ASSESSMENT OF REINFORCING STEELS IN CONCRETE EXPOSED TO SALINATION WATER BY USING NDT (HALF-CELL POTENTIAL)

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ABSTRACT

The behavior of steel bars in the concrete structure under salinated environments are differs from one environment to another, however as long the basis of electrolysis circuit is completed which consists of anode, cathode and electrolyte medium is presence in particular environment, the corrosion process can occur to any metal that were to be place along with this environment. In this study, investigation of severity in corrosion for a reinforcing steel in concrete for 4 type of water sources which is sea water, salt marsh water, river water and tap water were explored. Results of all 4 water mediums explain that the exposition of concrete to natural environment results in different pattern of corrosion behavior. This relates to the conclusion of having similar grade of concrete not necessarily results in similar form of corrosion map. The easier water to penetrate through the concrete cube and create electrolysis circuit the more severe the concrete cube was affected with corrosion elements.

ABSTRAK

Tingkah laku batang keluli dalam bahan konkrit binaan di persekitaran kemasinan adalah berbeza dari satu persekitaran kepada yang lain, akan tetapi selagi mana litar elektrolisis dilengkapkan yang mana terdapat anod, katod dan bahantara elektrolit dalam persekitaran tertentu, proses kakisan boleh berlaku kepada sebarang logam yang diletakkan bersama persekitaran ini. Dalam kajian ini, siasatan kelampauan kakisan untuk batang keluli pengukuh dalam konkrit untuk 4 sumber jenis air yang merupakan air laut, air kawasan paya, air sungai dan air paip telah dibuat. Keputusan dari kesemua 4 medium air menjelaskan bahawa pameran konkrit kepada keputusan-keputusan alam sekitar di jiwa lain tingkah laku kakisan. Ini berkaitan dengan kesimpulan mempunyai gred serupa membubuh simen bukan semestinya menyebabkan di bentuk selari peta kakisan. Air lebih mudah akan meresapi kiub konkrit dan mewujudkan litar elektrolisis yang lebih teruk kiub konkrit telah terjejas dengan unsur-unsur kakisan.

Keywords: half-cell potential, concrete, steel, sea water

INTRODUCTION

Reinforcing steel in concrete is a type of steel which embedded into a particular building structure and act as sort of bones to the building. The main idea of the steel is to retain the surface tension of the concrete and without it the concrete would crack and degrade to collapse. Basically the steel within stops it flexing and therefore holds it together. In a nuclear power plant, reinforced concrete structures are constructed for protecting the nuclear reactor core, besides serving as biological shielding for ionizing radiations emitted from the reactor core. Since most of the nuclear power plants are built near the seaside or near to a river mouth, these structure are exposed to a chlorinated water from the earth ground and salty moisture from the surrounding atmosphere (Browne R.D. *et al.,* 1979). Corrosion is one the main regime for the structure degradation and deterioration.

Corrosive activity can occur in metal substances mainly through an electrochemical process (M. Daud *et al.,* 2013). In order for this corrosion circumstances to occur, a complete electrical circuit must exist as in Figure 1.

The corrosion process actually involves two separate, but coupled chemical reactions that take place simultaneously at two different sites of the steel surface. An electric current must flow in a closed loop between the two sites for the reactions to proceed. In corrosion, the two-electrochemical reactions are known as 'anodic' and 'cathodic' reactions, respectively, and the areas on which they occur in the steel are called 'anodic' and 'cathodic' areas or simply anodes and cathodes as in Figure 2.

