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Design of Heavy Structures in Coastal Areas with Anti-Corrosion Footing Technique with LDR Sensor

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ABSTRACT

Foundation of the building plays a major role in proving stability to the entire structure. Soil in the Coastal region having lot of sea water intrusion. The salt content and several minerals present in the sea water cause erosion of materials. 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 the uneven settlement causing 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 circuit.

KEYWORDS: Cathodic protection, Electric Polarization, LDR

1. INTRODUCTION

1.1 General

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.

A Technique called as **Cathodic protection** is used in this project for the prevention of deterioration of reinforcements in foundation concrete.

1.2 Is Coastal construction different?

Yes, building in a coastal environment is different.

• **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.

1.3 Coastal Building expectations

For a coastal building to be considered a "success," four things must occur:
• The building must be designed to withstand coastal forces and conditions.
• The building must be constructed as designed.
• The building must be sited so that erosion does not undermine the building or render it uninhabitable.
• The building must be maintained or repaired.

In coastal areas, a building can be considered a success only if it is capable of resisting damage from coastal hazards and coastal processes over a period of decades. The building **foundation** must remain intact and functional.

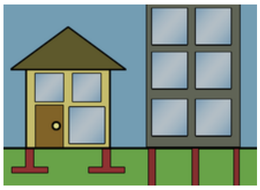
1.4 Need for Protecting Foundation

Foundations provide the structure's stability from the ground:

- To distribute the weight of the structure over a large area 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 to increase the service life of the building.

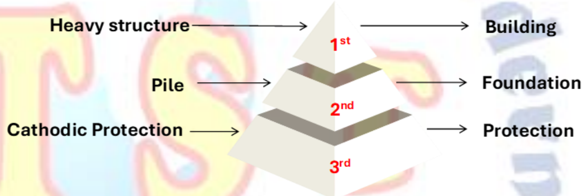


Foundation

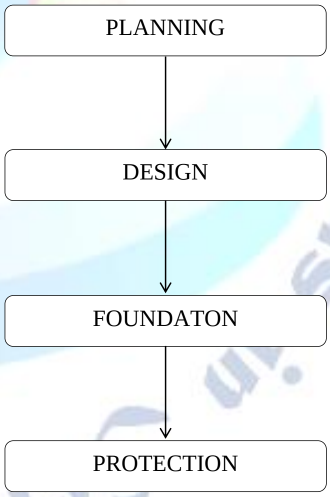
2. OBJECTIVE

- Design and analysis of high rise building near coastal areas using STAAD Pro software.
- Sea water intrusion in the foundation is a major problem in the coastal areas. Which cause gradual corrosion of reinforcement in the footing.
- The progressive damage of reinforcement in the foundation can be prevented by an idea called Anti-Corrosion footing technique.

CONCEPT



3. METHODOLOGY



4. DESIGN

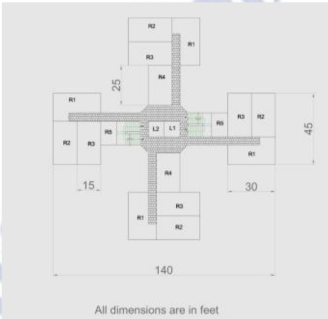
4.1 General

Building design refers to the broadly based architectural, engineering, and technical applications to the design of buildings. The main aim of structural engineer is to design the structures for a safe technology in the computing field; the structural engineer can dare to tackle much more large and complex structure subjected to various type of loading condition. All these software's are developed as the basis of advanced Finite element analysis which includes the effect of dynamic load such as wind effect, earthquake effect bets etc.

4.2 CAD & STAAD pictures

I designed a (C+G+5) storey building. The building is designed for the six residential flats. Residential flat consists of ten 3BHK and four 2BHK. The floor-to-floor distance is 10 ft. There are many classical methods to solve design

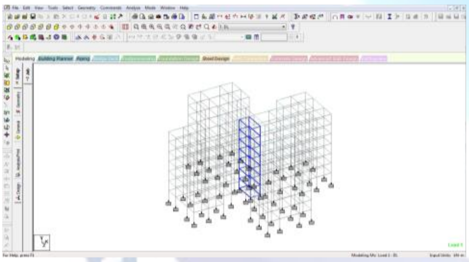
The top view of the CAD line diagram is shown below,



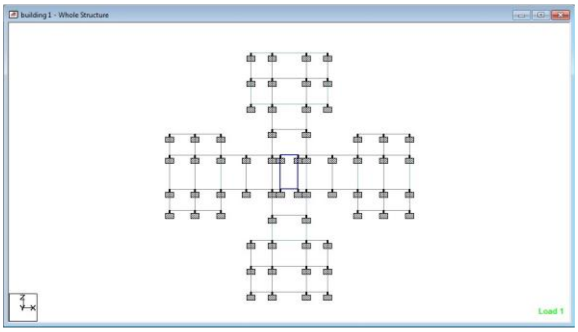
Line diagram of building

problem, and with time new software's also coming into play. Here in this project work based on software named "STAAD. Pro" has been used.

