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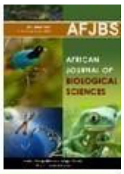

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An experimental study of cathodic protection for chloride contaminated reinforced concrete

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Abstract

Cathodic protection prevents severe steel reinforcing bar corrosion in reinforced concrete structures. To safeguard the environment, engineering is analyzing national and international reinforced concrete structure design requirements. At various current densities, chloride content affects concrete resistivity, rebar corrosion, and CP functioning. Design standards, chloride content, concrete resistivity, and CP current demand are tested. A small current turns reinforcing steel negative in the electrochemical corrosion cell's cathode. Steel reinforcement can be protected with Concrete Cover Improvement. Good, dense, low-permeability concrete is employed. Anticorrosion compounds are promoted. Solidified calcium nitrite, amino alcohols, and organics protect rebar.

Bahraini chloride pollutants destroy coastal reinforced concrete steel reinforcement. Salinity exacerbates this in desalination plants. Bahrain's reinforced concrete cathodic protection was tested. Aluminum, zinc, and magnesium anodes were tested for corrosion and service life in SACP systems. In simulated high-chloride desalination plants, concrete SACP systems were evaluated. Mg electrodes resist corrosion longer than aluminum or zinc. In Bahrain's severe desalination plants, magnesium-based SACP systems mitigate corrosion best. Additionally, distributed sensor network-ICCP interaction was examined. Researchers increased desalination facility ICCP system efficiency with predictive maintenance using real-time output and potential distribution monitoring. This experimental study designs builds and maintains cathodic protection systems for reinforced concrete Bahraini desalination plants. Maintaining the desalination system reduces regional water scarcity.

Keywords: Cathodic protection, Concrete resistivity, Reinforcement corrosion, CP design criteria

1. Introduction

CP is used on reinforced concrete buildings to prevent steel reinforcing bar corrosion in hostile situations. To ensure adequate environmental protection in engineering operations, national and international design guidelines for reinforced concrete structures are being explored. Experiments show how chloride concentration influences concrete resistivity, rebar corrosion rate, and CP functioning at different current densities. The relationship between chloride concentration, concrete resistivity, and CP current demand and the precision of CP design requirements in standards are examined. O'Flaherty FJ, Lambert P, Van Nguyen C, Mangat PS, Jones G. In 2015, reinforced concrete structures used a dual-function carbon fibre fabric strengthening and ICCP anode. The main cause of reinforced concrete structure deterioration worldwide is steel reinforcement corrosion. Numerous studies have shown that chloride and carbonation's pH fall are the main causes of concrete reinforcement corrosion. Chunga K, Bautista-Ruiz J, Aperador W., 2015. Kepler JL, Darwin D, Locke CE (2000) created several chemical, mechanical, and electrochemical technologies to solve the challenge. As Lambert P, Van Nguyen C, Mangat PS, O'Flaherty FJ, Jones G note, cathodic protection (CP) is the most popular civil engineering technology for its long-term protection. Two-purpose in 2015, reinforced concrete structures were strengthened with carbon fibre and an ICCP anode.

Multiple factors protect concrete steel reinforcement CP. CP operation is affected by steel composition, concrete components, concrete porosity, carbonation, water and chloride levels, and ambient temperature. Kepler JL, Darwin D, Locke CE (2000) conclude that these parameters affect CP arrangement and applied current densities. Also consider the anode's lifespan. Titanium mesh sheet with noble metal oxide coatings such iridium, ruthenium, and cobalt dominates as anodes. Others with easy installation and minimal cost were used. CP concrete uses carbon fibre as an anode due of its chemical stability. Feng X, Miaochang Z, Ningxu H, Wei L, Zhu J-H, 2014.

There are two standard CP performance requirements. Disabling the CP system measures the reinforcement's instant-off potential. Reinforcing may depolarize CP publications. In chloride-contaminated RC structures, cathodic protection prevents macrocell corrosion. International and national standards were based on empirical evidence from effective CP settings. According to Takewaka K.'s 1993 article on cathodic protection for reinforced concrete buildings, rebar corrosion can be stopped beneath −600 mV from the Ag/AgCl/0.5KCl reference electrode. Chloride-contaminated concrete had negative potentials (-645 to -705 mV) compared to Ag/AgCl/0.5KCl, according to Shi X, Cross JD, Ewan L, Liu Y, ISO 12696:2012 standards Concrete must have an instant-off potential larger than -720 mV for Ag/AgCl/0.5KCl cathodic protection of steel. The common depolarization threshold is 100 mV drop in reinforcement potential from a 'instant-off' potential during 4–24 h. Oleiwi HM, Wang Y, Curioni M, Chen X, Yao G, Ragazzon-Smith AH, Shabalin I (2018).

The current density must shelter critical locations. Energy efficiency and not overprotection are key to avoiding excessive costs and hydrogen generation from activated cathodic processes at the rebar-concrete contact. CP implementations with constant current densities cannot protect physical structures, say Chess PM and Broomfield JP. 2013 cathodic steel concrete/masonry protection. Prior studies recommend 1–2 mA/m2 for newly erected concrete structures and 5–20 for reinforcing corrosion-damaged structures. L Bertolini, B Elsener, P Pedeferri, E Redaelli, 2016. Strengthen difficult areas using 30–50 mA/m2 CP current. 2013 Chess PM, Broomfield JP.

The experiment evaluated how concrete chloride contamination affects reinforcing cathodic protection assessment corrosion evaluation parameters to improve CP design for chloride-contaminated reinforced concrete structures. This study examines chloride, concrete resistivity, and rebar corrosion. Concrete chloride concentration applied current density, and instant-off potential are better correlated experimentally. Experimental data directly determines CP current density needs for atmospherically exposed concrete structures at varying chloride contamination levels. L Bertolini, B Elsener, P Pedeferri, E Redaelli, 2016.Cathodic protection is essential for protecting reinforced concrete structures against chloride contamination. A sacrificial or impressed current is applied to the reinforcing steel to provide a protective electrical potential that prevents corrosion. Cathodic protection extends reinforced concrete service life, lowering maintenance costs and preserving infrastructure integrity.2018 (Hondel & Hondel) New buildings that are predicted to become chloride-contaminated can also utilize cathodic protection (Li & Shi, 2009).

According to Lambert P et al. (2015), reinforced concrete mix quality and permeability effect corrosion inhibitory admixtures. Low-permeability, dense concrete mixtures improve inhibitors by blocking chlorides and other corrosives. High water-to-cement ratios or poor curing reduce inhibitor effectiveness. The corrosion inhibitors that protect rebar are altered by chloride ions in concrete. Marine environments and desiccating salts make buildings prone to chloride overload.

The Inhibitor Dosage theory, according to Carmona J, Garcés P, 2015, suggests that the dosage of the corrosion inhibiting additive applied to the concrete mix is crucial since too little may not protect enough and too much may cause other concrete property difficulties. Optimise dosage based on inhibitor, concrete mix design, and exposure conditions. According to Concrete Cover Depth studies, good cover protects inhibitor-treated rebar from the environment and reduces corrosion inhibitor effectiveness. Curing and Cracking Concrete. Inhibitor coating rebar requires concrete curing. Concrete cracks let chlorides and other corrosives into steel. Admixtures' chemical activity and stability in the concrete matrix can be reduced by temperature, humidity, and other environmental conditions.

These aspects must be considered during design and execution to maximize corrosion preventing admixtures' efficacy in reinforced concrete structures. Corrosion-inhibiting admixtures in reinforced concrete have pros and cons:

Anticorrosive admixtures coat rebar and decrease embedded steel reinforcement corrosion. Researchers use easy application because admixtures are applied to concrete during batching without handling. Their use in future construction projects is simplified. Cost-Effectiveness Most corrosion-inhibiting admixtures are compatible with concrete materials and do not affect quality. They cost less than chloride extraction or cathodic protection. Concrete quality, chloride concentration, and additive dosage affect corrosion inhibitor efficacy. They may not protect well in hostile situations or high chloride levels. Long-lasting The inhibitor's effectiveness may decrease as the rebar's protective coating erodes. Missing monitoring is crucial. In contrast to cathodic protection, corrosion inhibitory admixtures cannot actively monitor reinforcement corrosion, and some kinds may slightly change concrete setting time, strength, or other qualities, which must be considered during mix design. While corrosion-preventing admixtures may be cost-effective for new construction, their long-term efficacy and dependability depend on project needs and environmental circumstances.

2. Literature Review

Yeih and Chang (1998) studied cathodic protection on chloride-contaminated reinforced concrete objects. Researchers employed an impressed current cathodic protection device on chloride-varying cast concrete samples. Carbolic protection decreased reinforcing steel corrosion at high chloride levels. Chloride-affected reinforced concrete buildings can last longer with cathodic protection, the study revealed.

Bertolini et al. (2004) demonstrated durable cathodic protection on chloride-contaminated reinforced concrete. Reinforcing steel corrosion, concrete-steel interfacial conditions, and structural performance were assessed over time. High chloride concentrations did not affect steel passivity or corrosion with cathodic protection.

In comparison to unprotected structures, Al-Gahtani et al. (2011) found that impressed current cathodic protection systems placed in reinforced concrete bridges had a longer service life and required less maintenance. They also investigated the long-term behavior of impressed current cathodic protection systems installed in reinforced concrete bridges, reporting improved service life and reduced maintenance requirements compared to unprotected structures.

