HEAVY MOVABLE STRUCTURES, INC.
THIRTEENTH BIENNIAL SYMPOSIUM

October 25-28, 2010

The Changing Culture of Wire Ropes for Vertical Lift Bridges

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Abstract

The paper describes the recent developments made in the design and manufacturing of wire rope for specific use as Counterweight and Auxiliary ropes on vertical lift bridges. New wire rope materials and designs provide increased strengths and improved mechanical properties allowing designers and engineers to take full advantage of the material strengths available. These developments involve high tenacity synthetic materials protected by high strength corrosion resistant carbon steel wires. This provides a hybrid wire rope with a high strength to weight ratio, low torque, and excellent operating characteristics that can outpace any product currently available on the market. The results are longer field service, increased corrosion protection, less maintenance, and smaller diameter wire ropes in service applications. All of these characteristics are beneficial to the owner/operator of the movable structure. The paper will discuss the mechanical properties and benefits of improved wire rope constructions verses those currently specified for use by AASHTO and AREMA.

The use of new technology in Vertical Lift Bridge applications is none existent in the United States however the European communities utilize the types of wire rope products as described above to transform movable structures into iconic bridges. AASHTO and AREMA have made recent progress in adopting new wire rope standards however the ever changing developments in wire rope will require more change over time.

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 their major advancements in the field of wire rope design and the improved manufacturing technology. While AASHTO and AREMA have incorporated modern specifications the 6x25 filler wire construction with hard fiber core is still the standard wire rope specification used today for counterweight wire ropes. With the current technology and manufacturing capabilities available in the wire rope industry this construction no longer recommends the best or most reasonable choice for wire rope selection. The following text will explain various wire rope constructions and how they operate to provide superior performance.

Wire Rope Construction

High Carbon steel 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 wires can be galvanized to finish or hot-dip galvanize to increase the corrosion resistance of the wire rope. The compaction or forming of the outer strands is very common in wire rope production today. The strand compaction provides greater surface area and more steel per given diameter increasing rope stability and strength. Figure 1 and 2 below show the compacted strand configuration. The compaction also results in a longer service life and less sheave and drum wear. Fatigue testing has shown time and time again the superior performance of compacted strand products verses non-compacted products.

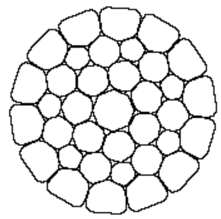

Figure 1
Compacted
Strand

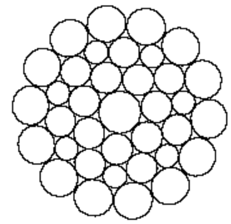

Figure 2
Non-Compacted
Strand

The standard construction for general purpose wire ropes is the 6 strand configuration. While 6 strand constructions are still common 8 strand configurations have become standard for applications requiring better bending fatigue. The 8 strand constructions require smaller diameter strands resulting in higher metallic fill factor. This also results in smaller wire diameters resulting in increased bending fatigue results. The metallic cross sectional area of the core in an 8 strand rope is 25% of the whole rope, the core of a 6 strand rope only represents 15% of the metallic area. This increases several characteristics of the wire rope including the strength, bending fatigue, and elasticity.

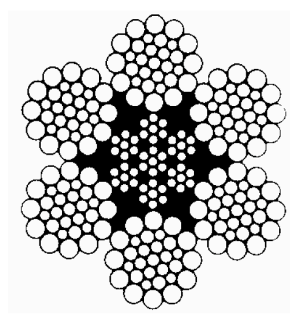

Figure 3 – 6 Strand

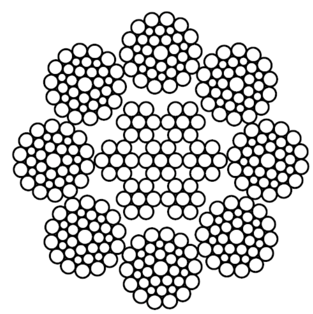

Figure 4 – 8 Strand

Figure 3 and 4 show a 6 strand configuration and an 8 strand configuration. The increased core diameter and decreased strand diameter are seen in the figures.