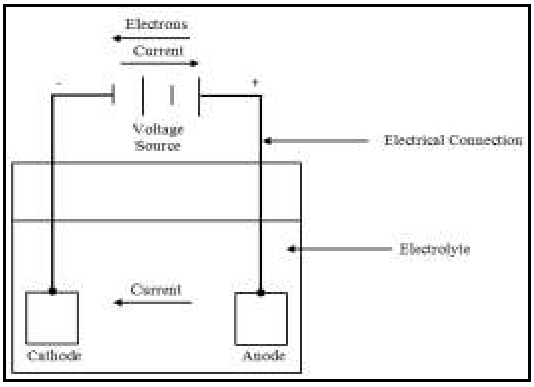


Figure 1. Schematic of a corrosion cell

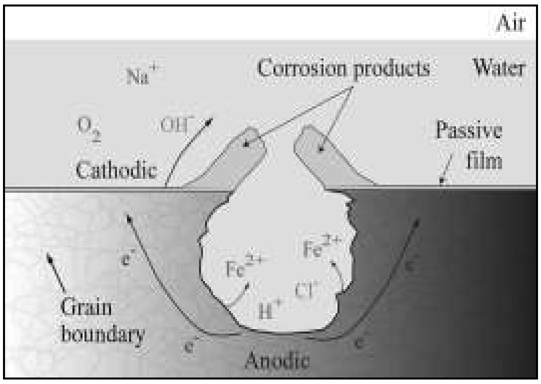


Figure 2. Corrosion processes on the steel surface (Fontana M.G., 1986)

The corrosion in steel rebar consists of 3 stages. The first stage or the initiation stage is the depassivation cause by the diffusion of CO_2 or chlorides to the steel. The second stage or activation stage witness the rebar network to start to corrode and the formation of rust start to appear visibly. The third stage is the deterioration due to the cracking and spalling failures (John P. Broomfield, 1997).

In this work, a study of various types of chlorinated water on concrete with reinforced bars had been envisaged in order to establish a relationship of physical parameters, such as temperature, relative humidity, the depth coverage of concrete to the steel reinforcement and the presence of cracks within concrete structure, with the values of the half-cell potential difference in corresponding to corrosion severity occurred on steel bars used as reinforcing materials in concrete. It is also to understand basic knowledge on corrosion mechanism of steel in concrete and method of inspection (K.G. Papakonstantinou *et al.,* 2013). This will give a better assessment on the state of concrete structures from the half-cell potential difference data obtained.

MATERIAL AND METHOD

The water samples, steel and concrete types and technique used in this study are described as follows:

Water Samples

There are 4 samples of water were studies, namely, sea water, salt marsh water, river water and normal water. The proposition of collecting water is divided into 4 different places scatter across Selangor to Negeri Sembilan. However for this study, the water content properties only focused on sea water contents, thus other water type were provided only the location of it.

Sea water - The original source for sea water is at Port Dickson, Negeri Sembilan. With latitude and longitude to be 2.5167° N, 101.8000° E, the location were selected due to vicinity of the location as compared to other source of sea water. Figure 3 shows the location of the water source.

The composition of the seawater is shown in the Table 1. This data is obtained from previous research done using induced Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Table 1. Composition of natural seawater - Daud 1997.

Elements	Cation, (mg/l)	Anion (mg/l)
Natrium	11.1×10^3	
Calcium	3.63×10^2	
Magnesium	11.9×10^2	
Kalium	9.75×10^2	
Boron	4.21×10^2	
Strontium	7.69	
Barium	$<0.08 \times 10^{-1}$	
Manganese	0.02×10^{-1}	
Copper	$0,08 \times 10^{-2}$	
Zinc	2.05×10^{-1}	
Argentum	$<0.05 \times 10^{-1}$	
Plumbum	<0.03	
Chloride		126.74×10^2
Sulphate		8.37×10^2
Floride		Not detected
Bromide		Not detected
Nitrate		Not detected

Salt marsh water - The original source for river water is a source near Institut Latihan Pentadbiran dan Pengurusan Pengangkutan Laut, Pulau Indah, Selangor. With latitude and longitude to be 2.992371° N, 101.349944° E, the location were selected due to vicinity of the location as compared to other source of salt marsh that are suitable for study. Figure 4 highlights the location of the water source whilst Figure 5 shows the actual nature of the location.

