

**CATHODIC PROTECTION OF ICE SHIELDS  
ON THE CONFEDERATION BRIDGE  
NORTHUMBERLAND STRAIT CROSSING PROJECT**

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**ABSTRACT**

This paper presents the issues considered during the design of an impressed current type cathodic protection (ICCP) system for corrosion control on the submerged external surfaces of the steel ice shields on the piers of Confederation Bridge. General information and facts are presented on the Confederation Bridge and ice conditions in the Northumberland Strait. The challenges and cathodic protection (CP) system design solutions, associated with providing protection to the underwater CP components against ice damage, are discussed. The ICCP system is described including the different CP equipment arrangements utilized, based on the various pier configurations and construction methods. Results of the system effectiveness are also discussed.

Keywords: cathodic protection, impressed current, bridge piers, ice shields, ice environment, Confederation Bridge, Northumberland Strait

**INTRODUCTION**

In 1997 the Confederation Bridge which links the provinces of Prince Edward Island (PEI) and New Brunswick (NB) was opened. It is the worlds longest (12.9 km) continuous span bridge over ice covered water and is the only one of its class subjected to conditions as harsh as those that prevail in the Northumberland Strait. It is built in one of the windiest sites in Canada and must withstand the force of ice floes driven by tides, winds and currents through this restricted arm of the Gulf of St. Lawrence.<sup>1</sup>

The bridge piers (Figure 1) must withstand the forces of ice ridges, having an underwater depth up to 20 m, which form when ice flows collide in the strait. Accordingly, the bridge piers are designed to resist a maximum 3000 tonne force when exposed to large masses of compressed ice rubble. Typical ice formations are shown in Figure 2. Conical shaped ice shields, sloped at a 52 degree angle, are installed at the water line to minimize the force of ice impact on the piers. As ice is strong in compression but weak in tension, ice floes deflect, crack, and break when they ride up the side of the cone shaped ice shields. Ice floes are in effect sliced as they move past the bridge piers.

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Some ice shields include a 1 cm thick mild carbon steel (CS) barrier skin to prevent ice abrasion to the underlying concrete surface. Ice shields on piers installed during the later stages of bridge construction were made of ultra high strength concrete, and hence have no steel barrier skins on the outer surface.

Construction of staging facilities for fabrication of the precast concrete bridge elements commenced in 1993. During 1994 the first East Approach Piers and related ICCP equipment (anodes and reference electrodes) were installed on the PEI side. Some facts on the Confederation Bridge are outlined in Table 1.<sup>2</sup>

The bridge construction schedule was critical and close communication between the owner/operator, bridge designer, installation contractor and CP system designer was required to meet essential construction deadlines. Based on this communication process, unique CP system equipment arrangements were utilized throughout the bridge design/construction period to allow for the varied configurations of the East-PEI Approach, West-NB Approach and Main Bridge Piers.

### **THE NEED FOR CORROSION CONTROL/CATHODIC PROTECTION**

Carbon steel structures corrode when subjected to a marine environment. Corrosion control techniques are therefore, normally employed to extend their useful service life. Various methods of corrosion control are usually required for the above water and underwater portions of these structures.

Protective coatings are utilized above the water on the ice shields for atmospheric corrosion control. The underwater surfaces of the ice shields are also coated; however, the long term effectiveness of protective coatings is reduced considerably on surfaces subjected to the abrasive effects of ice formations in the Northumberland Strait.

Cathodic protection was chosen to control corrosion of the underwater surfaces of the ice shields. The two primary corrosion mechanisms encountered underwater are:

1. Differential aeration corrosion caused by tidal action would result in preferential corrosion of the ice shields just below the mean low tide level.
2. Galvanic corrosion caused by dissimilar environments would result from electrical contact between the ice shield and reinforcing steel. The surfaces of the ice shields immersed in seawater are the anode of this galvanic cell, and will corrode preferentially relative to the reinforcing steel in the concrete pier bases.

### **SELECTION OF CATHODIC PROTECTION SYSTEM TYPE**

The choice between a sacrificial or impressed current cathodic protection system was determined during the initial design stage. A study was carried out to evaluate the economic and technical comparison between the two types of systems.

An ICCP system was chosen primarily for the following reasons:

1. Lower cost over bridge design life (100 years).
2. Anodes having the same design life as the bridge could be installed during original construction, therefore eliminating the need to replace anodes.
3. If a main pier anode is damaged, it is easier to replace a lightweight ICCP anode rather than relatively heavy sacrificial anodes.
4. Suitability for remote monitoring data acquisition and control of output current.

### **SYSTEM DESIGN - BASICS AND FEATURES**

The final design of the CP system was affected by the three techniques utilized to construct the piers.

*East Approach Pier* ice shields were cast in-situ. Temporary steel sheet pile (SSP) cofferdams surrounded some of these piers to create a dry construction work space.

