# Decommissioning & Installation of Wind Energy Equipment with Synthetic Sling Solutions

Alvin Abraham, Kris Volpenhein, Dustin Heins
Samson Rope Technologies
2090 Thornton St.
Ferndale, WA USA
aabraham@samsonrope.com Tel +1.360.526.1787 Fax +1.360.384.0572

***Summary***- High performance synthetic sling solutions have provided many benefits to the lifting world since they were initially introduced to the market over a decade ago. With the known advantages of these slings, the process of installing wind energy structures has been simplified. Not only does the technology offered by high-performance synthetic slings increase loading capacity, it also provides faster and safer rigging.

Riggers and planners alike face similar challenges when it comes to the choice of sling types and ideal configuration. Optimization through application of specific fiber performance characteristics is needed to improve upon the efficiency of heavy engineered lifts. Over the years, Samson has perfected our engineered lifting capabilities by predicting accurate strength retention and tight length tolerance by taking into account the termination, bending impacts, and environmental effects on the sling, along with numerous other factors.

This paper discusses how to identify solutions to various lifting cases following the fiber characterization process, identification of critical application requirements, and “fit-for-purpose” principles. Details from multiple field case studies from other industries will be presented to demonstrate the inherent advantages of using these principles. There is no “one-size-fits-all” product designed to accommodate the needs across all engineered lifts, thus understanding these details is critical.

Lastly, the introduction of the rope round sling configuration, with its benefits, is a game changer for the engineered lifting industry. It uses widely available grommet configurations, and, by increasing the number of loops, reduces the rope diameter used while increasing efficiency in order to maintain similar high strength.

***Objective***- This paper will provide the industry with a thoughtful comparison between the existing rigging technology options of single-leg and grommet sling versus the newly designed multiple-loop configuration to support the installation or decommissioning of wind energy equipment.

Application parameters will be defined, and considering the connecting limitations, this paper concludes with a table of pros and cons for the three systems, which will fully embody the fit-for-purpose principle.

***Background***- In today’s energy market, it is understood that the days of decommissioning older wind structures are approaching. The equipment operating in these early wind turbine fields is nearing the end of its original life expectancy. Whether the owners decide that the equipment needs to be removed from existing sites or rebuilt to incorporate modern improvements in the technology, efficient lifting solutions will be required.

High performance fibers such as High Modulus Polyethylene (HMPE) are utilized frequently for engineered critical lifts across industries. User awareness of the high strength, durability, and ease of rigging that synthetic solutions provide is becoming increasingly common. It is also becoming common for industry experts to design around these benefits when installing subsea and topside structures such as conductor pipelines, windfarm monopiles, and floating production storage and offloading (FPSO) pumping stations in the development of offshore energy systems.

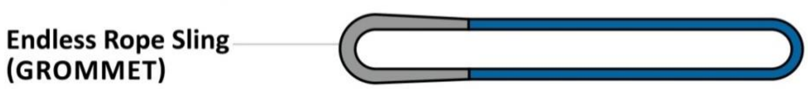
The key element for helping engineers and lift planners to identify the ideal solutions to demanding rigging operations is understanding the details of intended use during the operation. Design of specific lifting solutions can vary widely based on a range of factors –frequency and number of lifts to be performed, length tolerance requirements for matched rigging, potential dynamic scenarios, as well as integration of mating hardware and equipment in the rigging system.

Following a discussion of the successes of traditional heavy lift slings made with synthetic fiber rope, this paper will present the advantages provided by Samson's newest rigging technology of multiple-loop configuration known as AGILE™ Lifting System. This patented technology utilizes a configuration of multiple parts of high performance fiber rope integrated into a protective cover system, providing optimization in the world of lifting sling design. By providing increased loading capacities, shorter allowable lengths, access to load material for inspectors, and tightly controlled length tolerances, *AGILE* expands the rigging planners' options across a wide variety of lifting requirements.

***Approach***- Currently, there are 3 product design sling concepts that are available in the market today: **Single-Leg Eye**, **Grommet,** and **Multiple-Loop**.

