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Foundation Protection of Buildings in Coastal Areas Using Cathodic Protection

K.Akash
PG Scholar, Department of Civil Engineering,
Sengunthar Engineering College (Autonomous),
Tiruchengode, TamilNadu, INDIA
kash.k9750@gmail.com
Dr.V.Pavalan
Faculty of Engineering, Department of Civil Engineering,
Sengunthar Engineering College (Autonomous),
Tiruchengode, TamilNadu, INDIA

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Abstract : Foundation of the building plays a major role in proving stability to the entire structure. Foundation soil in the Coastal region having lot of sea water intrusion. The salt content and several minerals present in the sea water having the tendency to erosion of materials like metals and non-metals. The pile foundation present in the coastal region will have reinforcement incorporated on it. It should be strong enough to sustain the entire building loads until its service life. This reinforcement may continuously be exposed to the sea water intrusion on the underground, and it will cause deterioration of reinforcement and it leads to durability issues. The entire structure will be unstable if the foundation is damaged, or it can't take the building load. In several cases, entire building is collapsed due to the uneven settlement caused by the foundation failure. This can be prevented by using an Anti-corrosion method called Cathodic Protection. A demonstration is made on this idea with an electrical voltage supply by using battery.

INTRODUCTION

1.1 General

Heavy structures that is made of any material (ie., either steel or concrete) is having large structural loads that transfer to the foundation. Foundation design for this structure i marine water intrusion is in excess. Service life prediction is becoming one of the major tasks in the design of concrete structures. The durability design must be based on consistent models that can describe the deterioration models more accurately. In marine environment, the service life of reinforced concrete structures depends mainly on deterioration due to reinforcement corrosion. Two stages can be considered in this mechanism; the initiation period corresponding to the critical chloride penetration up to the level of reinforcement and the propagation period related to the reinforcement corrosion and its detrimental effects on the structure. So, major importance is given to the protection of the foundation particularly near the coastal areas. There are several techniques used widely all over the world for this problem and several research are being continued till this era

II. METHODOLOGY

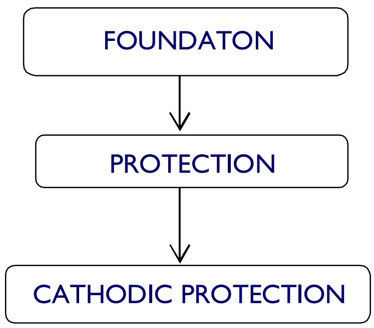


FIG.1 METHODOLOGY FLOW CHART

III. LITERATURE REVIEW

1 Govt. of India, _No.2012/Proj./Chennai/30/6_ Ministry of railways "Chennai metro rail Project- Phase1" >>> Various Design assumptions for pile foundation.

2 U.S Department of Homeland Security & FEMA 499/August 2005_"Coastal Building successes and failures" >>> Buildings subjected to various environmental conditions in coastal areas. In general, homes in coastal areas must be designed and built to withstand higher loads and more extreme conditions. Homes in coastal areas will require more maintenance and upkeep. Because of their exposure to higher loads and extreme conditions, homes in coastal areas will cost more to design, construct, maintain, repair, and insure

3 Norwegian University of Science and Technology, Norway, Vol.2_ "Corrosion in seawater-Biological Effects" by E.Bardal >>> Research carried out during the last two decades on stainless steels and other corrosion resistant materials in natural seawater has shown that the detrimental effects are due to the formation of a micro-biological film (a biofilm) on the surface. This film affects the local corrosion initiation tendency as well as the propagation rate at temperatures below 30-40°C. The effects of the biofilm depend much on other factors, particularly the existence of crevices and deposits on the surface, welds and the quality of welding, aeration, periods of exposure in seawater and flow conditions.

4 International Journal of Structural and Civil Engineering, _Vol.3, No.4, Nov 2014_ (Research paper) "Estimation of Marine salts behavior around the bridge structures >>> Comparative Testing of concrete structures by using Seawater. In marine environment, the service life of reinforced concrete structures depends mainly on deterioration due to reinforcement corrosion. Two stages can be considered in this mechanism; the initiation period corresponding to the critical chloride penetration up to the level of reinforcement and the propagation period related to the reinforcement corrosion and its detrimental effects on the structure.