Figure 3. Sea water location (Port Dickson, Negeri Sembilan) – Google maps

Figure 4. Salt marsh water location (Institut Latihan Pentadbiran dan Pengurusan Pengangkutan Laut, Pulau Indah, Selangor) – Google maps

Figure 5. The actual environment for Salt marsh water

River water - The original source for river water is a source near Lembaga Perlesenan Tenaga Atom, Dengkil, Selangor. With latitude and longitude to be 2.899173° N, 101.754526° E, the location were selected due to vicinity of the location as compared to other source of sea water. Figure 6 highlights the location of the water source and the distance from University.

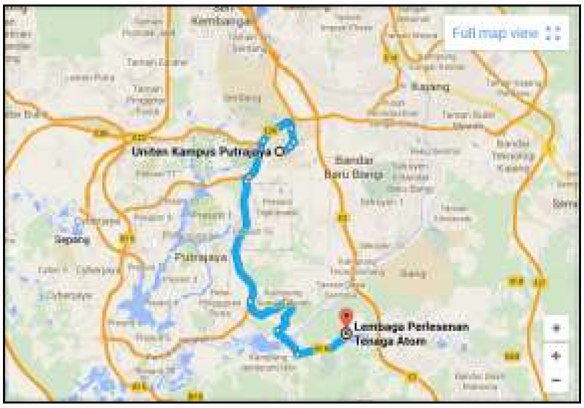


Figure 6. River water location (Lembaga Perlesenan Tenaga Atom, Dengkil, Selangor) – Google maps

Tap water - The tap water used in this study is the tap water supplied to population living in Klang valley area. Due to the fact that people in Klang valley water were being processed under the same source thus in assumption any water used in this area has the same chemical compositions.

Concrete Samples

There are various type of concrete grade for industrial use, however for this experiment the selection of concrete were to be specified as grade 25. Concrete mixture is crucial in civil engineering aspect as it determines the total strength of specific structure. Standardization was set in order to segregate the application of that particular grade on industrial scale. Table 2 shows the mixture and usage of several grade of concrete and its usage. The selection of concrete grade in this study was the G25. Using this grade the concrete cube were created to simulate the behavior of the particular concrete in other forms of environment using all 4 types of water sample. The measurement of concrete cube is as highlighted in Figure 7.

Table 2. Concrete grade and applications [9]

Concrete Grade (N/mm^2)	Ratio cement, sand aggregate	Usage
10	1:4:8	Blinding concrete
15	1:3:6	Mass concrete
20	1:2.5:5	Light reinforce concrete
25	1:2:4	Reinforced concrete
30	1:1.5:3	Heavy reinforced concrete pre-cast
35	1:1.5:2	Pre-stress concrete/pre-cast
40	1:1:1	Very heavy reinforced concrete pre-stress/pre-cast

