# Structural Rehabilitation

renovation and restoration of existing structures

n 2009, maintenance workers at Canada Place observed brown spots on several stay cables of its large fabric membrane roof. Based on this observation, Canada Place Corporation, the authority for maintaining the facility, launched an evaluation of the cables and the protective coating of the wires that make up the cables.

Wires that make up the cables are protected against corrosion as they generally are used at high-stress levels. Corrosion of the wires causes surface discontinuities that can result in stress risers and reduce the load capacity of the wires and, thus, the cable.

#### Canada Place

Canada Place was built in 1986 in Vancouver, British Columbia. It houses a hotel and convention center that also serves as the terminal for cruise ships that frequently dock in Vancouver's

harbor. It is owned and operated by the Vancouver Fraser Port Authority, which is responsible for the stewardship of federal port lands in and around Vancouver. The main fea-

ture of the building is a large tent-like fabric membrane structure that covers most of the convention center space (*Figure 1*).

The roof spans 170 feet and is 478 feet long. Its system of cable-stayed masts are spaced 80 feet apart and are 125 feet high. The masts anchor the ridge cables that support the membrane roof and are located along promenades at each side of the roof. The stay cables are anchored along the edge of the promenade and cross over it to the top of the masts (*Figure 2*). The stay and ridge cables are 27%-inch diameter wire strands and are comprised of one hundred 1/4-inch diameter wires. The ridge cables are positioned external to the fabric and thus are exposed to the environment. Stainless steel loops wrap over the cables and are bolted to a clamp system that holds the fabric (*Figure 3*). Due to the proximity to the salty sea water of the bay, a Class C coating (see below) was specified for all cables.

#### Cable Fabrication and Protection

Wires for cables are fabricated from high-strength steel that are rolled to a circular or Z-shaped section and then drawn through a mandrel to their final size. The cold working of the steel during this process increases the strength of the wires. A protective coating is applied after the cold working process.

There are several corrosion-resistant systems for cables. The most common one is a process of coating its wires. Various protective wire coatings include epoxy, zinc-aluminum-mischmetal, and pure zinc coatings, though the zinc coating is by far the most common one. Three levels of zinc protection are listed in the American Society for Testing and Materials ASTM A475-03 (*Standard Specification For Zinc-Coated Steel Wire Strand*) and ASTM A603 (*Standard Specification For Zinc-Coated Structural Wire Rope*), the specifications for strand and rope cables.

Class A is the most widely used and sufficient for the most common applications. Class B is used



Figure 1. Canada Place.

### Repair of Corrosion Protection for Cables

A Case Study

By Paul A. Gossen, P.E., F.ASCE

Paul A. Gossen is a Member of the ASCE Committee 19 – Structural Application of Steel Cables for Buildings, as well as the ASCE Committee 55 – Tension Membrane Structures Standards Committee. He can be reached at **pag@geigerengineers.com**.







Figure 2. Promenade along the convention center.

in more corrosive environments such as frequent water exposure. It consists of a thicker zinc coating on the wires. Class C, with an even thicker zinc coating, is prescribed for the most severe corrosion-causing environments. Though Class B and C coatings have better

corrosion resistance than Class A coatings, their coating is less abrasion resistant than Class A coatings.

Cables can be fabricated with a combination of Class B or Class C for the outer wires and Class A for the interior wires, or Class A, B, or C for all the wires of the cable.

Thick layers of zinc coating, like the one used for the wires of Class B and C, are generally deposited through an electrolytic process, while the coating for the Class A protection is commonly applied through a "hot dip" zinc bath. The temperature of the zinc bath, 840°F, does not change the metallurgical structure of the steel that was obtained during the cold deform process because the exposure time is very short. Thus, there is no or very little loss of strength in the wires.

#### Cable Observations and **Remedial Measures**

The observations of the brown spots on the stay cables in 2009 caused concern that the cables may be corroding. As a result, the Canada Place Authority launched a detailed investigation to evaluate their condition. Unfortunately, there is no reliable method to detect corrosion within a cable other than through destructive testing. Destructive testing (cutting the cable

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Figure 3. Ridge cables supporting the fabric.



Figure 4. Depleted zinc coating on cable.

open) implies that it must be replaced. Thus, the option is either just to replace the cable outright or to visually inspect them for signs that could indicate corrosion of the hidden inner wires. Rust stain (bleeding) or bulging

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from expanding corrosion can be an indication of corrosion within the cable.

