be clean and in good condition.
Wear and abrasion can occur over greater lengths or locally. Particular attention should be paid to the splice area and the eye.
Frayed and broken yarns should be removed and the damaged area should be estimated.

Friction Burns

Friction burns can occur over greater lengths or locally. Direct contact with hot objects should always be avoided (eg. exhaust pipes). Also when using the rope on a winch, capstan, sheave, etc. care should be taken to avoid surging the rope while it is under load. When the rope slips a lot of heat can be generated through friction.

When friction burns are detected, the rope should be opened and it should be estimated how much of the rope is fused. The damaged area should be considered to be about twice the fused area.

Creep

For polyester ropes creep does not play a role for dynamic applications.

Crushing/pinching

When a rope has been crushed or pinched it should be removed from service. Typically with this type of problem the resulting damage in the rope is a combination of broken/cut yarns and pulled yarns or strands, the assessment of this type of damage is extremely difficult. Thus this gives very unreliable estimates of the resulting reduction in strength. A knot has a similar effect.

Local Damage

Depending on the extent of localised damage it may be possible to repair the rope rather than remove it from service. Options include local repair plus downgrading or removal of the damaged section and resplicing.

A second, independent evaluation by a competent person (e.g. the ropemaker) is strongly recommended before resplicing.

Pulled cover braid yarns or strands

Individual yarns or strands can be caught behind objects (nails, burrs, etc.) and be pulled out of the rope. This damage makes the rope very unsafe, because the pulled yarns can easily snag behind an object. Thus care should be taken to work the yarn or strand back into the rope. If a cover yarn pull is too severe the yarn can be cut and the ends worked back into the rope. A pulled core yarn or strand should not be cut. Rather, the pull should be buried back into the interior of the rope.

The number of pulled yarns or strands should be counted and noted in the inspection card. The cause should be traced and alleviated.

Cut yarns or strands

Individual yarns or strands can be cut through chafing against sharp objects (e.g. the side of a steel plate).

The number of cut yarns or strands should be counted and the damaged area per strand estimated.

Others

No attempt is made here to list a complete catalogue of discard criteria. Many different types of damage to a rope are possible. Thus common sense during inspection to assess the Residual Strength is paramount.

Estimating residual strength

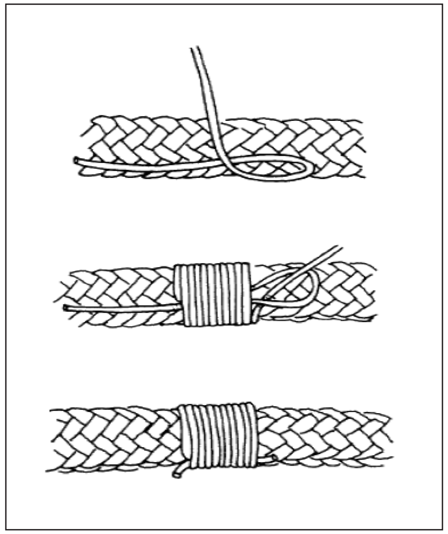
The Breaking Strength of a rope is reduced by damage to the yarns. Through inspection the reduction in strength is estimated per damaged spot. All damages over the inspected length of the rope should then be added together. Only the damage on the three-strand cores should be evaluated.

The cover braid does not contribute to the strength of the rope.

On the basis of that total estimate the rope is downgraded or removed from service.

When the cover is damaged we recommend inspection of the inner strength member. If the inner strength member is damaged then it may be necessary to downgrade the rope. The cause of the damage should be determined and if possible removed.

Depending on the extent of the damage either a small repair or an extensive repair is recommended.



Small Repairs

The most durable method to make small repairs on the jacket braid requires the use of nylon whipping twine and polyurethane glue.

