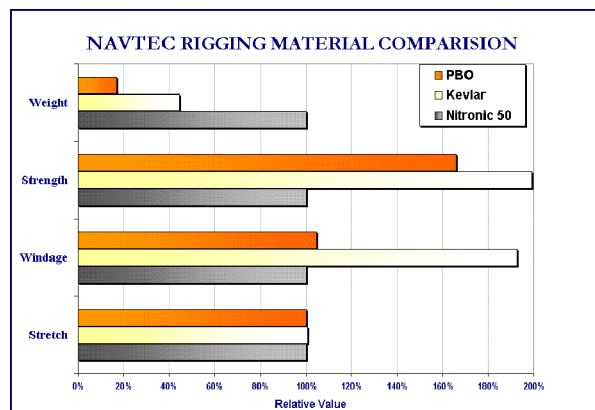


NAVTEC PBO FIBER RIGGING

Through innovation and rigorous engineering Navtec has been at the forefront of yacht rigging for over 25 years. As yacht design has evolved, Navtec has played an integral role in emerging rigging technology. Since 1997, Navtec has minimized weight and maximized performance by taking advantage of the extraordinary benefits of Zylon® Fiber.

Zylon, better known as PBO, has allowed Navtec's engineers to create rigging that is 50% stronger and 80% lighter than equivalent N-50 steel rigging. Navtec maximizes the performance of the fiber through the use of unidirectional cables. These unidirectional cables were first introduced 8 years ago with a bi-conic termination. More recently Navtec has developed a continuously wound unidirectional cable. The combination of these two approaches creates the Z-System, the most complete high performance fiber rigging system Navtec has to offer.



Z-SYSTEM

Navtec's approach to fiber rigging is to maximize performance and safety while minimizing weight. PBO fiber is incredibly strong but it must be protected from sunlight, moisture and physical damage. The Z-system accomplishes this through the use of high-strength thimbles, ultra lightweight carbon composite termination covers, and a highly chafe resistant midspan braid. The cables are manufactured with pin point accuracy on Navtec's proprietary computer controlled equipment. The resulting cable is extremely strong, lightweight and completely protected from the environment.

Thimbles: Provide the bearing surface between the fiber and the pin or lashing. Precisely engineered and machined to minimize weight and windage while maximizing fatigue life.

End Cover: Incredibly lightweight and strong carbon fiber composite covers seal and protect the PBO fiber around the thimble.



Fiber Bundle: Flexible PBO fiber core provides the cable's strength and stiffness. The amount of PBO fiber is highly customizable to best suit the shrouds specific requirements. The assembly process minimizes the cable diameter to reduce midspan windage.

Midspan: Internally sealed to protect fibers from harmful moisture and both UV and visible light. The outer braid provides exceptional chafe resistance. Additional protection is available for high chafe regions.

CABLE SIZING: Z-SIZES

Navtec's continuously wound PBO cables are identified using a Z-size, which represents the cable's stiffness properties (EA) in MegaNewtons. Cables can be sized according to either stiffness or strength characteristics depending on the application. For quoting or ordering purposes, Navtec needs to know the desired length, end fittings, rated strength or max working load and one of the following:

- equivalent rod dash size
- stiffness (EA) : Z-Size

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Z-Sizing Based on CABLE STIFFNESS

In many applications (verticals, diagonals, jumpers, etc.) cable sizes are driven by **stiffness** requirements, and Navtec's N-50 Rod Rigging dash sizes are used as stiffness benchmarks. Navtec dash sizes are based on the breaking strength of the rod, but each dash size also has specific stiffness characteristics. As the world leader in rod rigging, Navtec is uniquely capable of making PBO cables that accurately match the stiffness of our rod rigging.

