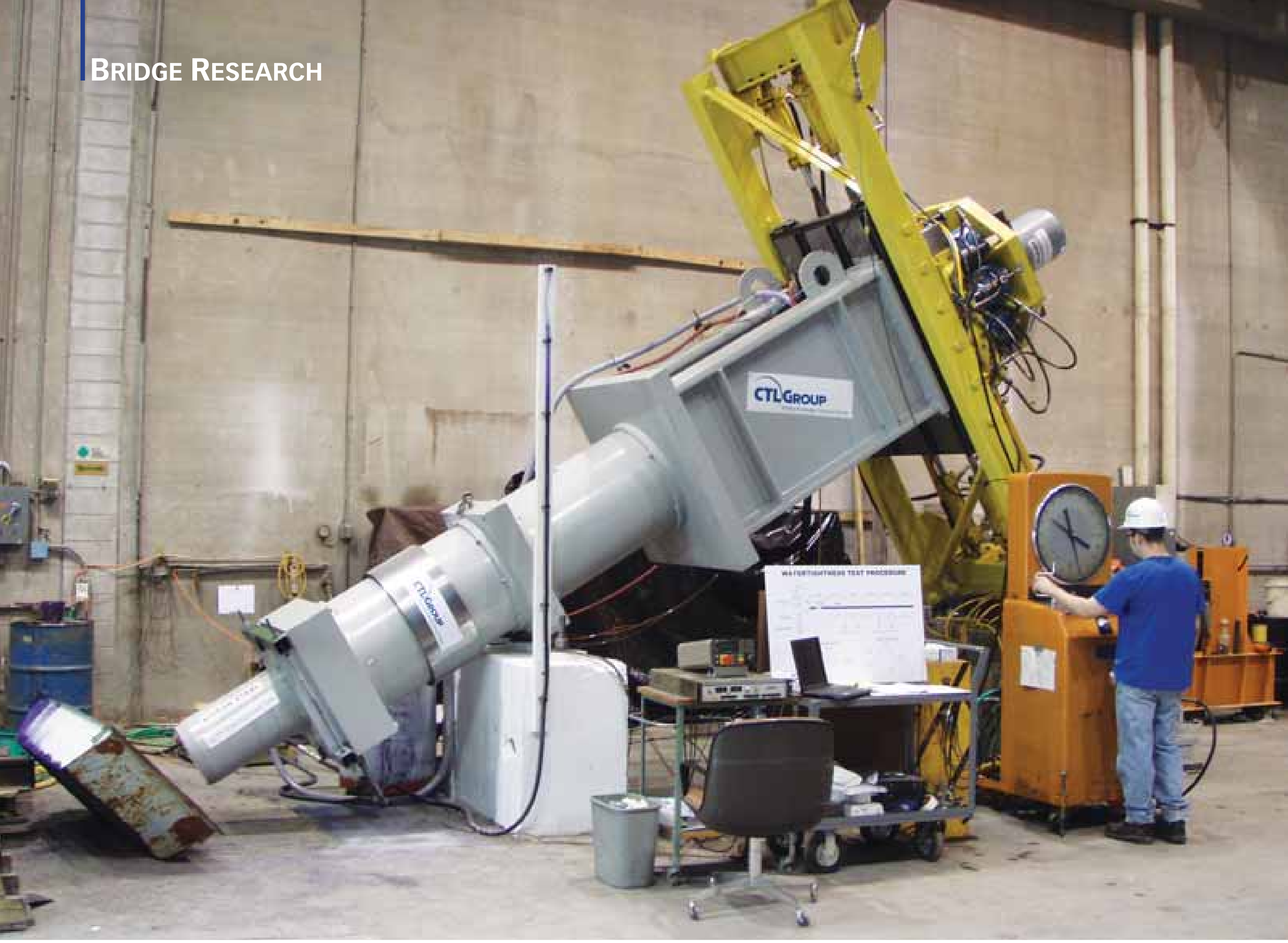


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# Gaining acceptance

## Testing of stay-cable systems assures durability

Many designers today choose stay-cable systems for medium- to long-span bridges due to their structural efficiency, durability and aesthetic appearance.

Both the harp and the fan classes of cable-stayed bridges exhibit a simple, clean elegance that is appealing to the bridge designers and the governmental authorities funding the new bridge construction. As part of the qualification process, a systematic testing program is generally instituted to ensure the healthy, safe and long service life of a bridge. The protocols within the guidelines encompass the cable system as a whole as well as its individual components, testing extensively to characterize strength and serviceability, with particular emphasis on the fatigue behavior and the performance of the corrosion protection system.