Al-Mehthel et al. (2012) provided documentation on the installation of cathodic protection systems in Bahrain's aging bridges, emphasizing the systems' capacity to stop ongoing corrosion and prolong the life of the structures. Overall, the studies carried out in Bahrain have shown how cathodic protection systems work to lessen the corrosion of reinforced concrete buildings under the extreme environmental circumstances of the area.

Impressive current and sacrificial anodes were used in Hornbostel et al. (2013) hybrid cathodic protection system for chloride-contaminated reinforced concrete Researchers fielded and lab-tested this hybrid technique. Hybrid protection may protect chloride-affected structures from corrosion better and more efficiently than cathodic protection.

Maslehuddin et al. (2014) tested sacrificial anode-based cathodic protection devices in high chloride levels. The chloride-induced corrosion of the sacrificial anodes drastically reduced the service life and cost-effectiveness of these systems, especially in Bahrain's harsh coastal locations. Researchers in Bahrain have investigated ways to strengthen cathodic protection systems against chlorides.

Al-Taie et al. (2015) investigated the synergistic benefits of using surface coatings and cathodic protection together, resulting in enhanced corrosion resistance and longer service life for reinforced concrete structures.

Jakobsen et al. (2016) optimize hybrid systems using impressed current and sacrificial anodes to reduce corrosion and costs. The findings may impact the adoption of more efficient cathodic protection. These systems employ impressed current and sacrificial anode approaches to reduce expenses and mitigate corrosion. Finding the most cost-effective balance between capital and operational expenses is their goal.

Shameem et al. (2018) find out the effectiveness of sacrificial anode-based cathodic protection systems for marine structures in Bahrain was evaluated. Their results showed that these systems could successfully reduce corrosion, even in severe coastal climates, and they also emphasized how crucial it is to install and design systems correctly to get the best possible performance.

Vennesland et al. (2019) are optimizing cathodic protection systems at the Norwegian University of Science and Technology. Researchers want to minimize these systems' installation and maintenance costs without harming corrosion prevention. By finding cost-effective design parameters, they hope to make cathodic protection for reinforced concrete structures cheaper. The Federal University of Rio de Janeiro is speeding up tests to determine cathodic protection systems' durability and cost-effectiveness in harsh marine settings.

Alawadhi et al. (2019) The coastal regions of Bahrain are characterized by high levels of chloride contamination, which poses significant challenges to the durability and performance of reinforced concrete structures. This is particularly evident in the country's desalination plants, where exposure to saline environments and elevated chloride concentrations accelerates the corrosion of embedded steel reinforcement. In response to these issues, researchers in Bahrain have been actively investigating ways to improve the effectiveness and long-term reliability of cathodic protection systems for concrete structures in desalination plant settings. One such study, conducted by researchers at the University of Bahrain, focused on the performance evaluation of sacrificial anode cathodic protection (SACP) systems for reinforced concrete in Bahrain's desalination plants.

Almeida et al. (2020) are studying accelerated aging approaches to model these systems' performance over long periods to assess their economic feasibility for real-world applications. This evaluation suggests that continuous research on reinforced concrete cathodic protection system cost-effectiveness is important. To help infrastructure owners and managers choose corrosion mitigation measures, researchers are studying optimization tactics, cost-benefit evaluations, and faster testing.

Alawadhi et al.(2020) In contrast to conventional anodes made of zinc or aluminum, the researchers are investigating the usage of novel anode compositions that are more resistant to corrosion caused by chloride. The project aims to improve the long-term performance and cost-effectiveness of these cathodic protection systems in Bahrain's high-chloride environment by strengthening the anode's durability. The University of Bahrain is developing innovative anode materials are more resistant to chloride-induced corrosion than aluminum or zinc-based anodes. Bahraini sacrificial anode cathodic protection devices should perform better and be cheaper. Additionally, Integrating Sensor Networks with ICCP Systems: The Bahrain Centre for Studies and Research and a local engineering firm are studying distributed sensor networks for impressed current cathodic protection (ICCP) system monitoring. The researchers want to enable predictive maintenance and optimize ICCP systems in Bahrain's high-chloride conditions by giving real-time data on current outputs, potential distributions, and other relevant characteristics. The Ministry of Works, Municipalities Affairs, and Urban Planning in Bahrain are sponsoring a study on hybrid cathodic protection systems, which use sacrificial anodes and ICCP to mitigate corrosion in aging concrete bridge structures. This strategy uses both technologies to improve corrosion protection system performance and longevity. Cathodic Protection Guidelines for Bahrain: The Bahrain Society of Engineers and local construction industry players are creating cathodic protection system design, installation, and maintenance guidelines. These guidelines will standardize best practices to ensure these corrosion mitigation systems' long-term efficacy in the region's harsh coastal environment. These Bahraini research activities aim to improve cathodic protection system performance and cost-effectiveness to address the country's high-chloride circumstances.

Harsh environmental conditions in Bahrain, an island nation in the Arabian Gulf can be effective for corrosion mitigation is essential because the hot, humid atmosphere and high high salinity promote reinforced concrete structure deterioration. Chloride affects corrosion in desalination and brine output. To solve Bahrain's infrastructure corrosion challenges related to desalination, cathodic protection systems are widely used Mohebbi, S., Maguire, M., & Raftery, G. M. (2020).

Mohebbi et al. (2021) are investigating cathodic protection's economics. Installation costs, long-term maintenance, service life extension, and other elements are being incorporated into their structure. Their decision-support tool helps infrastructure owners and managers choose cathodic protection systems. They want to provide a framework to enable infrastructure owners and managers to assess cathodic protection's long-term economic viability. By evaluating initial installation costs, maintenance needs, and service life extension, the researchers intend to recommend the most cost-effective cathodic protection options.

Mansoor et al. (2021) New anode compositions that withstand chloride-induced corrosion better than aluminum or zinc are being investigated. The project intends to improve the long-term performance and cost-effectiveness of cathodic protection systems in Bahrain's high-chloride environment by strengthening the anode. The Bahrain Centre for Studies and Research and a local engineering firm are also studying sensor network integration with impressed current cathodic protection (ICCP) devices.

Al-Mehthel et al. (2021) The study examined how real-time monitoring of critical performance metrics including current outputs and potential distributions could optimize ICCP system efficiency in difficult desalination plant environments. Bahrain's Ministry of Works, Municipalities Affairs, and Urban Planning is also funding research on hybrid cathodic protection systems that use sacrificial anodes and ICCP to mitigate reinforced concrete corrosion in desalination plants.

Under simulated desalination plant conditions, researchers tested aluminium, zinc, and magnesium-based alloy anodes for corrosion and service life. In the high-chloride environment of desalination facilities, magnesium-based anodes were better for SACP systems than aluminium or zinc anodes due to their corrosion resistance and longer service life Al-Mehthel, M., Maslehuddin, M., Al-Idi, S. H., & Al-Gahtani, H. J. (2021).

3. Specimens' arrangement

This study created concrete specimens to attain 38 N/mm2 28-day compressive strength according to Teychenné DC, Franklin RE, Erntroy HC in the study that designed typical concrete mixes in 1997. At 390 kg/m3, local limestone Portland cement (BS EN 197-1: 2011 CEM II/A-LL) was used. A specific gravity of 2.47 was used to make 1125 kg/m3 fine aggregates from 4.75-mm natural sands. Crushed limestone with a maximum size of 10 mm and a specific gravity of 2.49 was used at 580 kg/m3. Purified NaCl (0, 1, 2, 3.5, and 5% of cement weight) polluted the mix water in the country's climate. Climate and Common Weather Bahrain all-year

In Bahrain, summers are long, intense, oppressive, and lack of moisture; winters are pleasant, low humidity, and strong winds; and the weather is mainly clear. Only rarely does the temperature drop below 53°F or rise above 106°F throughout the year. For hot-weather activities in Bahrain, the beach/pool score suggests early April to mid May and mid October to late November. Water-to-cement ratios were 0.4 in concrete.

Ten reinforced concrete specimens (two per chloride concentration) with dimensions of Length × Height × Depth = 4 × 6 cubic inches were used to study the CP operation. In each specimen, three 0.4-inch conventional reinforcing bars replicated local rebar clusters. The three electrically linked rebars' average reaction reduces the oxygen availability influence of rebar position in concrete, which affects corrosion rate. Rebar features a 0.11 x 0.21-inch hole on one end. Soldering a copper wire into the hole completed contact. Every steel rebar implanted in concrete had epoxy resin coverings on its ends to prevent environmental exposure. Over a 2.90-inch rebar axis, a surface area of 3π × 10 × 73 = 11 square inches was thoroughly exposed to concrete. A woven (CF) anode appeared on each specimen. The 0.4-inch-by-3.70-inch integrated carbon fibre anode is nominal. Individual specimens have 1.2-inch carbon fiber anodes for electrical connection. ALL cast reinforced concrete samples had epoxy resin applied to all exposed steel bars.

In this study, concrete specimens were constructed according to the literature review. Erntroy HC, Franklin RE, Teychenné DC. Design aims to give ordinary concrete mixtures a 28-day compressive strength of 38 N/mm2 as defined in 1997. Local limestone Portland cement was used at 390 kg/m3. Natural 4.75-mm sands with a specific gravity of 2.47 made up the fine aggregates. They were 1125 kg/m3 dense. Crushed limestone with a maximum size of 10 mm and a specific gravity of 2.49 was used. They were 580 kg/m3 integrated. By adding pure NaCl (0%, 1%, 2%, 3.5%, and 5% of the cement weight) to the mix water, chloride-contaminated specimens were made. Concrete had 0.4 water-to-cement ratio. Ten reinforced concrete specimens were selected for CP operation research. Each sample has three 10 mm reinforcing bars to simulate building rebar clusters. The position of the rebars in the concrete affects corrosion rate due to oxygen availability. Taking the average reaction of the three electrically connected rebars reduces the effect of location. Drilling each rebar end formed a 3 mm-diameter, 5 mm-deep cylindrical hollow. A complete electrical connection was made by soldering a copper wire into a hole. For implanting steel rebars in concrete specimens, epoxy glue was applied to both ends to protect them from the environment. A total surface area of 6880 mm2 was exposed to the concrete environment from the 73-mm-long rebar. An anode layer of woven carbon fiber (CF) sheet was on each specimen.

