Advancements in the Field of Wire Rope Design and Manufacturing

By
Timothy W. Klein
Fabricated Products Engineer
Email – timklein@wirecoworldgroup.com

Abstract

The current specifications governing the construction of wire rope and the fabrication of the assemblies used in movable bridges are no longer the best or most reasonable choice for wire rope selection. The current AASHTO and AREMA specifications for wire rope list "6x19 class improved plow steel wire rope of 6x25 filler wire construction with hard fiber core" as the construction for both operating and counterweight ropes. This paper describes the developments made in the design and manufacturing of wire rope since these specifications were written. Numerous wire rope constructions are available now that outperform the above mentioned construction in fatigue cycle testing as well as producing higher minimum breaking forces for a given rope diameter. Some of the developments include the ability to produce higher strength drawn-galvanized wires, compacted strands, corrosion inhibitive lubricants, and low torque wire ropes. This paper compares the reverse bending fatigue life cycles of the 6x25 filler wire rope construction with a fiber core to various constructions of ropes with a focus on the importance of an independent wire rope core (IWRC) center in the construction of any wire rope.

Introduction

The competitive nature of the wire rope industry has resulted in a select few viable wire rope producers. Those remaining producers have realized that quality and performance of their products must continually improve for an ever-demanding consumer. The wide range of wire rope constructions offered today have higher breaking forces, greater fatigue properties, and better corrosion resistance due to the major advancements in the field of wire rope design and the improved manufacturing technology. This leads to the current specifications by AASHTO and AREMA governing the construction of wire rope used in movable bridges. These specifications call for a preformed 6x19 class improved plow steel wire rope of 6x25 filler wire construction with hard fiber core. With the current technology and manufacturing capabilities available in the wire rope industry these specifications no longer recommend the best or most reasonable choice for wire rope selection. The following text will explain various wire rope constructions and how they perform in fatigue loading conditions. It also explains the importance of independent wire rope cores and proper lubrication for good fatigue performance of any wire rope.

Wire Rope Construction

Wires are the basic building blocks of a wire rope. The wires are laid around a “center” in a specified pattern in one or more layers to form a strand. Wire rope characteristics like fatigue resistance and abrasion resistance are directly affected by the construction of the strands. Strands with large outer wires will be more abrasion resistant but less fatigue resistant and strands with smaller outer wires are more fatigue resistant but not as abrasion resistant. The outer strands of the wire rope lay around a core. Two types of cores are available, Fiber Core (FC) and an Independent Wire Rope Core (IWRC). The fibers making up a fiber core are typically polypropylene but sisal and jute materials are also available along with other man made materials. The ability of the core to support the outer strands will significantly affect the fatigue performance of the rope. The purpose of the core is to provide support for the outer strands and maintain clearances between the strands while the rope bends. The grade of the finished rope also contributes to the performance of the rope. The standard grade wire rope available today is Extra Improved Plow steel. This is denoted as EIP or XIP. Higher grade ropes are becoming more common and readily available with advanced manufacturing processes. Higher grade steel allows the rope to better support loads when operating under tensions.

Wire Rope Fatigue

Wire ropes operating over sheaves and drums are subject to bending stresses. These stresses will eventually lead to the fatigue of the wire rope. The amount of the stress depends on the ratio of sheave or drum diameter to that of the rope and the amount of tension in the rope during operation. The ability of the rope's strands and wires to move relative to one another when bending around a sheave or drum is essential for good fatigue life in a wire rope. The movement of the strands and wires compensates for the difference in diameter between the underside and the topside of the rope, the distance being greater along the topside than the underside next to the surface. The rope service life is adversely affected if the wires cannot move to compensate for this situation. There are typically two types of wire rope fatigue, simple bending fatigue and reverse bending fatigue. Simple bending fatigue is the bending of the rope in one direction around a single sheave. Reverse bending fatigue is changing the bending direction from one sheave to another. Figure #1 shows a typical reverse bend schematic. This action accelerates the fatigue of wire rope by compounding the bending stresses on the wires.