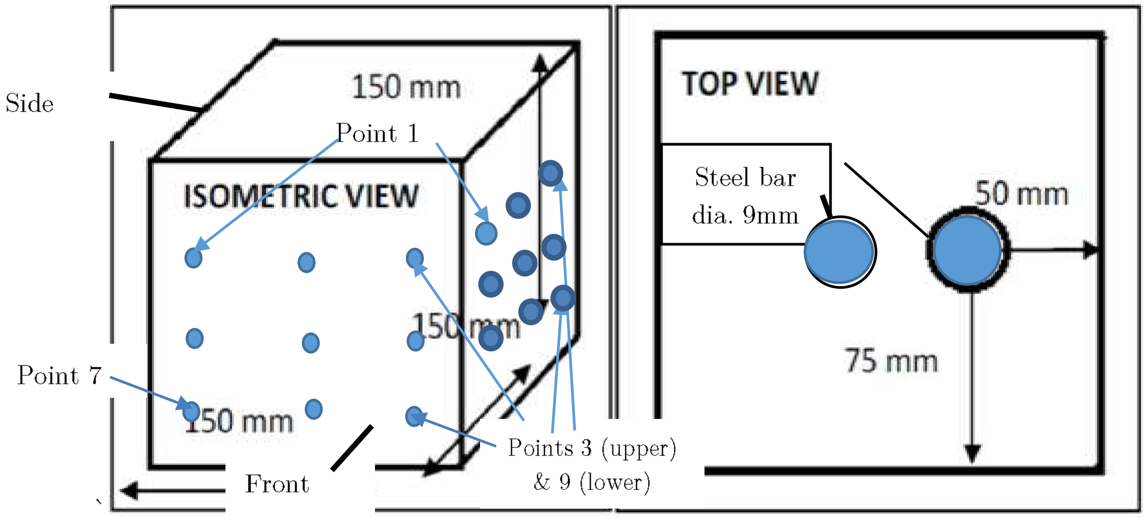


Figure 7. Concrete cube dimensions for testing purposes; points of half-cell probe measurement are indicated

Steel Samples

The reinforced steel for this study are specified to be mild steel with a diameter of 9mm. The rebar material is a normal rebar used a standard concrete structure. It may have a shape like plate, and bar. It is also meet the structural quality for using in riveted, bolted, or welded construction of bridges and buildings, and for general structural purposes.

The mild steel is also known as carbon steel and the manufacturing process were normally hot rolled. Other than rebar, this type of steel is also available in the form of I-Beams and H-beams for other type of steel frame structure. The properties and strength of this material are shown in Table 3.

The sample preparation of reinforced bar normally comes in a long rod and needs to be cut to specific dimensions as desired. As for this study, the length of rebar should be higher than the height of concrete cube. The allowable range of cut is set to be from 200 to 250 mm.

Table 3. Material properties of mild steel rebar [8]

ASTM A36 Mild (low-carbon) steel		
Minimum properties	Ultimate Tensile Strength (Psi)	58k – 79.8k
	Yield Strength (Psi)	36.3k
	Elongation	20%
Chemical composition	Iron (Fe)	99%
	Carbon (C)	0.26%
	Manganese (Mn)	0.75
	Copper (Cu)	0.2%
	Phosphorus (P)	0.04% max
	Sulfur (S)	0.05% max

The sample between mild steel rebar considered complete once the rebar were submersed into the half hard concrete. The complete sample that ready to be used for experiment purposes is shown in Figure 8.

Figure 8. Actual concrete samples ready for experiment

Corrosion Processes

Simulation of corrosion were made using a direct current (DC) applied on both rebars where one connected to anode and the other connected to cathode. The test was carried out by submersing the concrete cube to the test waters which is acted as an electrolyte. The set-up of the corrosion simulation is shown in Figure 9. The effective voltage for accelerating the corrosion process was 0.09 Volts. After running the DC current testing, specimens were dried for one day. To stimulate back the corrosion particle, the concrete cubes were dipped into carboxylic acid solution in the form of soap water as per Figure 10.

Figure 9. Actual setup for DC supply for simulating the corrosion process

Figure 10. Concrete cubes dipped into carboxylic acid solution to stimulate the corrosion particle for half-cell analysis

Half-Cell Potential Measurement

The half-cell potential measurement was used in this study. It is an electrochemical technique commonly used by engineers to assess the severity of corrosion in reinforced concrete structures. The normal conceptual of this measurement is using copper/copper sulphate ($Cu/CuSO_4$) as reference electrode and placed on the surface of the concrete with the steel reinforcement underneath (Salihu Andaa Yunusa, 2011). The schematic diagram of the method is shown in Figure 9.

(a) (b)

Figure 9. (a) Schematic diagram of half-cell potential measurement technique [7] and (b) Actual half-cell potential measurement using the reference electrode

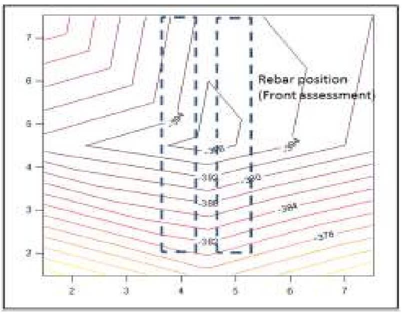
From Figure 9, the reference electrode is connected to the negative end of the voltmeter and the steel reinforcement to the positive, refer to Figure 9(a). This method is found to be a success for the case of bridge deck corrosion surveys thus formed the basis of the ASTM standard of C876 that provides general guidelines for evaluating corrosion in concrete structures (Ping Gu *et al.*, 1998). Points of measurement as indicated in Figure 7. Figure 9(b) shows the placement of reference electrode to the concrete surface.