*West Approach Pier* ice shields were also cast in-situ similar to those on the PEI side; however, temporary earth cofferdams were utilized on some of these piers during construction rather than SSP cofferdams. Ice shield soffit forms used to cast foundation of piers in deep water (W10 to W14) increased the submerged area to be protected by more than 90%.

*Main Pier* ice shields were pre-cast on shore at the PEI staging facility. The ice shield and pier shaft, having a combined weight of up to 4500 tonnes, were transported to location and placed on the pier base as one unit.

It was evident that special precautions were necessary to prevent ice damage to the underwater ICCP system components. Most important of the measures taken to minimize the possibility of mechanical damage by ice formations are:

1. Anodes and reference electrodes on main piers were installed in recesses such that they were flush with the ice shield.
2. Anodes and reference electrodes on approach piers were designed to share the scour protection of the pier foundation.
3. Anodes on approach piers in deep water were installed in concrete boxes and the reference electrodes were installed in recesses similar to the main piers.
4. Where possible, ICCP system cables were installed within the concrete beneath the steel ice shields. Structure bond cables were embedded directly in concrete while all anode and reference cables were installed in non-metallic conduits.

In addition to special considerations for mechanical protection against ice damage to the underwater cathodic protection system components, the basic ICCP system design for the ice shields was based on the following:

1. Output ratings of the controlled current source (CCS) rectifiers were based on industry accepted recommended practices.<sup>3,4</sup> All rectifiers had an output voltage of 12 volts DC with a current output of either 80 or 150 amps DC.
  - Initial: 200 mA/sqm
  - Mean\*: 125 mA/sqm
  - Final: 130 mA/sqm

\*increased from 100 mA/sqm to 125 mA/sqm due to ice abrasion.

2. The design calculations assumed that the ice shields were uncoated below the high tide level owing to eventual deterioration of the ice shield protective coating system due to ice damage.
3. Additional current capacity was supplied to compensate for the current drain to reinforcing steel within the submerged portion of the pier bases.
4. A separate CCS rectifier was designed for each steel ice shield to provide individual output control and optimum protection.

Special design features were incorporated to optimize performance and minimize maintenance costs associated with the ice shield ICCP system as follows.

1. Mounting arrangement of anodes and reference electrodes on main piers were designed for minimum exposure to ice as well as ease of replacement.
2. In consideration of the harsh marine environment at the bridge site, the rectifiers and related cable termination enclosures were located in the utility corridor beneath the roadway; firstly, for protection of maintenance personnel doing work on the system and secondly, to minimize equipment exposure to the elements. A typical ICCP equipment arrangement in the utility corridor is shown in Figure 3.
3. Future remote monitoring and control of the operating parameters of each CCS rectifier is available using fiber optics cables already incorporated into the bridge design for traffic management and other purposes. In addition to

logging system operating parameters, the output current, output voltage and set potential for each CCS rectifier can be remotely controlled from a shore based computer terminal.

4. Dielectric shields were provided on the main piers around the impressed current anodes to optimize current distribution to the steel ice shields and minimize current drain to reinforcing steel within the underwater pier components.

## SYSTEM COMPONENTS

The primary ice shield ICCP system components are described below.

1. *Controlled Current Source (CCS) Rectifiers* were supplied in sealed/corrosion resistant NEMA 4X enclosures. Each CCS rectifier can be independently adjusted to operate in current, voltage or potential control mode.
2. *Splitter Box and Monitoring Box Enclosures* were also supplied as NEMA 4X to protect internal components from the marine environment.
3. *Main Pier Anodes* consisted of 3.2 mm thick platinum clad niobium/titanium plates with a surface area of 950 cm<sup>2</sup>. The nominal thickness of platinum provided over the niobium/titanium substrate is 2.7 microns to satisfy the 100 year design life. The anode plates were mounted in rubber holders and the anode assembly was secured to the concrete soffit with non-metallic fasteners.
4. *Approach Pier Anodes* consisted of tubular high silicon chromium iron anodes having a nominal original weight of 104 kg. The anodes were surrounded by carbon backfill material and packaged in steel canisters. The outer 254 mm diameter steel anode casing was covered with geotextile fabric to prevent migration of the carbon backfill.
5. *Reference Electrodes* are high purity ASTM B418 Type II zinc. Zinc electrodes were preferred in this application owing to their ruggedness and because freezing of a filling solution was not a concern as would be the case with a liquid filled electrode such as some types of silver chloride references.
6. *Anode Cables* were specially designed to withstand the chemical and physical abuse of severe anode installations. Exposed underwater sections of approach pier anode cables were installed in flexible non-metallic conduit for mechanical protection. Heavy wall cross linked polyethylene cables were used for structure bonds and reference electrodes.

