Corrosion Monitoring System on Concrete Using Concrete Resistivity Test Based on The Internet of Things

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***Abstract*— Reinforced concrete, which is currently widely used as the main material for the establishment of a building infrastructure, consists of cement and iron and steel, which have the potential for corrosion by the active and passive layers of concrete. So with the high potential for corrosion that causes cracks to break and the building collapses, it is necessary to monitor the corrosion rate which can be used as a preventive measure for corrosion in concrete structures. Corrosion that occurs is also greatly influenced by the permeability and resistance of the concrete which causes the gaps of other elements to enter the concrete structure and accelerates the corrosion rate of the concrete. This study designed a corrosion Monitoring system in concrete with an IoT-based concrete resistivity test by injecting the concrete through an electric current which can be monitored with the Blynk application according to the area of the concrete.**

***Keywords*— Concrete, Monitoring, Resistivity**

I. Introduction

Reinforced concrete is one of the parts most susceptible to corrosion. Corrosion in reinforced concrete is a chemical or electrochemical reaction between steel bars and the corrosive concrete environment. Therefore, corrosion of reinforced concrete is a serious problem that must be resolved immediately [1]. Corrosion is a common problem in steel bars in concrete structures. If the bone is allowed to develop, the concrete will crack and cause structural damage [2]. Corrosion loss studies conducted by the National Association of Corrosion Engineers (NACE) reported that direct losses due to corrosion had a fantastic value, this loss was estimated at 276 billion US dollars or equal to 3.1% of gross domestic product (GDP). A follow-up study was carried out by Jackson in 2013 which reported that losses due to corrosion experienced a significant increase with a loss value of 1 trillion US dollars or amounting to 1-5% of the gross national product (GNP) in each country [1]. Corrosion is the result of decaying metals reacting electrochemically with the environment. Corrosion or rust is a chemical phenomenon based on metal reacting the metal with ions on the metal surface in direct contact with the water and oxygen environment. The most common example is ferrous metal damaged due to rust oxide [3].

The Industrial Revolution 4.0 in Indonesia has now penetrated into various fields in the community and government sectors to support the performance of the community and government who have demands for work that can be done quickly and effectively. With these demands, people will think creatively to realize what is needed with implementation supported by the entry of digitalization and the influence of the development of today's increasingly rapid technology. The existence of this technology, which is supported by the application needs, monitoring also greatly influences various problems that often occur in Indonesia regarding infrastructure in Indonesia that will pose a danger if it is not properly cared for and maintained. With this technology, it will be a good prospect in terms of detecting and maintaining infrastructure with system Monitoring which also provides monitoring feedback based IoT which is the latest breakthrough in the infrastructure sector. Internet of things refers to the identification of an object that is visually explained to the virtual world (Internet) via a wired or wireless network and using special application software for processing some information. The realization of IoT depends on the wishes of the developers, including the software developed by the developers [4].

With the increasing number of infrastructure accidents related to the collapse of concrete structures due to concrete corrosion in Indonesia, early detection of corrosion phenomena can provide information on the schedule of preventive maintenance actions to extend the life of concrete structures and reduce catastrophic failure, so this research is designed to design system monitoring corrosion in concrete structures with concrete resistivity test. The resistivity test of concrete is basically to determine the durability of concrete if the level of durability of concrete is high so that the absorption of water is high which can increase the potential for corrosion in the concrete. This study designed system monitoring using the Blynk application so that it can be viewed via a smartphone.

II. Method

A. Corrosion On Concrete

Corrosion generally has the potential to occur in areas with very large pH levels, where dissolved ions or non-protective oxides/hydroxides are corrosion agents. An example of this type of corrosion is rust caused by steel in an outdoor environment. General corrosion of concrete can usually result from a decrease in the pH of an unstable and damaged passive layer, which will leach out of the steel and dissolve or form non-protective oxides/hydroxides (in

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very low pH solutions) so that the depletion of these metals will eventually damage them. components and cause corrosion [5].

The corrosion potential of metal in a particular electrolyte has a characteristic value. It can be seen from Figure 2.1 below which contains certain values for steel, stainless steel, copper, and galvanized concrete steel, that the corrosion potential of concrete steel can vary by several hundred millivolts.