3. RESULTS AND DISCUSSION

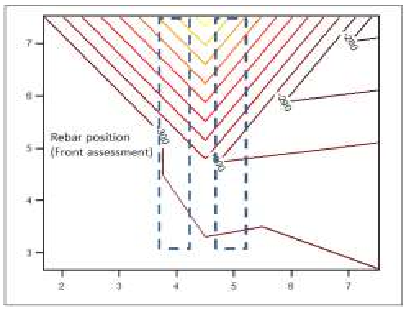
The following figures show some results on the half-cell measurement between the sea water and other water which is the most severe corrosion occurred studied in this work, see Figure 10. In this work, the level of corrosion currents and the degree of corrosivity of the steels are based on the ASTM criteria as shown in Table 4.

Table 4 . ASTM criteria for corrosion of steel in concrete using the half-cell method

HCP in mV ($Cu/CuSO_4$)	**HCP in mV (Calomel electrode)**	**Probability of corrosion**
> -200	> -126	Low (<10%)
-200 to -350	-126 to -276	Intermediate / unknown
< -350	< -276	High (>90%)
< -500	< -426	Severe

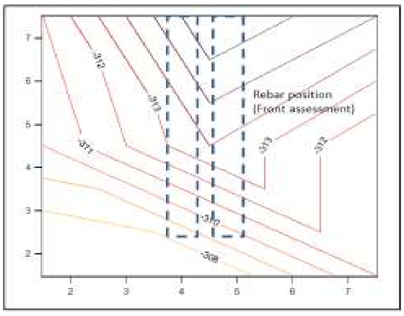


(Front assessment) Sea Water

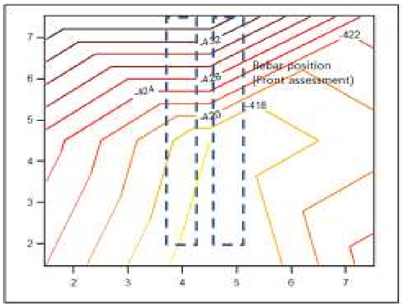


(Front assessment) Tap Water

(a) 2 hours

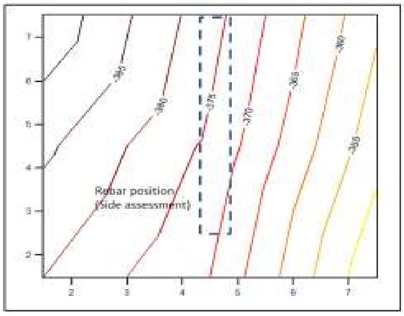


4 hours(Front assessment) Sea Water

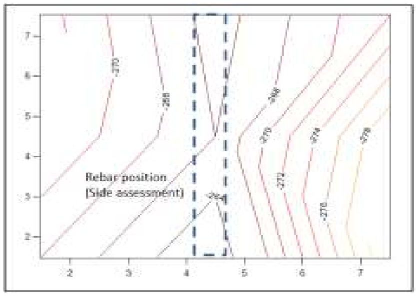


4 hours (Front assessment) Salt Marsh Water

(b) 4 hours

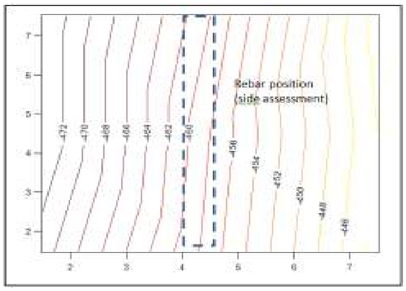


6 hours(Side assessment) Sea Water

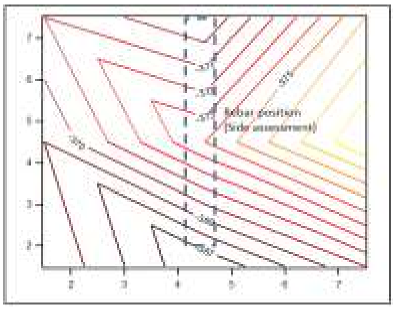


6 hours(Side assessment) Tap Water

(c) 6 hours



8 hours(Side assessment) Sea Water



8 hours(Side assessment) River Water

(d) 8 hours

Figure 10. The half-cell measurement between the sea water and other water which is the most severe corrosion occurred; (a) 2 hours, (b). 4 hours, (c) 6 hours and (d) 8 hours