## CATHODIC PROTECTION SYSTEM ARRANGEMENTS

The CCS rectifier, splitter box and monitoring box for each ice shield were located within the utility corridor directly above each pier as outlined previously and shown in Figure 3. The design incorporated multiple structure connections to allow for cabling damage expected during construction. The arrangement of the anodes and reference electrodes fall into one of the following categories, depending on pier configuration:

*Main Pier* anodes were installed in pre-cast recesses on the concrete soffit portion of the ice shield assembly to minimize the possibility of ice damage. Six anodes were equally spaced around the perimeter of each ice shield to optimize current distribution as shown in Figure 4. Prior to anode installation, an epoxy coating dielectric shield was applied to the concrete surface to minimize current drain to reinforcing steel. Two flush mounted reference electrodes were provided on each main pier ice shield to enable automatic potential control operation of the CCS rectifier and system monitoring. All anodes and reference electrodes were installed on land at the PEI staging facility. Flush mounted clad platinum/niobium/titanium anodes were utilized with the intermediate niobium layer specified to minimize the possibility of substrate breakdown during the design life of the system.

*East and West Approach Pier* systems were field installed and consisted of two permanent zinc reference electrodes and high silicon cast iron (chromium containing) canister type anodes installed around the pier foundations. The number of anodes was standardized at six, twelve and twenty four to cover the range of design current requirements. Typical Approach Pier ICCP arrangements are shown in Figure 5 for individual anodes and in Figure 6 for box mounted anodes.

## CATHODIC PROTECTION SYSTEM COMMISSIONING RESULTS

The East Approach and Main Pier systems were energized during December 1996 and tested in May 1997. The rectifiers were operated either in potential control at +100 mV<sub>ZRE</sub> or in current control, at the calculated initial currents. ON potentials ranged from -300 mV<sub>ZRE</sub> to +98 mV<sub>ZRE</sub>, with I-R drops of less than 1.5 mV/A. Figure 7 depicts the output current for a typical pier over a three month period, indicating the time dependence of the ice shield polarization. A comprehensive underwater survey performed on pier E5 at the East Approach confirmed that all the external immersed areas of the ice shield are fully protected according to NACE criteria. The West Approach piers were energized during May 1997 and will be surveyed in 1998.

As expected, some of the anode and structure connection wiring was damaged during construction verifying the need to design the systems with redundant cables as well as excess anode capacity.

As previously discussed, the rectifiers were supplied in NEMA 4X enclosures to prevent exposure of internal components to the marine environment. Unfortunately, gases created by the anode reactions penetrated the enclosures via the conduit. This problem needs to be corrected to optimize system operation over the 100 year design life of the system.

### CONCLUSIONS

1. On large projects of this nature, it is apparent that close communication is required between all parties, early in the design process, to ensure effective corrosion control measures are included to prolong the useful structure service life.
2. Impressed Current Cathodic Protection systems can be designed and installed on structures subjected to harsh ice covered seawater environments.
3. Structure mounted, custom designed anodes and reference electrodes developed for this specific application satisfied all of the operating requirements and provided mechanical protection against ice damage under extremely harsh conditions.
4. The design of cathodic protection systems for major construction projects such as the Confederation Bridge should incorporate redundancy in the number of cables, excess anode capacity, and the use of automatic rectifiers with both potential and current control capability.