1. Single-Leg, also known as Eye-and-Eye Rope Sling, is a rope configuration which is done by splicing an eye to both ends of the rope.


2. Grommet, also known as Endless Rope Sling, is a rope configuration which is done by splicing end of the rope to the other end, essentially creating a loop.




3. Multiple-Loop, also known as Rope Round Sling, is a rope configuration which is done by splicing one end of the rope to the other end after creating two or more loops. It is then finished by putting a non-loading bearing cover for protection and containment of the ropes.


Fiber rope experts often recommend HMPE for engineered lifting slings based on its durability, demonstrated through historical use.

Given the level of complexity of engineered lifting slings, Samson has built proprietary sling configurations by taking into consideration the customer's critical requirements. In turn, these factors are used to provide sling design options. These parameters and other critical factors are discussed in the following paragraphs.

The following exercise, defining the application parameters and its connecting limitation, is critical in selecting which of these sling configurations that is best to recommend, including but not limited to lead time, cost and performance.

Application Parameters

1. ***Effective working length*** is defined as the distance between two extreme end-bearing points of the sling under working conditions. High performance rope will experience initial elongation when the sling is put under load. Thus, many sling manufacturers offer pre-stretching to stabilize length and remove initial elongation to achieve working length required. This exercise is known as proof-loading.

Initial, or constructional, elongation is defined as the initial stretch of a loaded rope that results from compaction as the fibers and strands align and adjust. This elongation varies based on clear rope length, eye size, and splice length. A typical 12-strand braided HMPE rope sling (i.e., Amsteel$^{TM}$-Blue) has constructional elongation values of 3% for clear rope and 11% for the splice area. The following is an example elongation chart which highlights the differences between initial (constructional) elongation and elastic (working) elongation.

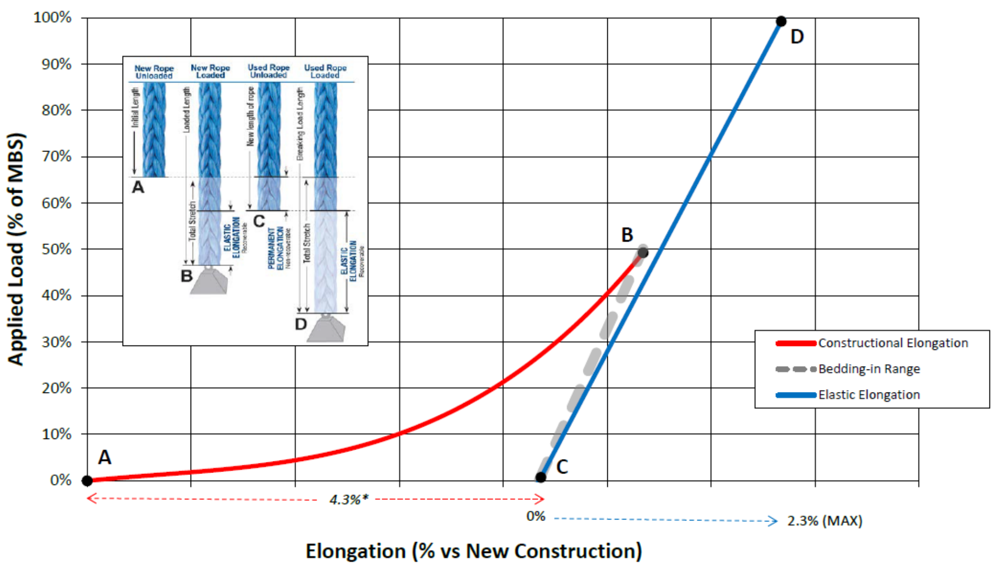



Figure.1.*Amsteel-Blue* elongation properties

The first time a new rope (i.e., point A) is loaded, the structural elements within the braid compact, and depending on the construction, small helical changes take place. Cycling it a number of times results in further compaction as the fiber and strands align and adjust. Eventually, constructional elongation is removed after the rope is allowed to rest, but there remains some elongation that is not recoverable, resulting in longer length of rope (i.e. point C). This phenomenon is non-reversible.