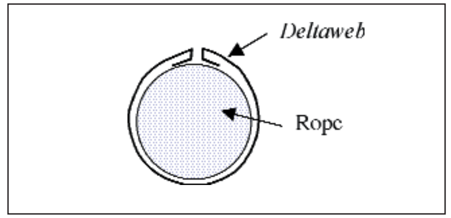
Remove all the damaged yarns and coat the free yarn ends with the glue, in order to prevent further unraveling of the cover. Start whipping at least three centimeters away from the damage, as shown in the drawing. Lay a loop of twine across the rope, leaving a free tail after the damage zone of about ten centimeters. This tail has to be grasped later, so avoid covering it completely with whipping.
With the working end of the twine, make multiple wraps around the rope from the tail end toward the apex of the loop, covering the loop until the whipping is at least three centimeters beyond the damage.

To finish the whipping, insert the working end of the small twine through the loop. Pull on the very end or tail of the small twine until the loop slides completely out of sight. Clip the ends close to the whipping.

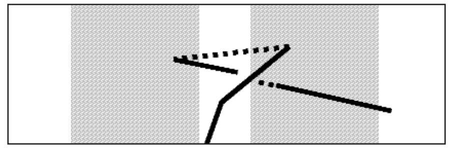
If necessary, a temporary cover repair can be made using high quality adhesive tapes such as vinyl electrical tape, etc. A more permanent repair, as described above, should replace the tape as soon as possible.

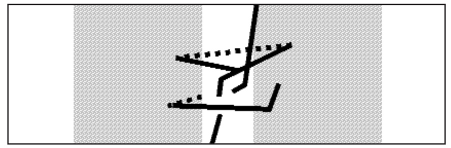
Extensive repairs

For extensive repairs the following tools are needed: Deltaweb, some sewing twine and a large sewing needle. Optionally additional protection can be obtained by a two-component polyurethane.



Remove all the damaged yarns and inspect the rope. After inspection coat the free yarn ends with the glue, in order to prevent further unraveling of the cover. Wrap the damaged part in Deltaweb. Please note that the sides should be folded back, see sketch and photo. Stitch the web together, with a special knot that will prevent the stitching yarn from loosening when it is torn.

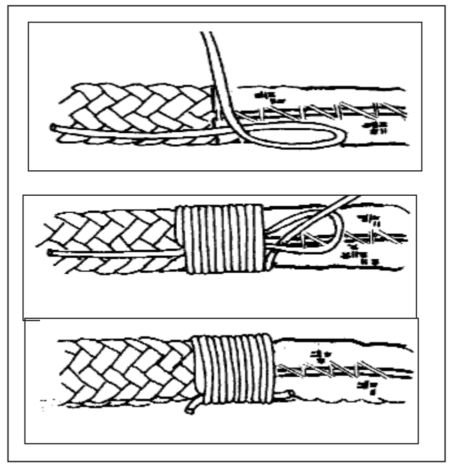




Protect the beginning and the end of the Deltaweb with whipping. Start whipping at least three centimeters away from the edge, as shown in the drawing. Lay a loop of twine across the rope, leaving a free tail after the damage zone of about ten centimeters. This tail has to be grasped later, so avoid covering it completely.

With the working end of the twine, make multiple wraps around the rope from the tail end toward the apex of the loop, covering the loop until the whipping is at least three centimeters beyond the damage.

To finish the whipping, insert the working end of the twine through the loop. Pull on the very end or tail of the twine until the loop slides completely out of sight. Clip the ends close to the whipping.