5 U.S Department of Interior, Office of saline water research and development progress report No.46, _December-1960_"Corrosion of metals in Seawater", by Frederic W. Fink >>> Aqueous corrosion is known to be electrochemical in nature. A simplified concept of the corrosion mechanism proposes anodic and cathodic areas on the metal surfaces. At the anodes, the atoms of the metal release electrons, become positively charged ions, and enter the solution. The electrons pass through the metal to the cathodic area where they discharge a positive ion, often hydrogen. Thus the process involves a flow of electrons through the metal and a flow of charged ions through the solution or electrolyte. The electrical currents which cause corrosion are modified by polarization at the electrodes, by the formation of passivating films, by scale formation, by local variations in concentration of soluble materials in the electrolyte, and by a number of other complicating effects.Indian Geotechnical society (IGC) 2009,Guntur, India_

"Special considerations in Marine Pile Design and Construction" by P.S. Sengupta. >>> Codes of practices for maritime structure. The India marine codes of practices are under series of IS 4651 (various parts), IS 9527 (various parts) and British Codes of Practices are BS 6349 (various parts). In all these codes general design and construction requirements are covered but for pile foundation of these structures, pile codes like IS 2911 (various parts) or BS 8004 has been referred. However, these pile codes specially IS 2911 is primarily meant for land based piles. As a result, there are some clauses which require special consideration in the design. Being very large, slender and cantilever type of piles, the deflection of the structure is often at variance with normal land based piles though structurally they are safe. Load test in marine condition is always difficult. Moreover, the permissible load carrying capacity and load deflection criteria of IS 2911 (Part–IV) sometimes gives conflicting results. Presently, there is no code of practice available for steel and prestressed concrete piles. With all these serious drawbacks, it is necessary to incorporate suitable provision in the code of practice for piles. International Journal of Engineering (IJE), Vol. 25, No. 4, November 2012 (Research note)

"Deterioration of Concrete in Ambient Marine Environment" by Department of Civil Engineering, Chittagong University of Engineering and Technology >>> Chloride attack is one of the most important aspects considering the durability of concrete and is particularly important because it primarily causes the corrosion of reinforcement in concrete. It is statistically reported that over 40 percent of structural failure occur due to the corrosion of reinforcement. Chloride enters the concrete from cement, water, aggregate, admixtures and by diffusion from the ambient environment. The compounds of chloride form the highest proportion i.e. around 89% of the total dissolved salts present in SW. Regarding ionic composition, it provides about 55% of the total salt ion concentration. The chloride salts presence in sea water reacts with the hydrated products of cement and form calcium chloroaluminate and calcium chloride. The calcium chloroaluminate also known as Friedels salts has a property of low to medium expansion. Calcium chloride being soluble gets leached out leading to material loss, weakening as well as strength reduction of concrete. Sulfate attack: Sulfate constitute the second largest component of the anionic components available in SW. Total contents of sulfate amounts,3.5 to 3.75 i.e. around 10 to 11 percent of the total salts in SW are present as sulfate of calcium, sodium and magnesium. According to Nevile [8], concrete attacked by sulfates has a characteristics whitish appearance. The damage is found initially at the edges and corners of the structures and then followed by progressive cracking and spalling of concrete.

Research Gate (Article)_DOI:10.1515/correv-2018, No.46_"Assessment of RCC structure in Marine Environment" by Giovanni Lorento. >>> The performance and service life of RC structures exposed to highly aggressive environments, such as the ones containing high chloride content, can be idealized by a modified version of Tutti's (1982) model. In looking at service life performance, a failure criterion based on serviceability requirements needs to be defined. In order to define such criterion, the first step is to characterize the service life behavior of RC structures, which can be divided into two phases.

The first phase that coincides with the breakage of the thin protective consists of the corrosion initiation film of hydrated iron oxides (passive film) on the surface of the steel reinforcement. The second phase, or propagation phase is considered the time to move from the onset of corrosion to a critical damage level.

International Conference on Case Histories in Geotechnical engineering, _6th conference, 13 Aug 2008_ "Foundation Design for Burj Dubai – The World's Tallest building" by Harry G. Poulos & Grahame Bunce. >>> Detailed methods of analysis for Heavy structures. P.L.S., Chief of Bureau of Coastal Engineering and Regulation, Division of Beaches and Shores, Florida Department of Natural Resources. "Structural Design Aspects of a Coastal Building Code" by Ralph R. Clark >>> Zones for construction and foundation design for erosion and scour. InTech "Marine Electrolysis for Building Materials and environmental Restoration" by Thomas J. Goreau. >>> Seawater electrolysis for galvanic protection can use sacrificial anodes, driven by the voltage potential difference between different metals, or actively impressed currents driven by a battery or a direct current power supply. In the first case the voltage differences are small, usually only tenths of a volt, according to the difference in electromotive potentials of the various metals or alloys used. The metal acting as the cathode is completely protected from rusting and corrosion as long as the electrical current flows. The metal acting as the anode usually dissolves away as the reaction proceeds, and needs to be periodically replaced in order to continue to prevent corrosion of the cathode.

