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INTEGRITY ASSURED

Identifying the appropriate testing regime is very important for cable systems, particularly in terms of corrosion resistance, report **Scott Wyatt**, **Quan Gan** and **Thomas Weinmann**

Standards governing testing procedures for stay cable systems are surprisingly diverse. Various organisations around the world have developed different specifications to govern the design, testing, acceptance, installation, qualification, and maintenance of stay cable systems. In addition, most owners develop their own project-specific testing specifications that combine requirements gleaned from multiple standards with others they define themselves.

In particular, tests required to verify the integrity of corrosion protection systems vary considerably between international specifications. Because protecting stay cables against corrosion is critical to extending service life, since 1998 international cable acceptance criteria have focused on verifying the performance of corrosion protection systems.

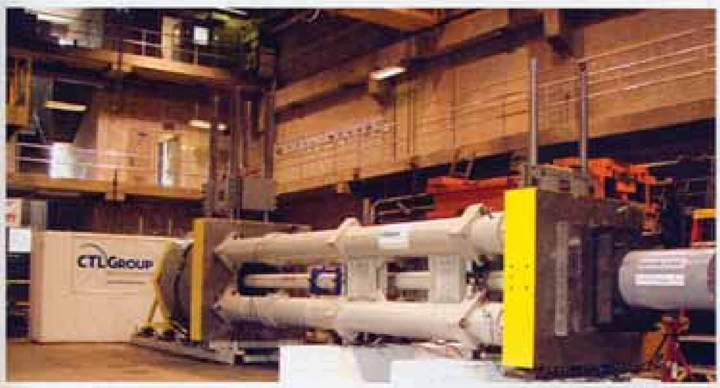
Cable systems and their individual components are tested extensively to assess both strength and serviceability. Testing verifies that the design assumptions are valid - or invalid - for a particular system by ensuring that the material properties and performance characteristics fall within accepted tolerances established in the specifications. Two specifications that are used as a basis for testing are the USA Post Tensioning Institute's *Recommendations for stay cable design, testing, and installation* and the International Federation of Structural Concrete (FIB)'s *Bulletin 30: Acceptance of stay cable systems using prestressing steels.*

One example of the disparity in testing requirements can be seen in comments in Bulletin 30 about leaktightness testing: 'The procedure specified in the PTI recommendations was also considered but was felt to insufficiently represent the relevant effects of movements and temperature and therefore, was not retained here.' There are also specific differences in the tensile and fatigue tests required by Setra/CIP, PTI, and FIB. Such discrepancies can cause problems when the test procedures draw on various specifications. Unless the testing agency is certified and proficient in performing all the specified test procedures, keeping the project on schedule may be difficult.

A recent illustration was the testing for the cable system for Stonecutters Bridge in Hong Kong, which was carried out by CTL Group. The 1018m-long main span of this bridge will be one of the world's longest when it is completed, and the single-tower, asymmetrical fan-type bridge has more than 100 cables which support the deck.

The bridge could be regarded as truly international; the initial concept by Halcrow, Flint & Neill Partnership and Dissing & Weitling was developed to detailed design by a joint venture of Arup and Cowi; the cable systems were designed by Nippon Steel Corporation in Japan and manufactured in China; the specifications were written using US and French criteria; and the testing was performed in the USA. The owner, Hong Kong Highways Department collaborated with Arup to develop its own stay cable testing specification, because of the extreme environment in which the bridge will be built. The fatigue and tensile tests were adopted from those outlined in the PTI recommendations [4th edition 2001] while the watertightness test was specified per Setra/CIP's *Cable stays - recommendations of the French interministerial commission on prestressing.*

CTL Group was able to draw on its prior testing knowledge and experience to accommodate the various procedures required; firstly by re-orienting its stay cable test frame, which has the world's highest capacity. This was to accommodate the length of the specimens, and provide a workable arrangement for the watertightness test.