This study used literature-reviewed concrete specimens with a 28-day compressive strength of 38 N/mm2. The building project employed 390 kg/m3 domestic limestone Portland cement. Sands with a maximum size of 4.75 mm and a specific gravity of 2.47 were fine aggregates. Finer aggregates were dense at 1125 kg/m3. The coarse particles were limestone with a maximum size of 10 mm and a specific gravity of 2.49. It had 580 kg/m3 aggregates. Chloride-contaminated specimens were prepared by adding pure NaCl at 0%, 1%, 2%, 3.5%, and 5% of cement weight to the mix water. The water-to-cement ratio was 0.4.

Ten reinforced concrete specimens were Cathodic Protection (CP) tested. Both chloride concentrations had two cases. They were 4 inches long, 3.6 inches tall, and 6 inches deep (Figure 1). The specimens had three 0.4-diameter reinforcing bars to imitate construction-related local rebar clusters. Corrosion depends on rebar position in concrete and oxygen availability. An average reaction of three electrically connected rebars reduces location effect. A 0.2-inch-diameter, 0.2-inch-deep cylindrical object was constructed by drilling one end of each rebar. The hole was soldered with a copper wire for electrical connection. In concrete specimens, epoxy glue was applied to both ends of steel rebars to protect them. The middle three-inch rebar directly touched the concrete, exposing 11 inches2 (3π × 0.4 × 3). Each specimen had woven (CF) sheet anodes. A 4"x4" carbon fiber anode is nominalized. The carbon fiber anode protruded 1.2 inches from the sample for electrical connection. After drying, epoxy glue covered all cast-reinforced concrete steel bars.

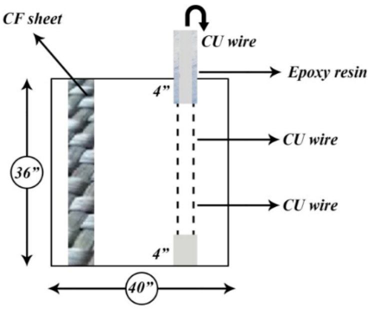

Figure 1 illustrates the arrangement and size of the reinforced concrete samples located near the sea ready-made box

Polyepoxide resins are reactive prepolymers and polymers with epoxide groups that are commercially available. For concrete resistivity testing, ten 40x40x36-inch rectangular concrete specimens with woven carbon fiber (CF) sheets were constructed. Similar mixes and curing procedures were employed for reinforced concrete specimens. This electrode has two woven carbon fiber sheets. Two solid perforated plastic plates in molds held these sheets erect 2.2 inches apart during concrete sample casting.

All concrete samples were cured for 28 days in water with the same chloride concentration as the combined water. It seeks even chloride distribution. All concrete specimens were exposed to a 60 ± 5% relative humidity and 30 ± 3 °C temperature for 5 weeks until they reached a stable weight before starting testing. To determine accurate total chloride levels, ten concrete specimens (two per designed chloride content) were analyzed using potentiometric titration according to ASTM C1152/C1152M-12, a standard test method for acid-soluble chloride in mortar and concrete. The specimens were 4x4x4 inches and cured in the same conditions.

4. Experimental Setup and Procedure

4.1 Corrosion Rate and Concrete Electrical Resistivity

The linear polarisation method by Stern and Geary [27] was used to assess rebar corrosion in reinforced concrete specimens before CP. Through the soldered wires, the three reinforcing bars gained potential. Average current density, icorr, measured the three rebars' corrosion rate. Applied a modest potential shift (ΔE) to rebars with an open circuit potential (Ecorr). According to Athiyanarayanan et al., the potential change ranged from -20 to +20 mV. Galvanostatic pulse technology for concrete steel corrosion monitoring. A computer-controlled potentiostat might advance the idea similarly at 0.125 mV/s, according to Cem Concr Compos. 2006. The programmable potentiostat corrected for IR decline. Polarisation resistance, Rp, was calculated from the slope of the applied voltage vs measured current plot at zero current. All specimens were compared using the same approach. Huang, Chang, and Wu employed the Stern-Geary equation to calculate corrosion current. Mater Lett. 1996: Rebar corrosion potential and polarisation resistance in concrete. The corrosion current (Icorr) is $(0.98{*}BRp\times10^{-3})$, where $B = (\beta a\beta c/2.3(\beta a + \beta c))$, βa and βc are Tafel constants, Rp is the polarisation resistance (ΔE/ΔI), and Icorr is the corrosion current (mA).

The constant B for chloride-contaminated specimens was 26 mV, while the constant B for chloride-free specimens was 52 mV. According to Zafeiropoulou T, Rakanta E, Batis G, icorr is in mA/m2. Organic coatings for concrete structures: carbonation resistance and anticorrosive qualities, where A is the total exposure surface area of all three rebars in a specimen using

Hornbostel K, Larsen CK, Geiker MR's equation. A literature review on concrete resistivity and corrosion. Hornbostel K, Larsen CK, Geiker MR, Cem Concr Compos. 2013; j.cemconcomp). A literature review on concrete resistivity and corrosion. J.cemconcomp.2013

Two electrodes assessed concrete electrical resistance (Fig. 2). Over the two parallel electrodes, a 3000 mV sinewave alternating current was delivered at 10 kHz. According to Hornbostel K, Larsen CK, Geiker MR, concrete's electrical resistivity was determined using the revised Ohm's equation. 2013. Concrete resistivity-corrosion rate relationship.

The study assessed rebar corrosion before applying cathodic protection (CP) on reinforced concrete specimens. Stern and Geary [27] measured corrosion rates using linear polarisation. Soldering wires gave them the combined potential of the three reinforcing bars. After measuring the average current density, icorr, the researchers calculated the corrosion rate of the three rebars. Rebars were perturbed by ΔE from their initial open circuit potential, Ecorr. The linear polarisation method is a non-destructive electrochemical method used to detect steel rebar corrosion. Measure the current response after applying a little potential variation around the open circuit potential. This calculates the corrosion current density (icorr), which is directly related to metal corrosion. Metal surface electrochemistry is also indicated by open circuit potential (Ecorr). In this reinforced concrete study, linear polarisation was used to determine rebar corrosion. The linear polarisation approach assumes that a corroding metal's polarisation resistance (Rp) is inversely linked to its corrosion current density. To determine the polarisation resistance (Rp), induce a small potential change (ΔE) around the open circuit potential (Ecorr) and measure the resulting current change (ΔI). The researcher worked with Determined the three reinforcing bars' open circuit potential (Ecorr). This reveals the rebar surface's electrochemistry. Use a small voltage (ΔE) change, typically ±10-20 mV from Ecorr. This causes an electrical current response (ΔI) from the rebar surface. Calculated polarisation resistance using the Stern-Geary equation. Rp = ΔE / ΔI displays the relationship between Rp, energy (ΔE), and current (ΔI). Next, the Stern-Geary coefficient (B) calculated corrosion current density (icorr): The formula for icorr is B/Rp. The anodic and cathodic Tafel slopes of the corroding metal determine the Stern-Geary coefficient (B), which is fixed. Steel active corrosion in concrete is typically 26–52 mV. The researchers measured the average icorr of the three rebars to evaluate the concrete specimens' reinforcing steel corrosion rate before cathodic protection. The study evaluates reinforced concrete corrosion rates using linear polarisation.

4.2 Quantifying Corrosion Rates

Linear polarisation experiments yield a corrosion current density (icorr) proportional to metal corrosion. The corrosion rate (CR) is usually stated in mils per year (mpy) or millimetres per year. To calculate corrosion rate, use Faraday's law: CR (mpy) = 0.13 * icorr (μA/cm^2) / metal density (g/cm^3). Concrete steel rebars have a density of 7.85 g/cm3. If the measured icorr is 1 μA/cm^2, the corrosion rate is 0.13 mpy or 0.003 mm/y. Corrosion factors. Steel rebar corrosion in concrete depends on concrete quality and moisture content, chlorides or other corrosive ions, oxygen at the rebar surface, concrete cover depth, and stray electrical currents. Linear polarisation measurements helped researchers determine the baseline corrosion rate before cathodic protection.

Structural damage and costly repairs can result from reinforced concrete corrosion. Calculating corrosion rates accurately is crucial for forecasting reinforced concrete service life and choosing maintenance measures. More than one approach has been developed to measure and monitor reinforced concrete deterioration. Linear polarisation resistance, electrochemical impedance spectroscopy, and Tafel extrapolation were reviewed by Andrade and Alonso (1996) for monitoring steel corrosion in concrete. These methods assess corrosion rates in-situ, non-destructively, and are widely used.Half-cell potential measurements were used to examine reinforced concrete corrosion by Macdonald and Hyne (1977). Active corrosion was likely for half-cell potential values greater than -0.35 V versus a saturated calomel electrode. More recently, Song and Saraswathy (2007) reviewed electrochemical methods for monitoring reinforced concrete corrosion, emphasising the importance of concrete cover depth, moisture content, and chloride concentration in interpretation. An Experimental Study of Chloride-Contaminated Reinforced Concrete Cathodic Protection. In reinforced concrete constructions, cathodic protection is commonly utilised to reduce corrosion. A little electrical current moves the reinforcing steel's potential in the noble direction, limiting corrosion. An experimental study by Bertolini et al. (2004) examined cathodic protection for chloride-contaminated reinforced concrete structures. Their findings showed that cathodic protection reduced corrosion rates and that concrete cover depth and chloride concentration affected current density. Christodoulou et al. (2010) found that cathodic protection systems on chloride-contaminated reinforced concrete structures maintained steel potential enough to prevent corrosion after several years. These investigations show that cathodic protection systems must be carefully designed and implemented to prevent corrosion in reinforced concrete structures.