Testing

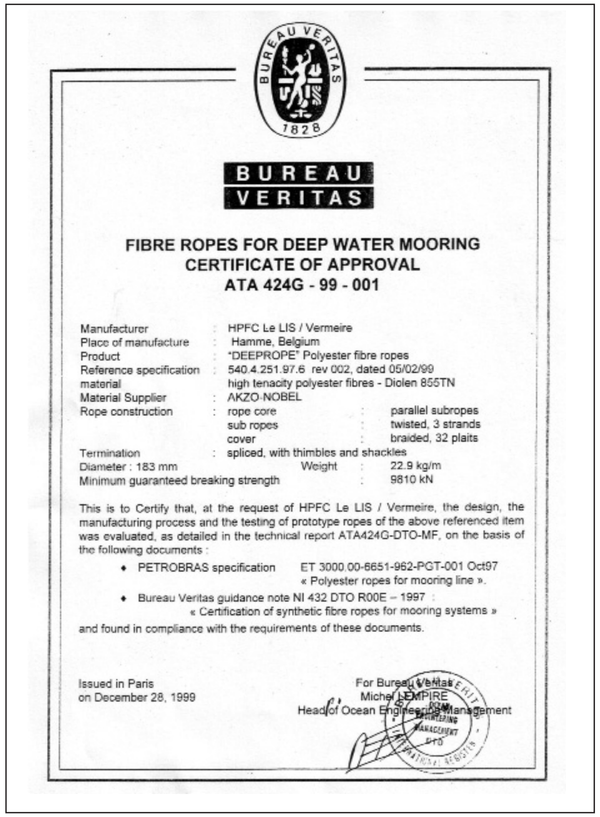
During production, sample tests will be carried out on yarns and strands and sub-ropes. An external surveyor will witness and certify all tests. Testing shall be in accordance with Le Lis QA Procedures for these tests, see also flow chart.

CERTIFICATE OF QUALITY SYSTEM
ISO 9001

Quality assurance

The Group Bexco N.V. and his subsidiaries has a Total Quality Management System (TQM) and is certified according to ISO 9001-2000.

A copy of the Quality Assurance Manual is available on request.



BUREAU VERITAS
1828

FIBRE ROPES FOR DEEP WATER MOORING
CERTIFICATE OF APPROVAL
ATA 424G - 99 - 001

Manufacturer : HPFC Le LIS / Vermeire
Place of manufacture : Hamme, Belgium
Product : "DEEPROPE" Polyester fibre ropes
Reference specification : 540.4.251.97.6 rev 002, dated 05/02/99
material : high tenacity polyester fibres - Diolen 855TN
Material Supplier : AKZO-NOBEL
Rope construction : rope core : parallel subropes
sub ropes : twisted, 3 strands
cover : braided, 32 plaits
Termination : spliced, with thimbles and shackles
Diameter : 183 mm Weight : 22.9 kg/m
Minimum guaranteed breaking strength : 9810 kN

This is to Certify that, at the request of HPFC Le LIS / Vermeire, the design, the manufacturing process and the testing of prototype ropes of the above referenced item was evaluated, as detailed in the technical report ATA424G-DTO-MF, on the basis of the following documents :

