Practical Solutions

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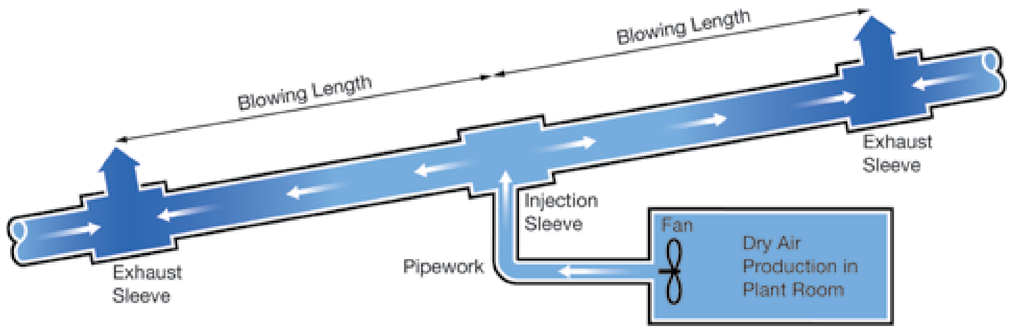

Figure 1. Cable dehumidification process.

Suspension Bridge Cable Dehumidification

A Matter of Life and Health

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Stretching down from the tower tops forming the main support for the load on the bridge, the cables of the suspension bridge are loosely akin to the human spine. Both cable and spine must be strong enough to withstand their load for a lifetime, responding to their imposed demands 24 hours a day, 7 days a week, and 365 days a year – without respite. As such, both cable and spine demand long-term proactive care and protection. Fail to take care and ignore the signs of ailment, and catastrophe could be right around the corner when least expected.

Main cable dehumidification is as much a prescription for an ailing cable as it is preventative care for a healthy cable. As a doctor may say that it is never too early to live a healthy lifestyle, a suspension bridge owner must institute the same logic for the cables – reflecting on the thought that it may never be too early to dehumidify.

History

The U.S. has the largest inventory of long-span suspension bridges in the world, and the problem of corrosion within the main cables of these bridges has been recognized for some time. As early as 1968, corrosion was found in the outer wires of the cables on the Golden Gate Bridge, and in 1978 the U.S. Grant Bridge over the Ohio River was closed after severe corrosion was detected in the main cables. In the 1980s, broken wires prompted rehabilitation efforts on the main cables of the Bear Mountain and Mid-Hudson Bridges in NY.

In 1990, corrosion was discovered on the outer main cable wires of a bridge in Japan that was just seven years old. Further inspections revealed corrosion in the main cables of other suspension bridges in Japan that were even younger. Investigations ensued, and accelerated testing led engineers to conclude that, even with improved wrapping and sealing, it was not possible to make a cable completely watertight – water, a cable's worst enemy, would always find its way into the cable. The idea was born that if a suitable dry-state environment was maintained by some artificial means, it would be a promising way to protect the cable against the spread of corrosion. The development of main cable dehumidification stemmed from this work.

Cable Dehumidification

Main cable dehumidification involves injecting dried-air into the cable microenvironment and allowing the air to permeate into the interstitial spaces (voids) between the individual cable-wires. The dried-air collects the trapped water before releasing the moisture-laden air through exhaust ports (*Figure 1*). Cable dehumidification addresses the root cause of corrosion by removing one of the two necessary components of the corrosion process – water – which is far easier than removing the other component – oxygen.

The premise of cable dehumidification is to protect the individual cable wires through the control of humidity within the cable. This is a long-proven technique dating back to the first half of the twentieth century, where work was carried out by W.H.J. Vernon and later by H.H. Uhlig of the MIT Corrosion Laboratory. The results of corrosion studies indicate that if the relative humidity (RH) is kept below 60%, the corrosion rate dramatically decreases, and below 40%, corrosion practically ceases (*Figure 2*).

Cable dehumidification is an active system for cable management similar to the routine daily

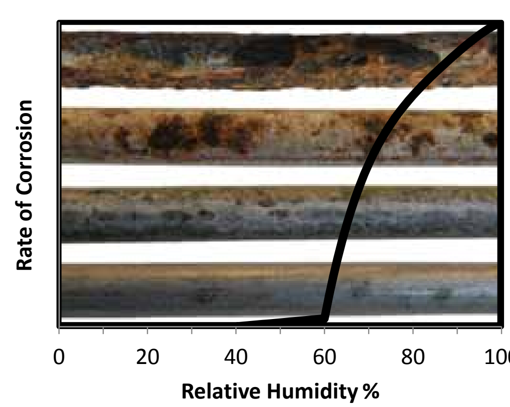

Figure 2. Rate of corrosion vs. relative humidity (background: 4 stages of cable wire corrosion).

workouts for a healthy body. The implementation of a series of injection and exhaust sleeves along the length of the cable, supported by a system of dehumidified air maintained below the threshold 40% RH, supplies a continuous lifeline of dried-air to combat corrosion. This can be contrasted with the original passive system of protection for most main cables, which typically included galvanized cable wires with a layer of red lead or zinc paste below a soft-annealed galvanized wire wrapping and paint system (*Figure 3*). Dehumidification also contrasts the historic approach to retrofitting cables with the added protection of oiling – an expensive process of unwrapping and wedging the cable wires apart and pouring in specially formulated oil in the hopes of protecting the cable against continued corrosion.