### ACKNOWLEDGEMENT

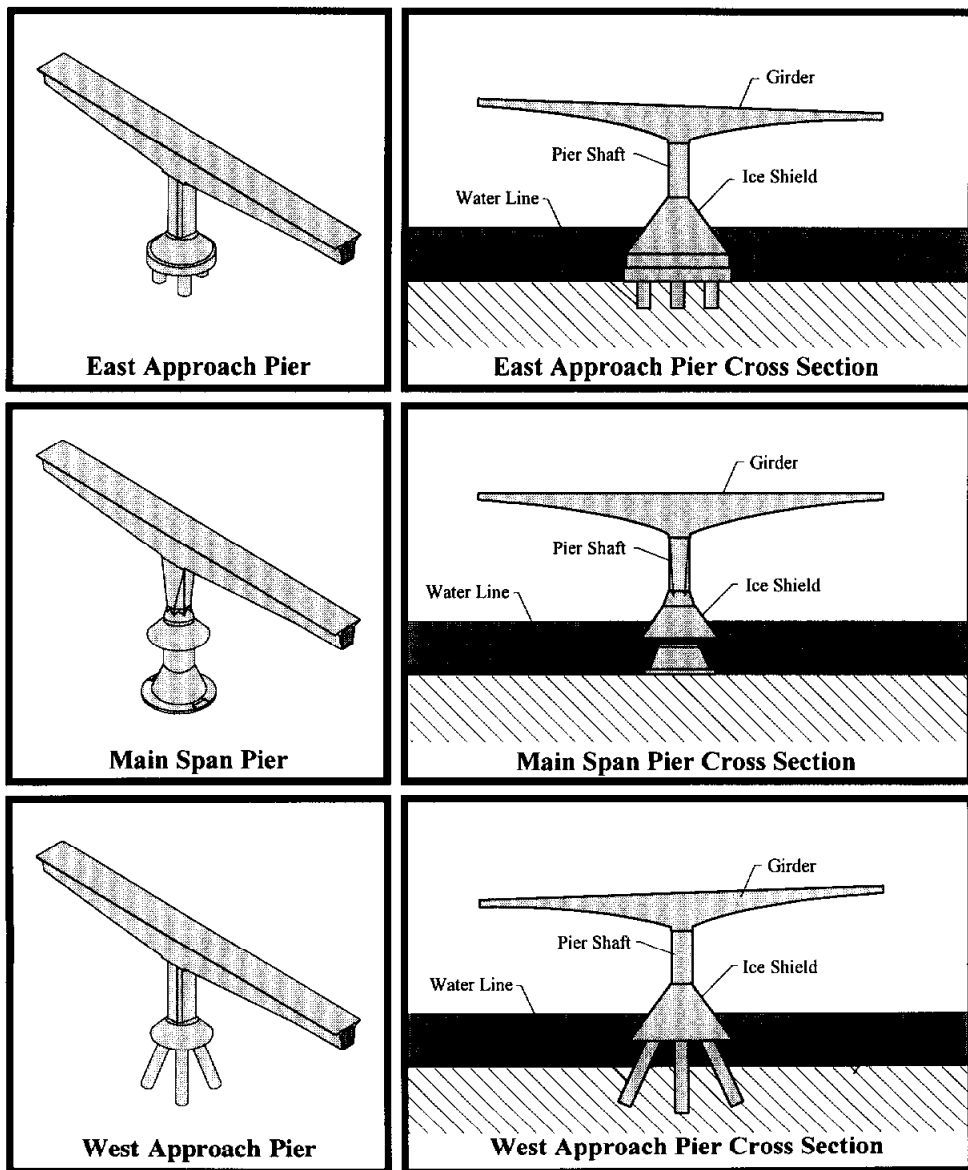
The authors wish to express their thanks to the bridge owner/operator Strait Crossing Bridge Limited for permission to present this paper.

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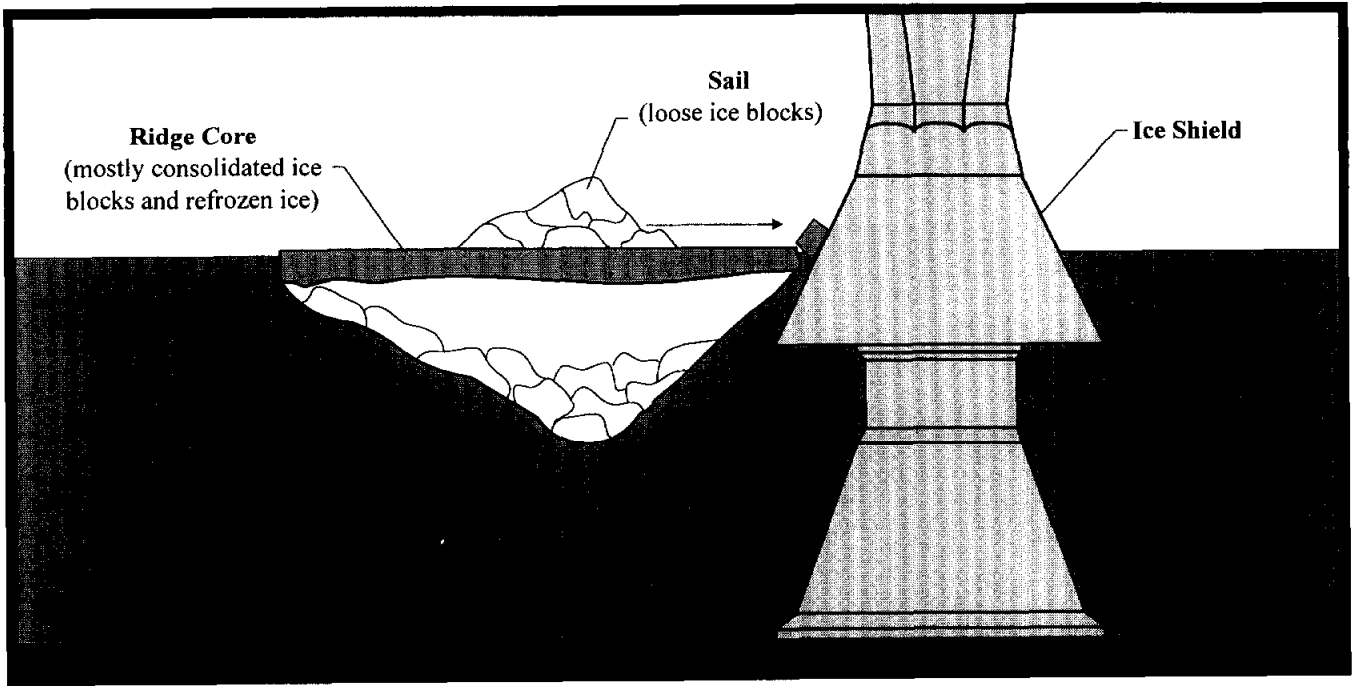
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**TABLE 1  
CONFEDERATION BRIDGE INFORMATION**