The designed purpose of the core in a wire rope is to provide support for the outer strands and maintain clearances between the strands while the rope bends. Two types of cores are available, Fiber Core (FC) and an Independent Wire Rope Core (IWRC). The traditional fibers making up a fiber core are typically polypropylene. The new construction of wire ropes being designed today are utilizing high strength fibers to increase the strength of the wire rope and decrease the weight while increasing the fatigue performance of the product. To obtain these properties the core must be an integral load sharing member rather than just providing support for the outer strands. The fibers making up these core types include para-aramids that are 8 times stronger than steel and 3 times stronger than fiberglass, polyester or nylon yarns. Also being used are ultra strong polyethylene fibers that offer maximum strength combined with minimum weight, up to 15 times stronger than quality steel and up to 40% stronger than aramid fibers. The idea of combing high strength fibers with steel to produce a Hybrid Rope is not a new concept. The Macwhyte Company patented the idea in 1988 with the goal of reducing the strength to weight ratio of the finished product. At that time the core member was made using new Kevlar® materials with one key element added. This element was a protective jacket over the fiber member to protect it from abrasion of the outer strands. The plastic layer forms a custom molded cushion layer or a bed for the outer strands. It fixes the elements of the rope in relation to each other, acting rather like a corset which maintains the rope's stability, even under the highest external forces. The most effective remedy against birdcaging or loose strands is to use a wire rope with an internal plastic layer. Figure 5 below shows the plastic layer after removing the outer strands and the core.

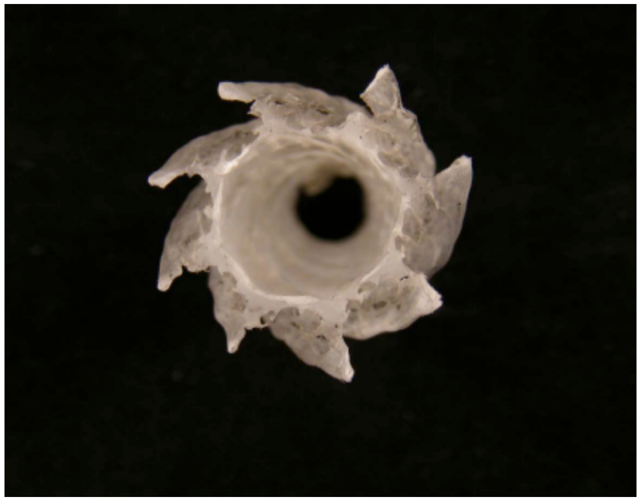

Figure 5

Hybrid Construction

The 8 strand wire rope design lends itself to the Hybrid construction due to the increased core diameter. The introduction of a fiber member in the core area allows the rope to take full advantage of the superior fatigue characteristics of the material as well as the high strength. Figure 6 below shows the cross section of an 8 strand rope with and without the introduction of the fiber element.