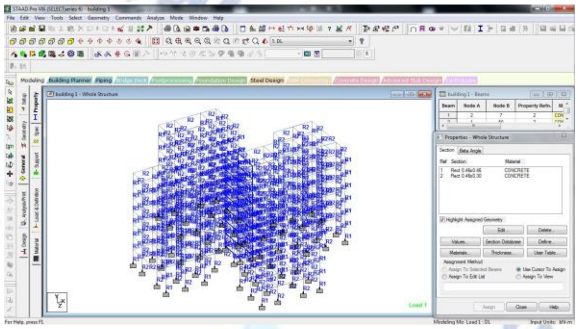
Model design done in STAAD Pro,



Entire structure

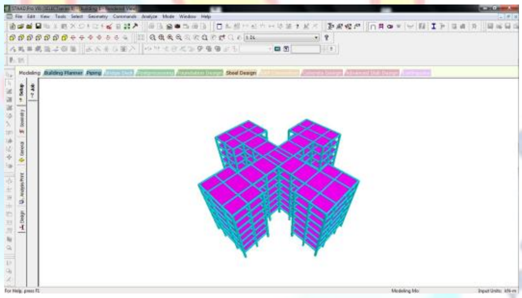


Top view

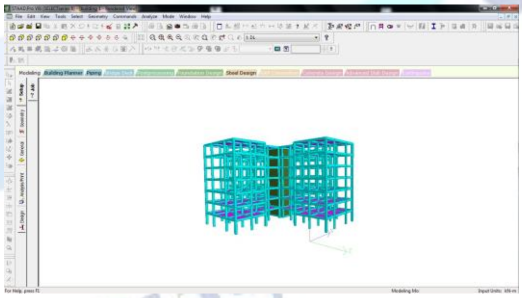


Member view

3D rendering view of building



3D view-1



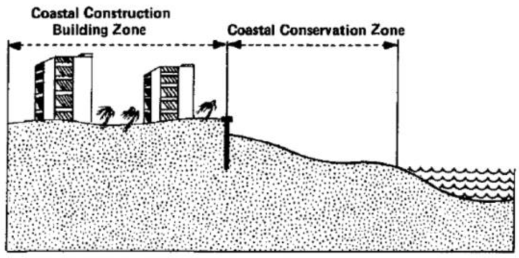
3D view-2

5. FOUNDATION

5.1 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.)



Coastal Zones

5.2 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. 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.

5.3 Foundation of famous building (in Dubai)

Foundation design of a famous building in the coastal area of United Arab countries is shown below.

Pile footing

The geology of the Arabian Gulf area has been substantially influenced by the deposition of marine sediments resulting from several changes in sea level during relatively recent geological time. The country is generally relatively low-lying (except for 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 to avoid any future troubles.

6. FOOTING PROTECTION

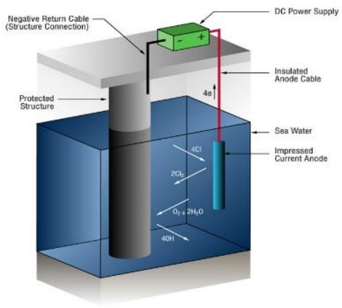
6.1 Necessity for protection

6.1.1 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 several other complicating effects.

6.1.2 Corrosive ions in sea water

The chloride ion is probably the most deleterious ionic constituent occurring in sea water in large quantities. Its corrosive nature comes from the fact that it readily penetrates passive protective films and thus enhances the corrosion reactions. In addition to chloride ions, the anions found to the greatest extent in sea water are sulphate, bromide, fluoride, and bicarbonate.



6.2 Methods

6.2.1 Protective Coatings

Protective coatings form a barrier to the environmental exposure and thereby delay the corrosion. These barriers invariably break down after several 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.

6.2.2 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.