Coatings 2020, School of Chemical Engineering and Technology, Sun Yat-Sen University, Zhuhai, China, _14 December 2020_ (Article) "Research on the Metal Corrosion Process in the Sea Mud / Seawater / Atmosphere Interface Zone" >>> The study found that the metal corrosion in the interface is a process of coupling a dual corrosion cell into a single corrosion cell. Initially, a corrosion cell is formed with the seawater/atmosphere interface acting as the cathode and the upper part of the metal in the seawater area as the anode. This is due to the oxygen concentration cell caused by the waterline effect. The cathode area is always enriched near the seawater/atmosphere interface. The lower part of the metal in the seawater area and the metal in the sea mud area are the anode and the cathode, respectively, of another corrosion cell. Along with the immersion time, the anodic area of the first corrosion cell gradually extends to the lower part of the metal in the seawater zone and finally the sea mud zone, resulting in the disappearance of the second corrosion cell.

YUXI corrosion control, Ningbo 315725, P.R.China, "Platinized Titanium Electrode Plate". >>> Platinized metal anodes are widely recognized as a practical part for various applications including hard chrome plating, metal electroplating, electronics and semiconductor industry, chemical process engineering, electroplating, electrodialysis, electroforming (Conforming anodes), electrochemical sensing, electrowinning and metal refining, electrolytic regeneration of chromic acid, sodium hypochlorite production, Electrosynthesis of organic and inorganic chemicals and cathodic protection applications. Functional Fenestration Inc. (FFI), Technical Dept. rev.011209_ "Dissimilar Metals - Preventing Electrolysis" >>> Electrolytic Corrosion (Electrolysis) occurs when dissimilar metals are in contact in the presence of an electrolyte, such as water (moisture) containing very small amounts of acid. The dissimilar metals set up a galvanic action which results in the deterioration of one of them.

Catalyst 2022, Beijing University of Technology, Beijing, China, 12/123_ (Review) "Recent Advances in Seawater Electrolysis" >>> Extensive research has been carried out on various materials, such as metal oxides (hydroxides), metal nitrides, metal phosphides, metal borides, noble metal alloy catalysts, and so on, for seawater electrolysis. Still, the catalytic activity and stability of most of the reported catalysts are not satisfactory to meet the requirement for practical application. As can be found from Tables 1 and 2, the over potential of these catalysts is not low enough. Furthermore, most of the electrolytes for current research are artificial saline water rather than real seawater, which increases the complexity of seawater electrolysis for hydrogen production.

Is Coastal construction different

The short answer is yes, building in a coastal environment is different from building in an inland area:

- Flood levels, velocities, and wave action in coastal areas tend to make coastal flooding more damaging than inland flooding.
- Coastal erosion can undermine buildings and destroy land, roads, utilities, and infrastructure.
- Wind speeds are typically higher in coastal areas and require stronger engineered building connections and more closely spaced nailing of building sheathing, siding, and roof shingles.
- Wind-driven rain, corrosion, and decay are frequent concerns in coastal areas.

In general, homes in coastal areas must be designed and built to withstand higher loads and more extreme conditions. Homes in coastal areas will require more maintenance and upkeep. Because of their exposure to higher loads and extreme

Need for Protecting Foundation

Foundations provide the structure's stability from the ground:

To distribute the weight of the structure over a large area in order to avoid overloading the underlying soil (possibly causing unequal settlement).

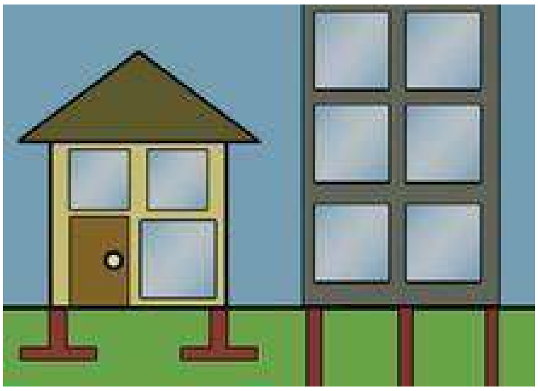
To anchor the structure against natural forces including earthquakes, floods, droughts, frost heaves, tornadoes and wind.