Elastic elongation (EE) refers to the portion of stretch or extension of a rope that is immediately recoverable after the load on a rope is released. The rope's tendency to recover is a result of the fiber(s), rather than the rope construction. Each type of synthetic fiber inherently displays a unique degree of elasticity. Elastic elongation is expressed as a percentage of the length at a standard load based on a percentage (10%, 20%, or 30%) of the breaking strength. In figure.1, the max percentage of EE is recorded up to when the rope is pulled apart. It is important to note that high-performance fiber has extremely low elasticity compared to a low-tenacity fiber, such as nylon.

Acceptable length tolerance should be specified by the customer, especially when multiple rope slings will be used at the same time. Typically, when rope slings are fabricated as matched sets, tighter tolerances are provided. More importantly, with the help of mechanical devices to fabricate rope round slings, closer length tolerances can be achieved when compared to hand-spliced rope.

2. ***Minimum Breaking Strength (MBS)*** is the required sling breaking strength derived from break load data testing of the rope and empirical model to describe bend loss for rope slings via our proprietary sling configurator software.

3. ***Safe Working Load = MBS / FoS*** *is* the maximum load that the sling is certified to lift under normal conditions in a given configuration. The factor of safety (FoS) required for the engineered lift, along with the load, is used to establish the safe working load of the system. This FoS is supplied by the customer based on their application. Some standards, such as DNV-OS-H205 by DNV GL Offshore, define a methodology for determining the FoS number by using several factors and assumptions, as detailed in the following.

$$\gamma_{sf} = \gamma_f \gamma_c \gamma_r \gamma_w \gamma_m \gamma_{tw}$$

$$\gamma_{sf} = (1.3)(1.3)(1.0)(1.1)(2.0)(1.0) = 3.72$$

Given that $\gamma_{SF}$ is at least 3 or greater.

| | | |
|---|---|---|
| Load factor | $\gamma_f = 1.3$ | Based on the normal assumption of the lifting points including uncertainties surrounding internal force distribution, skew loads, dynamic effects, and possible accidental loads. |
| Consequence factor | $\gamma_c = 1.3$ | Assumed to be appropriate for wind offshore/onshore installation projects, including lifting with equipment (i.e. spreader bar). |
| Reduction Factor | $\gamma_r = 1.0$ | Based on splicing factor that has been tested per industry standard to meet the maximum strength efficiency. |
| Wear Factor | $\gamma_w = 1.1$ | Based on the understanding that the slings will be used for multiple engineered lifts. |
| Material Factor | $\gamma_m = 2.0$ | DNV specified for HMPE fiber slings |
| Twist Factor | $\gamma_{tw} = 1.0$ | For the amount of strength efficiency based on the twist effect. |

Table.1.Safety factors breakdown

<u>Connecting Limitation</u>

1. **Bend Loss** is the amount of strength reduction in a lifting sling due to distortion of rope when bending around the connecting hardware. This loss of efficiency depends on the sling type and the diameter of the bearing surface, typically a pin or hook. For single leg slings this bend diameter has minimal impact on the sling strength as the load applied to the single rope section of

the sling body is shared by two sections of rope in the eye. The critical requirement for single leg slings is to utilize hardware which provides a bend diameter at least twice the diameter of the rope to ensure that the weakest point of the sling is located at the base of the termination (se fig.2) without cutting at the back of the eye. With a grommet sling configuration the greatest stress and weak point will be located at the back of the pin leading to the effect of bend diameter having a greater impact on grommet slings. Sufficient contact surface needs to be provided to spread the load around the rope bend in order to minimize the impact on the sling breaking load. The greater the bend diameter, the better the strength efficiency of the grommet sling. The ratio is known as D/d, which is the hardware bend radius to the rope diameter measurement.