6.2.3 Increased Section/Reduced Stresses

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 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.

6.2.4 Use of Special Steel

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

6.2.5 Jacketing with Concrete or Other Suitable Synthetic Material

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

6.3 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 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, to avoid growth of scale.

7. Why this Concept?

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 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 supply over the entire service life to protect the footing.

Once the DC 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.

7.1 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 supplying 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).

7.2 Key ideas

I. Conductivity
II. Electrodes
III. Voltage supply
IV. Polarity
V. Protective potential
VI. Over protection
VII. Corrosion rate

I. Conductivity:

Our project is based on the Deep foundation protection (i.e., pile). Normally the electric supply is possible only when the conductivity between the terminals is available. But under the ground there is almost no possibility for the presence of such conducting metals directly under our operation. This can be a serious trouble in areas other than coastal areas, Whereas the sea water intrusion up to 3Kms near the coastal region. Sea water is a good conductor of electricity so it can act as a **conducting electrolyte**. The conductivity of the sea water is based on the presence of salt concentrations in the water. However fresh water in other hand act as a non-conducting material. So we can only use this method of protection in the coastal areas or areas having salty ground water with a good water table throughout the year.

II. Electrodes:

The pile foundation is driven deeply by using methods like driven pile and bored pile. For this protection driven pile methods such as single acting hammer and double acting hammer methods are most preferable. Because this causes the surrounding soil to be shake well and allows the electrolyte (sea water) to make perfect contact with the pile surface. The pile act as an electrode (i.e., Cathode) and the piece of wire is connected to the reinforcement of the pile before casting. This is used for connecting the external voltage supply. Another electrode is a rod that is placed on the bore hole near the pile foundation. It is the sacrificial anode, and it can be replaced once in 3 years for the better cathodic protection. This is made in a way that is easy for removing and again fit in the same place for easy maintenance and repair work.

III. Voltage supply:

The two electrodes are externally connected to a voltage supply. The potential difference is only supplied by the DC (Direct Current) not by using the AC (Alternating Current). Reason: **Polarity** (i.e., positive, and negative) of terminal is required for connecting the anode and cathode to the electrodes. This can't be provided by the AC supply, only possible in the DC supply.

IV. Polarity:

Cathodic protection involves polarisation of a metal in the active direction, towards more reducing potentials. Cathodic polarisation has the effect of slowing or stopping metal oxidation, in other words, preventing corrosion.

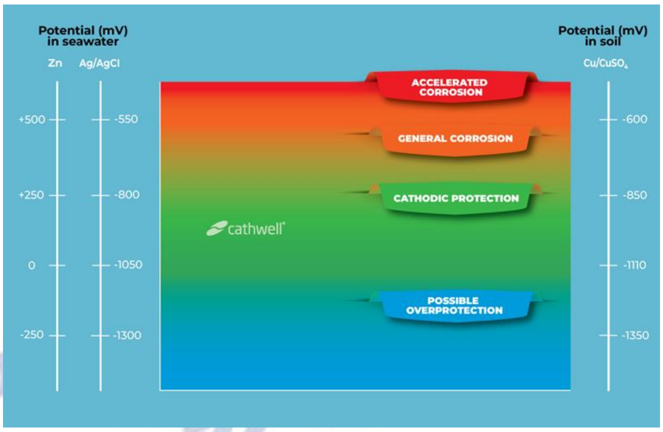
V. Protective potential:

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/CuSO4 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.

VI. Over protection:

The potential of steel under cathodic protection should not be lowered too much or, in other words, the cathodic current density should not be too high. In this case, some hydrogen can be formed, which can lead to risk of embrittlement of certain steels. The pH can become very alkaline, leading to coating damage.

VII. 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, p^H, and temperature and more, which makes it difficult to establish predictable rates of degradation. 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/m². 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.

8. EXPERIMENT

8.1 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.

Fig 8.1(a)

Fig 8.1(b)

Fig 8.1(c)

Fig 8.1(d)

Fig 8.1(e)

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).

8.2 Observation:

The corroded rod is protected by the cathodic protection technique and the rod is being coated by aluminium ions on the top surface. This ensures additional protection due to exposure of sea water. And if this process is continued the cathode portion is continuously exposed to the electric supply and the rod can be protected from being corroded by this technique.

8.3 Demonstration:

The experiment that done for checking the correct working principal of the **Cathodic protection**. That results in success and so, we can go further for the demonstration part of this project.