To provide a level surface for construction.

To anchor the structure deeply into the ground, increasing its stability and preventing overloading.

To prevent lateral movements of the supported structure (in some cases).

Building's strength and durability is indirectly related to the strong foundation and maintaining its strength respectively. There are many ways to increase the strength of the foundation but techniques used for protecting the foundation is less. The construction of building increases dramatically there is a need for the protecting the foundations in order to increase the service life of the building

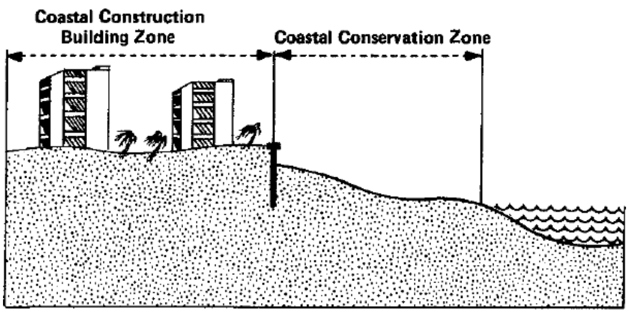


FOUNDATION

1 Building zones

A coastal building code should identify the zone within which major construction should be designed for the physical environmental conditions accompanying a major storm event. For coastal areas which are predicted to be flooded by the storm surge of a 100-year storm, a zone of impact is identified by the possible existence of breaking waves which are significantly large to cause structural damage. For developed coastal areas within which there exists a reasonably continuous line of rigid coastal protection structures, regardless of the design adequacy of these coastal protection structures, such a line should define the seaward limits of the coastal construction building zone. (See the following illustration.)

Foundation design



Foundation design within the coastal construction building zone should consider the topographic changes which may be expected over the design life of the structure. Foundation design should consider the erosion, scour, and loads accompanying a 100-year storm event. Soil bearing foundations are discouraged within the coastal construction building zone and should be prohibited above the design grade. The elevation of the soil surface to be used in the calculation of bearing capacities should not be higher than that which would result from the erosion of a design storm. Calculation of the design grade should account for localized scour due to the presence of structural components. The maximum elevation of a soil bearing foundation should be set below the design grade resulting from the erosion (including scour) of a 100-year storm event. Erosion computations for foundation design should account for all vertical and lateral erosion and scour producing forces. All habitable structures within the coastal construction building zone are recommended to be elevated on and securely anchored to an adequate pile foundation. The structure should be anchored in such a manner as to prevent flotation, collapse or lateral displacement. A pile foundation should be designed to withstand all anticipated loads resulting from a 100- year storm event including wave, hydrostatic, hydrodynamic, and wind loads acting simultaneously with live and dead loads. Design ratio of pile spacing to pile diameter is not recommended to be less than 8:1 for individual piles; however, this would not apply to pile clusters located below the design grade. Pile caps should be set below the design grade (which includes localized scour), while the piles should be driven to a penetration which achieves adequate bearing capacity taking into consideration the anticipated loss of soil above the design grade.

Foundation of famous building (in Dubai)

Foundation design of a famous building in the coastal area of United Arab countries is shown below The geology of the Arabian Gulf area has been substantially influenced by the deposition of marine sediments resulting from a number of changes in sea level during relatively recent geological time. The country is generally relatively low-lying (with the exception of the mountainous regions in the northeast of the country), with near-surface geology dominated by deposits of Quaternary to late Pleistocene age, including mobile Aeolian dune sands, evaporate deposits and marine sands. In this region the foundation design is so complicated and the piles foundation is recommended for heavy structures in order to avoid any future troubles.

FOOTING PROTECTION

The nature of corrosion

Aqueous corrosion is known to be electrochemical in nature. A simplified concept of the corrosion mechanism proposes anodic and cathodic areas on the metal surfaces. At the anodes, the atoms of the metal release electrons, become positively charged ions, and enter the solution. The electrons pass through the metal to the cathodic area where they discharge a positive ion, often hydrogen. Thus the process involves a flow of electrons through the metal and a flow of charged ions through the solution or electrolyte. The electrical currents which cause corrosion are modified by polarization at the electrodes, by the formation of passivating films, by scale formation, by local variations in concentration of soluble materials in the electrolyte, and by a number of other complicating effects.