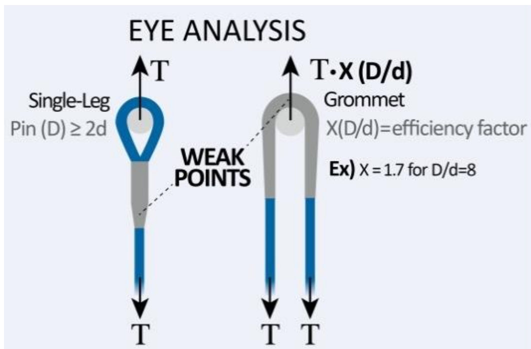



Figure.2.Eye analysis single- leg vs. grommet

**Minimum D/d for single-leg** is recommended to be 2 for frequent use; it could be built as low as 1 for occasional use, but no less than 1.

**Minimum D/d for grommet** is recommended to be 8 or more to maintain at least 1.7x the rope breaking strength. The following graph demonstrates the strength efficiency factors based on the D/d ratio.

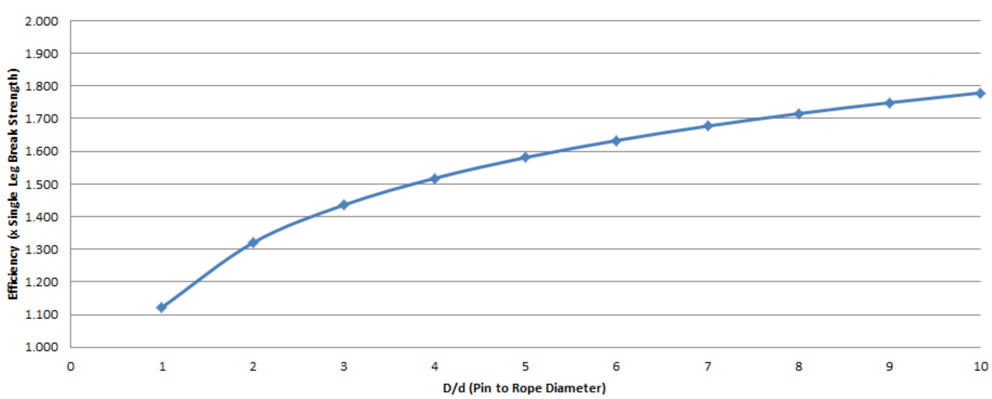



Figure.3. Grommet strength efficiency factors for Amsteel- Blue

**Minimum D/d for multi-loop** is not available due to the fact that many variances of the rope diameters are being used in the loop configuration, and the total width is not the factor, but rather individual rope. Thus, as the rope diameter gets smaller, while maintaining constant pin diameter, the strength efficiency would increase. The following illustration depicts the stark difference between grommet and multi-loop surface contact.

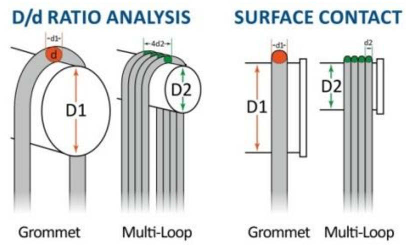



Figure.4. D/d ratio analysis between Grommet and Multi-loop

2. One **Twist** is defined as a 360-degree turn. Rope strength is decreased with the amount of twist introduced into the system. The reason: the tighter strand will carry more load than the loose strands, leading to a loss in rope strength efficiency. This effect of twist would also vary with fiber type, diameter, and construction of rope. As an example, the following figure illustrates how a small amount of twist could affect the strength retention on a 24mm Amsteel- Blue rope diameter in a 12-strand single braid construction. A mere three twists in a meter reduces 10% of its breaking strength. Thus, it is imperative tominimize twist as much as possible during usage.

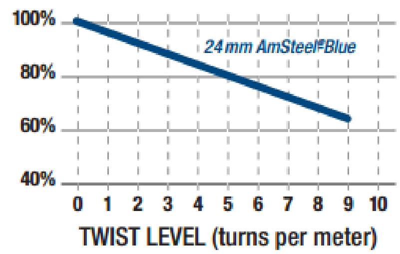



Figure.5. Twist effect on Amsteel- Blue

3. **Abrasion** is another factor that can shorten the life of the rope. Careful consideration should be given to protecting the load bearing member that is exposed or rubbed against contact surfaces repeatedly. Such material could be made to be permanently fixed or moveable, depending on the application limitation/ needs.