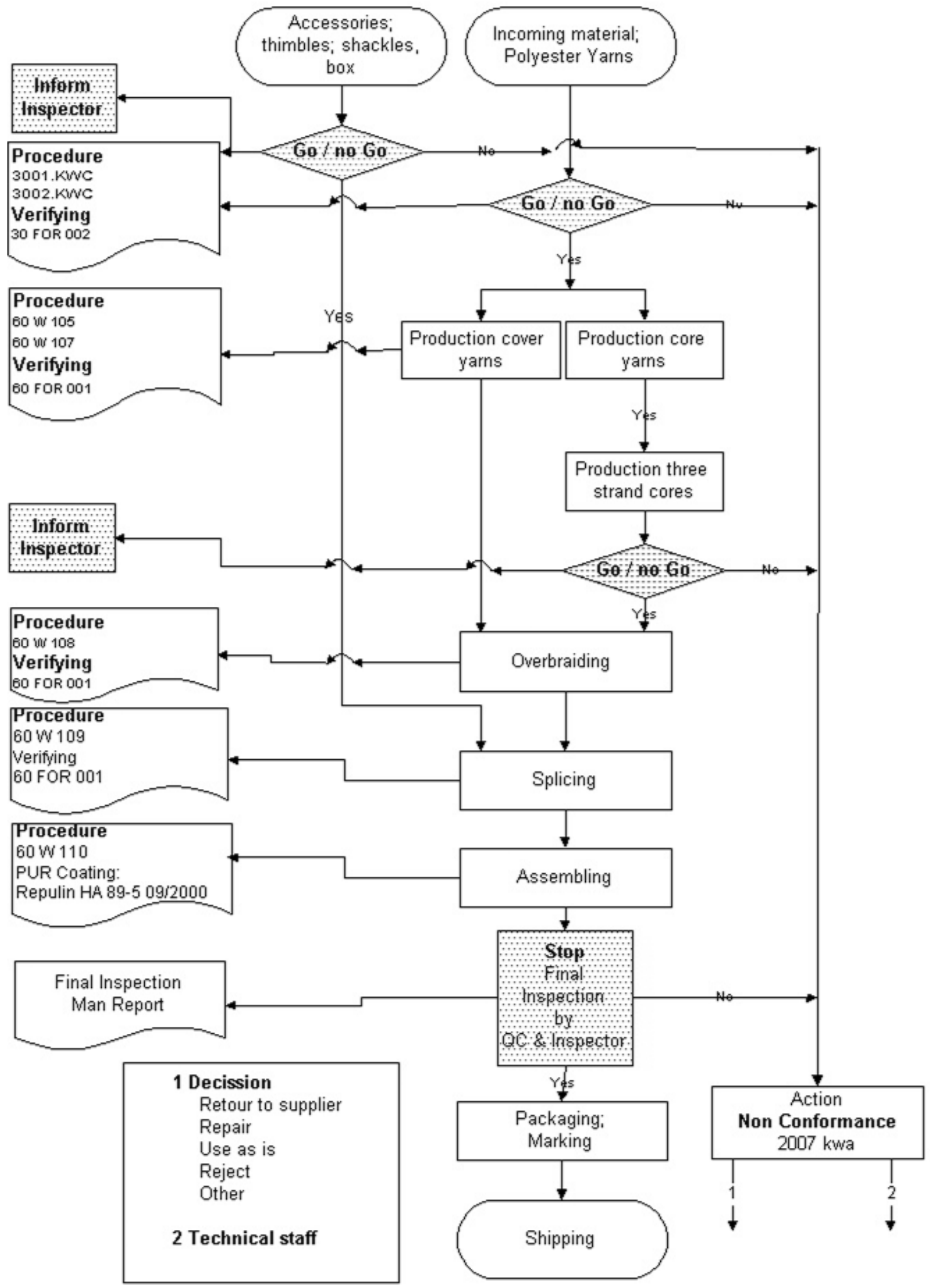
- PETROBRAS specification ET 3000.00-6651-962-PGT-001 Oct97 « Polyester ropes for mooring line ».
- Bureau Veritas guidance note NI 432 DTO R00E – 1997 « Certification of synthetic fibre ropes for mooring systems »

and found in compliance with the requirements of these documents.