Methods

Protective Coatings

Protective coatings form a barrier to the environmental exposure and thereby delay the corrosion. These barriers invariably break down after a number of years, specially under the suction and growth of barnacles. The choice of coatings, method of application, thickness of coats, possibility of recoating, etc, are important in ensuring optimum performance of coatings

Cathodic Protection

Corrosion of steel completely immersed under water or buried in ground (where possibility of electrolytic corrosion exists) can be substantially eliminated, and corrosion of steel alternatively exposed to wet and dry condition can be significantly protected by cathodic protection using an impressed current system or sacrificial anode system.

Increased Section/Reduced Stress

Where the-above mentioned measures are not practical or their maintenance a doubtful, extra thickness of metal or section may be considered for providing an economic solution. The actual recommendations as to the minimum metal thickness depend upon the nature of the structure and its projected life. As a general rule, it may be considered that any mild steel used in marine structure, should have a minimum thickness of 6 mm when cathodic protection is provided, and a minimum thickness of 10 mm when cathodic protection is not provided. In any case no structural steel should be used in marine conditions without protective coatings.

Use of Special Steel

Special alloy steels, such as, like those with 2 percent copper content can significantly arrest corrosion.

Jacketting with Concrete or Other Suitable Synthetic Material

Special care has to be taken in the splash zone where the protection could be given by a concrete lining applied by guniting or bv jacketting with suitable synthetic material. Out of these methods cathodic protection is selected for footing protection.

Cathodic protection

Seawater electrolysis for galvanic protection can use sacrificial anodes, driven by the voltage potential difference between different metals, or actively impressed currents driven by a battery or a direct current power supply. In the first case the voltage differences are small, usually only tenths of a volt, according to the difference in electromotive potentials of the various metals or alloys used. The metal acting as the cathode is completely protected from rusting and corrosion as long as the electrical current flows. The metal acting as the anode usually dissolves away as the reaction proceeds, and needs to be periodically replaced in order to continue to prevent corrosion of the cathode. Increased currents accelerate reaction rates, which can cause mineral growth or scale, something most uses of cathodic protection wish to avoid. For example, if a boiler is being cathodically protected from rusting, one does not want to precipitate a mineral scale layer on it, because that is less thermally conductive than the metal, and reduces heat transfer and boiler efficiency. Therefore most uses of cathode corrosion protection use the lowest possible voltages and currents needed to prevent rusting, in order to avoid growth of scale. The idea of footing protection is much needed in this era, whereas the construction technologies are developed vast but the concept of protecting the building to increase the service life of the structure is lagging everywhere across the country.

Moreover, many ideas that are in the present market are not cost effective and less durable. They are not protecting up to the building's service life. And they are needed to be maintained periodically throughout the lifetime. In coastal areas the steel used in the constructions are subjected to corrosion (i.e., decay of material) due to the chloride concentration in the sea water. There is a possibility of pitting corrosion in the surface of the steel, which leads to greater degradation of their strength. The footing protection idea that is suggested by me is based on concept called Cathodic protection. There is very much less chance of being error in this technique, and it is cost efficient too. It requires a minimum DC (Direct Current) voltage supply over the entire service life to protect the footing. Once the DC voltage is supplied the material is continuously galvanized by the metal that is connected to the anode region of the supply. This reduces the chance of metal being corroded and get degrade over time. So, this procedure is best suited for the coastal areas all over the world.

Working Principle

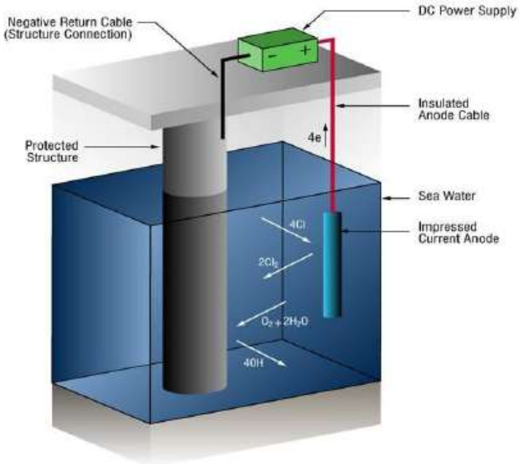
The technique is based on converting active areas on a metal surface to passive, in other words making them the *cathode* of an electrochemical cell. By supply of current, the potential of the metal is reduced, the corrosion attack will cease, and cathodic protection is achieved.