A close examination of the surface of the cable showed no rust stains or bulging, but the zinc coating was delaminating in little flakes on the exposed surfaces of the outer wires (Figure 4, page 25). The area of the wires, where the coating had delaminated, turned brown, indicating the onset of corrosion. There was no observed cratering or pitting from corrosion. Based on these findings, the consultant recommended using a cold galvanizing process that called for a recoating of the cables with a zinc-rich compound. A detailed preparation procedure and specification were drafted. It specified that the cables were wire-brushed with a soft wire wheel, with the brushing applied in the same lay, the twist direction of the wires, to avoid creating any scarring that could cause stress risers. The cables then were to be cleaned by air blasting and wiped to remove any dust. The surface had to be free of any contaminants that could diminish the bond of the zinc compound. The specification called for a coating thickness of 2.5 to 3.5 mils with 95% metal zinc content after drying.

The execution of the treatment followed in 2010. The stay cables on one side of the roof were treated first because both promenades could not be closed off due to fire escape considerations. The limited loading capacity of the promenade slab did not allow using large equipment with the required reach to cover the full length of the cables. As an alternative, scaffold towers that reached the top of the masts were erected. Tarps wrapped these towers to protect the work from rain and wind during the coating process. A concern with using a coating was the sealing of all surfaces. No coating is 100% waterproof over time, particularly cables composed of round wires. Even though there may be fill materials, such as grease or mischmetal to fill the voids between the wires of the inner construction, there can still be areas in which moisture may accumulate. Thus, pinholes in the coating were deliberately included to allow the venting of the inner structure of the cable.

Two years later, the stay cables on the other side of the roof were treated. During this work, brown spots were noticed on the exposed ridge cables of the roof. Again, an inspection was conducted in 2015 to evaluate these cables. The inspection was not as straight forward as that of the stay cables. Unlike the stay cables that could readily be observed from the floor of the promenade, these ridge cables were not as readily accessible. Not only do they span away from the promenades, but they also have a very steep incline at the masts. They start 125 feet above

the promenade's floor and span across the convention center. For the inspection, the owner engaged Pacific Ropes, a specialty firm that is equipped and experienced in inspecting cables. They accessed the ridge cables by climbing up the stay cables (Figure 5). The inspection was conducted by taking pictures of the ridge cables for evaluation. The pictures revealed that the same condition existed as previously observed on the stay cables. Again, a recoating with a zinc rich compound was chosen as a remedial treatment.

The recoating of the ridge cables is scheduled for this year. The recoating process will be more difficult and tedious due to the difficult access to these cables. Also, the stainless steel loops that anchor the fabric clamps will have to be unbolted to reach the covered area for treatment. Care will have to be taken not to damage the fabric.

#### Possible Cause of the Coating Failure

What could have caused the flaking of the coating on the outer wires? As mentioned earlier, the wires had a Class C coating in which the zinc is electrolytically deposited on the wires. In the electrolytic process, zinc is bonded to the steel through adhesion. The flaking of the coating from the wires suggests a bond failure between the zinc and the steel. We rarely see this problem in Class A coating, which is the hot- dipped galvanization protection. During the Class A process, a steel zinc alloy layer forms that bonds firmly to the steel. Only steel with a phosphorus content higher than 0.03% has the tendency to flake.

The answer of the delamination may lie in the fabrication process of the wires. When drawn through a mandrel to obtain the high strength, the wires are lubricated. This lubrication needs to be fully removed for wires that are electrolytically coated so that a strong bond between the steel and the zinc is obtained. It takes more than a solvent to remove the lubricant. A solvent only dilutes the lubricant but does not remove it fully. In the Class A coating process, the wires are also cleaned, but any remnant lubricant burns off in the zinc bath.

#### Life Span of Cables

The coating failure was caught in time before any damaging corrosion occurred. Thus, the remedial measure of a cold galvanizing coating was applicable. The alternative would have been to replace the cables, which essentially would have shut down the facility for an extensive period. The coating of the cables in place allowed the facility to be kept



Figure 5. Inspection of ridge cable.



Figure 6. Applied coating after 6 years.

open, though minor inconveniences such as blocking of portions of the promenades were required. The treatment of the ridge cables will again require the closing of some sections of the promenade but less than when scaffolds were used to coat the stay cables.

Inspections of the coating of the stay cables that were coated in 2010 showed it to be in excellent condition (Figure 6). A coating with a cold galvanizing compound is not as durable as a coating of the wires by hot dipping or even electrolytic depositing, but it is a viable alternative to replacing the cables.

It is understood that the cables need to be monitored and that their recoating in the future may be necessary.