NAVTEC Z-SYSTEM PBO CABLE INFORMATION FOR STANDARD ROD SIZES													
Standard PBO Cable Information							Standard N-50 Rod Information						
Z-System Size	Rated Strength		Diameter		Weight		N-50 Rod Size	Breaking Strength		Diameter		Weight	
	lbs	kg	in	mm	lbs/ft	kg/m		lbs	kg	in	mm	lbs/ft	kg/m
Z004	11,424	5,123	0.31	7.9	0.04	0.06	8	8,200	3,700	0.23	5.7	0.14	0.20
Z005	14,140	6,341	0.34	8.6	0.05	0.07	10	10,300	4,700	0.25	6.4	0.17	0.25
Z007	17,950	8,049	0.37	9.4	0.05	0.08	12	12,500	5,700	0.28	7.1	0.21	0.31
Z009	24,480	10,978	0.42	10.6	0.07	0.10	17	17,500	7,900	0.33	8.4	0.29	0.43
Z012	31,550	14,148	0.47	11.8	0.08	0.12	22	22,500	10,200	0.38	9.5	0.38	0.56
Z016	42,975	19,271	0.53	13.5	0.10	0.15	30	30,000	13,600	0.44	11.1	0.51	0.76
Z021	56,305	25,249	0.60	15.1	0.13	0.19	40	38,000	17,200	0.50	12.7	0.67	1.00
Z027	71,000	31,839	0.66	16.7	0.16	0.23	48	48,000	21,800	0.56	14.3	0.85	1.26
Z037	97,920	43,910	0.76	19.3	0.21	0.31	60	60,000	27,200	0.66	16.8	1.17	1.74
Z043	111,520	50,009	0.81	20.5	0.23	0.35	76	76,000	34,500	0.71	17.9	1.33	1.98
Z050	132,464	59,401	0.87	22.1	0.28	0.42	91	90,000	40,800	0.77	19.5	1.58	2.35
Z066	171,900	77,085	1.01	25.7	0.35	0.52	115	115,000	52,200	0.88	22.2	2.05	3.05
Z086	224,400	100,628	1.14	29.0	0.45	0.67	150	150,000	68,000	1.00	25.4	2.68	3.98
Z097	254,864	114,289	1.21	30.7	0.50	0.75	170	170,000	77,100	1.07	27.1	3.04	4.53
Z108	284,000	127,354	1.27	32.3	0.56	0.83	195	190,000	86,200	1.13	28.6	3.39	5.04

Specifications provided for informational purposes only, contact Navtec for detailed information on cable properties.

Unlike other rigging systems, Navtec has the capability to engineer and construct Z-System cables to meet specific stiffness requirements. To do so, Navtec needs to know the required cable stiffness in MegaNewtons (MN). Stiffness is defined as the modulus multiplied by area, or EA. As an approximation the custom size cable properties can be estimated by extrapolating between the properties of standard sizes. If more precise information is needed please provide Navtec with your requirements.

Due to the high breaking strength of PBO, cables that are sized according to stiffness are stronger than the equivalent stretch rod rigging, but it is always important to consider the loads on the cable and the cable's safe working load limits.

Z-SIZING BASED ON CABLE STRENGTH

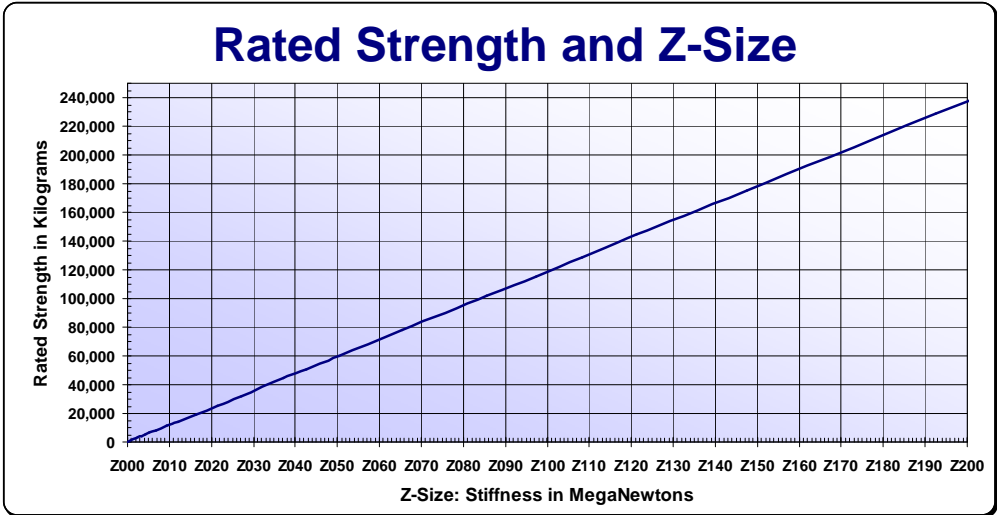
In some applications (backstays, runners, checkstays, etc) cable sizes are driven by **strength** requirements rather than stiffness characteristics. In this case, calculate the Maximum Working Load (MWL) of each shroud (based on the righting moment, beam, center of gravity, spreader lengths, etc.) Then multiply the MWL by a safety factor to get the Minimum Required Rated Strength. Based on our experience we strongly suggest a safety factor of at least 2.85.