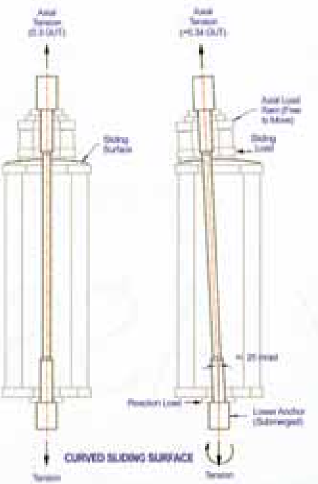
Far left: CTL reoriented its high-capacity fatigue test fixture to a horizontal configuration to accommodate the 8m-long cable specimens

Left: the fixture used for Setra/CIP watertightness testing holds the cable specimen at a 30° angle

The Stonecutters Bridge specification required a total of 11 tests for the parallel wire strand cables with the sockets and socket assemblies: five for fatigue, five for tension, and one for watertightness. The wires were standard 7mm diameter and the sockets were of the bond type containing epoxy resin, steel balls and rock dust. The tensile and watertightness tests were performed on 5.4m-long specimens, while the fatigue test specimens were 8m long. The diameter of the test specimens varied from 96mm to 144mm and contained from 187 to 421 individual wires. The nominal breaking loads provided by the manufacturer ranged from 12.7kN to 28.7kN. The fatigue tests and tensile tests were carried out in two CTL cable test frames. One test frame has maximum static capacity of 28.4MN and maximum dynamic capacity of 10.7MN. The other frame has static capacity of 42.6MN and dynamic capacity of 16MN.

The specification required the tensile test to establish the load/extension relationship for each of the test specimens within ±5% of 200,000MPa. At least three of the specimens were to be loaded to failure, which must occur within the central portion of the stay cable ▶

Schematic illustrates loading imposed during watertightness tests



specimen, away from the socket. Elongation was measured by a displacement transducer, and the sockets were instrumented to observe any possible socket draw. Accelerometers were used to detect any wire breaks. The cables were loaded incrementally to 1400MPa where final elongation readings were taken, then four of the five specimens were loaded to failure to establish the actual ultimate tensile strength. In general, after a wire breaks the load is redistributed among the other wires and the cable can withstand further loading. After a number of additional breaks, the load-carrying capacity will begin to diminish and the test is concluded.

The fatigue specimens were tested up to 796MPa with a stress range of 200MPa for 2,000,000 cycles. In addition, a constant angular deviation from the centre-line of 10mrad was applied during the test to reflect actual service conditions. Once this was complete, the specimens were loaded statically to failure. The cable was required to achieve the greater of 92% actual ultimate tensile strength or 95% specified minimum ultimate tensile strength after the fatigue test. According to the specification, no more than 2% of wire breaks was permitted and no failure of the sockets was to occur during the fatigue test. Due to the length of the cable specimens and lateral deviation requirement, the test frame had to be re-oriented horizontally. This allowed for a roller assembly, which was free to move along the axis of the cable, to be used to induce the required rotation of the cable. The socket ends were 'free' to rotate in conjunction with the cable to maintain a 90° angle between the socket assembly and cable. Upon completion of the fatigue test, the cable was examined for wire breaks, fretting of the wires and damage to the socket assemblies.

The watertightness test was designed to demonstrate that there is no ingress of water through the corrosion protection system and that the connection between the HDPE sheathing and the socket is watertight. The corrosion prevention system for the cable consisted of HDPE sheathing and galvanised wire. For the watertightness test, the cable specimen was simultaneously subjected to both bending and tension, while submerged in a dye solution that was alternately heated and allowed to cool. The specimen was fabricated with dye-indicating paper embedded on the wires, below the heat shrink polyethylene and below the sealed joint, which would be examined at the conclusion of the test. The watertightness test took about six weeks.

To perform this test, one end of the specimen was sealed in a steel tube with its anchorage and fittings. The tube was then inclined to approximately 30° and filled with the dye solution that was circulated through a heat exchanger. Next, the cable was loaded between 0.2 and 0.5 guaranteed ultimate tensile strength at room temperature for ten cycles, and then unloaded. The cable was then reloaded to 0.3 guaranteed ultimate tensile strength (6,029kN for a 295mm diameter cable) for the remainder of the test. The dye solution was subjected to two thermal cycles per week, which ranged from 20±5° C to 70±5° C. The free end of the cable was moved back and forth 100mm for total 1000 cycles, to simulate bending of the cable when the water is both hot and at room temperature. Upon completion of the test, the cable was dissected and the absorbent paper was examined for traces of dye. The protective coating is considered adequate in protecting the cable from water intrusion if no dye is present

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