This article describes the three current stay-cable-testing guidelines and their application to current bridge design and construction. The article also highlights emerging trends in stay-cable testing for use with the next generation of bridges. CTLGroup's work in the specialized field of full-scale stay-cable acceptance testing has contributed to the evaluation of better cable design and fabrication practices.

### Following guidelines

Although there are three major guidelines that govern stay-cable testing, most designers or owners rely on either the Post Tensioning


As the required design service life of cable-stayed bridges is now often 100 years or beyond, characterizing structural behavior and durability through the use of testing programs is an important step in providing confidence in the long-term performance of the bridge.

Institute's (PTI) "Recommendations for Stay Cable Design, Testing, and Installation" or the International Federation of Structural Concrete (fib)'s "Bulletin 30: Acceptance of Stay Cable Systems Using Prestressing Steels" as the basis for stay-cable design or development of the testing requirements included in the particular bridge specifications.

The third guideline, Setra/CIP, "Recommendations of French Interministerial Commission on Prestressing," is frequently used to provide specific additional testing procedures, such as dynamic deviation to simulate flexural effects on the cable fatigue tests and fatigue test parameters (stress range and upper stress load) for extradosed bridges (an extradosed bridge employs a structure that is frequently described as a cross between a girder bridge and a cable-stayed bridge).

Both PTI and fib require the cable specimen to be fatigue tested to 2 million cycles with an upper stress of 45% minimum ultimate tensile strength (MUTS). At the conclusion of testing, no more than 2% of wire breaks and no failure of the sockets are allowed. In the subsequent tensile test after the fatigue test, the cable must reach the larger value of 95% MUTS or 92% actual ultimate tensile strength (AUTS). No failure of the anchorage is allowed.

There are two major differences between the PTI and fib recommendations. The first difference is the specified fatigue stress range, which is calculated based on tensile element mechanical behavior and national design codes. PTI requires a stress range of 159 MPa for a parallel strand system and 194 MPa for a parallel wire system, while fib specifies a stress range of 200 MPa for both parallel strand and parallel wire cables. Fib states that improved materials make a stress range of 200 MPa for strand cable possible. The second significant difference between PTI and fib is the elongation requirement for the subsequent tensile test. Fib specifies an elongation of 1.5% at the maximum load, while PTI does not have a specified elongation.

In many cases, bridge designers specify a combination of testing procedures from both the PTI and fib guidelines. Specifically, in Asian countries, most of the bridge specifications reference the PTI recommendations with a stress range of 200 MPa for the strand system, which is identical to the stress range in fib. Often the designer may not refer to fib directly due to the elongation requirement, or because PTI is still the most commonly used stay-cable testing guideline. In recent years, almost all of the design specifications for the bridges in Asia and Europe demand a stress range of 200 MPa for strand cable. Testing facilities have been requested to load the stay-cable specimen in the subsequent tensile tests up to 2% elongation, which has been adopted from the tensile tests for post-tension systems.

Setra/CIP and fib developed a fatigue-testing procedure that considered not only the fatigue behavior in

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the axial direction of the cable, but also the bending effect caused by installation tolerances of anchorages and other sources of bending, such as cable vibration. Prior to PTI 4th Edition (2001) guidelines, the fatigue tests were performed with only axial loading, while the flexural effects experienced by the system in the field were disregarded. Both the 5th Edition (2007) and 6th Edition (2012) of the PTI guidelines account for bending effects and suggest the anchorages of the stay-cable specimens be supported on wedge-shaped shim plates with 10 mrad (0.6°) angular deviation and that the anchorages be oriented in the test frame in such a way as to create an S-shaped cable profile. Therefore, the latest editions of PTI (5th and 6th editions) are in accordance with fib Bulletin 30.

CTLGroup has performed several testing programs that required the fatigue test with wedge-shaped plates and a stress range of 250 MPa, 25% higher than the stress range specified in current fib. This testing specification was adopted in the bridge specification for the Hong Kong-Zhuhai-Macao Bridge (HZMB) which is currently under construction. The reasons for such a high stress range may be due to the type of bridge being constructed and/or a bridge specification adopting requirements from a local standard, as was the case with HZMB, which has a service life requirement of 120 years and refers to a Chinese standard (JTT775-2010, "Stay cable of parallel steel wire for large-span-cable-stayed bridge").