4. **Inspection/Retirement** are important principles to gauge how much of the life of the rope is left at any point. It is advisable to do a thorough inspection daily or weekly, or to discard rope periodically. Samson has a visual comparator in place to help make critical field inspection a simple matter, as follows:

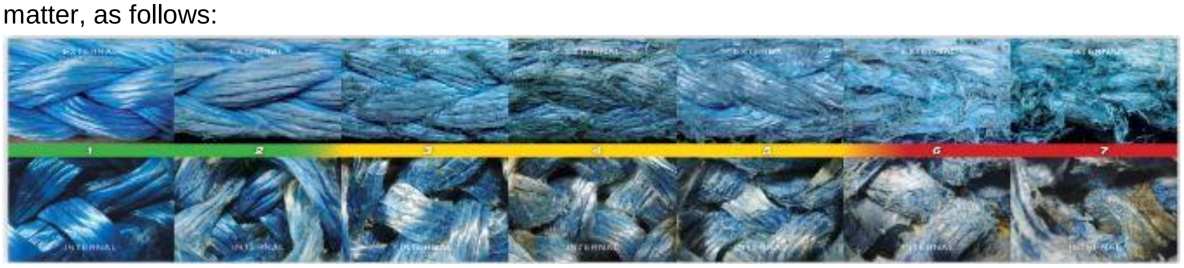


Figure.6. Visual comparator tool illustrating 7 levels of internal and external abrasion

***Result*** - One of the important criteria critical to the lifting application of wind power equipment would be the headroom savings (see.fig.7.) between the hook block to the object being lifted. Shorter length of the slings used in rigging can be beneficial both in terms of cost saving of the rope material and reduction in crane size needed for rental. In this case, multi-loop slings are able to be built to the shortest lengths while still maintaining strength similar to the other configurations (i.e., single-leg and grommet).

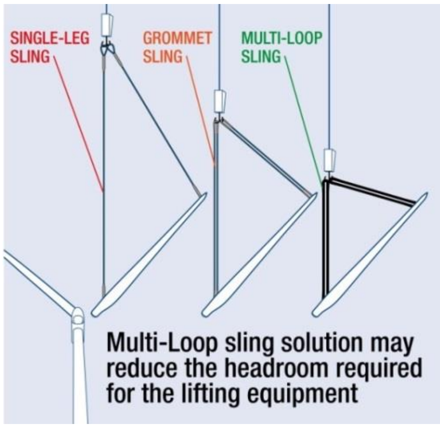



Figure.7. Headroom reduction due to shorter sling

By investigating the possible limitations on the lengths of each sling, we can predict which sling is suitable for a given application. The following figure depicts the minimum length comparison to meet specific target strength and the extent of how much these could be built (strength specific).

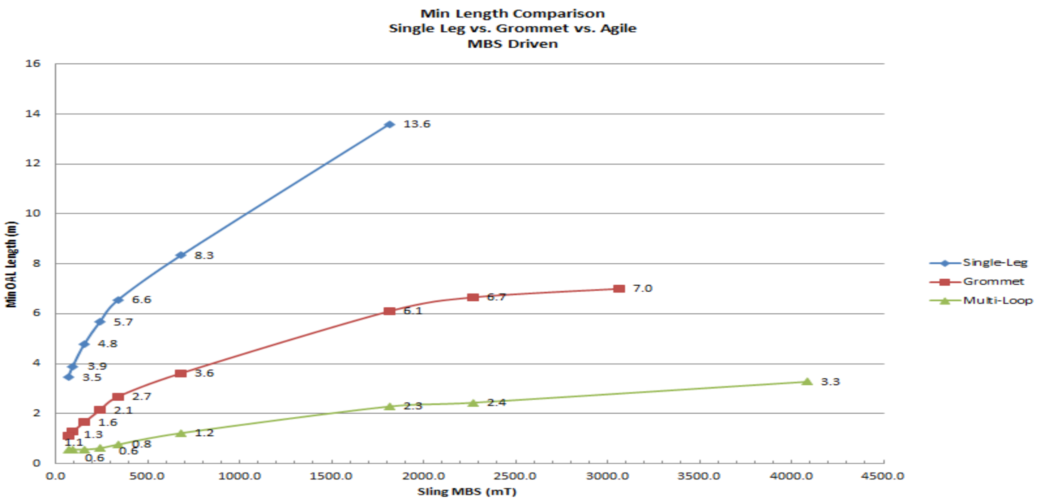
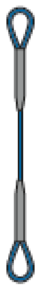