$$2.85 * MWL = \text{Minimum PBO Rated Strength}$$

Example: MWL = 18,500 kg; Min. PBO Rated Strength. = 52,725 kg;

Example: If the Maximum Working Load (MWL) is calculated to be 18,500 kg, then the recommended Rated Strength is 52,725 kg. The table below indicates that the corresponding Z-Size is **approximately** Z045. Contact Navtec for verification.

Compare this minimum rated strength with those in the standard rod equivalent Z-sizes in the table above. Choose the closest standard Z-size that is stronger than the calculated minimum rated strength. If the standard Z-size is significantly stronger than the calculated minimum rated strength consider the next lower standard Z-size. The lower size will result in a reduced safety factor; therefore the new safety factor should be calculated and assessed. In either case, confirm that the stiffness of this standard Z-size will work in the application.



If the standard Z-sizes fail to satisfy the specific strength requirements Navtec has the capability to supply a custom cable to match your exact requirements. The table above is for informational purposes and is provided to determine the approximate Z-size, for more specific information please contact Navtec with your requirements.

END FITTINGS

Navtec’s Z-System offers a full range of standard and hybrid end fitting options. These fittings are very lightweight but the exact weight varies with Z-size; contact Navtec for specifications. In addition to the fittings in the catalog, we also offer many other proprietary fiber rigging solutions that are not published for confidentiality reasons. Finally, our engineering department will work with you to develop a customized solution to meet your needs.

IMPORTANT NOTE: Sizing Methods and Fitting Strength

To provide an optimal rigging package, Navtec designs attachment fittings (threads, clevises, pins, etc.) based on the two different sizing options (stiffness and strength). Cables sized on rated strength require stronger fittings than cables sized based on stiffness. This fact must be considered when attaching to cables; attachment fitting should be sized appropriately according to sizing method. All cable end fittings (marine eye, lashing eye, spreader eye, forks, sockets, etc.) are designed based on the cables rated strength. Contact Navtec with questions.



STANDARD TERMINATION SOLUTIONS FOR CONTINUOUSLY WOUND CABLES

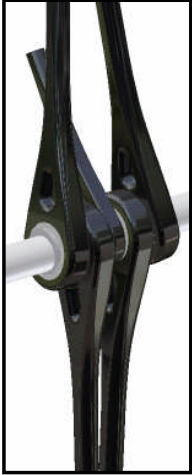
Our standard end fittings include; marine eye, lashing eye, spreader eye, spreader fork, bi-conic hybrid, stemball stud and telescoping turnbuckle. The metal thimble and carbon fiber composite cover are designed to maximize performance by protecting the PBO fibers from degradation while minimizing the overall weight.

Marine Eye: Classic termination for continuously wound cables; most often used in runner blocks, in conjunction with the Titanium Threaded Hanger or at deck level.

Lashing Eye: Multi-part soft connections provide a lightweight termination solution, generating the option to adjust length as required. Be aware that the lashing material may creep (permanently elongate) under load.



