Cathodic Protection

For Concrete Reinforcing Bars

factsheet

Corrocell Ltd have an extensive knowledge base in the mitigation of corrosion of steel reinforcing bars used in concrete structures.

Reinforced concrete structures deteriorate under attack from external elements such as freeze-thaw damage and erosion. Particular concern today is the corrosion of the reinforcing steel which is affected mainly through carbonation and chloride attack. Of particular concern today is the alkali silica reaction in the concrete and the corrosion of the reinforcing steel, both of which are affected by the alkalinity of Portland cement concrete.

Fig 1

Portland cement is made by burning constituents which include lime in a kiln and grinding the result to a fine powder. This produces a highly alkaline material which reacts with water and hardens. When it is added to coarse and fine aggregate and mixed with water, the cement combines with the aggregate and hardens to form concrete. The hardening process (hydration reaction) is complex and continues over many months if not years, depending on the amount of water in the mix. Excess calcium hydroxide and other alkaline hydroxides are present in the pores and a solution of pH 12.0 to 14.0 develops It is this pore network and the solutions it contains that are critical to the durability of the concrete. A protective coating of oxides and hydroxides is provided on the surface of the steel reinforcement known as a 'passive film' which protects the steel from corrosion.

CARBONATION

Carbon dioxide, which is present in the air of around 0.3 per cent by volume, dissolves in water to form a mildly acidic solution. This forms within the pores of the concrete, here it reacts with the alkaline calcium hydroxide forming insoluble calcium carbonate. The pH value then drops from more than 12 to about 8.5. The carbonation process moves as a front through the concrete, on reaching the reinforcing steel, the passive layer decays when the pH value drops below 10.5. The steel is then exposed to moisture and oxygen and is susceptible to corrosion.

CHLORIDE ATTACK

Chloride ingress causes corrosion by a different mechanism. Sodium chloride (salt) dissolved in water forms a versatile, highly corrosive solution of sodium ions (Na^+) and chloride ions (Cl^-). Salt is used for de-icing roads and its presence in sea water is a major problem for reinforced concrete structures. The chloride ions disperse through the concrete pores in solution and once they reach the reinforcing steel they attack the passive layer. Steel oxidises in the presence of air and water to form rust which has a volume of up to 10 times that of the steel consumed. Concrete having a low tensile strength will crack when as little as a tenth of a millimetre of steel has been consumed. Horizontal cracks form, causing corners to 'spall' and surfaces to 'delaminate' as the concrete becomes detached and falls away in large sections. fig 1and fig 2 shows typical results of such reactions.

CORROSION PROCESS

Corrosion is an electro-chemical process which involves exchanges of electrons similar to that which occurs in a battery. Negatively charged areas on the surface of the metal or 'anodes' where corrosion occurs `and positively charged areas or 'cathodes' where a harmless charge balancing reaction occurs. Iron dissolves at the surface of the anodic areas as positive ions leave the surface of the steel then reacts to form a solid corrosion product which we know as rust.

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REPAIR

Once corrosion damage has occurred, the damaged areas need to be cut out, replace any steel weakened by section loss and put back good quality concrete. Several problem with this approach are:

❑Repairs can lead to acceleration of corrosion in adjacent areas, especially with chloride-induced corrosion. The removal of corroding anodic steel causes loss of the protection cathodes around it and new anodes form when the metal is renewed.

❑Cutting out damaged areas may leave areas that are about to crack to spall.

❑Repairs may be visually intrusive as it is difficult to match the colour and texture of the original, and it is almost impossible to get the new material to weather in the same way.

Fig 2

CATHODIC PROTECTION (CP)

Application of and Impressed Current Cathodic Protection (ICCP) system who's components include a DC power supply, anode material, reference electrodes and a control system can be applied to prevent the onset of corrosion.

For new concrete installations components of the CP system can be installed prior to the concrete pour. Mixed Metal Oxide activated Titanium Anodes in the form of a ribbon mesh can be installed in close proximity and parallel to the reinforcement bars (rebar).

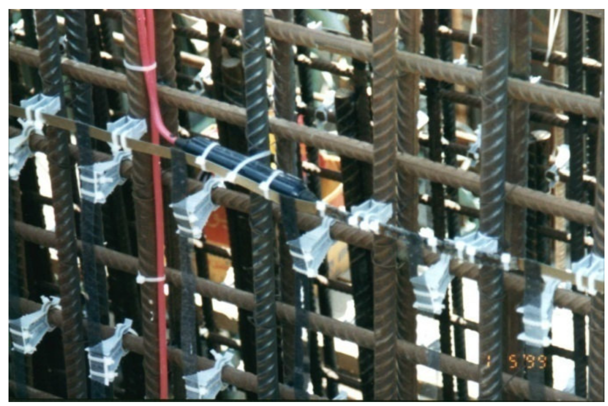

Fig 3

The anodes are secured in place using special plastic holders, these both ensure secure retention of the anode during the concrete pouring operation and they also provide the vital electrical isolation between the anode and the steel rebars (cathode) is ensured. The anode is then connected together using a thin strip of titanium distributor bar which is spot welded to the anode ribbon mesh at multiple points. The positive anode feeder cables from the DC power supplies are then connected to the distributor bar. The cathode cables are connected to the steel rebar at various locations to provide even current distribution throughout the rebar cages. A number of reference electrodes and instrument negative connections are positioned at strategic locations around the rebar providing adequate feedback of the steel rebar potential which are connected to the monitoring system.