Cathodic protection can be achieved by either:

i. Sacrificial anode cathodic protection
ii. Impressed current cathodic protection (ICCP)

Sacrificial anode cathodic protection

The simplest method to apply cathodic protection is by connecting the metal to be protected with another more easily corroded metal to act as the anode. Zinc, aluminium, and magnesium are the metals commonly used as anodes. The most



active metal (which also is the less noble) becomes the anode to the others and sacrifices itself by corroding (giving up metal) to protect the cathode. Hence, the term sacrificial anode. As the driving voltage of sacrificial anodes is low compared with impressed current anodes, the sacrificial anodes must be well distributed and located closer to the area being protected. Due to the potential difference between the anodic (less noble) and the cathodic area (steel), positively charged metal ions leave the anode surface, while electrons leave the surface at the cathode. For aluminium alloy anodes, the reaction at the anode surface is: $4Al \rightarrow 4Al^{+++} + 12e^-$.

Impressed current cathodic protection (ICCP)

ICCP systems uses an external source of electrical power provided by a regulated DC power supply, often referred to as control panel. The control panel provides the current necessary to polarise the surface to be protected. The protective current is distributed by specially designed inert anodes, generally a conductive material of a type that is not easily dissolved into metallic ions, but rather sustain alternative anodic reactions. In good sea water environmental conditions oxidation of the dissolved chloride ions will be the predominant anodic reaction resulting chlorine gas developed at the anode surface: $2Cl^- \rightarrow Cl_2 + 2e^-$. In low salinity waters the predominant anodic reaction will be decomposition of water: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$. One of the most common ICCP anode types for seawater application is the "MMO/Ti", which consists of titanium substrate (Ti) coated with a noble metal or metal oxide catalyst (MMO).

Protective potential:

Cathodic protection moves the potential of a metal surface in a cathodic direction to reduce the thermodynamic tendency for corrosion. When steel receives enough current to shift the potential to a certain level, the corrosion is essentially stopped. Potential values for corrosion protection is depending on environmental conditions. However, as a guiding practice, full cathodic protection of steel is usually obtained by a potential more negative than:

-800 mV vs Ag/AgCl in aerated seawater
+250 mV vs Zn in aerated seawater
-850 mV vs $Cu/CuSO_4$ in soil

Cathodic protection potential measurement is a method used to determine the adequacy of a cathodic protection system, applied to protect a certain structure. The adequacy, or the corrosion protection effect, is determined by comparing the measured potential with certain criteria. For adequate measurement, you must ensure proper selection and installation of equipment used in field measurements.

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Corrosion rate:

Corrosion rate can be defined as the speed at which any metal in a specific environment deteriorates. Life prediction of steel in water is challenging for existing structures as well as new. Corrosion is a complex function of many factors such as salinity, dissolved oxygen, stray currents, pH, and temperature and more, which makes it difficult to establish predictable rates of degradation. This explains why many corrosion rate charts exist, but mostly for unique locations and conditions. As a rough indication, the average corrosion rate for carbon steel in seawater can be assumed to be in 0.1 to 0.15 mm/year, which equals 100-150 mA/m^2. Localised corrosion rate, however, are often several orders of magnitude higher. Stainless steel may corrode either in active or passive state, dependent on the electrolyte conditions. In normal aerated water condition, the passive metal has an oxide film that prevents further attack, while the same metal become active and exhibit a potential near 0.5 volts in low-velocity or poorly aerated water.

EXPERIMENT

Test for corrosion resistance

The corroded steel rod is taken for experimenting cathodic protection, shown in Fig (a). The rod is connected to the negative end (cathode) of the battery. And a piece of aluminium is connected to the positive end (anode) of the battery, shown in fig (b).Then they are immersed in a salt solution having water and salt (NaCl). In the concentration of 3.5% as standard i.e., 35g for 1 litre of water (Approx). This is the approximate concentration of salt in the sea water. Then the experiment is kept undisturbed for 3 to 4 hours. The rust become progressively decreased and the rod is coated by aluminium on its surface. This is clearly seen on the following figures Fig (c, d, e).

CONCLUSION

Durability of the structure was the major consideration in this project. The building was designed and well planned for long duration of the entire structure with Anti-corrosion footing technique. With the help of several literatures and journals this idea has been created. The Cathodic protection is proved in this experiment by demonstrating the continuity of the voltage supply under the earth by using the salt water as an electrolyte. The over protection can be controlled by providing periodical supply of the voltage. The manual periodical services are costly, and a person should be appointed for these services. This can be automated by using LDR sensor, as the sensor is working based on the light it can automatically turn on and off the system as the day and night pattern. This way the building is to be protected effectively.

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