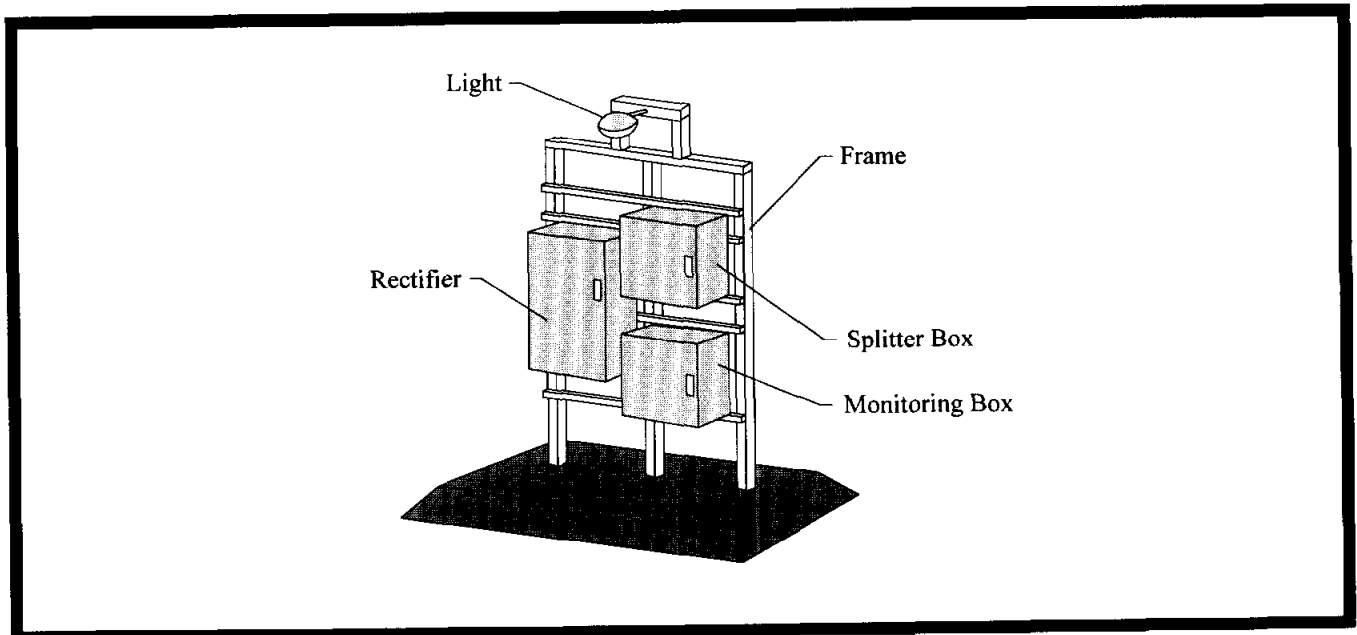
Total Length .....	12.9 km
Typical Elevation above water .....	40 m (60 m at Navigation Span)
Water Depth .....	up to 35 m
Width .....	11 m curb to curb
Number of East Approach Piers .....	7
Number of West Approach Piers .....	14
Number of Main Piers .....	44
Distance Between Main Piers .....	250 m
Amount of Concrete Used .....	478,000 m <sup>3</sup>
Amount of Reinforcing Steel Used .....	58,500 tonnes
Length of Post Tension Cables Used .....	12,690 km
Heaviest Single Bridge Component .....	Main Bridge Girder - 7500 tonnes
Bridge Design Life .....	100 years