The cathodic protection designer calculates the amount and distribution of the MMO anode ribbon mesh and current distributor bars depending upon the density of the rebars. The ICCP is designed to ensure a uniform level of cathodic protection current is afforded to all of the rebar. It is required that electrical continuity exists between all rebar to ensure they are bonded into the ICCP system, this may require welding of key rebar to achieve this or the addition of bonding cables.

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ZONING

When designing ICCP systems for large concrete structures the designer divides the CP system into multiple zones. Each zone comprises of an anode system, current distribution system, cathode cable connections, reference electrodes and instrument negative cable connections. There is one instrument negative connection for every reference electrode installed as the measuring point for the reference electrode. They are connected to the rebar adjacent to the site of its corresponding reference electrode.

The zoning is normally designed to have a cathodic protection current demand that is within acceptable limits. This is normally between 2 to 6 amperes with a maximum driving voltage of 10VDC.

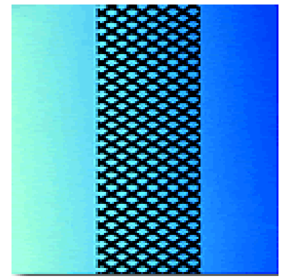

Fig 4

MMO Ribbon Mesh

25mm wide x 50m Rolls

NEW STRUCTURES

For new installations the rebars are protected using either a MMO ribbon mesh (see fig 4) or a solid MMO strip and is installed within a structure prior to the casting of the concrete. The material is manufactured in continuous 25 metres lengths. The anodes are installed in close proximity and parallel to the reinforcement bars. They are secured in place using special plastic holders, these both ensure secure retention of the anode during the concrete pouring operation and they also ensure electrical isolation between the anode itself and the steel reinforcement bars (this is vital).

The anodes are distributed about the reinforcement cage to ensure a uniform level of current is distributed to the entire rebar system. Because the electrical conductivity of titanium is not particularly good, the anode network requires multiple connection points to the positive current circuit. This is achieved by the use of current distributor bars comprising of titanium strips that interlink between parallel anode strips. The current distributor bars are connected directly to the positive cabling network from the LRU (Local rectifier Unit). The cable to distributor bar connection is made using a special encapsulated titanium crimp arrangement thus ensuring electrical insulation of the joint. The cathodic protection designer calculates the amount and distribution of the MMO anode strips and current distributor bars depending upon the density of the reinforcement bars. It is vital that electrical continuity exists between all reinforcement bars to ensure they are bonded into the ICCP system. This may require welding of key reinforcement bars to achieve electrical continuity through out.

RETROFITTED SYSTEMS – EXPANDED MESH

This type of system is designed for existing structures where the installation of a continuous anode system within the concrete is not possible. The MMO anode is produced in the form of a highly expanded mesh. The mesh is fastened directly to the outer face of the concrete structure (see Fig 5) following the surface preparation procedure. The mesh is attached using special plastic fasteners. Following installation of the mesh a series of positive cable connections are made directly to the mesh to ensure a uniform level of DC current is achieved throughout the expanded mesh anode.

Reference electrodes are installed into the structure normally within pre-drilled holes prior to the laying of the expanded anode mesh which are then grouted in place (see fig 6). A cementaceous grout is normally sprayed on, therefore totally covering and encapsulating the anode system, reference electrodes and cabling.

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Due to the high flexibility of the expanded mesh anode it is possible to cathodically protect complicated geometric concrete structures using this system.

It is again imperative that all of the reinforcement bars are made and confirmed to be electrically continuous, (including across expansion joints). This is normally achieved by drilling test holes to enable direct electrical contact to be made with the reinforcement bar, and then low voltage continuity testing carried out through out the structure that is to be protected.

Fig 5

A series of cathode cables are connected directly to the reinforcement bars and conveyed back to the LRU negative terminal. The ICCP system is designed to separate the structure into zones requiring an acceptable cathodic protection current demand normally between 2 and 6 amperes.

This system has been widely used throughout Europe and particularly North America for the retrofit cathodic protection of bridge decks that have suffered from corrosion mainly due to the use of de-icing salts and the resultant chloride contamination.

Fig 6

RETROFITTED SYSTEMS – POINT SYSTEM

This type of ICCP system is designed for existing structures where the installation of continuous anode systems within the concrete is not possible. The anodes comprise of MMO tubes typically 10mm in diameter and 150mm in length. The anodes are installed within pre-drilled holes directly into the structure. The hole is filled with a special cementaceous grout and the anodes are then pushed into the grout filled holes therefore ensuring an intimate contact between the anode outer surface area and the surrounding mass of concrete. The anode tubes are fitted with titanium wires spot-welded to their surface and these wires are used to connect the positive feed cables. The anodes are installed in a grid pattern design to provide a uniform spread of the cathodic protection current onto the reinforcement bars.

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