Correctly measuring and monitoring reinforced concrete corrosion rates is essential for forecasting service life and choosing maintenance measures. Almeida, N. G., Teixeira, P. F., & Gomes, A. P. (2020) discuss the Linear Polarisation Resistance (LPR) method, which involves applying a small potential perturbation around the open-circuit potential and measuring the current response. Electrochemical Impedance Spectroscopy (EIS) applies an AC signal over a range of frequencies and measures the reinforcement-concrete system's impedance response to quantify corrosion rate. This explains corrosion dynamics and processes, Tafel Extrapolation: Applying a higher potential perturbation and extrapolating Tafel slopes determines corrosion current density, which can be used to measure corrosion rate. More negative half-cell potentials indicate active corrosion. These electrochemical methods should be interpreted using concrete cover depth, moisture content, and chloride concentration, according to the review. According to Almeida, N. G., Teixeira, P. F., & Gomes, A. P. (2020), cathodic protection is a common strategy for preventing corrosion in reinforced concrete structures. Applying a modest electrical current to reinforcing steel alters its potential in the noble direction, inhibiting corrosion. The research evaluated show that cathodic protection reduces chloride-contaminated reinforced concrete corrosion. Almeida, N. G., Teixeira, P. F., & Gomes, A. P. (2020) found that the required current density for effective cathodic protection is influenced by concrete cover depth and chloride content, and that well-designed and implemented systems can hold the steel potential high enough to prevent further corrosion. Cathodic protection systems must be monitored to prevent corrosion. These studies emphasise the need to consider reinforced concrete structural conditions while planning and installing a cathodic protection system. Gomes, A. P., & Almeida, N. G. (2020).

4.3 Cathodic protection

This experiment examines cathodic protection on reinforced concrete. Under cathodic protection, the study will assess reinforced concrete building corrosion resistance and durability. Electrochemical and physical tests will do this. Cathodic protection system, concrete mix design, and exposure circumstances are used in the experiment. This study will shed light on cathodic protection on reinforced concrete buildings, improving corrosion prevention measures.

The rebars in each specimen were subjected to ten CP current densities using galvanostatic polarisation. Each is 5, 10, 15, 20, 25, 35, 45, 55, 65, and 75 mA/m^2. Figure 3 shows that each test connected 10 specimens (two for each chloride content) in series immediately. Reference electrodes were Ag/AgCl/0.5KCl half cells. A 10,000 kΩ input impedance multi-channel data logger with 0.1 mV resolution was utilised to record all potential values.

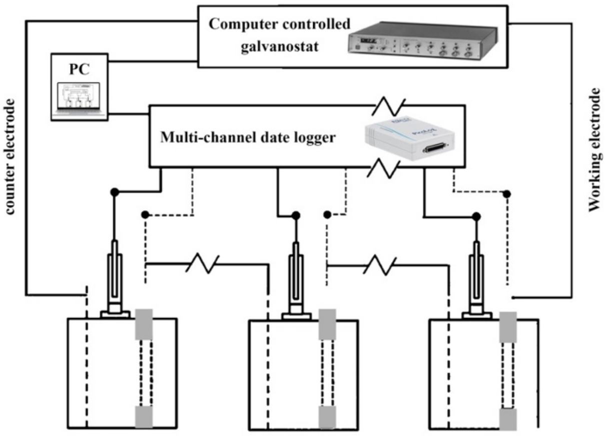

Fig. 2: Experimental design for specimens strengthened by cathodic protection (CP)

Each test had a certain CP current density applied for 24 hours and afterward switched off for more than one day (24 hours) to ensure a sufficient depolarization of the rebars. In the time, the potential of rebars was continuously recorded from the start and until 4 hours after the interruption of the CP current in the time of depolarization. Based on the recorded data, the instant-off potential, and 4-h potential decay can be obtained.

5. Results

The current study expands on Teychenné, Franklin, and Erntroy (1997)'s landmark work on concrete mix compressive strength. Building concrete samples according to the literature, the researchers aim for a 28-day compressive strength of 38 N/mm2.Study used local limestone Portland cement. Its 390 kg/m3 density makes it the concrete mix's principal binder. Fine aggregates, 1125 kg/m3 of 4.75-mm natural sands with a specific gravity of 2.47, are selected to enhance packing density and mechanical properties. Limestone produces 10 mm coarse aggregates with a specific gravity of 2.49 at 580 kg/m3. Specifically, mix water is purposely polluted with pure NaCl (0%, 1%, 2%, 3.5%, and 5% of the cement weight) to examine the effect of saline environment on concrete performance. Experiments reveal the link between material composition, ambient circumstances, and compressive strength. In this study, thorough testing and empirical confirmation show that the suggested mix design achieves the desired compressive strength. The study emphasizes how NaCl contamination impacts concrete properties, which is significant for salty or coastal applications. Based on Teychenné, Franklin, and Erntroy's work, the study highlights concrete mix design fundamentals. By combining theory and experiment, the researchers advance materials science and engineering methodologies. Contextualizing the subject in Bahrain's atmosphere offers practitioners and scholars regional insights.

5.1 Analysis of chloride concentrations, corrosion rate, and concrete resistivity

The measured chloride contents in the cured specimens of each mix with different added NaCl and the corresponding electrical resistivity of the concrete are listed in figure 3 Chloride contents are expressed in terms of the percentage of the cement weight of specimens.

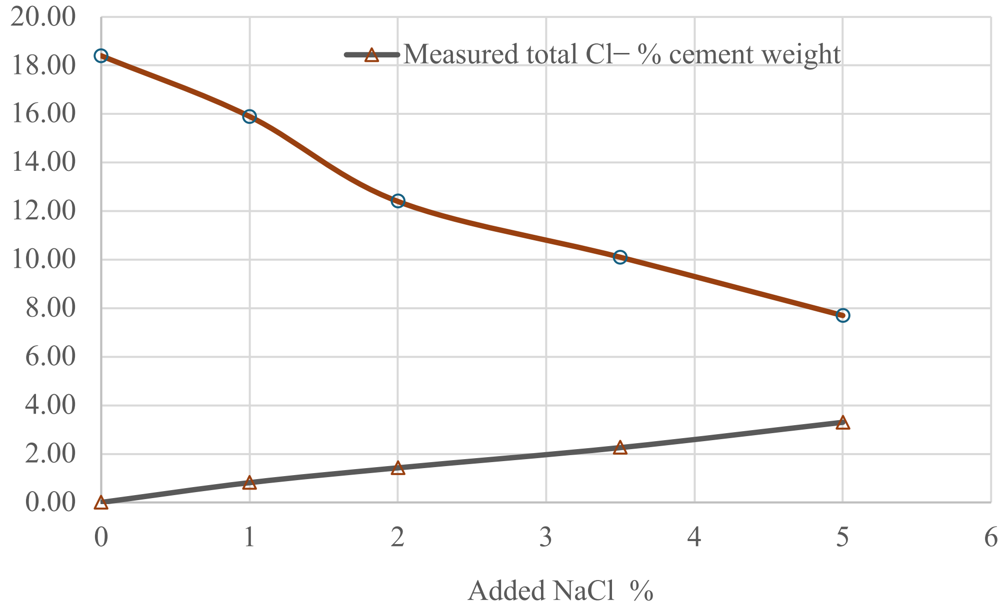

Figure 3 Chloride content concentration, reinforcement corrosion rate, and concrete resistivity

In Figure 3, corrosion rate, chloride concentration, and concrete electrical resistance correspond for these specimens. Rebar corrosion rises with chloride content or concrete resistance. Corrosion risk is minimal when the corrosion rate is 1–5 mA/m2, moderate when 5–10 mA/m2, and significant when greater than 10 mA/m2, according to Broomfield JP. To estimate reinforcement corrosion risk, reinforcements with a total chloride concentration of less than 0.45% by cement mass have a low corrosion rate. Reinforcements over 1.4% chloride corrode. Based on Broomfield JP 2007, the threshold is 0.4–1% chloride by cement weight. According to Fig. 4, reinforcements with concrete electrical resistivity exceeding 17 kΩ cm have low corrosion rates, while those below 12.5 kΩ cm have high rates. Results mirror prior research. Morris W, Vico A, Vázquez M modified literature research. The 2004 study found that chloride-induced corrosion of reinforcing steel was significant for concrete resistivity < 10 kΩ cm. Vassie and Cavalier investigated highway bridge corrosion. Cavalier and Vassie (1981) indicated that concrete with resistivity below 5 kΩ cm is susceptible to corrosion, but it is usually negligible beyond 12 kΩ cm. The study by Gonzalez et al. indicated that corrosion risk is low above 20 kΩ cm resistivity and substantial below 5 kΩ cm. Repeatability of reinforced concrete potential and corrosion rate measurements is connected. Finish 2004.