Issued in Paris on December 28, 1999

For Bureau Veritas
Michel LEMPIRE
Head of Ocean Engineering Management

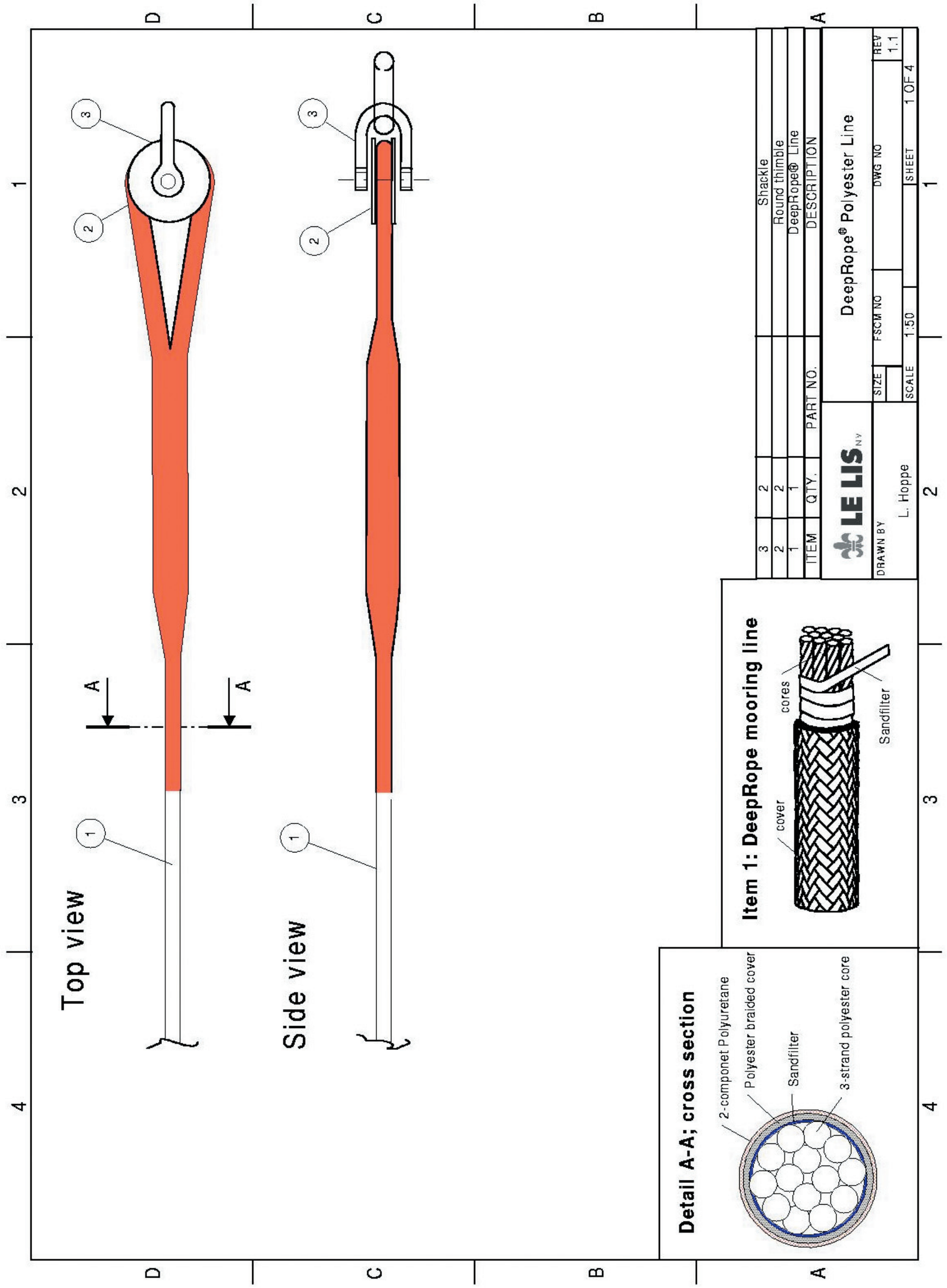
Other sizes with official Type Approval: 400 mT, 450 mT, 630 mT, 710 mT and 750 mtT.