The influence of chloride and carbonation is the main cause. Both processes are unique in that they do not damage the integrity of the concrete. Aggressive chemical organisms, on the other hand, enter through the pores and attack the steel. The integrity of the concrete is damaged by acids and other violent ions such as sulfates to the extent that the steel is affected. Therefore, most kinds of chemical influences are concrete problems before they become corrosion problems.

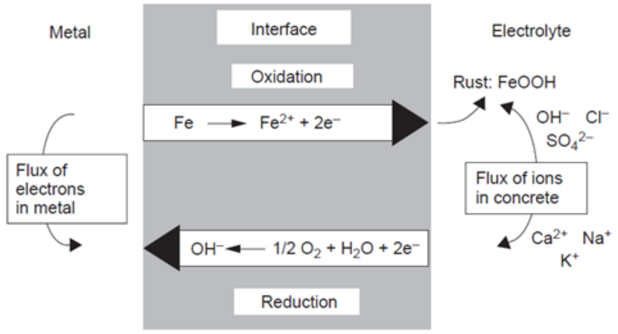

Figure 1. Electrochemical Corrosion Process [6]

B. Monitoring System in Concrete

The system monitoring corrosion in concrete is an effort to be able to see and monitor the speed and rate of corrosion found in reinforced concrete where system monitoring uses a concrete resistivity test based on the compressive strength of concrete known as resistance polarization. This corrosion monitoring system using current and voltage sensors, from these sensors the resistance of the concrete reinforcement will be calculated[7]. Then from that resistance, the resistance of the concrete can be calculated, the results of which are processed by Nodemcu as a microcontroller so that the graph of the speed and rate of corrosion of reinforcement can be known.

C. Concrete Resistivity Against Concrete Corrosion Rate

The resistivity of concrete is the resistance of the concrete to electricity through the probe with the injection of electric current and voltage [8], which then calculates the electrical resistance flowing in the media which here use concrete media. This concrete resistance also shows the level of concrete quality where the quality of concrete is based on the durability and permeability of concrete which causes corrosion potential that occurs in concrete structures. The better the quality or resistance of the concrete, the lower the permeability, which allows the corrosive level to be higher [9]. To find out the resistance of concrete in reinforced concrete, it is with the following equation:

$$\rho = 2\,R\,D\;(\Omega.cm) \quad (1)$$

Where:

R = Concrete reinforcement resistance

TABLE 1.
CORROSION RATE BASED ON CONCRETE RESISTANCE”

Resistivity (kΩ.cm)	Rate of Corrosion
< 5	Very High
5 - 10	High
10 - 20	Medium
> 20	Slow

Table 1 is a table of the level of corrosion against the resistance or quality of concrete which is generally referred to as the Linear Polarization Resistance method. The corrosion rate is calculated by the following equation:

$$p = \frac{M\, i_{corr}\, t}{\rho\, z\, F} \quad (2)$$

Where:

M = atomic weight (=55.85g/mol for iron)

$i_{corr} = \frac{I_{corr}}{A}$ (Corrosion current density (A cm^{-2}))

I_{corr} = corrosion current $\left(\frac{B}{R_p}\right)$ based on the current due to corrosion against the polarization resistance of the Stern-Gear constant for corrosion-active iron, which is 25mV, so that:

$I_{corr} = \frac{25mV}{2\,R\,D}$, where R_p is the concrete resistance with reinforcing bars

A = The cross-sectional area of the iron being measured, for the iron used as reinforcement for this concrete, is 50.24 mm^2, so 0.5 cm^2.

t = measurement time, the measurement time shows the time of testing exposure to concrete under an observation condition (in this study, it was for 5 days).

ρ = density of iron (= 7.95 g/cm^2).

z = number of electrons transferred per atom (=2 for iron).

F = Faraday constant (=96500 C/mol).