Sea water

Based on Figure 11, the result for 4 hours contributes lesser mV as compared to 2 hours of exposure. This can be due to the porosity of the concrete cube. Even though similar process implemented during the mixture of concrete, however the uniformity of the concrete still varies among all cubes. The corrosion of 2 hours were supposed to occur on the surface of the concrete as per 4 hours results, however, the middle part of the concrete leads to higher corrosion potential. This means that the electrolysis circuit that leads to corrosion completes for 2 hours test specimen due to porosity of the middle part of the concrete. For 6 and 8 hours of exposure, the pattern was as expected.

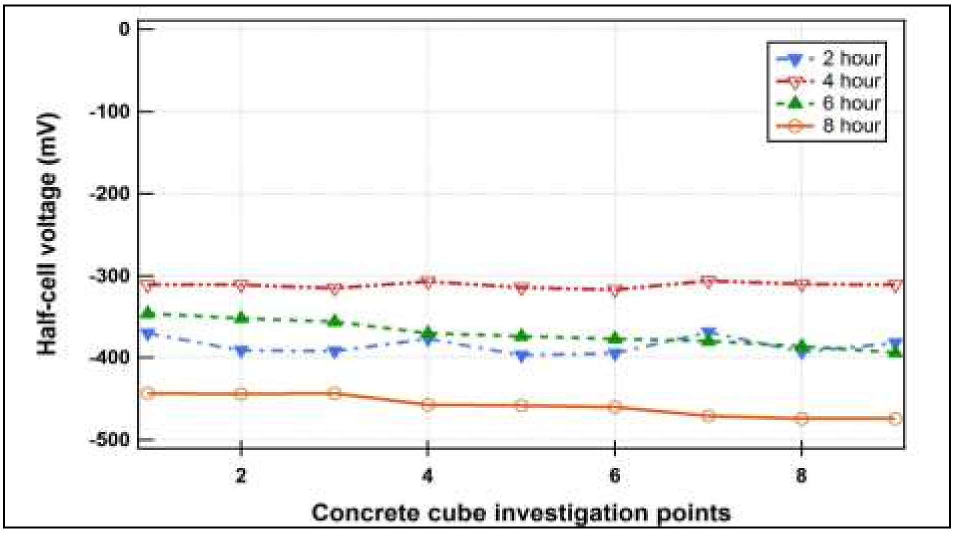


Figure 11. Half-cell voltage measurement on concrete cube investigation points for sea water analysis with different hours under the exposure of DC current.

Salt marsh water

Figure 12 shows the irregularities on data profiles for 4 hours of exposure. As we know, the salt marsh also has the presence of salt in its content and can boost up the corrosion potential value. It is shown that the highest potential of corrosion occur at top surface of the concrete which is justified because the area of rebar exposure is high on the top surface. This phenomenon is unexplainable since the procedure of experiment is standard between all specimens.