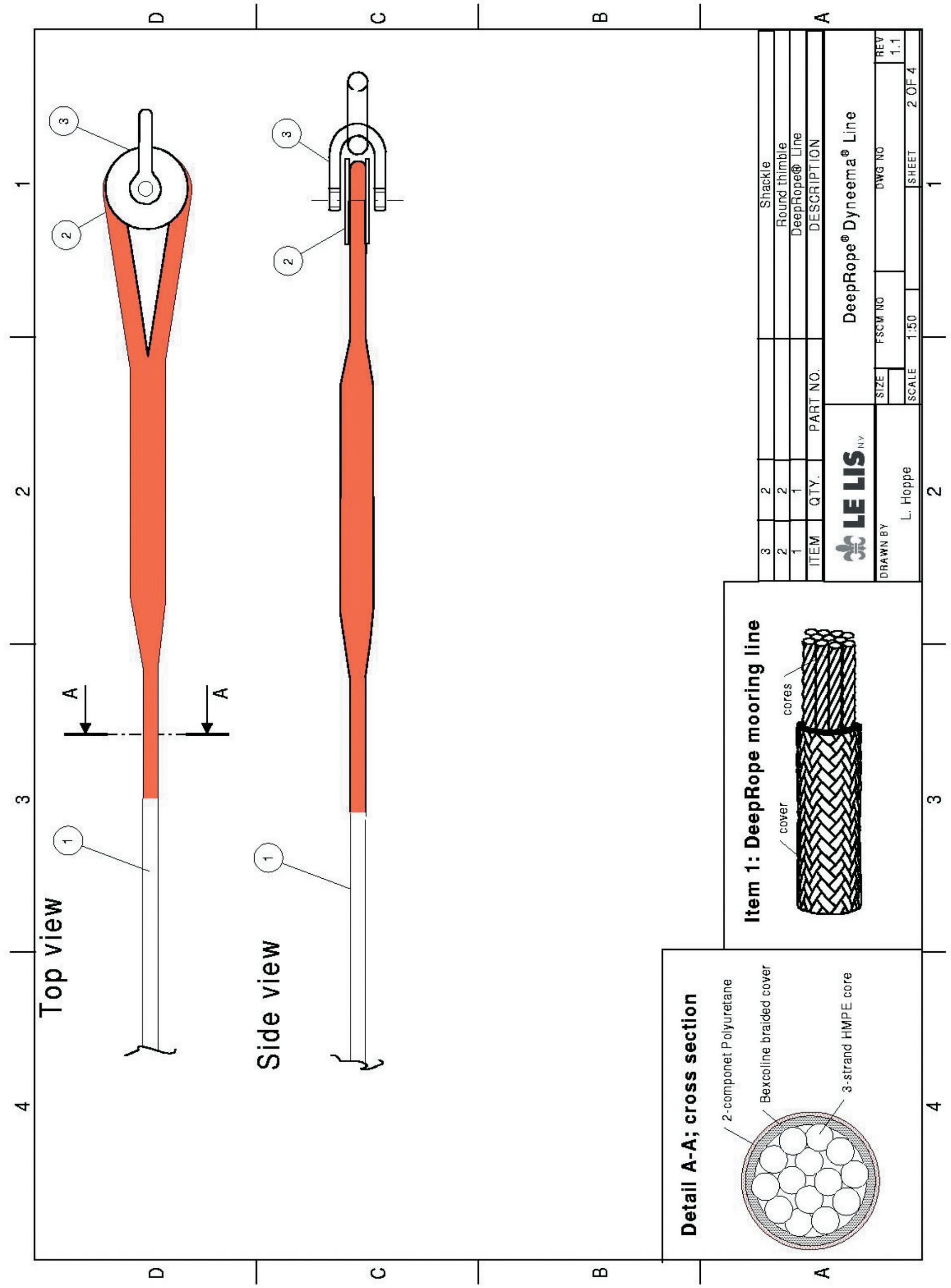
ELF, FRANCE	1 x 500 m Polyester, DeepRope® mooring line, 500 Tf, (Congo)
ELF, FRANCE	2 x 1450 m, 113 Tf, Deepwater Anchorline, Dyneema (HMPE, Angola)
COSALT, UK	4000 m one length Polyester rope, 30 Tf for pipe laying
COSALT, UK	1000 m Polyester rope cable laying 26,4 Tf.
COSALT, UK	1000 m Polyester rope cable laying 50,0 Tf.
COSALT, UK	1000 m Dyneema rope cable laying 20,0 Tf.
FYNS KRAN, DENMARK	10 x 2000 m Polyester rope cable laying 36,4 Tf.
FYNS KRAN, DENMARK	10 x 2000 m Polyester rope cable laying 52,5 Tf.
FYNS KRAN, DENMARK	25 x 1000 m Polyester rope cable laying 52,5 Tf.
DREYFUS, FRANCE	20 x 1000 m Polyester rope cable laying 30 Tf
KOS, NORWAY	Dyneema ropes with special terminations, 90 Tf, for ROV use
SAGA, NORWAY	1 x 500 m Polyester, DeepRope® mooring line, 500 Tf.
PETROBRAS, BRAZIL	3 x 600 m Polyester, DeepRope® mooring lines, 1000 Tf, DW P36.
PETROBRAS, BRAZIL	1 x 300 m Polyester, DeepRope® mooring line, 710 Tf.
PETROBRAS, BRAZIL	1 x 500 m, 1 x 600 m, 1 x 700 m, DeepRope® mooring lines, 1000 Tf.
PETROBRAS, BRAZIL	2 x 200 m, 1 x 970 m Polyester, DeepRope® mooring lines, 710 Tf.
COFLEXIP STENA, UK	200 m Dyneema, 900 Tf for trenching plough 2 x 50 m Deltaflex stretcher.
SBM, MONACO (Shell Bonga)	6280 m Polyester, DeepRope® mooring lines, 400 Tf 5028 m Polyester, DeepRope® mooring lines, 450 Tf
FMC Technologies (Enterprise Oil – Bijupirà & Salema)	8235 m Polyester, DeepRope® mooring lines, 750 Tf
SPECIAL VESSELS CONSUS LLC – BRAZIL	2 x 300 m Polyester, DeepRope® towing pennants, 431 Tf
FRANKLIN OFFSHORE: SUPPLY & ENGINEERING PTE LTD, SINGAPORE(TotalFinaElf)	9 x 610 m, Polyester, DeepRope® mooring lines, 425 Tf 2 X 1220 M Polyester, DeepRope® mooring lines, 525 Tf
SAIBOS, USA	2 x 130 m Grommet Ultraline Nylon mooring hawser 515 Tf (Elf Canyon Express)