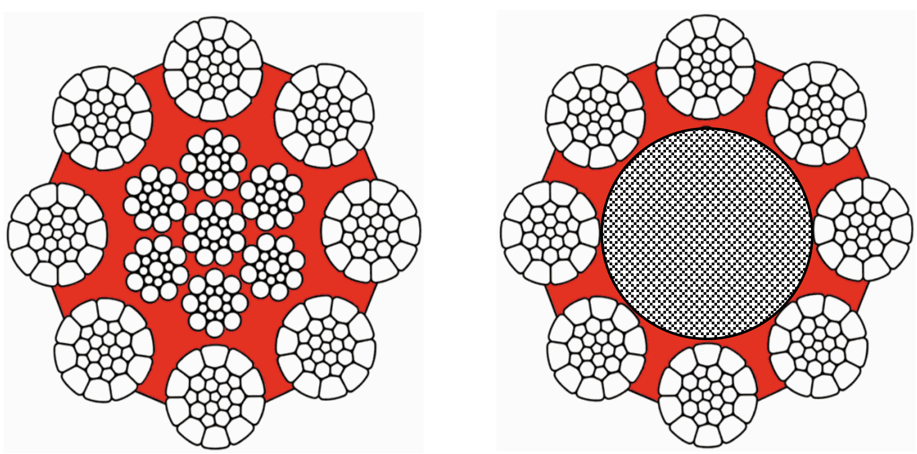

Figure 6 – 8 Strand Turboplast with IWRC and Fiber Element

One of the main goals in the design of the Hybrid construction is to take full advantage of the performance characteristics of the fiber element. Balancing the load sharing between the fiber and the steel elements requires the lay of the outer steel strands to be matched perfectly with the fiber braids. The final design incorporates a high strength braided fiber element, plastic infused core, with compacted steel outer strands. A langs lay was used to increase the fatigue characteristics and reduce outer strand contact stresses on the core. Figure 7 and 8 below show the cross section and lay pattern of the produced Hybrid construction. Figure 7 shows the large cross section of the core element and the support requirements for the outer strands.

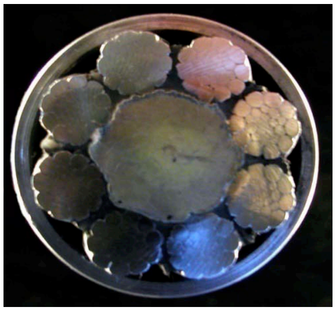

Figure 7 – Cross Section

Figure 8 – Lay Pattern

The concepts surrounding the Hybrid construction arose from a need for a high strength light weight wire rope. In applications requiring long lengths of wire rope the weight of the rope can become a limiting factor in the application. If the tensile strength of the wire rope cannot safely support the required weight of the cable itself the lifting capacity of the cable will be nonexistent.

Tensile Strength – Elongation

Table 1 below listed the typical wire rope constructions and Minimum Breaking Force (MBF) requirements. The traditional 6x25FW Fiber Core is listed as well to provide a bench mark for the Hybrid constructions. The Hybrid construction provides a 40% increase in strength from the base 6x25FW FC construction with a 4% reduction in the weight per foot. The core strength member provides a tremendous increase in strength due to the load sharing capabilities of the core member.

Description	Diameter	Lbs/Ft	Min Break Force (Lbs)
6x25FW XIP FC	1-1/2"	3.78	202,000
6x25FW XIP IWRC	1-1/2"	4.16	228,000
Flex-X Compact	1-1/2"	5.01	250,000
6x31 DGXIP PC	1-1/2"	3.64	215,000
Hybrid Rope	38mm (1-1/2")	3.66	283,800

Table 1

When comparing the Hybrid construction to the constructions with Independent Wire Rope Cores it is apparent the greatest attribute is the reduction in the weight per foot of the cable. When compared to the Flex-X Compacted design there is a 14% increase in strength with a 37% decrease in the weight per foot of the cable. The 37% decrease in weight for the 1-1/2" diameter is 1.35 pounds per foot. Looking at the typical vertical lift structure with assemblies in excess of 100 feet the reduction in weight could be substantial in regards to the tower. As stated previously the reduction in the weight in long fall applications allows more rope to be used in the lifting system without reducing the lifting capacity of the wire rope.

The measured Modulus of Elasticity of the Hybrid construction is approximately 15,000 ksi. This is comparable to the traditional Polypropylene and Polyester fiber cores. A Load verses Elongation curve is shown below in Figure 9 to demonstrate the elasticity of the cable during cyclic loading. The sample tested in the loading below was 8 meters long. A total elongation of approximately 260mm was recorded during the test to failure. The Hybrid rope provides a smooth load curve with continued elongation during the loading.