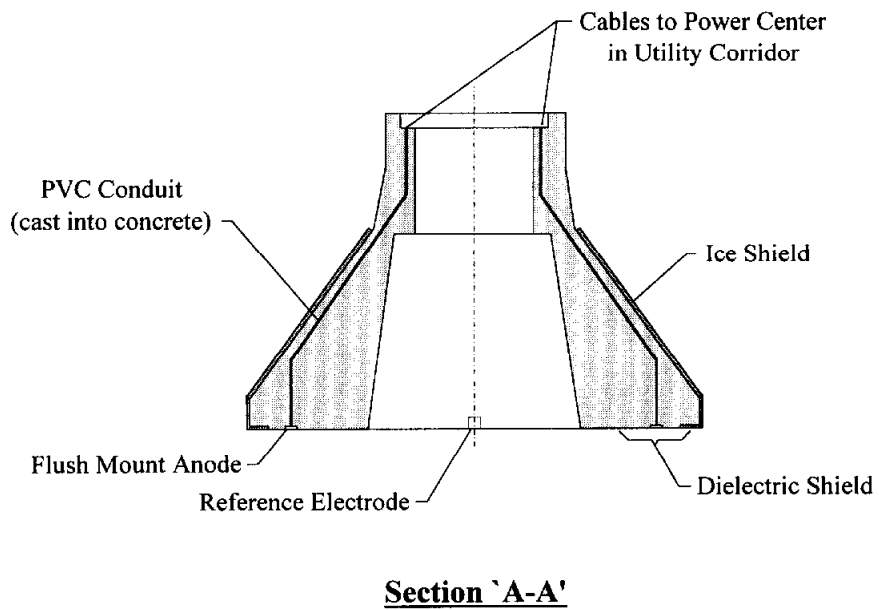
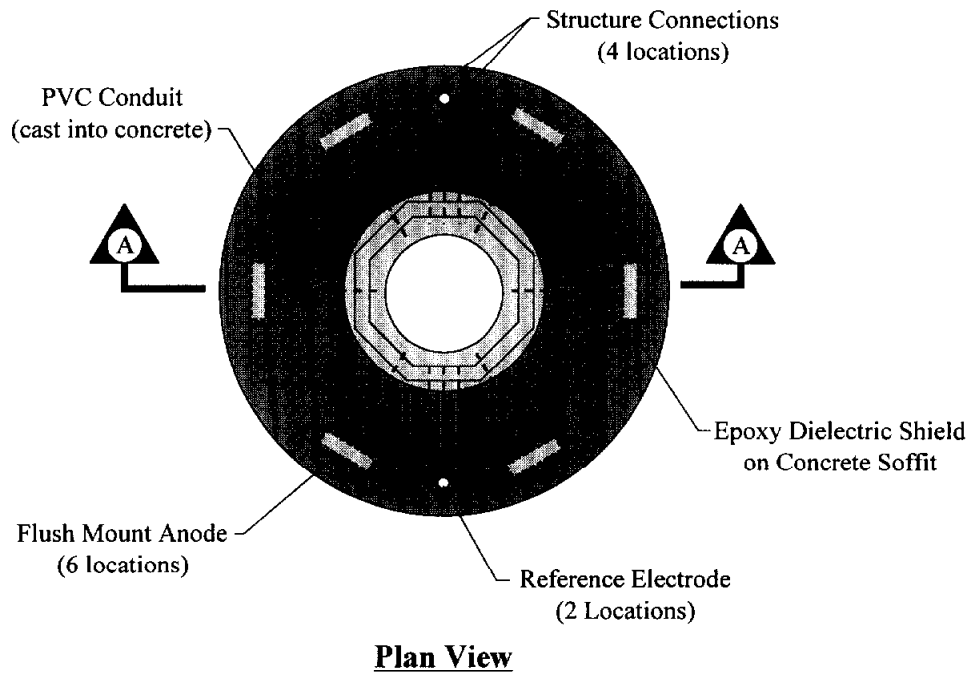
**FIGURE 1 - The three pier types**