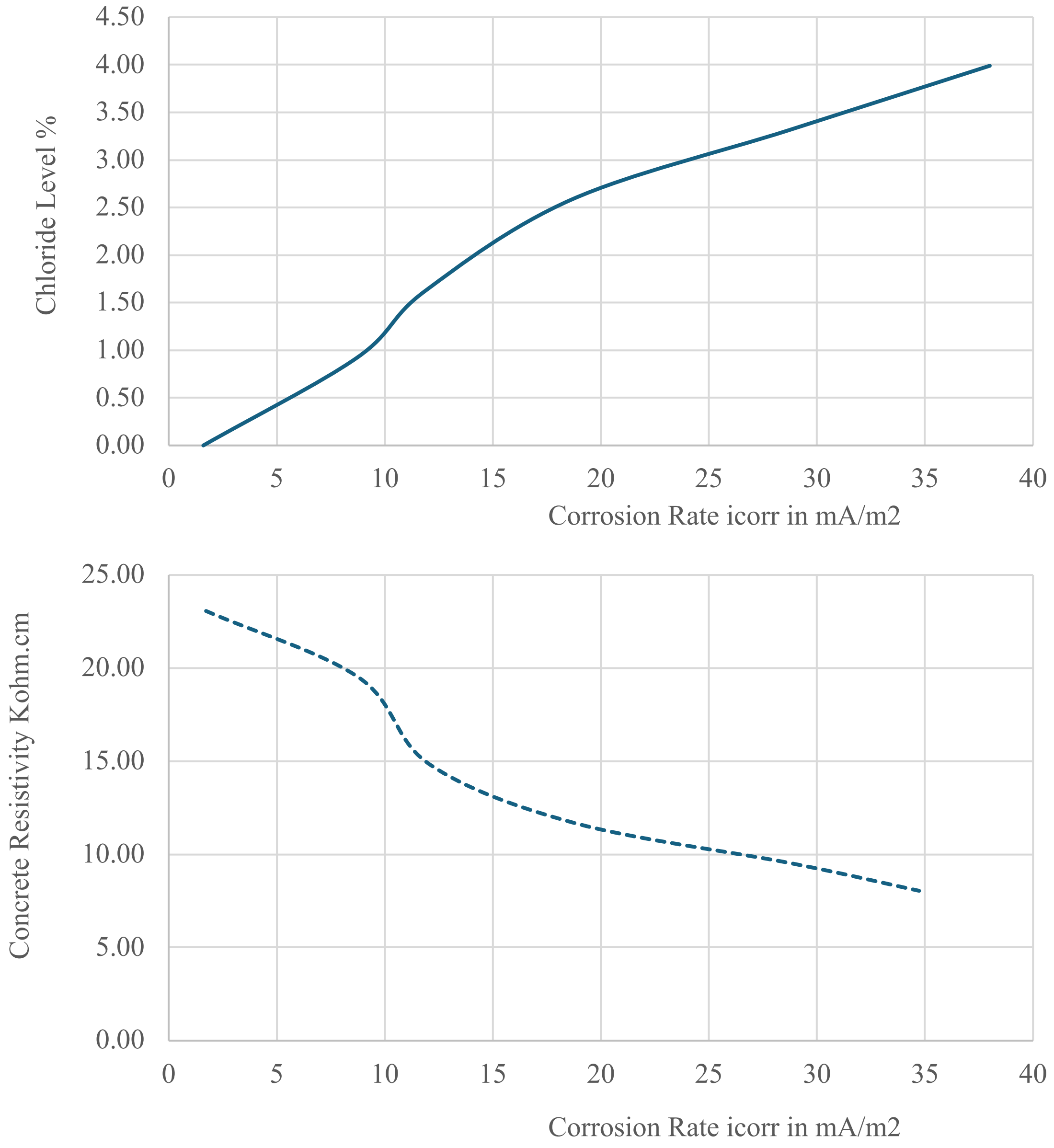

Figure 4: Reinforcement corrosion rate in mAmps per square meter vs chloride content in percentages and concrete resistivity.

5.2 The impact of the duration of CP operation on the immediate cessation of potential difference.

In this study, the reinforcements' instant-off potential was automatically measured in 1 s after CP was turned off according to BS EN ISO 12696 (2012) Figure 5 shows the relationship between reinforcement instant-off potential and operation time. The 20 mA/m2 example was measured for 120 h (5 days), while the other two were stopped after 25 h. In all three examples, the instant-off potential changes significantly in the first 3 hours of CP operation under all current densities. After 3 hours, all curves are flat with a minor change, indicating that the system is stable. The figures below 5 show that all CP performance assessment parameters were gathered 24 hours following CP implementation.

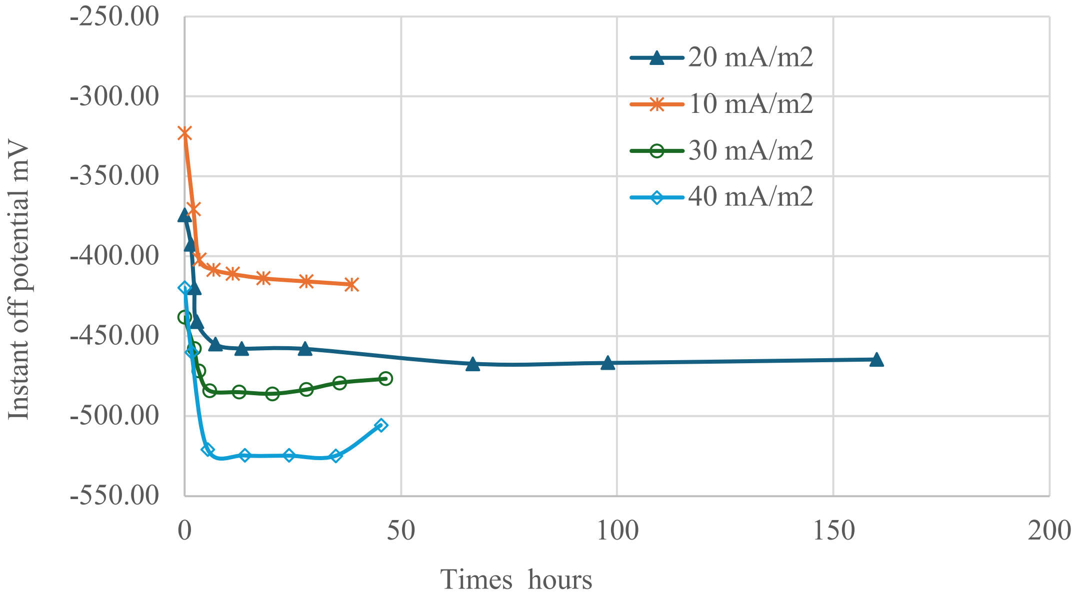

Figure 5 Reinforcement instant off potential versus operation time that Effects of CP current density and chloride content on instant-off potential

In NACE SP0290 (2007) Impressed current cathodic protection of reinforcing steel in atmospherically exposed concrete structures, instant-off potential is a key CP performance indicator. At NACE International, Houston, TX.Consider the -720 mV.Figure 6 illustrates the reinforcements' 24-hour CP instant-off potential in specimens with varying chloride concentrations and CP current densities. The absolute instant-off potential increases with the applied CP current density, while the curve slope becomes flat as concrete chloride concentration increases. Results indicate that the − 720 mV threshold remains unattainable even with the greatest applied current density (75 mA/m2) for all chloride-contaminated specimens.

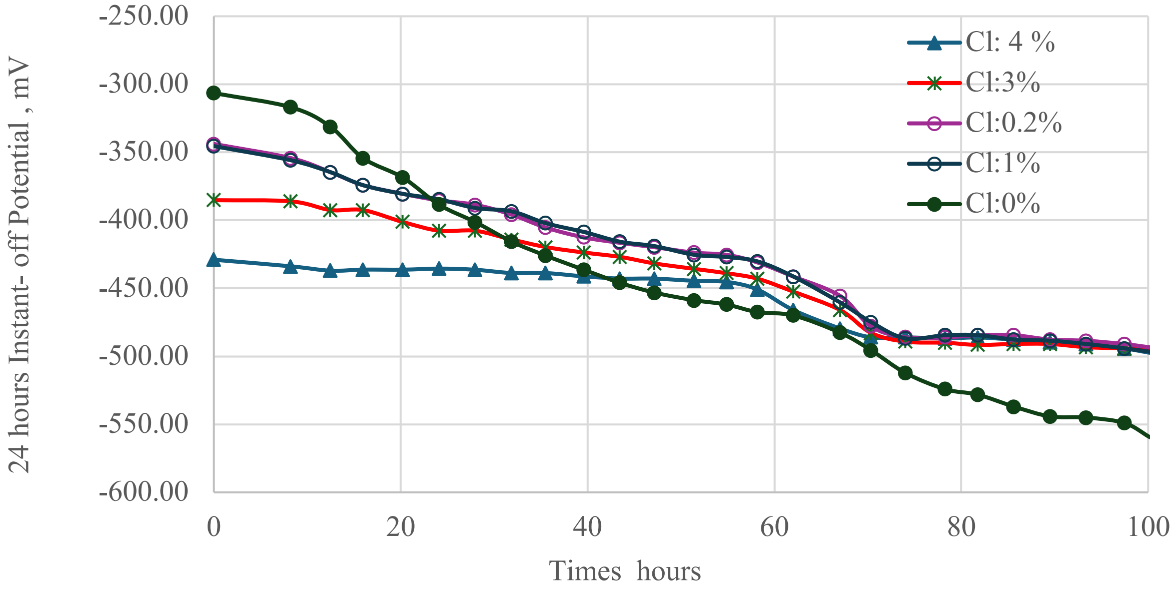

Fig 6 Twenty-Four hours instant-off potential versus CP current density at different chloride contents four hours potential decay

