Corroded Suspension Bridge Cables: Some Lessons Learned

David COOPER
Technical Director
Flint & Neill
London, UK
d.cooper@flintneill.com

David Cooper graduated from the University of Cambridge in 1972. He has been with Flint & Neill for over 35 years. He has worked on many long span bridge traffic load models; and on main cable strength assessment for UK suspension bridges

Summary

This paper presents some observations on current methods of strength assessment of corroded parallel wire cables in large suspension bridges. It will present views about aspects of the current methods of strength assessment in general, and the NCHRP 534[1] approach in particular.

Keywords: suspension bridges; cables; strength; corrosion; dehumidification; wire; cable wrapping.

1. Introduction

Many suspension bridges cables have been internally inspected, often to expose considerable corrosion and many broken wires. The methodology presented in NCHRP 534 has been widely used in the USA and UK to provide estimates of cable strength. The document is probably the closest we have to a recognised peer-reviewed Engineering Code of Practice; although it presents some difficulties to its users.

2. NCHRP 534 Issues

2.1 Wire Classification

NCHRP 534 classifies wires in stages based on the amount of corrosion visible to the inspector. These are used to provide four different wire strength models. Different proportions of these are then used in strength models for different cable panels. However, wire corrosion is a continuous process and wire strength should be modelled by a continuous distribution. A continuous frequency curve will give very different predictions (especially at extreme values near its tail) than will a mixed distribution comprising a set of overlapping frequency curves. Continuous functions should not be used to model mixed sets of data.

2.2 Minimum Wire Strength between Cable Bands

Short specimens are tension tested, and the sample mean μ and standard deviation σ are found. NCHRP 534 then defines the estimate of the smallest tensile strength from a long chain of such specimens between any pair of cable bands is given by $x = \mu + \Phi^{-1}(L_0/L).\sigma$, where $\Phi^{-1}(L_0/L)$ is the inverse of the standard normal cumulative distribution (the normal CDF). This fraction L_0/L might be 1/60 in this case; for which the expectation, x, is at $\mu - 2.2\sigma$. However, this is not correct. The true 'expectation' lies at the centre of gravity of the total area of the normal CDF below that point and is closer to $\mu - 2.4\sigma$.

2.3 Wire strengths based on Classification

The lengths of wire used to provide test specimens usually contain wires in varying condition along their lengths. The sample strengths are thus from mixed statistical populations. The wire strength models end up with too many values in the lower tails of their frequency distributions. This unnecessarily reduces the theoretical cable strength.

https://doi.org/10.2749/222137813806521441

2.4 Cracked Wires

Wire tensile tests have shown that some wires break at points where pre-existing 'thumbnail' defects already exist. NCHRP 534 assumes that wires with such defects are 'cracked wires', and treats them very differently from the others. However, micrographs indicate to us that 'cracked wires' would be better described as having 'crack-like corrosion defects'; in which case they should be treated as other wires. This is very important since the theoretical cable strength is very sensitive to the numbers of cracked wires, and the numbers of such wires are very difficult to establish with any confidence.

2.5 Effect of Differing Wire Diameters

If we follow the recommended procedure of taking independent models of area lost by corrosion and material strength we obtain a wider dispersion in the resulting wire strength model than we see in the original strength data. Therefore conversion of tension test failure forces to stress units appears to be both over-complicated and misleading.

2.6 Strength Redevelopment

The clamping action of the cable bands used to support suspender ropes allows some of the load in a broken wire in a cable panel between one pair of bands to be re-established in the adjacent panels. But NCHRP 534 takes no account of the effects of any cable wrapping system. Typically, one wire break reduces the strength of as many as 5 cable panels between cable bands; so the theoretical capacity of a cable is very sensitive to the ‘redevelopment length’ due to cable band friction. However, if wrapping wire is effective, this would greatly reduce the ‘redevelopment length’ and increase the theoretical cable strength. This effect has been theoretically quantified in a paper by Raoof and Huang[2]; and it would appear to merit experimental investigation

2.7 Wire Failure Mechanism

Some bridges have recently had their cables wrapped using a heat-cured polymer system. In one case an acoustic monitoring system was active during the period of cable heating, and recorded more wire breaks than the total before or since. We believe this was because a 100C temperature rise expanded the wrapping wire enough to remove the clamping action, which altered the tensile loading condition for the wires from 'displacement control' to 'load control'. Wires under true displacement control conditions will all be able to develop their full aggregate strengths as cable strain increases. If this is the normal condition of a wire-wrapped suspension bridge cable, NCHRP 534 analysis is not necessary and the cable will be very much stronger than NCHRP 534 would indicate.

3. Conclusions

NCHRP 534 provides very valuable guidance to those seeking to assess the strength of suspension bridge main cables. Aspects such as the effectiveness of wrapping wire and the benefit (or otherwise) of using polymer wrapping systems appear to be topics worthy of more research. The most useful test tension test information that the author has identified dates from the 1920's and although that work is clearly reported it leaves scope for further investigation; particularly in tensile testing bundles of parallel wires with varying degrees of wrapping wire tension, but also in the effects of lateral pressures on the strengths of wires in deflector saddles.

4. References

[1] MAYRBAURL R.M. and CAMO, S., “Guidelines for Inspection and Strength Evaluation of Suspension Bridge Parallel Wire Cables”, *National Cooperative Highway Research Program*, Report 534, 2004.

[2] RAOOF M., and HUANG Y P., “Wire Recovery Length in Suspension Bridge Cable”, *ASCE Journal of Structural Engineering*, Vol. 118, No. 12, 1992, pp. 3225-3267.