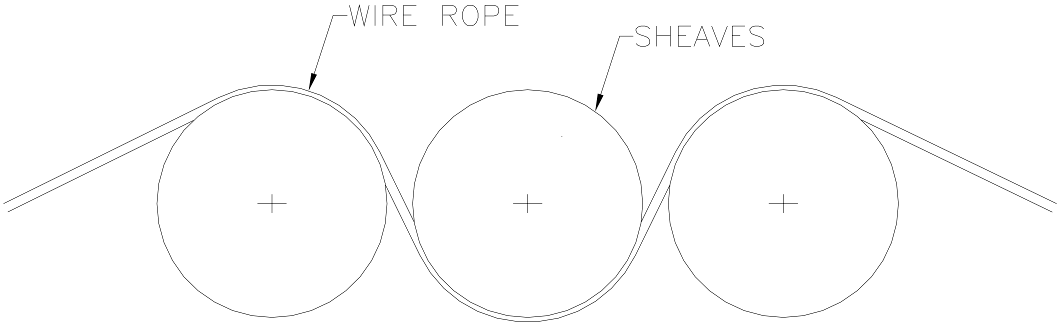
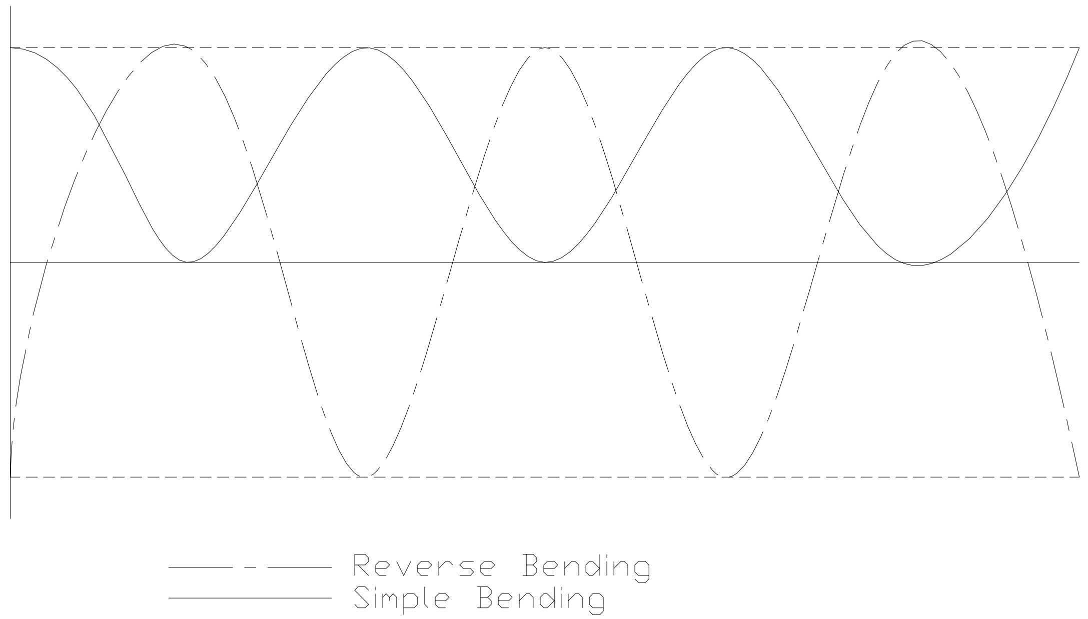


Figure #1
Reverse bending Fatigue



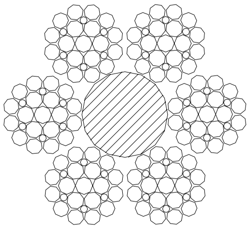
Graph #1
Change in Bending Stresses

Graph #1 shows the amplitude differences of the bending stresses for simple bending fatigue test and the reverse bending fatigue tests. ?σ in the graph represents the change in stress. The simple bend fatigue line goes from 0 to +?σ back to 0 in one cycle. The reverse bend fatigue goes from -?σ to +?σ in one complete cycle. This represents the double stresses seen by the wires during the testing. The reverse bend fatigue test is the most severe test for running rope constructions.