Table (1) displays the instantaneous potential for turning off a 24-hour current, compared to the current density of CP, at various chloride concentrations. Decay of 4-hours potential

	Cl: 4 %	Cl:3%	Cl:0.2%	Cl:1%	Cl:0%
Mean	-459.23	-459.23	-459.23	-431.08	-453.08
Standard Error	4.83	4.83	4.83	9.62	14.83
Median	-444.91	-444.91	-444.91	-426.18	-460.36
Standard Deviation	24.62	24.62	24.62	49.08	75.60
Sample Variance	606.25	606.25	606.25	2408.40	5715.39
Kurtosis	-1.77	-1.77	-1.77	-1.37	-0.79
Skewness	-0.37	-0.37	-0.37	0.08	0.42
Range	68.40	68.40	68.40	151.13	252.93
Minimum	-497.39	-497.39	-497.39	-496.59	-559.41
Maximum	-428.99	-428.99	-428.99	-345.46	-306.48
Sum	-11939.86	-11939.86	-11939.86	-11208.06	-11780.08
Count	26.00	26.00	26.00	26.00	26.00
Confidence Level(95.0%)	9.95	9.95	9.95	19.82	30.54

The 4-h potential decay, another essential statistic used to evaluate CP operation, is the difference between the instant-off potential and the potential recorded 4 h after switching off the CP current. Most accept 100 mV depolarization in 4 hours. Figure 6 displays reinforcing depolarization (4-hour potential decline) versus CP current density at varying chloride contamination. For some chloride content, reinforcing depolarization rises with applied current density. The 4-h potential decay curve for chloride-free specimens is over 100 mV (the horizontal solid line). Even without CP (i.e., I = 0), reinforcements in chloride-free concrete environments are corrosion-free. As shown in the Figures below, a current density of 15 mA/m^2 is sufficient to safeguard the reinforcement in 0.814% chloride concrete under the 100 mV potential decay requirement. Although chloride-free concrete meets the − 720 mV instant-off potential standard, current density of 75 mA/m^2 does not adequately protect the reinforcement.

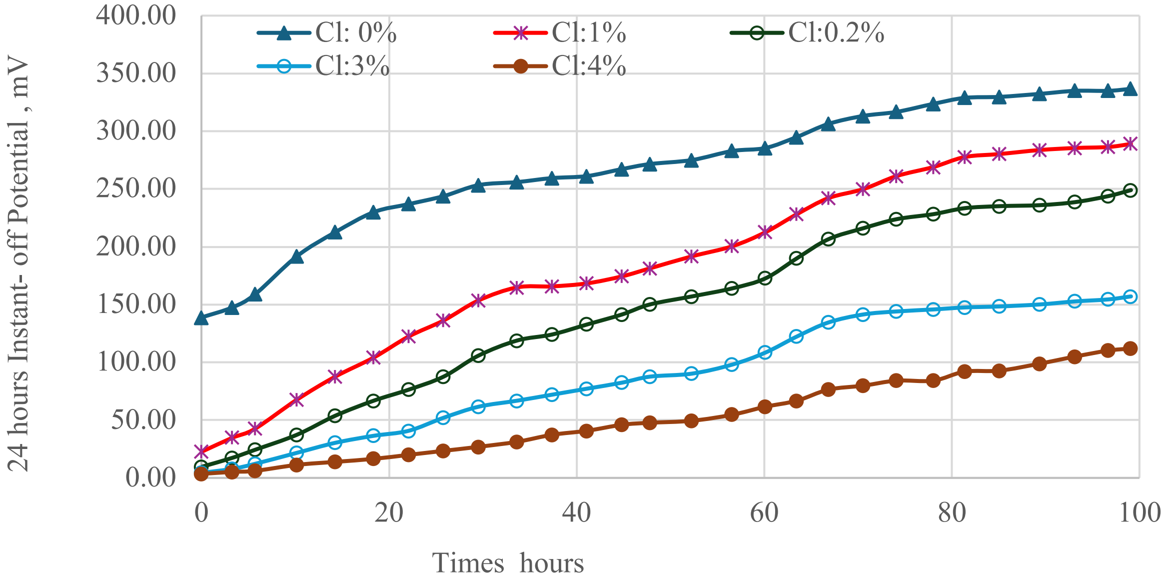

Figure 7 The comparison is between the depolarization caused by reinforcement and the current density of CP. The criterion for the horizontal solid line is 100 mV, whereas the dashed line represents 50 mV.

Table (2) Comparison between the depolarization caused by reinforcement and the current density of CP.

	Cl: 0%	Cl:1%	Cl:0.2%	Cl:3%	Cl:4%
Mean	268.73	185.13	147.88	91.01	53.49
Standard Error	10.98	15.83	14.76	9.76	6.63
Median	273.32	186.55	153.58	88.94	48.59
Standard Deviation	58.09	83.74	78.10	51.63	35.11
Sample Variance	3374.17	7012.65	6099.87	2666.17	1232.59
Kurtosis	-0.03	-0.86	-1.19	-1.35	-1.30
Skewness	-0.82	-0.46	-0.33	-0.22	0.17
Range	197.83	266.38	239.48	152.71	108.46
Minimum	138.83	22.56	9.54	4.34	3.47
Maximum	336.66	288.94	249.02	157.05	111.93
Sum	7524.51	5183.51	4140.57	2548.37	1497.61
Count	28.00	28.00	28.00	28.00	28.00
Confidence Level(95.0%)	22.52	32.47	30.28	20.02	13.61

Figure 7 compares the two conventional criterion parameters, i.e., the 24 h CP instant-off potential and 4-h potential decay at different CP current density in terms of the results in Figure 6,7 as it shows that in terms of the 100 mV 4-h potential decay criterion, − 500 mV 24-h CP instant-off potential is sufficient to protect the reinforcements in all the investigated contaminated concretes.

Table (3) Statistical evaluation of Reinforcement depolarization versus CP current density and 24-h CP instant-off potential (the horizontal solid line for 100 mV potential decay and the dash line for 50 mV while the vertical solid line for − 500 mV instant-off potential)

	Cl: 0%	Cl:1%	Cl:0.2%	Cl:3%	Cl:4%
Mean	245.35	139.73	164.88	86.09	54.55
Standard Error	14.21	20.55	20.56	15.01	10.97
Median	249.52	148.03	165.15	87.82	57.28
Standard Deviation	58.59	74.09	82.23	49.77	34.70
Sample Variance	3432.81	5489.19	6761.28	2477.23	1204.29
Kurtosis	-0.67	-0.91	-1.11	-1.38	-1.23
Skewness	-0.29	-0.24	-0.16	0.02	0.15
Range	206.52	234.51	260.71	143.46	98.15
Minimum	129.99	13.57	25.69	15.60	12.08
Maximum	336.51	248.08	286.41	159.05	110.23
Sum	4170.94	1816.51	2638.09	946.94	545.53
Count	17.00	13.00	16.00	11.00	10.00
Confidence Level(95.0%)	30.12	44.77	43.82	33.44	24.82

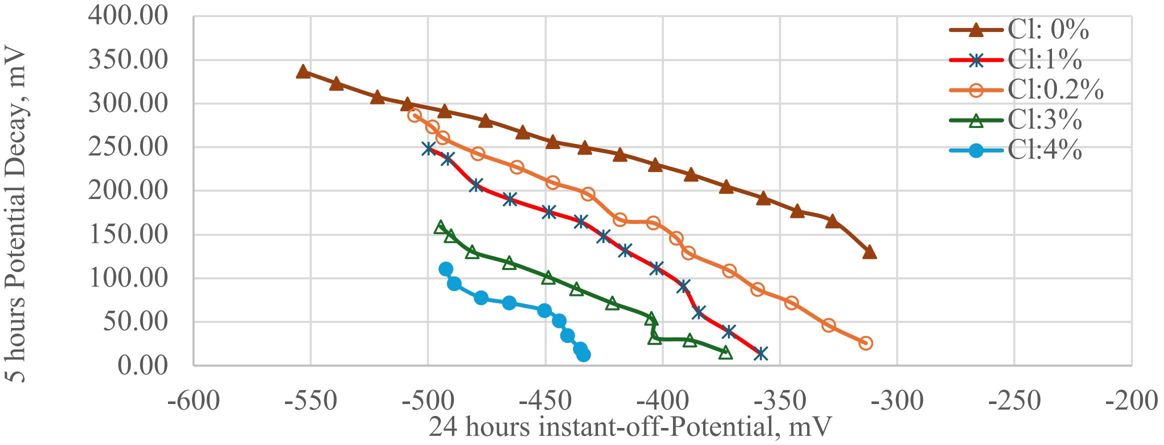

Figure 8 Reinforcement depolarization versus CP current density and 24-hours CP instant-off potential (the horizontal solid line for 100 mV potential decay and the dash line for 50 mV while the vertical solid line for − 500 mV instant-off potential)

Figure 8 shows the required current densities for 100 mV (the interception points on the horizontal solid line in Figure 7) and 50 mV (the interception points on the horizontal dash line in Figure 7) depolarization (the 4-h potential decay) for the reinforcements at different initial corrosion rates before CP operation. The dash-dot line indicates the condition when the applied CP current density equals the initial corrosion rate of the reinforcements. It can be seen that the suggested protection current density in terms of the 100 mV depolarization criterion is much higher than the corrosion rate of reinforcements. Particularly, the extra protection current density is projected at a high CP current density when reinforcement exposes to high chloride contamination or has a high initial corrosion rate. However, the CP current density in terms of the 50 mV depolarization condition is very close to the dash-dot line at all reinforcement initial corrosion rates.