Figure.8. Minimum length comparison between single- leg, grommet and multi- loop

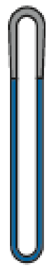
| Type | Min. D/d | MBS (mT) | Min. Length (m) |
|---|---|---|---|
| Single- Leg | 2 | 1800 | 13.6 |
| Grommet | 8 | 3060 | 7 |
| Multi- Loop | N/A | 4000 | 3.3 |

Table.2. Sling limitation by max breaking strength and min length

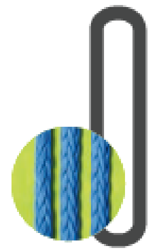
Based on Figure 8 and Table 2 above, one could easily identify which sling would fit the application scenario based on length and breaking strength requirements. If there are two or more available choices: the decision would be based on which sling would last longer given the parameters. A summary of pros and cons of the products are tabulated as follow.



| SINGLE-LEG + | SINGLE-LEG − |
|---|---|
| Ability to handle tightest bend radius (D/d) | Most limited short length |
| Highest fiber efficiency (Strength per length) | Longest lead time on bigger rope diameter |



| GROMMET + | GROMMET − |
|---|---|
| Narrower bearing point* | Highest strength reduction on bend loss (D/d) |
| | Lower fiber efficiency (strength per length)* |



| MULTIPLE-LOOP + | MULTIPLE-LOOP − |
|---|---|
| Shortest length possible | Wider bearing point |
| Less D/d effect as individual rope d is considered not total width of ropes | |
| Tightest length tolerance | |
| Less localized contact pressure | |

*When compared to Multiple-Loop option

Table.3.pros (+) and cons (-) of each sling configuration design

<u>Application Case Studies</u>

**Monopiles Installation For Offshore Wind Farm In North Sea**

This project involved the installation of 140 turbine foundation monopiles, done using 2 sets of lifting systems; each included two single-leg eye slings and one grommet. Each monopole weighed up to 676mt; the engineered lifting slings were fabricated from Samson 152mm-diameter *Amsteel-Blue*. Chafe protection was applied to all weight-bearing points. When the project was completed successfully, the slings were closely examined for wear and it was determined that there was no sign of damage, allowing for the set to be commissioned again for future use.

**Conductor Pipelines Installation In Brazil - Offshore For Deep Water Drilling**

The deployment of conductor pipes from barge to seabed was done with just two single-leg eye slings, fabricated from Samson's 120mm-diameter *Amsteel-Blue*. This validated the point that the task could be done without the aid of a drillship or rig, and could not possibly have been done with traditional steel slings, as they were too heavy and difficult to work on this application.

**Installation Of Subsea Pump Station In The Gulf Of Mexico**

First use of an FPSO in U.S. waters: The *Amsteel-Blue* 88mm-diameter single-leg eye was used as a "hand-off" sling. Due to water depth, the 400mt outboard crane could not reach bottom. Therefore, they used the crane to overboard the package, and lower it a hundred meters. Using ROVs, they then attached the *Amsteel-Blue* sling to a winch with a much higher capacity to lower the package to the sea floor. The *Amsteel-Blue* sling successfully managed the load all the way down -- the "wet handshake" was successful.

***Conclusion*** - To conclude, there is no one-size-fits-all product designed for engineered lifts. Each specific lift calls for a sling designed for that unique operation. Therefore, understanding the intent of the project is critical.