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Spreader End: One of the major advantages of Navtec’s Z-System is the ability to replace a tip cup with a simple pin to create a lightweight, zero-moment spreader tip configuration. The spreader end is typically comprised of two sets of spreader forks (verticals), one spreader eye (diagonal) and a high strength pin. The lower vertical is the inner fork and the upper vertical is the outer fork. Navtec’s engineering department uses computer simulation (ANSYS) to analyze the stresses to ensure minimum pin weight while maximizing safety and strength.

Spreader Eye: Similar to the Marine Eye, but designed with less width to reduce the overall stack height in a spreader end configuration. The spreader eye can also be used in other locations where termination width is the issue, and the thinner thimble works better than the standard Marine Eye. The hole dimension specifications listed are for the maximum allowable pin.

Spreader Fork: Designed primarily to be used at the spreader end in conjunction with a spreader eye. The spreader fork thimbles are precisely machined to have angled sides that correctly align the legs of the fork. The angle of the hole and sides varies depending on the spreader tip configurations. The pin holes will also vary depending on the spreader tip configuration. Cable forks can also be used in other applications but pin stresses must be properly analyzed.

Titanium Fork: The titanium threaded fork provides a lightweight approach to adapt a continuously wound cable end to a wide variety of Navtec’s threaded fittings including stemball studs, turnbuckles, etc. There are two versions of this fitting; **adjustable** and **fixed**. The **adjustable forks** provide a small amount of stroke for minimal adjustment such as at the top of a diagonal. The **fixed forks** provide a lighter option but have zero thread adjustment and are most often used in conjunction with Navtec’s Telescoping Turnbuckle. Forks are available to adapt between all pin and thread combinations.



The Standard Terminations are available in Sizes A through F. The following table details the terminations sizes and the corresponding cable size ranges.

Cable & Termination Cover Crossovers

Cover Size	A	B	C	D	E	F
Z-Size	≤ Z003	≤ Z007	≤ Z014	≤ Z028	≤ Z056	≤ Z112
Stiffness (MN)	≤ 3.5	≤ 6.8	≤ 14.1	≤ 28	≤ 56.2	≤ 112
Rod Dash Size	≤ -6	≤ -12	≤ -25	≤ -50	≤ -100	≤ -200
Rated Strength (lbs)	≤ 9,000	≤ 18,000	≤ 37,500	≤ 75,000	≤ 150,000	≤ 300,000
Rated Strength (kgs)	≤ 4,080	≤ 8,170	≤ 17,010	≤ 34,030	≤ 68,050	≤ 136,100

Range maximums and minimums are general guidelines. Depending on the application, the possibility may exist to shift the transition point. Larger sizes may be possible. Please contact NAVTEC with specific requirements.

Bi-Conic End Fittings

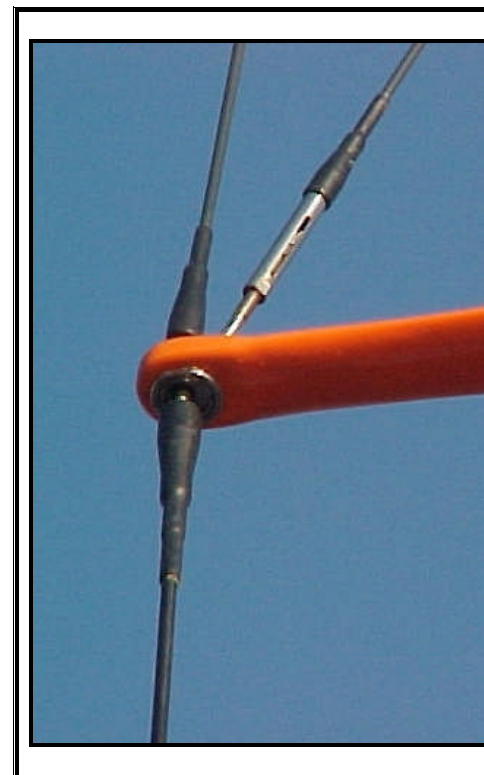
One major advantage of Navtec’s Z-System is the ability to combine the continuously wound cables with our bi-conic compression sockets, creating a “hybrid” cable. In certain applications, a hybrid cable with a bi-conic termination offers several advantages over a complete continuously wound cable. The lightweight titanium sockets provide a highly fatigue resistant termination capable of adapting to a wide variety of threaded fittings (turnbuckles, stemball studs, etc.).