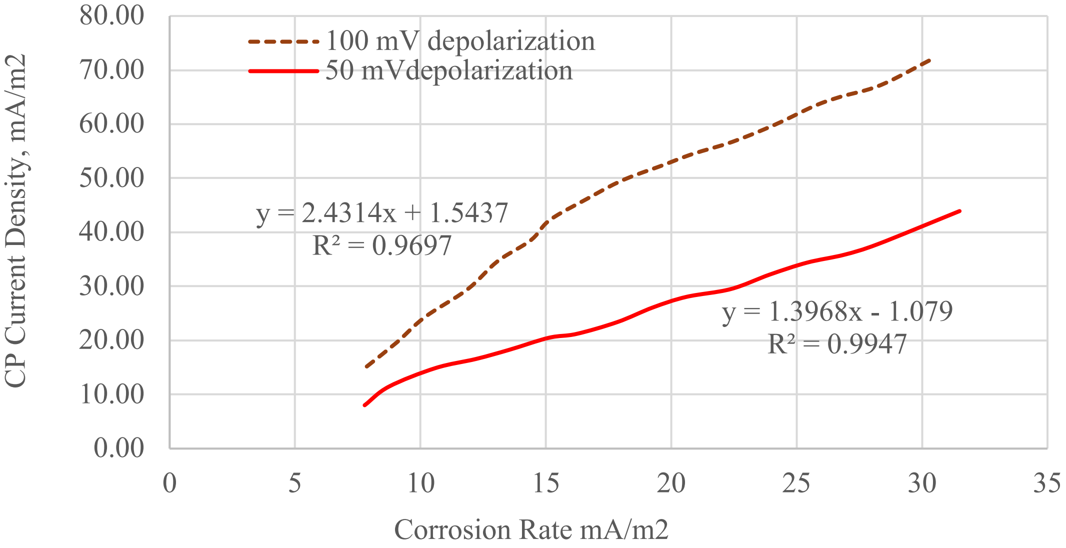

Figure 9 displays the necessary current density for cathodic protection (CP) at various levels of depolarization, a s compared to the initial corrosion rate of reinforcements.

Figure 9 shows the CP current densities and electrical resistance that cause 100 mV and 50 mV depolarization (the decay of the 4-h potential) in concrete reinforcements with different chloride contents. Figure 7 shows the data when all curves cross with the solid horizontal line at 100 mV and the dotted horizontal line at 50 mV after a 4-hour drop. For both 100 and 50 mV depolarization, the CP current density and chloride concentration are linearly related. A linear relationship with concrete resistivity is also suitable for practical applications. The data show that corrosion prevention (CP) is unnecessary below 0.31% chloride. This figure is 75% of Broomfield's classification's low risk upper limit, mentioned in Section 4.1. Additionally, CP is not necessary for concrete resistivity over 17 kΩ cm.

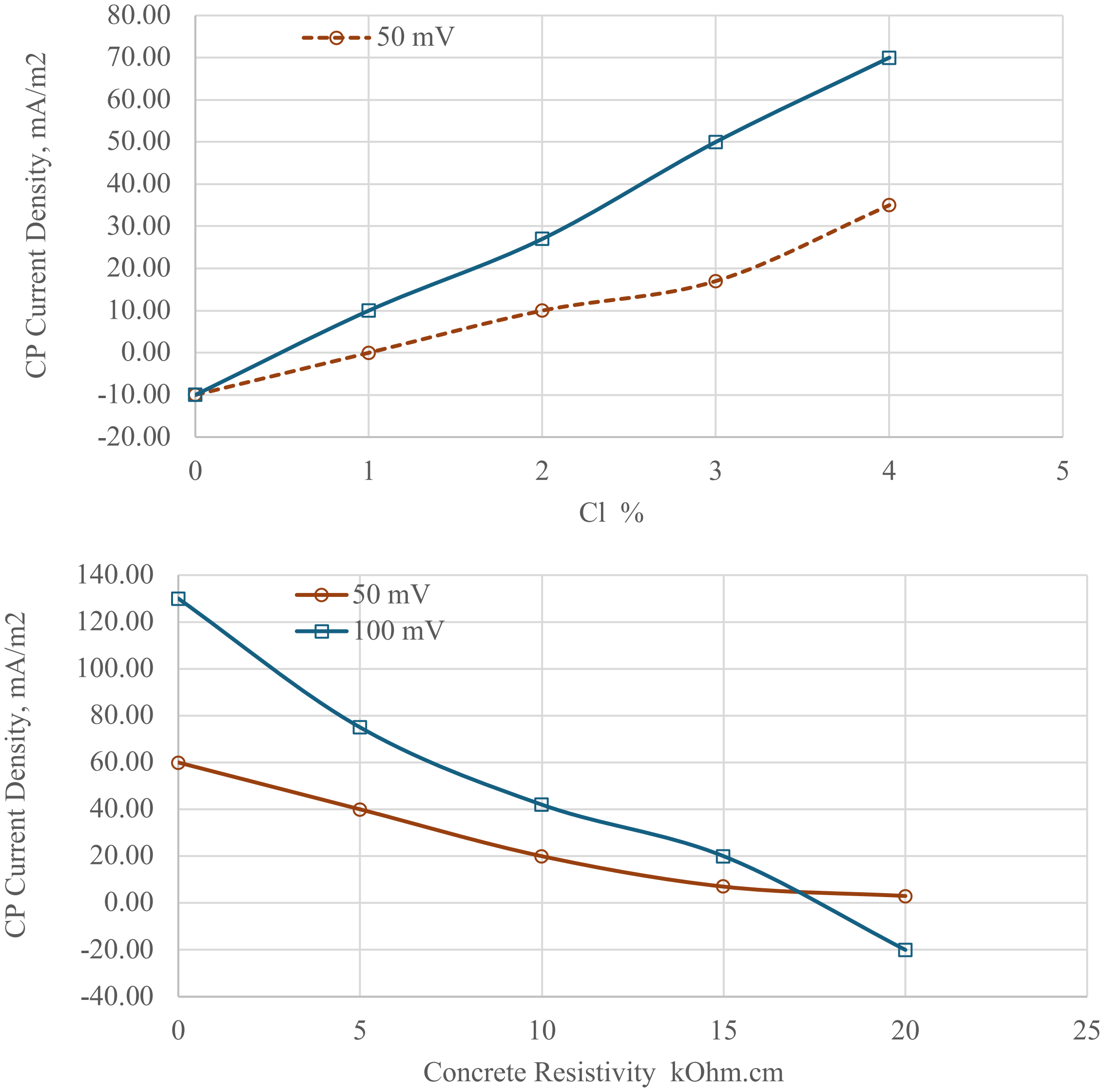

Figure 10 displays the necessary current density for cathodic protection (CP) at depolarization levels of 100 mV and 50 mV. The graph shows how the required CP current density varies based on the chloride content and concrete resistivity. The horizontal lines on the graph represent situations when no CP current is needed.

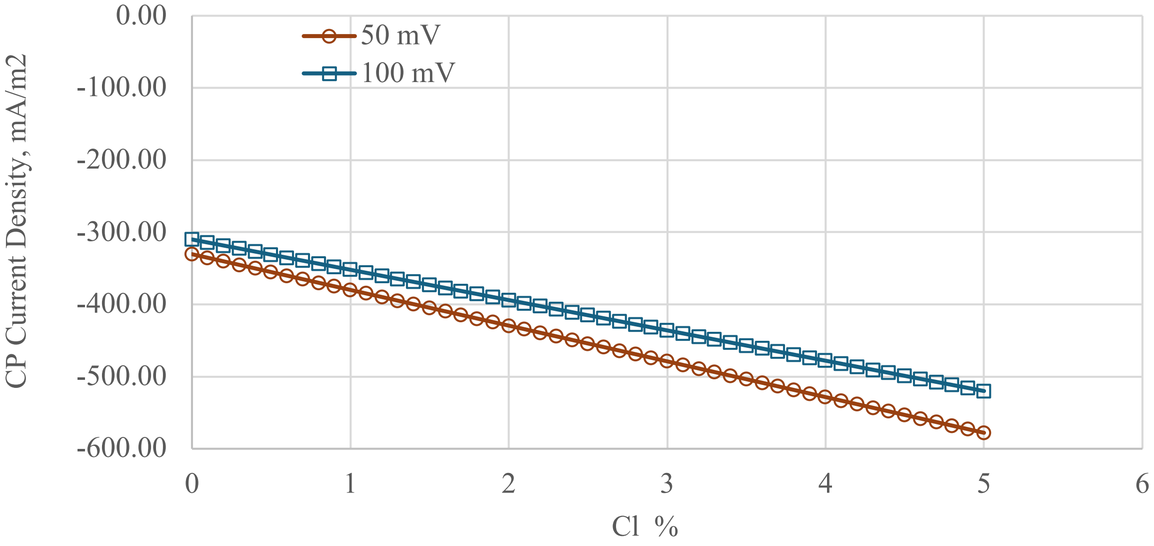

Figure 11 illustrates the 24-hour corrosion potential of the reinforcements in concrete with varying chloride content and related electrical resistivity.