The multiple-loop concept is designed to exactly embody the principle of fit-for-purpose functionality. Its benefits allow the product to adapt to rigorous tasks in the ever-demanding engineered lifting industry.

Using a multiple-loop sling solution enables users to dictate precisely engineered lifting sling requirements. With the addition of engineered rope round sling designs, lifting operations can be completed more efficiently. Shorter slings at the same strength allow for less hassle and lower material cost. By reducing the rope diameter for each pass wrapping over the bearing point, hardware dimensions can be altered to take advantage of the efficiency on sling breaking strength. In addition, weight savings in the material used make handling and setup of the operation faster and easier for the team making the lift.

A simple study was conducted to see the savings in terms of weight of the fiber in each configuration. The first weight comparison is being made on a relatively short length sling where it is fixed at 10m with target strength of 156mt. By varying the pin diameter (i.e. 192mm, 384mm, 768mm) we are able to explore the impact on fiber efficiency with different D/d ratios applied. The second comparison explored varying sling lengths while maintaining a constant pin diameter of 79.5mm with target strength of 156mt, and increasing overall sling length (i.e. 20m, 40m to 80m).

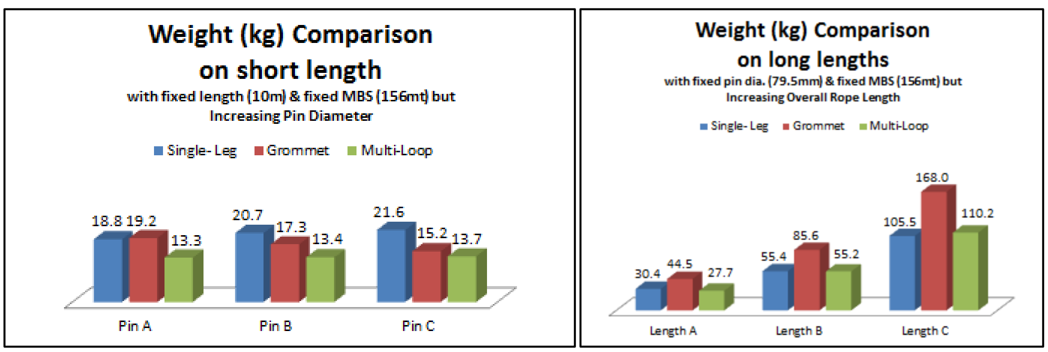


Figure.9. Weight comparison short and long lengths

We found the order of most fiber efficiency on short length with increasing pin diameter would be **Multi-loop, Grommet,** and, lastly, **Single-leg**. In the case where the slings' configuration is fabricated in increasingly long lengths, the order of most fiber efficiency would be **Multi-loop, Single-Leg,** with **Grommet** being the last.

In creating this comparison, we learned that single-leg strength is not affected by the change in D/d ratio, thus the rope diameter remains unchanged. However grommet and multi-loop configurations require different fiber quantities to maximize efficiency, hence they are using different rope sizes to minimize its D/d effect. Also, worth mentioning is that, in longer length, multi-loop and single-leg are comparable to certain long lengths. However, where one of the goals is to save headroom, shorter length is preferable.

To conclude, as the pin diameter increases, and/or longer lengths are required, multi-loop has the clear advantage in weight saving, and has the maximized fiber efficiency.

**References**

[1] The American Society of Mechanical Engineers, safety standards for cableways, cranes, derricks, hoists, hooks, jacks and slings “ASME B30.9-4” September 2014

[2] Cordage Institute International Standard for Synthetic Roundslings “CI-1905” May 2014

[3] Det Norske Veritas AS Offshore standard lifting operations “DNV-OS-H205” June 2016

[4] Samson Rope “Heavy Lift Slings” April 2014

[5] Samson Rope “Agile Lifting System” April 2016

[6] Heins D, Mozsgai G, Tanzarella A “Inspection Criteria for HMPE Rope” *Oceans* 2013

[7] Volpenhein K, Chou R “Abrasion and Twist Effect on High-Performance Synthetic Ropes for Towing Applications” *Tug and Salvage Technology Symposium* January 2009