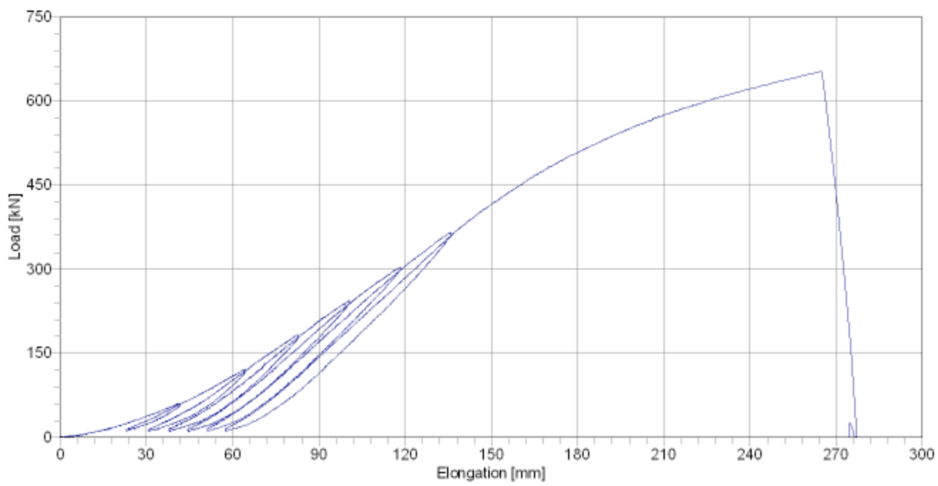

Figure 9

Fatigue Performance and Evaluation

The added benefit of the Hybrid construction is the fatigue performance of the wire rope. The cyclic test performed on the samples is a simple bend test around a single sheave. This configuration is considered a simple bend due to the single one dimension amplitude stresses applied to the wire during the fatigue cycle. Figure 9 below shows the schematic of the test setup.

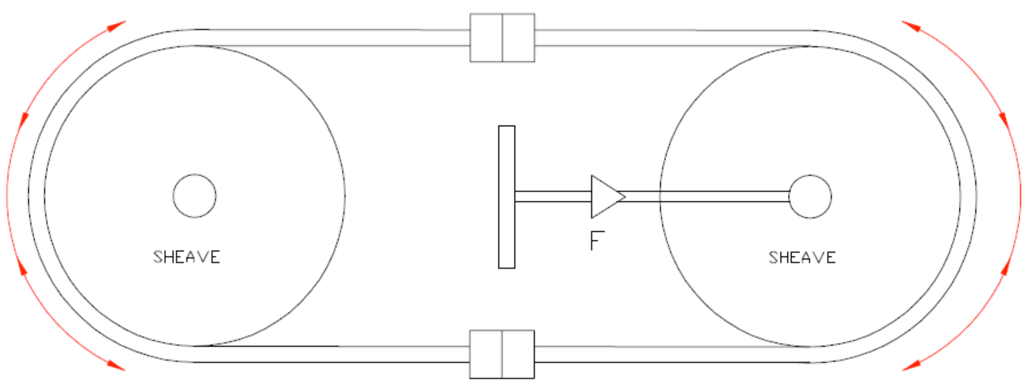

Figure 9

All of the cyclic testing information provided was obtained from testing performed while the wire rope test piece is under load. The testing performed in this scenario had a load of 120,000 lbs. applied during the testing. The high loading accelerates the test and stresses the material to perform under extreme conditions. The sheave groove diameter in the testing setup was 28” in diameter. Table 2 below lists the fatigue testing results of the benchmark rope and the Hybrid rope. The benchmark wire rope used in the testing was a 6x31 WS with a High Density Polyester core. This wire rope construction performed 13,241 cycles before reaching the retirement criteria. The Hybrid rope performed 28,091 cycles before reaching retirement criteria. The initial testing of the benchmark wire rope verses the Hybrid construction showed a 220% increase in the cyclic fatigue capabilities of the wire rope. The significant increase in fatigue performance is attributed to two factors. One being the Hybrid ropes increased load carrying capacity. The second being the load carrying ability of the fatigue resistant core yarns. The natural ability of a synthetic cable to carry high stress loads lends the Hybrid cable to increasing fatigue performance.