Yarns	Strength Weight Specific strength	Newton (N), kilogram (kgf) tex, dtex, denier (den), g/m N/tex, cN/dtex of g/den
Rope	Strength Weight Specific strength Diameter	kilo Newton (kN), ton (tf) g/m, kg/100m kN/ (g/m) of N/tex mm, Size (=circumference in inches; size = diameter / 8)
	Example	A rope with a diameter of 48 mm = 48 / 8 = 6 inch circumference
Units	Runnage Yarn count	meter / kilogram (m/kg) tex = gram / 1000 meter dtex =gram / 10 000 meter den = gram / 9000 meter
	Conversion	tex = 1 000 000 / runnage dtex = 0,1 tex = 10 000 000 / runnage den = 0,9 dtex = 9 000 000 / runnage
	Example	A yarn with a runnage of 420 m/kg has a yarn count of 1 000 000 / 420 = 2381 tex or 23810 dtex and this gives a denier of 21430 den.
	Textile units according to ISO:	Fibre: Newton & tex (dtex) Rope: Newton (kN) & kg/m
	Prefixes according to ISO:	mili = 1/1000 ... deci = 1/10 1dtex = 1 decitex = 1 g /10 000 m = 0,1 tex kilo = 1000 ...

Polyester



Dyneema®



Conversion to and from ISO can be done using the tables on following pages. Please note that total cross-sectional surface of a yarn is a function not only of the material surface, but also of the packing factor. In the conversion only the material surface is considered.

The total surface can only be correlated to the material surface using experimental data, as this relation is influenced by construction and manufacturing.

A \ B	GPA	N/m²	N/mm²	g/den	g/tex	g/dtex	N/tex	cN/tex	cN/dtex	kgf/cm²	ton/cm²	PSI
GPA	1	10^{9}	10^{3}	11.33/	$102x^{-1}$	$102x^{-1}$	$^{-1}$	$100x^{-1}$	$10x^{-1}$	$1.02x10^{4}$	10.2	$1.45x10^{5}$
N/m²	10^{-9}	1	10-^{6}	$1.13x10^{-8}$/	$1.02x10^{-}$	$1.02x10^{-}$	10^{-9}/	10^{-7}/	10^{-8}/	$1.02x10^{-5}$	$1.02x10^{-8}$	$1.45x10\text{-}^{4}$
N/mm²	0.001	10^{6}	1	$1.13x10^{-2}$/	0.102/	$1.02x10^{-}$	10^{-3}/	0.1/	0.01/	10.2	0.0102	145
g/den	0.0883x	8.83x10-	88.3x	1	9.01	0.901	$8.83x10^{-2}$	8.83	0.883	901x	0.901x	$1.28x10^{4}x$
g/tex	$9.80x0^{-3}x$	$9.80x10^{6}x$	9.8x	0.111	1	0.1	$9.80x10^{-3}$	0.980	0.0980	100x	0.1x	1420x
G/dtex	0.098x	9.80x10-	98x	1.11	10	1	$9.80x10^{-2}$	9.80	0.98	1000x		$1.42x10^{-4}x$
N/tex		$10^{9}x$	1000x	11.33	102	10.2	1	100	10	10 200x	10.2x	$1.45x10^{5}x$
CN/tex	0.01x	$10^{7}x$	10x	0.1133	1.02	0.102	0.01	1	0.1	102x	0.102x_	1450x_
CN/dtex	0.1x	$10^{8}x$	100x	1.133	10.2	1.02	0.1	10	1	1020x	1.02x	$1.45x10^{4}x$
Kgf/cm²	$9.81x10^{-5}$	98100	0.0981	1110/	0.01/	0.001/	$9.81x10^{-5}$/	0.00981/	$9.81x10^{-4}$/	1	0.001	14.20
Ton/cm²	0.0981	$9.81x10^{7}$	98.1	1.11/	10/	1/_	0.0981/	9.81/	0.981/	1000	1	$1.42x10^{4}$
PSI	$6.90x10^{-6}$	6900	0.0069	$7.82x10^{-5}$/	$7.04x10^{-}$	$7.04x10^{-}$	$6.90x10^{-6}$/	$6.90x10^{-4}$/	$6.9x10^{-5}$/	0.0704	$7.04x10^{-5}$	1