**FIGURE 2 - Ice formation**

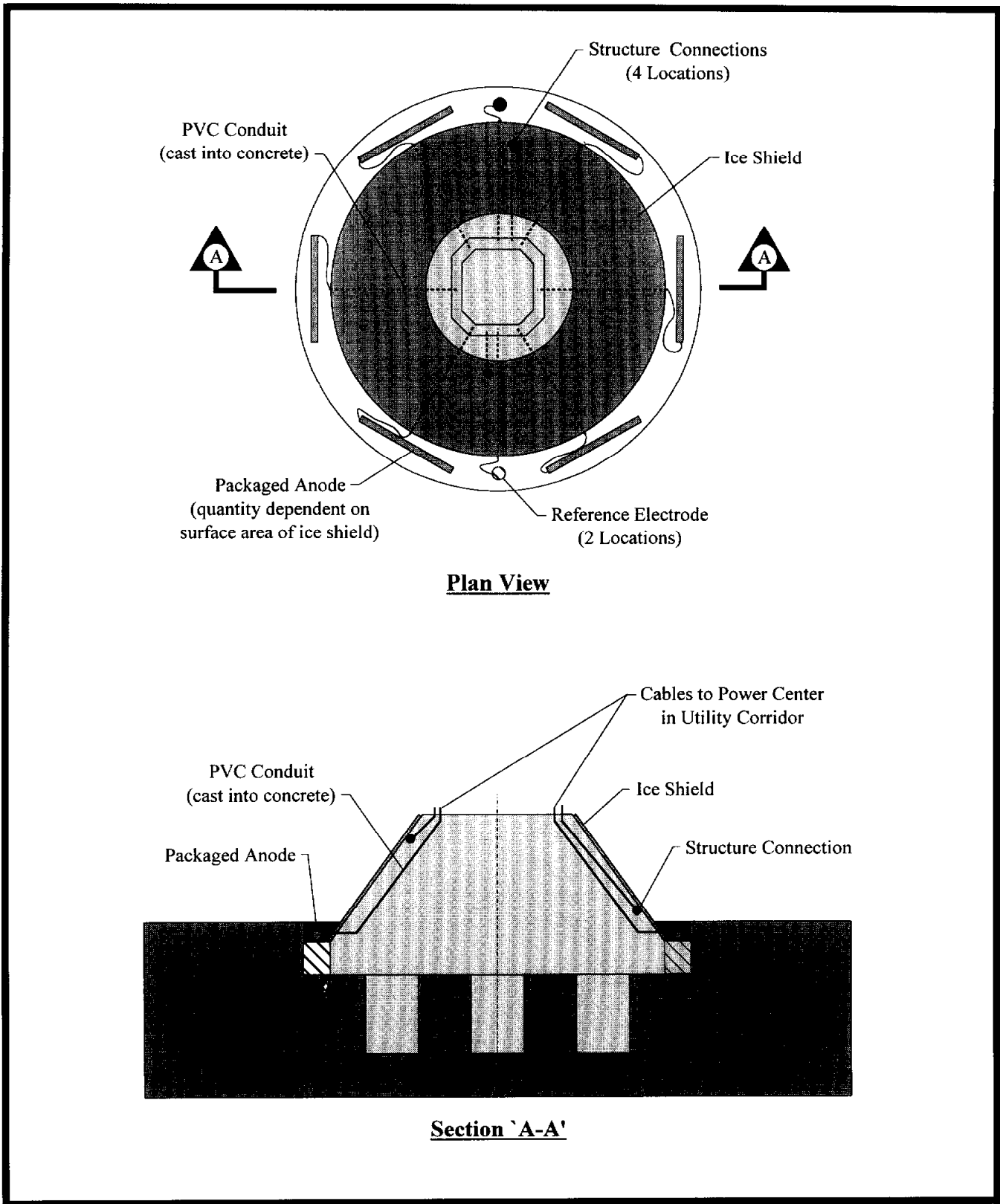


**FIGURE 3 - Rectifier, splitter, and monitoring enclosure configuration**

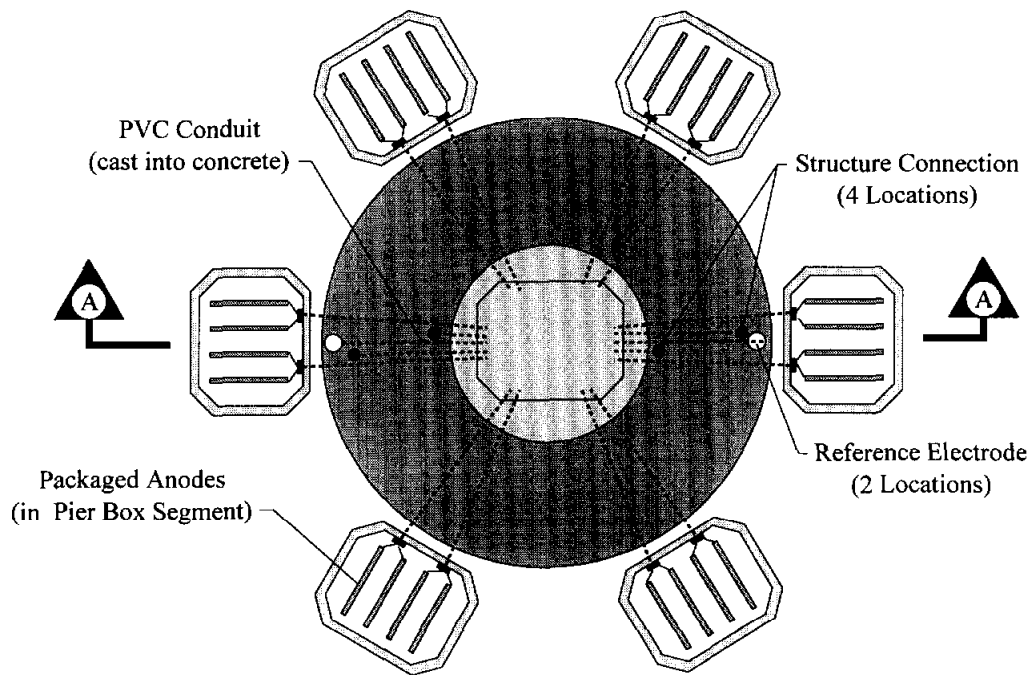


**FIGURE 4 - Main pier anode and reference electrode configuration**

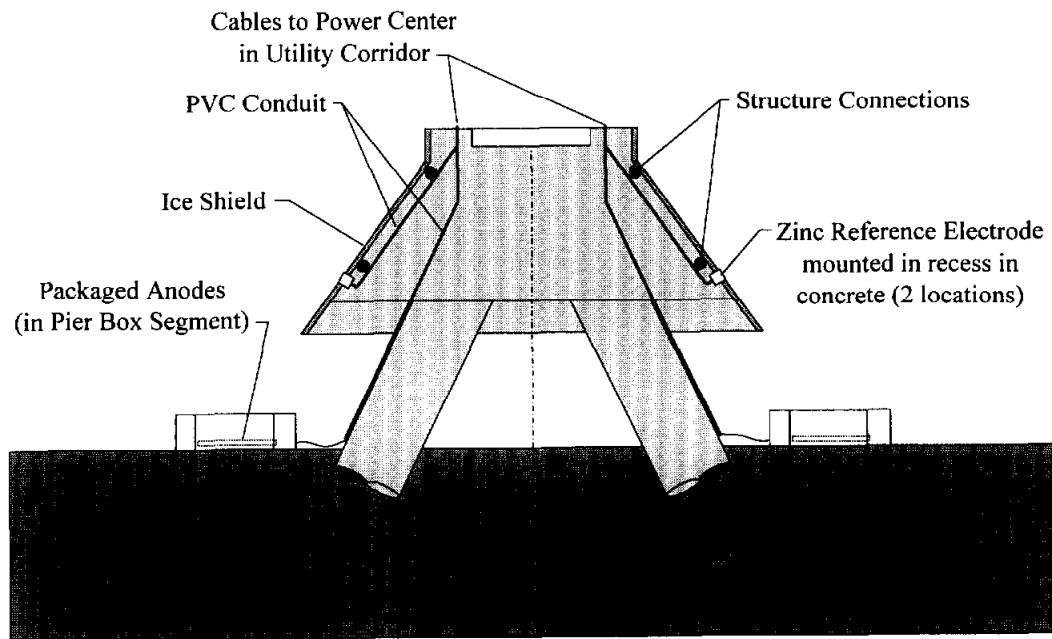