	Diameter	Lbs/Ft	Min Break Force (Lbs)	Strength To Weight Ratio	Fatigue Results (Cycles)	
Standard 6x36 PC	1-1/2"	3.64	215,000	59,066	13,241	
Hybrid Rope	38mm (1-1/2")	3.66	283,800	77,541	28,091	
Hybrid Rope	35mm (1-3/8")	3.09	239,700	77,573	32,000	*Projected
Hybrid Rope	33mm (1-5/16")	2.82	218,400	77,447	32,000	*Projected

Table 2

The last two rows of Table 2 show the projected Fatigue Results and reduction in diameter that can be achieved to match the required Minimum Breaking Force of the standard 6x36 Fiber Core. Based on design calculations a 1-5/16" diameter cable could be used in lieu of an 1-1/2" diameter. The 1-5/16" Hybrid construction would theoretically match the strength requirements while increasing the fatigue performance by 240%. The smaller diameter also provides a reduction in weight of 0.82 pounds per foot when compared to the standard 6x36 PC. Figure 10 below shows the strength to weight ratio and the fatigue cycle performance of the above wire rope constructions in a table format.

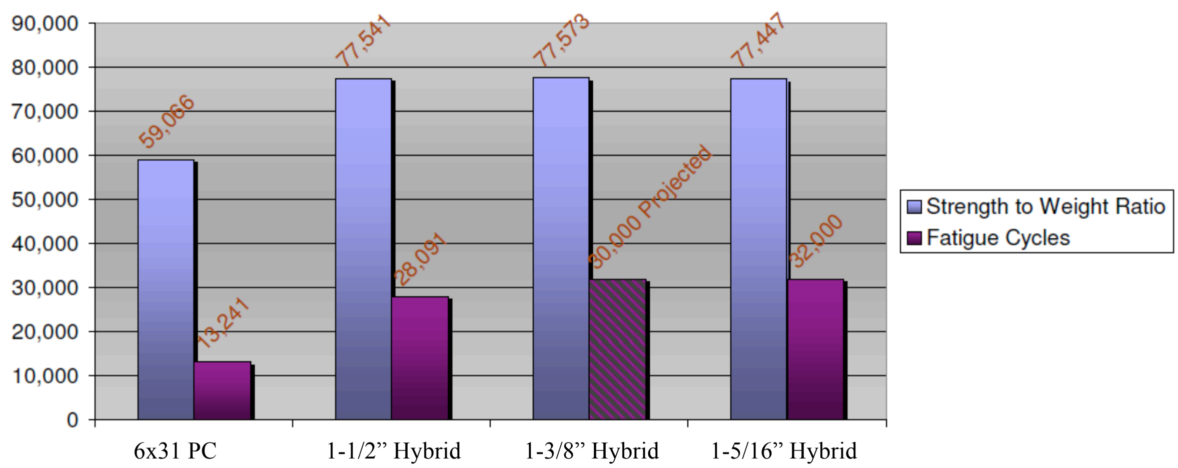

Figure 10 – Fatigue Table

The comparison is clear between the Hybrid cable and the standard product. The projected increase in fatigue is based on the reduction in diameter. This increases the diameter ratio between the rope and the operating sheave therefore increasing the fatigue bending factor.

Inspection and Maintenance

The inspection of wire ropes in service is critical in evaluating the serviceability and life of the wire rope. Visual inspections are the easiest to perform but depending on the condition of the ropes this may not be feasible. Heavy lubricants are typically applied to the operating ropes concealing the surface of the rope. The cleaning of the ropes to provide a visible surface may require expensive and time consuming processes. The disposal of this material may also require the handling of hazardous waste. In the case of most vertical lift bridges this operation must be performed over a waterway. Therefore it is recommended to have the ropes electromagnetic inspected to evaluate the condition prior to the removal of coatings.

Many types of non-destructive testing methods for the inspection of wire rope have been experimented with over the years to include acoustic emissions and radiography. The use of electromagnetic inspection is the only proven practical way to efficiently inspect wire rope. The mining industry has used electromagnetic inspection on wire rope since the early 1950's. In many countries, including the United States and Canada, the use of electromagnetic inspection is mandated for the inspection. In addition, the visual method of inspection must be used as an important aid to electromagnetic testing.