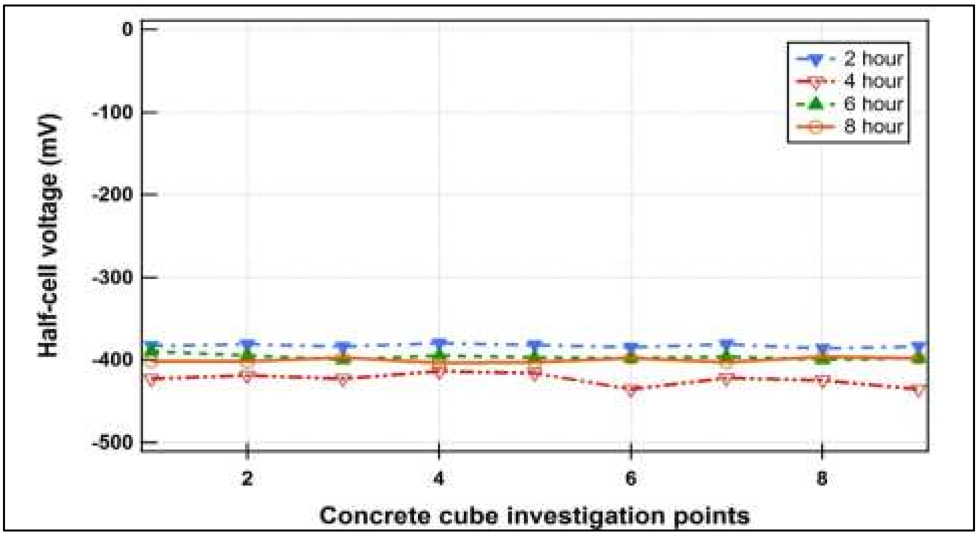


Figure 12. Half-cell voltage measurement on concrete cube investigation points for salt marsh water analysis with different hours under the exposure of DC current.

River water

The pattern of corrosion potential for river water data as per Figure 13 is quite as expected and merge with the initial assumption which is as the longer exposure of test specimen towards DC current more corrode the rebar will be. However, the porosity issue can also be the contributing factor of the curve for 4 hours exposure is more than 6 hour. The potential of corrosion is high on the right side of the cube, thus the concrete is less uniform on the left side of the cube.

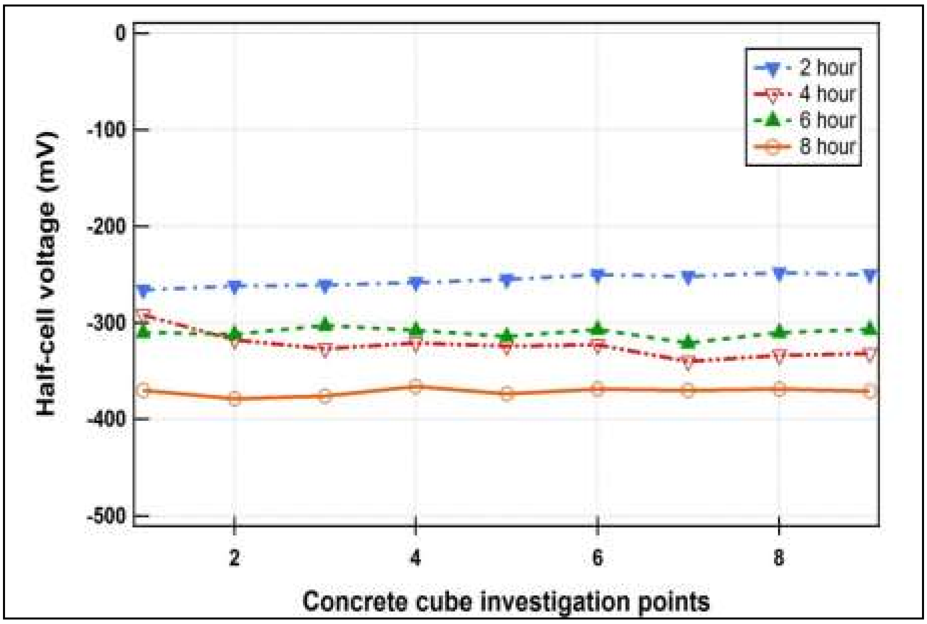


Figure 13. Half-cell voltage measurement on concrete cube investigation points for river water analysis with different hours under the exposure of DC current.