The older methods of protection have proven unsuccessful and may be seen as dressing a bad wound with a Band-Aid, whereas, cable dehumidification is a holistic approach addressing the root cause of cable-ailment.

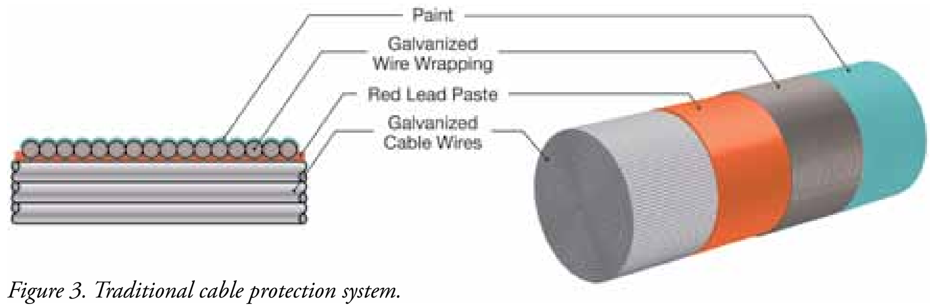

Figure 3. Traditional cable protection system.

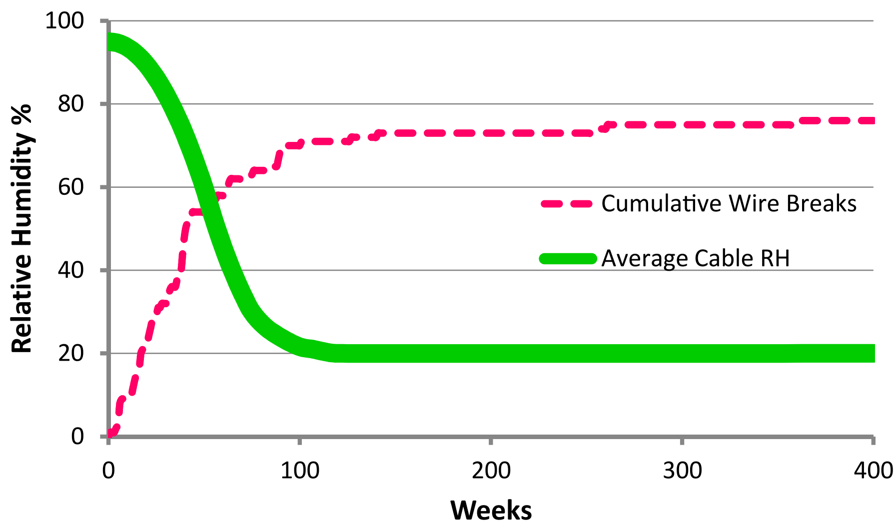

Figure 4. Reduction in cumulative wires breaks on dehumified cables.

Fracture Mechanics of Cable Wires

Cable wires are usually about 0.196 inch in diameter (nearly the size of a No.2 pencil) and have a tensile strength of 225,000 psi. The wires are usually galvanized, pulled across the spans, and then compacted together to form a near circular cable cross-section, comprised of thousands of individual wires, or tens-of-thousands in longer-span bridges.

There are many contributing factors to cable corrosion and loss of strength. However, it is the initiation and propagation of cracks that ultimately cause cable wires to break. This process starts with the water that has collected within the cable reacting with atmospheric pollutants leading to zinc depletion – the degradation of the galvanized coating on the cable wires. Once the zinc protection is depleted, corrosion pitting will occur; some of the pits develop cracks, which then grow into the cable wire cross-section. The very high strength of the steel used in cable wire makes it more brittle in nature and more susceptible to hydrogen embrittlement and associated cracking. Hydrogen embrittlement is a result of hydrogen at the subatomic level migrating into the steel matrix, causing the cable wire to become brittle and prone to wire cracking and fracture at normal levels of working stress.

To arrest the corrosion process, it is essential to remove water – both in the form of trapped water in the cable and water that inevitably finds its way into the cable over time. Historical data on existing bridge cables that have been retrofitted with a dehumidification system demonstrate a marked reduction and near-cessation of wire breaks over time (*Figure 4*), illustrating the effectiveness of main cable dehumidification on the overall health of the cables.

Monitoring the Vital Signs of the Cable

Assessing the condition of the cables by visual and hands-on inspections can be supplemented by acoustic monitoring. Depending on the condition of the cable, internal cable inspections typically occur but once a decade and focus on just a few locations along the cable. The estimated strength of the cables therefore requires statistical extrapolation from the relatively small amount of data collected. Cable wires gradually deteriorate through corrosion, crack initiation, and crack growth, culminating in a sudden break. This releases energy which can be detected through a network of acoustic sensors.