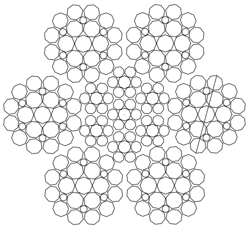
Fatigue Testing of General Purpose Wire Rope

All of the results presented in this paper were generated from reverse bending fatigue tests conducted at Wire Rope Corporation of America, Inc. in St. Joseph Missouri. The tests were conducted with various 19mm (¾”) diameter wire ropes in a controlled environment. The sheave diameter used for all of the testing was 457mm (18”) in diameter. This results in a sheave to rope (D/d) ratio of 24. A constant tension was applied to the rope during the cyclic testing. The retirement criteria of the test samples were based on the inability of the wire rope to support the applied load. These tests were conducted to failure of one strand or the complete failure of the rope.

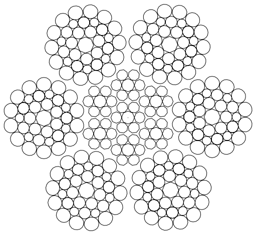
Table 1 shows the test results of four general purpose 19mm (¾") diameter wire ropes tested in reverse bend fatigue. Sample # 1 is a 6x25FW extra improved plow steel wire rope with a fiber core. Sample # 2 is a 6x25FW extra improved plow steel wire rope with an independent wire rope core. Sample # 3 is a 6x25FW extra extra improved plow steel wire rope with an independent wire rope core. Sample # 4 is a 6x36WS extra improved plow steel wire rope with an independent wire rope core. A load of 78.5 kN (17,650 lbs.) was applied to the test samples during the cycling. This tension load is 30% of the minimum breaking force specified for 19mm (¾") diameter XIP IWRC wire rope. Standard lubrication was applied to the samples during the manufacturing process but no additional lubrication was applied during the testing of the ropes.



Sample # 1
6x25FW Fiber Core



Sample # 2 & # 3
6x25FW Independent
Wire Rope Core



Sample # 4
6x36WS Independent
Wire Rope Core

Sample #	Rope Description	Avg. RBF Cycles
1	6x25FW XIP FC	7,907
2	6x25FW XIP IWRC	11,880
3	6x25FW XXIP IWRC	12,086
4	6x36WS XIP IWRC	12,932

Table 1

An initial examination of the results in Table 1 clearly shows the wire ropes with independent wire rope cores outperform the fiber core sample #1. Fiber core sample #1 had 33% less average reverse bending fatigue cycles compared to the wire ropes samples # 2 and # 3 with independent wire rope cores and identical outer strand constructions. The poor results of sample #1 are due to the inability of the fiber core to support the outer strands during operation. Once the fiber core has begun to deteriorate the outer strands no longer have the support for proper strand placement. This allows the outer strands to begin nicking and scrubbing against one another accelerating the fatigue. The comparison of samples # 2 and # 3 show a 2% increase in reverse bend cycles. This is due to the increased ability of the XXIP strength wire rope to support the tension load. It is no surprise that the fatigue sample with the best results was sample # 4. Sample # 4 is an XIP grade 36WS strand construction with an independent wire rope core. The 36WS construction is primarily designed to be the most efficient in fatigue resistance and still offer adequate abrasion resistance.

The results of this set of fatigue tests show that a high tensile wire rope with a greater number of wires per strand with an independent wire rope core will out perform a lower tensile wire rope with a fiber core. High tensile wire ropes are more available due to the advancements seen in the quality of high carbon rod. These advancements allow direct drawing of high tensile wires without a loss of torsional properties. The current drawing practices of the wires contribute significantly to the surface finish of the wires which in turn affect the fatigue resistance of the wire rope. Poor surface finish on drawn wires leads to early crack initiation. These cracks propagate under repeated stress cycles until the remaining sound metal fails.