Titanium Bi-conic fittings can be used with either our standard size jacketed cables or to create “hybrids” with our continuously wound cables.

Cables with bi-conic terminations at both ends can take advantage of Navtec’s industrially produced unidirectional cables. These cables come in standard sizes and have a smooth, polyethylene cover with exceptional abrasion resistance. The standard bi-conic cable sizes are listed in the table below.

BI-CONIC CABLE SIZES								
Sizes		EA	Break Load		Outer Diameter		Weight	
Ton	Z-Size	MN	kg	lbs	mm	in	kg/m	lbs/ft
2T7	Z003	2.1	2700	5950	5.9	0.23	0.028	0.019
5T3	Z004	4.2	5300	11690	8.0	0.31	0.05	0.034
8T7	Z007	6.9	8700	19180	10.0	0.39	0.076	0.051
12T4	Z009	9.9	12400	27340	11.8	0.46	0.111	0.075
16T	Z012	12.6	16000	35280	13.1	0.52	0.133	0.089
21T	Z016	16.9	21000	46310	15.0	0.59	0.175	0.118
27T	Z021	21.3	27000	59540	16.8	0.66	0.223	0.150
35T	Z027	28.2	35000	77180	19.2	0.76	0.283	0.190
45T	Z037	36.7	45000	99230	21.5	0.85	0.385	0.259
57T	Z043	46.4	57000	125690	23.6	0.93	0.471	0.316
71T	Z051	58.5	71000	156560	26.2	1.03	0.577	0.388
88T	Z066	71.6	88000	194040	28.7	1.13	0.693	0.466
110T	Z086	89.1	110000	242550	31.8	1.25	0.852	0.573



Z-Size		BI-CONIC
min	max	SIZE
Z003.6	Z004.4	5.3T
Z006.0	Z007.3	8.7T
Z009.5	Z010.5	12.4T
Z012.1	Z013.3	16T
Z016.1	Z017.8	21T
Z020.4	Z022.4	27T
Z027.0	Z029.6	35T
Z035.1	Z038.6	45T
Z044.3	Z048.8	57T

Hybrid Cables

Although cutting the end off a continuous wound cable may seem counterintuitive, extensive testing reveals that bi-conic fittings can be applied to one end of a continuous cable with no loss in strength or fatigue life. Each socket size is designed to work with a range of cable sizes, the table to the left details the Z-size ranges and the bi-conic termination sizes.

the Z-size ranges and the bi-conic termination sizes.

DECK LEVEL ATTACHMENT/ADJUSTMENT



Navtec offers a range of deck level fittings with varying levels of adjustment. Navtec's telescoping turnbuckle offers considerable adjustment, for example, 6.5" of stroke for Z028 (-48 rod equiv.) cable. Navtec's Adjustable Eye End, weighs much less but only offers 2 inches of stroke for the same Z028 cable.

Telescoping Turnbuckle:

Navtec's Telescoping Turnbuckle is an appealing, lightweight turnbuckle designed specifically for PBO rigging. The telescoping feature creates the most compact turnbuckle for its stroke. The telescoping turnbuckle can be used in conjunction with either a standard marine eye end and titanium fork or in conjunction with a bi-conic termination.

Adjustable Eye End:

Navtec's Adjustable Eye End is lightweight, continuously wound termination capable of small length adjustments without a threaded connection. The cable length can be adjusted by changing the location of the pin hole through the use of a removable thimble insert. The Adjustable Eye works best with rigs that are tensioned using a mast jack.