In addition to the constant angular deviation of 10 mrad (0.6°) created by the wedge-shaped shim plates as in PTI and fib, Setra/CIP has recommended the tested cable systems be exposed to a dynamic deviation, in which the angles of deviation are generated from the anchorage centerline using an actuator connected with the middle of the cable specimen through a deflection collar. The maximum deviation angle is 10 mrad (0.6°) and the minimum deviation angle is 0 mrad (0°). In the constant angular deviation, the deviation is kept constant on the anchorages throughout the fatigue test and the subsequent tensile test, and all anchorages are under deviation. In the dynamic deviation, the cable free length is exposed to the deviation only during the fatigue test, not in the subsequent tensile test. Since the anchorages maintain the alignment of the cable during fatigue testing, the boundary conditions in the fatigue tests with dynamic deviation closely mirror the performance of the cables in service. The stress at the anchorage caused by the dynamic deviation (cyclic rotation) will be higher than the stress by the static deviation (wedge plates).

A relatively new type of bridge has emerged, known as an extradosed bridge. The North Arm Fraser River Bridge in Vancouver, Canada, was the first extradosed bridge in North America. The Pearl Harbor Memorial Bridge (locally known as the Q-Bridge) in New Haven, Conn., is believed to be the first extradosed bridge in the U.S. Currently only one (Setra/CIP) of the three guidelines have testing recommendations for extradosed bridges. However, fib Bulletin 30 is in the process of developing a guideline, and the latest edition of PTI (6th Edition, 2012) implicitly specifies test ranges similar to those generally accepted for extradosed bridges, "The third cable specimen shall be tested for 2 million cycles at an upper stress of 0.55 fs' and a stress range of 6.5% fs' for strand or bars, 7.5% fs' for wire." Setra/CIP clearly provides the axial fatigue range of 140 MPa, no angular range for flexural effect, and an upper fatigue load of 55% MUTS. These values are typically accepted for testing cables from extradosed bridges.

## Seeking protection

In addition to the fatigue tests, a critical issue in stay-cable design is the corrosion-protection system. Severe corrosion has been observed on numerous stay-cable bridges in the U.S. and throughout the world. Typical corrosion-protection systems for stay cables include a high-density polyethylene (HDPE) sheathing, epoxy coating, galvanizing and grease or wax. The water tightness test, or the leak test, was designed to demonstrate no ingress of water through the corrosion-protection system and that the connection between the HDPE sheathing and the socket was watertight.

All three standards have different testing procedures for the corrosion-protection system of large cables.

The Setra/CIP water tightness test procedure was adopted in the bridge specification for Stonecutters Bridge in

Hong Kong, China, which is the third longest cable-stayed bridge in the world. The water tightness test for this bridge was performed in 2006. The cable was inclined to 30° from horizontal and placed inside a tube filled with dye solution at a water head pressure of 2 meters. First, the cables were loaded for 10 cycles between 20% MUTS and 50% MUTS in the axial direction at room temperature. The cable was then stressed to 30% MUTS and held for the entire six-week duration of the testing. From the second week to the fifth week, the water temperature was varied between 20°C and 70°C two full cycles per week. Additionally, 250 angular deviation cycles were applied at the top anchorage (free end) in the transverse direction by six lateral hydraulic rams, simulating the bending of the cable. The stroke in the transverse direction was 250 mm. This cycling in the transverse direction also was repeated weekly from the second week to the fifth week.

Upon completion of the water tightness test, the cable was dissected and examined for traces of dye within the sealed section. The corrosion protection system was considered adequate if no dye was found.

The fib leak tightness test is a simplified version of the Setra/CIP water tightness test with a shorter test duration (around eight days) and a 3-meter water head.

The PTI leak test is performed on the smallest cable specimen of a series of three cables, which is fatigue-tested for 2 million cycles prior to the leak test. The PTI leak test itself is a much simpler testing procedure and excludes consideration of the factors of changing temperature and lateral movement of the anchorage. The cable specimen is placed in a chamber with 3-meter water head on the anchorage assembly continuously for a period of 96 hours at room temperature.

The stay-cable testing program is not only for system acceptance, but also for quality control (QC) and quality assurance (QA) of the entire system. Although the design of one specific cable system may not change for decades, the characteristics of the components within the system—such as the quality of the raw materials, fabrication procedures and even the QA/QC of the component manufacturers—change constantly. As a result, a comprehensive testing program for a specific cable-stayed bridge is necessary.

As the required design service life of cable-stayed bridges is now often 100 years or beyond, characterizing structural behavior and durability through the use of well-executed testing programs is an important step in providing confidence in the long-term performance of the bridge. R&B

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