D. Hardware Design

Based on the design of the system design that has been made, the next step is to design hardware with the design that has been planned as follows:

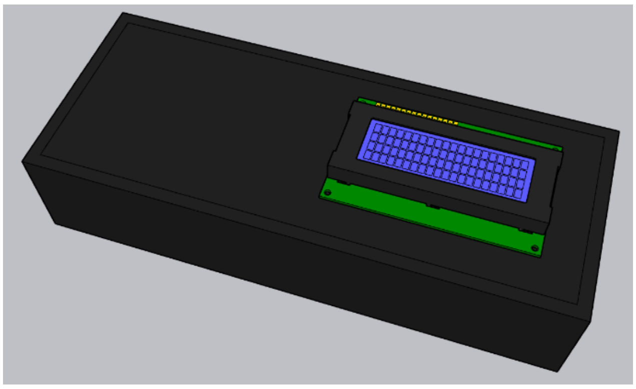

Figure 2. Protoype Design

Figure 2. Shows the prototype design with the display of corrosion rate and concrete resistance displayed on the LCD. Then the data will be sent to the application Blynk which can be viewed directly through the application installed on the smartphone.

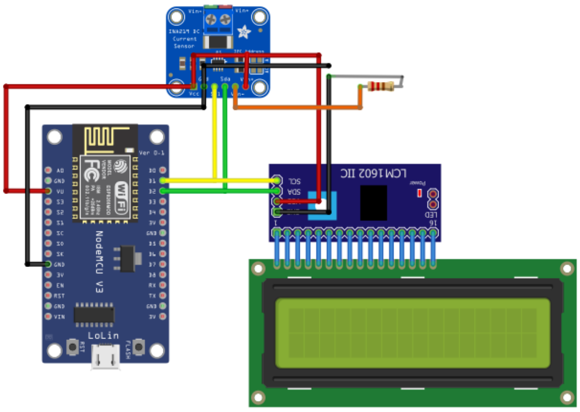

Figure 3. Design wiring prototype

In the design of system monitoring using the INA219 sensor as a current and voltage sensor so that it can calculate resistance and will be processed by the NodeMCU as a microcontroller then the data is sent via the internet using the ESP8266 wifi module on the NodeMCU so that it can display data to the application Blynk.

E. Preparation for Sample

As for in this study, using reinforced concrete test material in the form of a cylinder which is a standard for testing concrete in accordance with SNI 03-4810-1998 having a height of 30 cm and a diameter of 15 cm which has a concrete quality of K-175. As for the manufacture of the test object in this study was carried out at PT. Varia Varia Usaha Beton at Gresik plant Jl. Mayjen Sungkono, Kebonpoh, Segoromadu, Kec. Gresik, Gresik Regency, East Java. There are several stages in the process of making concrete test objects, namely as follows:

a. Determination of the mix design of the concrete mix with the quality of K-175. The purpose of this mix design is to be able to calculate each concrete mixture material so that it is obtained according to the desired concrete quality, the following mix design from the manufacture of test concrete:

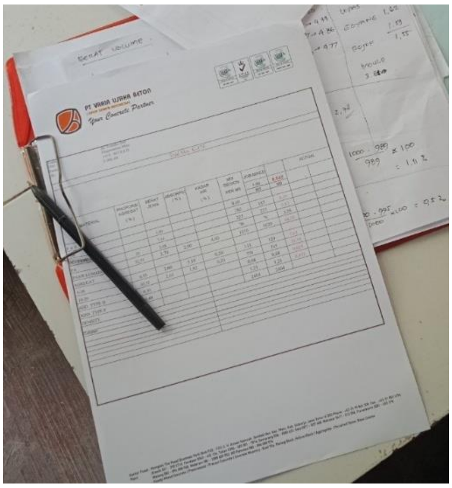

Figure 4. Mix design concrete mixture K-175

b. Calculation of the concrete mixture using a scale so that the material is in accordance with the mix design that has been made.

Figure 5. Concrete mix scale

The materials needed in the manufacture of concrete test objects are coarse aggregate (2 types of gravel), fine aggregate (cement and sand), water, fly ash, medicine. for concrete.

c. Mixing of materials for making concrete, this mixing is done periodically, starting from coarse aggregate, fine aggregate, water, fly ash and medicine for concrete.

Figure 6. Concrete Mixing Process

d. Slum Test, this test is carried out to find out how thick the concrete mix will be so that the thickness is in accordance with the planned compressive strength of the concrete, the slum value is 8-10 cm.

Figure 7. Slum test

e. Molding of the concrete mixture into the concrete cylinder mold. In this molding, it is done by compacting the concrete mixture by pricking the mixture in the mold by dividing into three phases, each phase is compacted by stabbing 27 times.