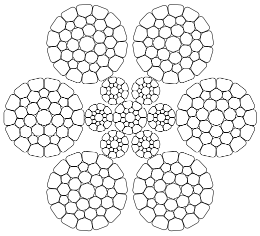
Fatigue Testing of Value Added Ropes

Additional fatigue testing has been performed on various value added wire ropes to show that additional manufacturing steps can be taken to increase the life of the ropes.

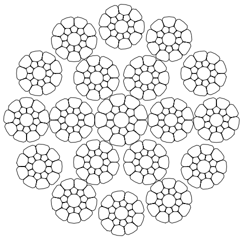
Sample #	Rope Description	Avg. RBF Cycles
5	6x25FW XIP IWRC	10,445
6	6x25FW XIP IWRC Heavy Lube	12,487
7	Flex-X 6	15,181

8	Flex-X 19	20,155

Table 2



Sample # 7
Flex-X 6



Sample # 8
Flex-X 19

Table 2 shows the test results of four 19mm (¾”) wire rope constructions. Due to the higher minimum breaking forces of the ropes the tension load was increased to 82.3 kN (18,500 lbs.) during the cycling test of these samples. Sample # 5 is the same construction as tested in initial fatigue tests on general purpose ropes. The tests were run again on this construction at the higher tension load to provide a benchmark for the value added ropes. Sample # 6 is an identical construction to sample # 5 with the addition of a heavy overcoat of lubricant. The added lubricant resulted in a 20% increase in reverse bend cycles. Lubrication is vital to the performance of the ropes and is normally overlooked as a means of rope protection. Lubrication reduces friction between the rope’s components as well as friction between the rope and the sheaves. It is also important to note that lubrication is usually the only means of corrosion protection of bright wire ropes used in the filed. Therefore it is important the lubricant penetrate to the ropes core and contain adhesives that stick to the wires in the rope without being easily washed away. Sample # 7 is a compacted 6 stranded rope trade named Flex-X 6 manufactured by WRCA, Inc. The compaction of the strands permits the metallic area to be increased 5-18% as compared to non-compacted ropes. When compared to conventional 6 stranded ropes the Flex-X 6 compacted ropes provided greater contact surface area and more steel per given diameter. This results in an increase of 45% in fatigue life as shown in the reverse bending cycles. The smooth surfaces of the outer strands also results in less sheave and drum wear. Sample # 8 is a high strength multi-stranded wire rope with rotation resistant properties trade named Flex-X 19 manufactured by WRCA, Inc. This rope is made from 19 individual 19-wire Seale strands. Six of the strands are laid around a core strand in one direction, 12 strands are then laid around this first operation in the opposite direction. Due to this tightly compacted, smooth design the resistance to bending fatigue is 93% more than a standard 6 stranded rope. The smooth outer surface of compacted rope strands reduces contact pressures between the strands as well as reducing the radial pressures over sheaves and drums.

Advances in Rope Design and Manufacturing

Modern tools and technology have brought about substantial improvements in wire rope constructions and quality. These tools in turn increase the durability and service life of the wire rope. The ideas all begin in the design phase of the wire rope. The advent of computer aided drafting software allows conceptual design and analysis of the complete wire rope constructions to ensure proper wire placement and strand clearances. The ability to determine the rope specifications that provide optimum strength and fatigue in hours instead of days greatly enhances turn around time to meet customer requirements. New and radical designs push the limits for strength and dependability everyday. Ropes containing 4 strands to 35 strands allow engineers to dream and design exciting new systems using wire rope.