Approximate densities g/cm³

Polypropylene	0.91
Polyethylene	0.97
Nylon 6	1.18
Nylon 6.6	1.17
Polyester	1.38
Steel	7.8
Polyaramide	1.44

Conversion: from A to B

Example: 1 g/den = 0.883 cN/dtex

Other conversions

Length		
1 millimeter (mm)	= 0.0394 in	
1 centimeter (cm)	= 10 mm	= 0.3937 in
1 meter (m)	= 100 cm	= 1.0936 yd
1 kilometer (km)	= 1000 m	= 0.6214 mile
1 inch (in)	= 25.4 mm	
1 foot (ft)	= 12 in	= 0.3048 m
1 yard (yd)	= 3 ft	= 0.9144 m
1 mile	= 1760 yd	= 1.6093 km

Area		
1 sq cm (cm²)	= 100 mm²)	= 0.1550 in²
1 sq meter (m²)	= 10 000 cm²	= 1.1960 yd²
1 hectare (ha)	= 10 000 m²)	= 2.4711 acres
1 sq km (km²)	= 100 ha	= 0.3861 mile²
1 sq inch (in²)	= 645.16 mm²	
1 sq yard (yd²)	= 9ft2	= 0.8361 m²
1 acre	= 4840 yd²	= 4046.86 m²
1 sq mile (mile²)	= 640 acres	= 2.59 km²

Volume / capacity		
1 cu cm (cm³)	= 0.0610 in³	
1 cu decimeter (dm³)	= 1000 cm³	= 0.353 ft³
1 cu meter (m³)	= 1 dm³	= 1.3080 yd³
1 liter (l)	= 1 dm³	= 0.2642 US gal
1 liter (l)	= 1 dm³	= 0.2200 Imp gal
1 hectoliter (hl)	= 100 l	= 2.8378 US bu
1 cu foot (ft³)	= 0.0283 m³	
1 cu yard (yd³)	= 27 ft³	= 0.7646 m³
1 US dry pint	= 0.9689 Imp pt	= 0.5506 l
1 US bushel	= 64 US dry pt	= 35.239 l
1 US liquid pint	= 0.8327 Imp pt	= 0.4732 l
1 US gallon	= 8 US liquid pt	= 3.7854 l

Mass (weight)		
1 gram (g)	= 1000 mg	= 0.0353 oz
1 kilogram (kg)	= 1000 g	= 2.2046 lb
1 tonne (t)	= 1000 kg	= 1.1023 short tons
1 tonne (t)	= 1000 kg	= 0.9842 long tons
1 ounce (oz)	= 437.5 grains	= 28.350 g
1 pound (lb)	= 16 oz	= 0.4536 kg
1 short cwt	= 100 lb	= 45.359 kg
1 long cwt	= 112 lb	= 50.802 kg
1 short ton	= 2000 lb	= 0.9072 t
1 long ton	= 2240 lb	= 1.0161 t