**FIGURE 5 - East approach pier anode and reference electrode configuration**

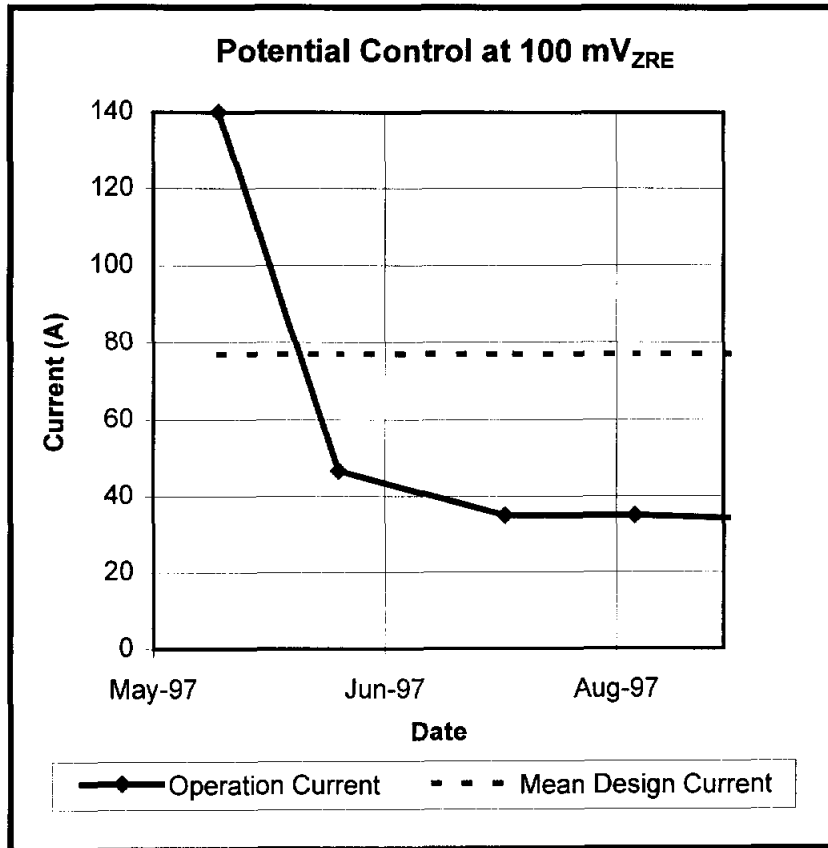


**Plan View**



**Section 'A-A'**

**FIGURE 6 - West approach pier anode and reference electrode configuration**



**FIGURE 7 - Typical current output to protect a pier vs. time at a controlled potential of 100 mV vs. zinc**