Tap water

Irregularities also occur for tap water result as per Figure 14 which the arrangement between 2 hour, 4 hour and 6 hour is not based on the initial assumption. However the values that fluctuate between these 3 results is on the range of intermediate corrosion potential, therefore the result variation is not a big different. However the sudden fluctuation do occur for 2 hours result which is at point 6 located on the middle right of the concrete cube. There may be some error on the reading because point 3 and point 9 which located also on the right side of the cube provides with almost similar but lower values of mV.

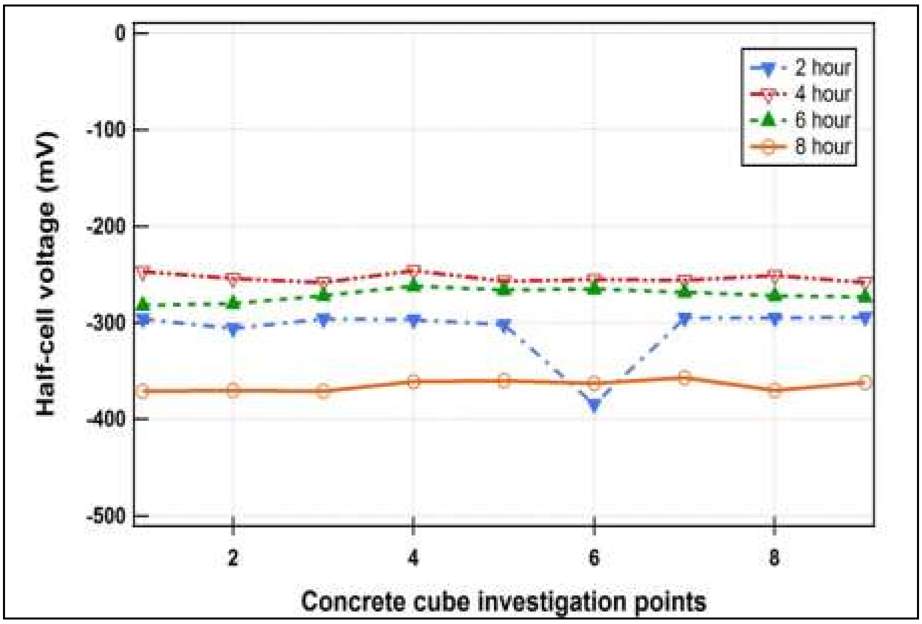


Figure 14. Half-cell voltage measurement on concrete cube investigation points for tap water analysis with different hours under the exposure of DC current.

There are few irregularities of results detected after running the half-cell potential experiment. With the same procedure implemented for all type of test specimen, the irregularities may occur resultant from a lot of contributing factors.

Sea water did provide with some abnormal results with the early assumptions as the longer exposure of DC current towards the rebar, the percentage of corrosion will increase simultaneously. This assumption is not true for sea water experiment due to the 2 hours exposure of DC leads to higher value of mV as compared to 4 hours.

Irregularities also detected for salt marsh water results as 4 hour of DC exposure leads more mV value compared to 6 hours to 8 hours. Major fluctuation also detected for 4 hours data.

CONCLUSIONS

Corrosion of steel in any environment is a process that involves progressive removal of atoms of iron (Fe) from the steel being corroded. The existence of electrolysis circuits will allow this condition to happen. This condition is inevitable for corrosive environment such as any water medium that have the presence of salt that will resultant faster corrosion process as compared to other form of water medium.

Results of all 4 water medium explain that the exposition of concrete to natural environment results in different pattern of corrosion behavior. This relates to the conclusion of having similar grade of concrete not necessarily results in similar form of corrosion map. A lot of factors can cause the corrosion to takes place, however for concrete; the main reason is the concrete porosity. The easier water to penetrate through the concrete cube and create electrolysis circuit the more severe the concrete cube was affected with corrosion elements.

Structures which were built under the effect of corrosive environment involving sea water or salt marsh water should use concrete grade with less porosity. The uniformity study of the concrete should be mandatory using rebound hammer technique and justified using ultrasonic testing. This is to ensure that the building or structure is safe and serve its lifetime limits accordingly.

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