Some bridge owners have installed acoustic monitoring systems that listen 24/7 to the whole length of the cables for breaking wires. This provides valuable and in some cases crucial important long-term information on the structural health of main cables.

Two key pieces of data are generated by the acoustic monitoring – hotspots indicating significant wire-break activity and the long-term trend of cumulative wire breaks. This data enables the bridge owner to have an increased knowledge and confidence in the actual health of the cables.

Achieving the Life Expectancy of the Bridge

Maintaining the overall health of the main cables is crucial to achieving the design-life of the bridge. Historically, suspension bridge cable design has been developed without a full and proper understanding of the potential rate of deterioration. As critical as this is, it is still not effectively reflected in design guidance.

The long time-horizon associated with discovering cable durability problems has required suspension bridge owners to take a long-term view of monitoring such problems and installing countermeasures. It has also stimulated the sharing of knowledge across the suspension bridge engineering community so that lessons are learned.

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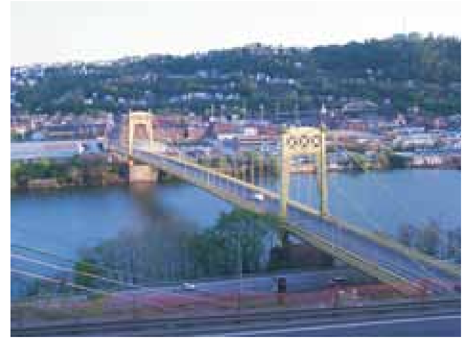

Figure 5. Representative AECOM cable dehumidification projects – Forth Road Bridge, UK (left), WPL Bay Bridge, Stevensville, MD (center), S. 10th Street Bridge, Pittsburgh, PA (right).

Cable strength and durability are influenced by many complex interrelated factors including construction quality, long-term performance of constituent materials, and human responses to these. As main cables are the primary load carrying elements of the structure, it is important that their condition is known and closely monitored. Diminishing tensile strength factor of safety is the main concern for suspension bridge owners and generally drives the implementation of preservation strategies.

In most cases, if main cables are to remain sufficiently durable and still have an adequate tensile strength factor of safety for their target design life of 100+ years, it is necessary to provide active corrosion protection in the form of cable and anchorage dehumidification. Installing cable dehumidification can prolong the service life of suspension bridges, sustain the cables at a reasonable cost, and maximize the return on public investment for these critical assets – results which strongly align with many of the objectives of suspension bridge owners.

Monitoring the Trends

As a doctor would monitor the latest advances in the treatment of illness, bridge owners must keep their fingers on the pulse of the latest techniques to protect the health of the cables. It is becoming evident that the only effective form of positive intervention that can be implemented to preserve the condition of the main cables is dehumidification.

Although first implemented in Japan almost 18 years ago, application of cable dehumidification has steadily increased, with installation on bridges in the UK, Scandinavia, South Korea, and China. The trend for main cable dehumidification crossed the pond with its first implementation in the US on the William Preston Lane Jr. Memorial (Bay) Bridge in Maryland. Studies began in 2011 and culminated with system commissioning on the WB Bay Bridge in early 2014, and anticipated commissioning on the EB Bay Bridge in 2015. Numerous other cable dehumidification projects are underway in the U.S., including the Delaware Memorial Bridge and the S. 10th Street Bridge (*Figure 5*).

Maintaining the Health of the Bridge

The implementation of cable dehumidification should not be considered in isolation, but rather as part of an overall holistic approach to suspension bridge maintenance, utilizing modern technologies and proven strategies for all suspension bridge components.

Such a strategies should seek to maximize the benefit of maintenance and capital improvement work, with special emphasis on long-term suspension system reliability. For example, weigh-in-motion studies originally intended to address fatigue can and should be leveraged to identify bridge-specific loading which can, in turn, be used to refine cable tensile strength factor-of-safety calculations. A thorough understanding of cable health will also inform decisions related to the timing and type (weight) of deck replacement, often the most costly and disruptive work that a suspension bridge owner will undertake.

A practical understanding of cable wire behavior and overall cable health should also drive routine maintenance activities, including worker training across multiple trades and disciplines. This will ensure that power and communication systems, drainage, and other civil works all function to sustain long-term suspension system reliability.

Conclusion

There are approximately fifty main suspension bridges in the U.S. with span lengths greater than 700 feet. About fifty-percent of these bridges are over 75 years old. Coupled with an average bridge sufficiency rating of approximately 46 out of 100, suspension bridge owners are challenged with repairing, rehabilitating and preserving these critical assets – particularly during a time when there is a lack of long-term transportation funding.

Cable corrosion on suspension bridges is insidious. Corrosion will begin slowly and may not be readily apparent through external examination of the cables. By the time the cables are opened for internal inspection, significant corrosion may have already occurred. Of even greater concern is that wires may have already cracked and a number may already be broken, leading to reduced cable reliability and strength.

Unfortunately, cable corrosion cannot be reversed; however, through an active cable and bridge management strategy, main cable dehumidification can be leveraged to practically arrest corrosion in the cables and prolong the life of a major infrastructure asset.▪

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