Advances in wire production are by far leading the way on new innovations and thought processes. Direct drawing wire diameters without patenting is now possible utilizing as received material. The quality of the rod coming from steel mills today verses 20 years past has greatly improved. Superior microstructures due to improved rolling processes in the steel mill allow wire manufactures to perform more cold working of the steel. The ability to galvanize rod to produce drawn galvanized finish wires is a tremendous advantage in wire production. This produces a high quality zinc coating that is well bonded to the steel surface. Drawn galvanized ropes can now offer the same properties as bright ropes with the addition of the added corrosion protection. A greater number of the ropes produced today are from drawn galvanized wires. As the wire rope properties increase due to design and application the service life of the rope is becoming dictated by the corrosion resistance. The cost difference of the galvanized wires is easily offset with the high cost and difficulty of rope change out. As mentioned previously lubricants, also termed field dressings, play and important role in the corrosion resistance of the rope as well as the fatigue life of the rope. Lubricants can provide high levels of corrosion resistance and moisture displacements for use in high humidity environments and near salt water applications. The bonding of the lubricant to the wire surface becomes critical for continual protection during operation.

The stranding and closing operations of the wire rope fabrication have remained consistent over many years with a few exceptions. One of the recent advancements in the stranding operation of the wire rope has been the ability to compact strands and independent wire rope cores to improve fatigue life, strength, and dependability. As seen from the fatigue testing performed on the value added ropes the fatigue life of the rope can be increased by as mush as 45% compared to a standard rope. The compacting process actually reduces the diameter of the strand which increases the metallic area. This process can be carried out by swaging, rolling, or drawing the product. All of theses methods add cold working properties to the steel. Figure 1 and 2 show 6x36WS strands in the compacted and non-compacted designs respectively. Quality lubrication becomes a major factor for compacted ropes since the compacting process actually reduces the areas and voids were excess amounts of lubrication would be present to protect the wire surfaces internally in the strand. The ability of the lubricant to bond with the wire surface is critical in this application.

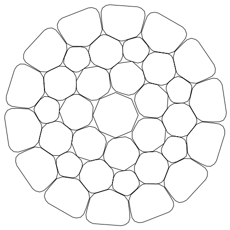


Figure 1
Compacted
Strand

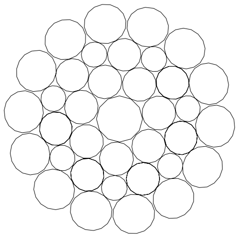


Figure 2
Non-Compacted
Strand

A good example of the use of compacted strand rope is the recent completed change out on the Tule Lake vertical bridge crossing in Corpus Christi, TX. The 1-1/2" 6x25FW IPS FC ropes were replaced with 1-1/2" 6x31WS Flex-X construction strands with a high density polyester core. The ropes are operating very well in place of the previous construction. The elastic stretch of the rope was very well controlled making the installation process very smooth.

One rope construction that was not represented in the above fatigue test data is plastic impregnated ropes. Several variations of this technology have been introduced in the market. This process impregnates polymers under high pressure into the wire rope. This serves to cushion the strands, distribute internal stresses, keep in wire rope lubricant, and keep out dirt and debris. Wire rope constructions are available with coated cores as well as completely coated ropes to help provide longer service life and cleaner operations. This jacketing should not be considered a corrosion inhibitor but a means to protect the rope from harmful dirt and debris.

The most recent developments in wire rope constructions are low torque wire ropes. These are typically 4 stranded ropes that are formed with round strands to produce a round finished rope. There is no core in this type of rope. Due to its design, extremely high strengths are obtainable based on strength to diameter ratios. The near zero torque of the rope combined with the strand construction make the rope very stabile during operation.

Conclusion

This paper is by no means a complete analysis of rope construction or design. Individual studies could be completed on each of the wire rope constructions mentioned. This paper was written to educate the bridge community on the developments in the field of wire rope for use as both counterweight and operating ropes in movable bridge applications. The current specifications for AASHTO and AREMA list the 6x19 class improved plow steel with a hard fiber core as the recommended rope. The fatigue tests data presented in this paper has shown that the performance of these types of wire ropes is easily exceeded when compared to other wire rope constructions currently available on the market. The fatigue tests presented have also shown the importance lubrication and independent wire rope cores for stability and good service life.

It has been stated clearly by several contractors, designers, and engineers that they are very comfortable with wire rope as a consumable product. The advancements in wire rope design offer the Engineer alternatives in movable bridge rope constructions. The next step is to take advantage of them.

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