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You Can't Judge a Cable by Its Cover

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"Getting to the heart of the matter" is a good philosophy to adopt when evaluating suspension bridge cables.

THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM (NCHRP), IN 2004, PUBLISHED THE FIRST-EVER STANDARDIZED GUIDELINES FOR INSPECTING AND EVALUATING SUSPENSION BRIDGE PARALLEL-WIRE CABLES. A report on background research accompanied the book, concluding a four-year effort by Weidlinger Associates to develop a nationally recognized procedure. It was a significant milestone in the battle to extend the service life of cables on U.S. bridges, the majority of which are more than 50 years old and carry increasingly heavy traffic.

Less conservative and rigorous techniques, based on limited data and unexplored assumptions, can lead to overestimations of strength or unnecessary repairs. Weidlinger's method is statistical, encompassing other methods that depend on minimum or average wire strengths. When a bundle of wires is tested in a machine, the wires break one at a time as the strain is increased. By exploiting this phenomenon, Weidlinger's strength calculations rationalize the process and give owners of aging bridges a crucial bonus: information about how the cable is likely to fail.

The cables on Scotland's 3,300-ft-long Forth Road Bridge were recently inspected for damage.

Survey Says

The cables are the major carrying elements on a suspension bridge. They are constructed of many thousands of individual wires, usually laid parallel to one another and clamped at points where the suspenders connect with them to support the deck. The wires are galvanized or otherwise protected, but are susceptible to corrosion and an even more sinister form of degradation: the development of transverse cracks. In a survey of U.S. and Canadian suspension bridge owners, Weidlinger confirmed that the degree of internal corrosion can vary widely, from zinc deterioration to the presence of broken wires inside the cable. The survey results indicated that inspections are limited and inconsistent (wrapping removed for several inches to full cable length), but sufficient to correlate degree of damage (major vs. minor) with bridge age at inspection, leading to the conclusion that early inspection is best.

No Crystal Ball

There is no shorthand method or engineer's sixth sense that can predict cable condition. The only foolproof method is to unwrap the cable and do sample wire testing, because even bridges with perfectly formed and well-maintained cables surprise inspectors. Weidlinger's experience inspecting bridge cables since 1978 confirms that it is prudent to begin at 30 years or soon thereafter and make sure the inspections are complete enough to determine the type and

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severity of deterioration. Early intervention is always more effective, because the type of protective measures to be implemented, if needed, and the schedule of future inspections can be better tailored to the conditions on a particular bridge. That's late-arriving advice, as most existing suspension bridges have passed the 30-year milestone; because of the costs involved, rare is the bridge inspected before 60 years.

Forth Road Bridge

A recent investigation of the cables on the Forth Road Bridge in Scotland should persuade everyone to rethink the one-size-fits-all, let's-wait-to-the-last-possible-minute approach.

Alastair Andrew, general manager and bridge master of the Forth Road Bridge, first learned about Weidlinger's work during one of many presentations made at national and international conferences. Andrew was impressed enough to think it wise, if overcautious, to inspect his 40-year-old cables. Based on their excellent external condition, he surmised they were "a long, long way from wires breaking" and would pass inspection easily. One of the longest suspension bridges in Europe, the Forth spans 3,300 ft and carries 24 million vehicles a year in four traffic lanes. Its construction in 1964 ended an 800-year history of ferry-boat transport across the Firth of Forth. Weidlinger led the investigation and trained engineers from the UK firm Faber Maunsell in its new standardized technique; testing was conducted by Bodycote, Ltd.

The process began with a cable walk to observe the condition of the wrapping. The cable appeared to be well maintained: There were no visible water leaks, rust stains, or bulges, although the presence of ridges indicated that wires were crossed and susceptible to rust because of the voids they created. Next, a total of ten cable panels were unwrapped. To be economical, several feet of wrapping wire were left in place at one end of each inspected panel, so that only one machine was required for rewrapping. That still left a generous 55 ft per panel for internal inspection. Eight lines of wedges were driven into the center of the cable, and the condition of visible wires was recorded by inspectors. Much to everyone's surprise, broken wires were found to a six-wire depth, as well as a considerable number of corroded wires. Eighty wires were removed and rigorously tested. The wires were graded according to the corrosion stages developed by Hopwood and Havens (1984), from 1 (wire and zinc coating barely oxidizing) to 4 (more than 30% covered with brown rust). The data were used to estimate how many of the 11,618 wires in each cable were in each stage and how many were cracked.

Analysis confirmed that the cable had lost 8% to 10% of its strength. Early estimates before the number of cracked wires was known suggested almost double that loss, based on experience with other bridges. Testing revealed fewer cracked wires than anticipated and confirmed that every bridge is unique in this regard. Cracked wires are the major determinant in calculating cable strength. Unfortunately, cracks are not visible during inspection. When broken wires are found, cracks are likely to exist in unbroken wires; but they only become evident after testing, when the failure surface is inspected under a microscope. When wire sample selection and testing are as rigorously specified to yield consistent and sufficient data as they were on the Forth Road Bridge, it ensures confidence in the conclusion. An owner armed with a statistically clean set of data and a safety factor rating can plan and budget more efficiently. As more inspections take place, a central database of test results would be invaluable to keep track of cable strength results versus age and help engineers estimate future deterioration rates more precisely.

Digging Deeper

One cannot safely predict cable condition from observation alone, nor how much strength loss can be sustained on a particular bridge. There is no rule about permissible strength loss, but a safety factor below 2 spells trouble. Even this number is not absolute when there is careful monitoring. Based on the sobering experience with the Forth Road Bridge, another suspension bridge in Great Britain was inspected and yet another is under consideration. The NCHRP guidelines are also being used to assess cables on the Bear Mountain Bridge in New York, among other spans. MSC

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Cable Dehumidification

Although early inspection may be controversial, the cure is not. Dehumidification at the early stages of deterioration extends cable life, as does improving the wrapping to prevent water from entering. Acoustic monitoring to detect breaking wires and dehumidification using the Japanese system of dry-air injection for prevention are being implemented on the Forth Road Bridge in Scotland. Both cables should be water-free by late 2009 or early 2010. The bridge continues to be monitored for further wire breaks.

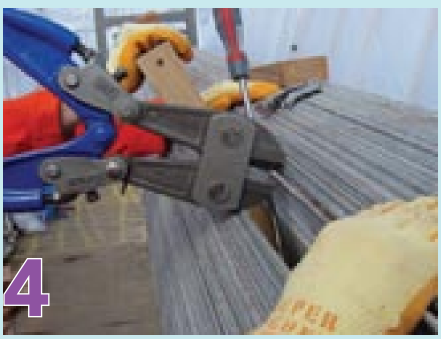
Close-up view of cable corrosion on the Forth Road Bridge.

All Wrapped Up

Here's what's involved in inspecting and repairing the cables for Scotland's Forth Road Bridge.

The existing wrapping is removed from the cable.

Wedges are driven into the center of the cable so that they can be inspected.

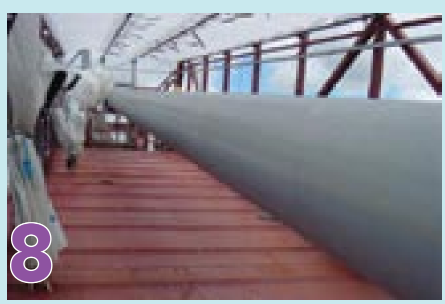


A sample wire is cut and tested.

New wires are installed as necessary.

The cable is recompacted…

…rewrapped…



…and repainted.