MAST ATTACHMENT/ADJUSTMENT



Navtec Tangs: Navtec offers an extensive range of mast attachments. Both the Z System and Bi-Conic tang attachment system is comprised of a Navtec K550 Tang with a fully machined, proprietary micro stemball stud and seat washer. The micro stemball stud is connected to a PBO cable with either a titanium fork hanger or a hybrid cable end. Depending on the amount of stroke necessary, an integral tip turnbuckle which threads directly into the socket or long reducer can be used. Details of this tang system are available at www.navtec.net.

Z-System Tangs: Navtec is also in the process of developing a low profile, low windage tang system that will work directly with continuously wound cable eye ends. We have purposely chosen not to publish the details of these solutions for confidentiality reasons but we are eager to discuss them with you in the context of your specific project. Please contact Navtec for more information.

LIFE EXPECTANCY

Navtec has supplied well over 1200 bi-conic PBO cables that have been used in many different applications on all types of boats. These PBO shrouds have been used on ACC, Multihulls, and Open 60's over the years, and the close relationship NAVTEC has with its customers has enabled us to get cables back for testing that have been used and abused under a wide range of sailing conditions.

Our PBO shrouds have completed the "Vendee Globe" and have been tested after approximately 30,000 miles to quantify the degradation that takes place over time. Additionally, we have spent several years testing continuously wound Z-System PBO cables in our labs. This extensive testing has given Navtec's engineers a thorough understanding of the fiber's fatigue characteristics and has allowed us to improve our designs to provide superior performance. Based on both real world experience and extensive testing Navtec can provide the following recommendations concerning the life and usage of the Z-System.

UV and the Elements

Damage is a concern in any rigging material, especially for PBO cable rigging, and two environmental conditions cause PBO fiber to lose strength over time: exposure to visible or UV light and high relative humidity at elevated temperatures. These conditions are very common on a yacht so it is very important to inspect fiber rigging on a regular basis for any damage to the protective jacket and carbon termination covers which may expose the core fibers of the cable.

Cable Inspection

Careful inspection is critical for the safe and prolonged use of any fiber cable rigging system. Routine visual inspection of the jacket and its termination points should be frequently carried out in order to maximize the working life of the cable. On passages or during regattas this state of the art rigging technology should be inspected daily.

Carefully monitoring for signs of damage, abrasion points or breaks in the cover is critical in keeping potential damage from UV light or water retention to a minimum. The other inspection point of fiber rigging is at the heat shrink and termination cover at either end of the cable. Over time there may be a tendency for the heat shrink to pull away from the socket or cable slightly. This is normal, and shouldn't pose any immediate problem because it has an inner glue layer that creates a seal between the cable and the heat shrink. Yet regardless of this glue seal, it should be checked as part of the routine visual inspection. On the carbon termination cover it is important to monitor for any cracking across the cover or opening at the glue seam. These covers are sealed against the elements, so any breach of the watertight seal will allow UV light and moisture into the termination, thus compromising the lifespan of the cable.

Also, be advised that the following installation issues should be avoided; redirecting cables over bearing surfaces, excessive loading, point loading by tying working lines onto cables, running cables over working sheaves or deflector plates without secondary chafe protection, misalignment greater than 2.5 degrees and applications that result in excessive impact on end fittings.

Proposed Life Expectancy

The following is an outline of Navtec's life expectancy recommendations based on our experience with different cable usage and applications:

- If the working Load is **less** than 25% of the PBO rated strength, we would recommend changing the cable following 3 years or 26,000-30,000 miles of use.
- If the working Load is **more** than 25% (but **less** than 35%*) of the PBO rated strength, we would recommend changing the cable following 2 years or 17,000-20,000 miles of use. *working load should never exceed 35%

These recommendations apply **only** to cables that have not been damaged, such that the protection we have applied to the fibers has not been compromised in any way. In such cases where damage is present, consult NAVTEC Engineering for an evaluation of the amount of usage and damage, before a decision is made to replace or re-use.