This potential corresponds to a depolarization of 100 mV and 50 mV, which results in a decrease of the potential over a 4-hour period. The data represents the places where all the curves intersect with the solid horizontal line at a depolarization of 100 mV and the dashed horizontal line at a depolarization of 50 mV, as shown in Figure 8. Furthermore, it shows that the necessary immediate shutdown capability for both the 100 and 50 mV depolarization can be accurately described by linear connection with the chloride concentration and concrete resistivity, respectively. It is evident that a potential of -500 mV may effectively protect the reinforcement in concrete against corrosion caused by chloride concentration of up to 3.4% or a resistivity of more than 6.7 kΩ cm, based on the 100 mV potential decay criteria. Using a 50 mV potential decline as a standard, the − 500 mV instant-off potential may effectively safeguard against chloride content up to 4.5% or concrete resistivity below 3.8 kΩ cm.

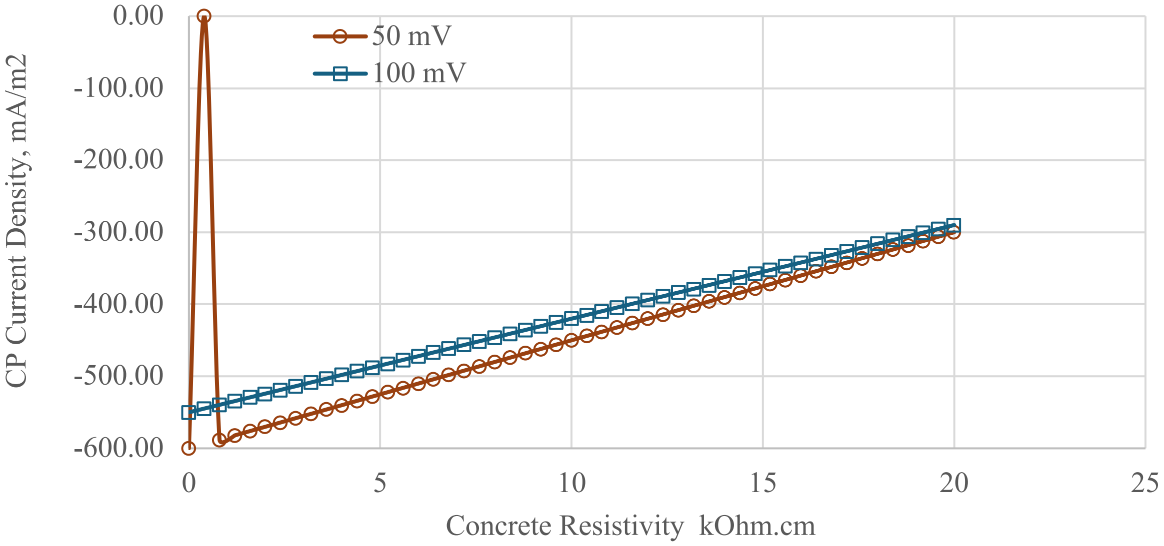

Figure. 12 The required 24-h CP instant-off potential for the 100 mV and 50 mV depolarization (4-h decay potential) versus chloride content and concrete resistivity (the horizontal lines indicate − 500 mV instant-off potential)

Figure 12 from Bertolini et al. (2004) demonstrates the relationship between chloride concentration, concrete resistivity, and 24-hour cathodic protection (CP) instant-off potential in chloride-contaminated reinforced concrete. Reinforcement corrosion rate, chloride concentration, and concrete resistivity in reinforced concrete buildings a complex relationship. First, Chloride Content—Chloride ions induce reinforcement corrosion in concrete buildings—increases the risk of corrosion and the speed of reinforcing steel corrosion. Once chloride reaches 0.4 to 1.0% by cement mass, corrosion accelerates dramatically. The inverse relationship between conductivity and resistivity measures concrete's electrical current carrying capacity. More dense, less porous concrete slows ion flow for electrochemical corrosion. High resistivity concrete (>20 kΩ·cm) has little corrosion risk, while low resistivity (<5 kΩ·cm) poses significant threat. The corrosion rate relationship Steel corrosion exponentially increases in concrete with greater chloride content. Due to ionic flow resistance, high-resistivity concrete has a lower corrosion rate than low-resistivity concrete, which increases fast with chloride levels. Other factors, such as concrete cover depth, quality, and climate, may affect the link between chloride content, concrete resistivity, and corrosion rate. Sufficient concrete cover and high-quality, low-permeability concrete decrease chloride effects and boost concrete resistance. For assessing corrosion risk, mitigating corrosion, and predicting reinforced concrete building longevity, understanding how these factors interact is crucial. Balance chloride concentration and concrete resistivity for reinforcement corrosion. Coefficient of Corrosion: Even with high chloride concentration, concrete resistivity moderates chloride-induced corrosion and ionic flow resistance lowers corrosion in high-resistivity concrete. High chlorine levels worsen low-resistivity concrete deterioration, but concrete cover depth, quality, and climate can affect chloride content, concrete resistivity, and corrosion rate. High-quality, low-permeability concrete and enough concrete cover reduce salt effects and increase concrete resistivity. How these parameters combine affects corrosion risk assessment, mitigation, and reinforced concrete structure lifetime prediction. Concrete resistivity and chloride content must balance reinforcing corrosion.

The key points illustrated in this figure are Chloride Content vs. Instant-Off Potential supposed to be clarifying the issue of chloride content.

1. As the chloride content in the concrete increases, the required instant-off potential (more negative value) needed for effective cathodic protection also increases. This indicates that higher chloride contamination requires a more negative potential to be applied to the reinforcing steel to adequately protect it from corrosion.

2. Concrete Resistivity vs. Instant-Off Potential where the figure shows that as the concrete resistivity increases, the required instant-off potential becomes more negative. The Higher concrete resistivity means the concrete is less conductive, which makes it more difficult to achieve the necessary potential at the steel surface for effective cathodic protection.

3. Horizontal Lines at -500 mV that the horizontal lines in the figure represent the commonly accepted threshold of -500 mV (vs. a saturated calomel electrode) for the instant-off potential to provide adequate cathodic protection.

This suggests that for concrete with high chloride content and/or high resistivity, the -500-mV instant-off potential may not be sufficient, and a more negative potential may be required. An effective cathodic protection system for reinforced concrete structures must consider chloride concentration and concrete resistivity, as shown in this picture. Environment affects instant-off potential. This study's findings suggest that the initial passive layer was neglected because chloride was added to the water to hasten corrosion. This study only recommends actively corroding reinforcements like chloride-contaminated concrete with a low pH pore solution without passivation. 2 is the second point. Tests presume that rebar corrosion is evenly distributed, indicating that while corrosion may be minute, there are no serious pockets. The standard method of adding Cl to the mixing water and curing the concrete specimens in water with equal chlorides improved chloride distribution. On all accessible surfaces, CP-measured rebars had corrosion.

6. Conclusion

This study examined Portland cement concrete's corrosion protection (CP) under air chloride contamination. The work outlined yields the following findings. For cathodic protection (CP) in Portland concrete, a chloride concentration of 0.31% by weight of cement or an electrical resistance of 17 kΩ cm is recommended to prevent reinforcing corrosion. With an A potential of -500 mV relative to the Ag/AgCl/0.5KCl electrode, reinforced concrete with chloride contamination up to 3.4% by weight of cement or 6.7 kΩ cm concrete resistivity can be protected, depending on the 100-mV depolarization requirement. CP current (cathodic protection) was strongly correlated with concrete chloride concentration and resistivity. Characterization modelling is also suggested.

Corrosion Inhibiting admixtures can slow corrosion and form a protective film on rebar surfaces, reducing corrosion initiation and propagation. Providing enough concrete cover over reinforcing steel slows chloride intrusion and delays corrosion. Building rules and standards provide minimum cover depths based on exposure circumstances. High-quality, low-permeability mixes reduce chloride infiltration and improve concrete quality. The methods include low water-to-cement ratios, proper curing, and fly ash or slag SCMs. More dense concrete limits chloride ion movement to steel. Surface treatments and coating, electrochemical chloride extraction, concrete restoration, and replacement are more options.

Use of cathodic protection has reduced corrosion in desalination plants. To maximise system efficiency, the design and installation process must overcome many challenges. CP system efficiency depends on proper design and implementation. This method involves selecting ICCP or SACP cathodic protection, situating anodes, and ensuring power supply and distribution. It also covers maintenance and monitoring. CP system efficiency requires regular maintenance and monitoring. This includes inspecting ICCP systems, checking sacrificial anodes, and monitoring current and potential. Environmental factors Temperature, salinity, and live organisms affect CP's potency. Along with those above listed, these must be considered when constructing and operating CP systems. To ensure compatibility, CP is often used with coatings and inhibitors. For comprehensive corrosion prevention, techniques must be compatible and synergistic.

Desalination plant cathodic protection will focus on efficiency, cost reduction, and monitoring and control. Advance anode material research and development. Novel anode materials with improved performance and lifespan can reduce maintenance costs and boost cathodic protection system efficiency. Monitoring Smart Systems: Using IoT and AI, smart monitoring and control systems can provide real-time data and predictive maintenance. By preventing corrosion in critical components, cathodic protection keeps desalination facilities reliable. Technological, material, and monitoring and maintenance advances can improve CP system performance despite obstacles. Effective corrosion prevention will become more important as desalination solves the global water problem. Integration enhances CP system dependability and efficacy while decreasing environmental impact. Researching ways to lessen the environmental impact of CP systems, such as greener sacrificial anodes and ICCP energy savings, is crucial for sustainability. Creating integrated corrosion management systems that synergistically combine cathodic protection (CP) with other techniques may improve desalination infrastructure durability and longevity.

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