The retirement criteria is mandated and provided by various agencies including the mining industry, ski industry, various States and Provinces in Canada, and other governmental agencies; OSHA, MSHA. The most widely used retirement criteria for wire rope is CFR 30 Part 75 (Code of Federal Regulations) which is associated with the mining hoist ropes and may be used for other wire rope use.

75.1434 Retirement Criteria:
Unless damage or deterioration is removed by cutoff, wire ropes shall be removed from service when any of the following conditions occur:

1. The number of broken wires within a rope lay length, excluding filler wires, exceeds either –
    a. 5% of the total number of wires
    b. 15% of the total number of wires within any strand
2. More than one broken wire in the valley between strands in one rope lay length.
3. A loss of more than one-third of the original diameter of the outer wires.
4. Rope deterioration from corrosion.
5. Distortion of the rope structure.
6. Heat damage from any source.
7. Diameter reduction due to wear that exceeds 6% of the baseline diameter measurement.
8. Loss of more than 10% of the rope strength as determined by non-destructive testing.

The inspection requirements of a Hybrid Construction wire rope vary from that of the traditional means. The standard fiber core rope does not rely on the core as a strength member. Therefore the Electromagnetic Inspection of the outer strands is sufficient in determining the remaining strength of the cable. The Hybrid construction requires a detailed visual inspection to examine rope diameter changes, strand lay pattern differences, or strand gap variations to determine if the core and the wire components are operating as designed. Figure 11 and 12 below show a new inspection method developed to constantly monitor the operating characteristics of wire rope using cameras.

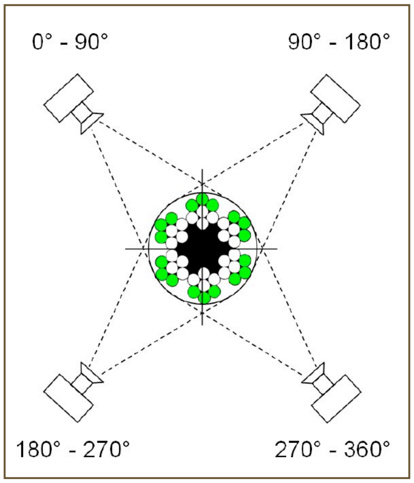

Figure 11

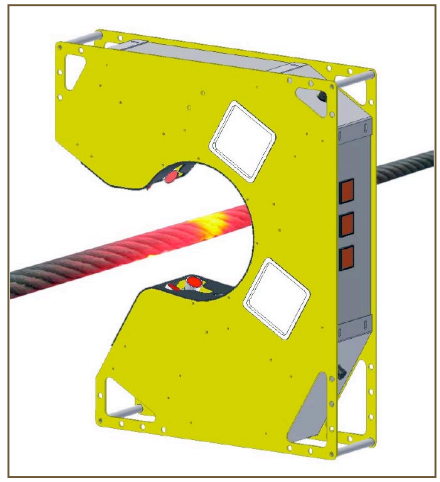

Figure 12

This method has successfully been employed in the mining industry for use as a constant monitoring system. Figure 13 below shows the system at work.

Figure 13

Due to the nature and operating characteristics of Vertical Lift Bridges wire rope systems this type of constant monitoring would not be required but the philosophy behind the system is a complete visual inspection of the wire rope. A complete evaluation is extremely helpful in determining the overall health of a wire rope. Variation in the outer strand patterns is a clear indication of an internal problem that may not be clear from a visual account.

Conclusion

This paper is by no means a complete analysis of new wire rope constructions or designs. 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 fatigue tests data presented in this paper has shown that the performance of traditional wire rope is easily exceeded when compared to other wire rope constructions currently available on the market. The fatigue tests presented have shown the importance of the core 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 the significant achievements in wire rope service life.

Acknowledgements

I would like to acknowledge the efforts of the Research and Development team and Product Engineering department at WireCo Worldgroup for their support of this paper. Specifically I would like acknowledge the efforts of Dr. Bamdad Pourladian who provided the testing information and analysis of the fatigue results.