Steps followed in demonstration:

1. Selection of materials
2. Formwork for demo-pile
3. Making small size concrete demo-pile
4. Curing of demo-pile
5. Demonstrating with electrical circuits

8.3.1 Selection of materials:

Sand: Medium to well graded Sand is collected from outdoors. Whereas the sand in the coastal area is poorly graded. Moderate and poorly graded sands are well suitable for this project since it has more porosity, and the salt concentration can easily pass through the pores of the soil. But well graded soil has slightly lower tendency as compared to poorly graded.

Reinforcement Bar: Aluminum bar of 1mm diameter is used as a reinforcement of demo-pile. A mild steel bar of small size is not easily available in the market. This project mainly focusses on the conductivity of the materials as it is needed to conduct the electricity. Although aluminum has less strength characters as compared to steel, it also has a greater conductivity property as equal to the normal mild steel that is used in the market. So, I chose aluminum as a reinforcement.

Electrical items: A battery having range 9 to 15V, wires, bulb, switches, etc.,

8.3.2 Formwork for demo-pile:

Four aluminum rods are cut into required lengths, and it is used for the main reinforcement. Then lateral ties are bent up into appropriate sizes and are tied with the steel strings. Then concrete is made, and the reinforcement is kept in the formwork. Shown in following figures.

Fig 8.2(a)

Fig 8.2(b)

Fig 8.3(c)

8.3.3 Making small size concrete demo-pile:

Concrete is poured into the formwork, and it is allowed to remain undisturbed for a week. And the formwork is removed, and the concrete is taken out from the formwork.

Fig 8.3(a)

Fig 8.3(b)

8.3.4 Curing of demo-pile:

After removal of formwork, the demo-pile prepared is then cured for 3weeks to prevent crack formation.

Fig 8.4(a)

Fig 8.4(b)

8.3.5 Demonstrating with electrical circuits:

The demo-pile is then immersed in the sand taken in the nylon container as shown in the figure below.

Fig 8.5(a)

Then the water mixed with 3.6% of NaCl is poured into the container. The water is then absorbed by the sand and the remaining water is in the sloping side of the container.

Fig 8.5(b)

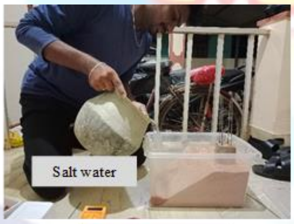


Fig 8.5(c)

Fig 8.5(d)

The fig (d) in above picture shows the multi-meter conductivity value of the water that is used in the experiment. If the value is nearer to zero (0), then there is a minimum loss in the conductivity and the value greater than zero is the indication of some loss in the conductance.

The voltage supply is made into a connection through the Bread board, Battery (9 V), Resistor (1k ohm), LDR (Light Dependent Resistor) and LED (blue) this indicates the circuit being connected and the supply is in active state. They are shown below.

Fig 8.5(e)

Fig 8.5(f)

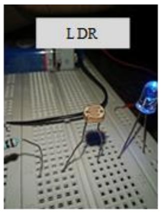


Fig 8.5(g)

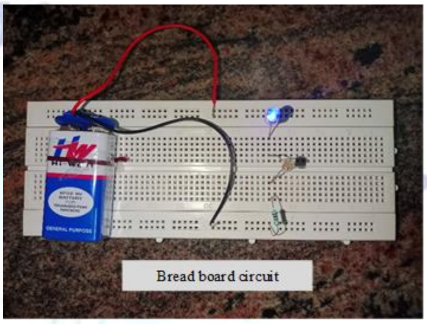


Fig 8.5(h)

Then the connectivity is made on the demo-pile as shown below.

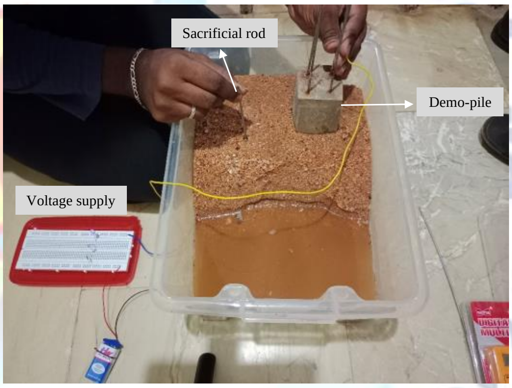


Fig 8.5(i)

9. CONCLUSION

Durability of the structure was the major consideration in this project. 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.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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