Then the concrete reinforcement is placed at a distance of 4 cm from the concrete blanket as shown in the following picture:

Figure 8. Concrete Compaction Results

f. Curing, which is a method of treating concrete with the aim that the concrete can harden and dry easily so that the water content in the concrete does not decrease which causes the evaporation of cement in the concrete, maintains structural dimensional stability and prevents cracks. This process is carried out by immersing the concrete for at least 3 days and it reaches the best time for setting time at the age of 7 days so that it can be said that the concrete is ready to be tested.

Figure 9. Curing

III. Results and Discussion

1) *Sensor Circuit*

In this study, for *monitoring* concrete corrosion using a resistivity test on reinforced concrete using a cylindrical concrete test material with a diameter of 8 mm of concrete reinforcement. Conditioning of concrete is also very necessary to be able to see the corrosion value of concrete which continues to increase due to the environment by immersing the test concrete in plain water and saltwater[10]. Then a pH meter is needed to determine how much environmental pH is in concrete water.

The results of the sensor circuit on the design that has been made are shown in Figure 10. The following is a series of hardware used for testing the corrosion rate in concrete using a resistivity test where the sensor uses an INA219 current and voltage sensor.

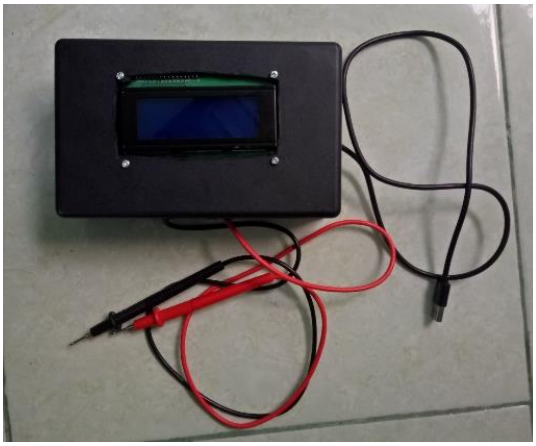

Figure 10. Hardware Monitoring System

2) *The Result of Prototype Test*

By testing the voltage-current sensor, it can display the value of concrete resistance so that it can be processed to determine the value of corrosion current, corrosion rate, and corrosion rate that occurs in concrete reinforcement[11]. The value can be used as a parameter and can be included in the slow, medium, high, and very high classification as shown below:

Figure 11. Display System Response on the Blynk app

In this test, the concrete was conditioned under two conditions, namely by soaking in salt water and fresh water. The purpose of this conditioning is to accelerate the corrosion process in concrete in order to facilitate the analysis of the corrosion rate.

Figure 12. Concrete soaking

By immersing the concrete in this study, the pH of the saltwater used in the immersion process was conditioned and observed, based on testing a series of systems monitoring with the conditioning of the test materials carried out every day for 5 days.

3) Testing of Concrete Corrosion Measurement Tool

In this study, data collection for prototype testing with a test concrete plant in the form of a cylindrical reinforcement with a total of 2 concretes and conditioned by immersion in saltwater in concrete 1 and fresh water in concrete 2, the test data retrieval was carried out in 5 days, so that the data analysis carried out obtained the data as below:

TABLE 2.
DATA RETRIEVAL

No.	**pH Concrete 1**	**Resistance (kΩ)**	
		Concrete 1	**Concrete 2**
1	8.15	51.43	25.72
2	8.17	51.35	25.68
3	8.17	51.32	25.66
4	8.19	51.24	25.62
5	8.22	51.15	25.53
$\sum$	40.9	256.49	128.21
$\bar{X}$	8.18	51.29	25.64

In table 2 obtained measurement data using a prototype with sensor INA219 is done on the first day to the fifth-day immersion in concrete 1 using a brine so that the conditioning is required of data pH at the time of measurement, while the concrete 2 soaking with freshwater. The purpose of conditioning by immersing two different water treatments is to accelerate the corrosion of concrete reinforcement so that the difference in water used for immersion can be used as a comparison. The graph of the resistivity test response on the prototype is as follows:

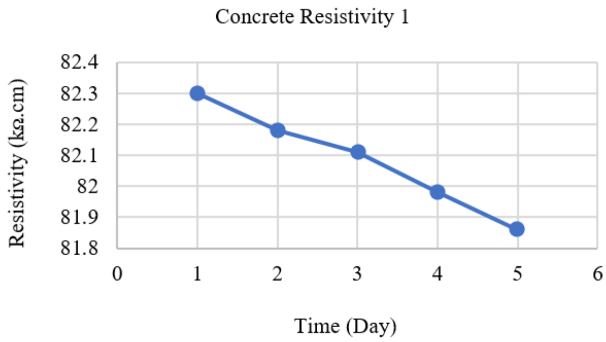

Figure 13. Concrete Resistivity Test Response in Salt Water Environment

Based on Figure 13 the resistivity test response on concrete 1 with environmental conditions of immersion with a mixture of saltwater is known to decrease the resistance of concrete over a period of 5 days with environmental conditions there is also an increase in the pH value of the saltwater mixture. It is known that within 5 days the average decrease in resistivity in concrete is 0.1kΩ.

The response of the resistivity test on concrete 2 with normal freshwater immersion for 5 days decreased every day. This also affects the corrosion rate of concrete. The graph shows that the average daily decline is 0.05kΩ to 0.1kΩ. With these environmental conditions, on the last day, it was known that the resistivity of the concrete was 40.85 kΩ with a concrete quality of K-175. The response of the resistivity test in a normal water environment is shown in the following graph:

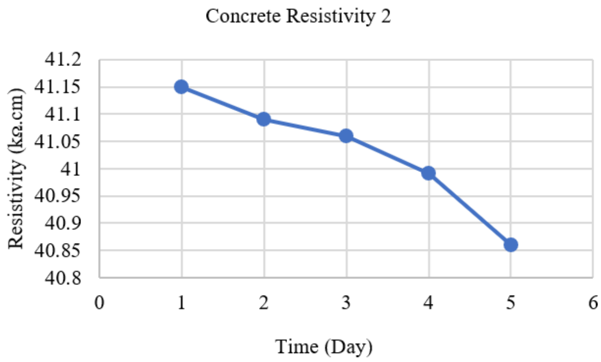

Figure 14. Concrete Resistivity Test Response in Fresh Water Environment

By knowing the resistivity value of concrete reinforcement that affects the permeability and durability of the concrete blanket, the corrosion rate of the concrete will also have an effect [12]. The corrosion rate of concrete in concrete 1 and concrete 2 with the existing concrete resistivity is as follows:

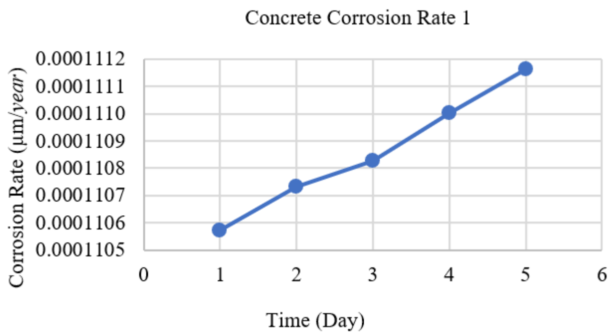

Figure 15. Concrete Corrosion Rate Response in Salt Water Environment

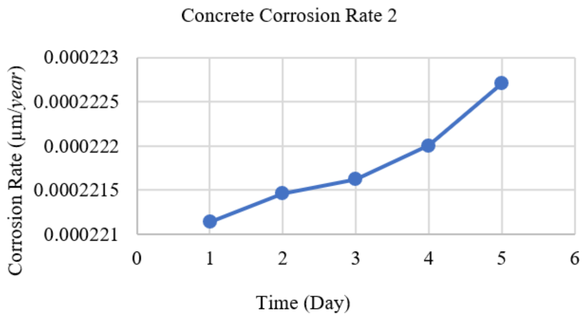

Figure 16. Concrete Corrosion Rate Response in Fresh Water Environment

Based on Figure 15 and Figure 16 environmental conditions of saltwater immersion, the corrosion rate of concrete 1 increases every day which is also influenced by a decrease in concrete resistance which reduces the flow and reduces the resistance and permeability of the concrete cover, thereby making water and other corrosion-inducing agents more likely to react with the concrete reinforcement. Figure 15 and Figure 16 also show that the corrosion rate of concrete on the last day is 0.0001112 m/year. The response of the corrosion rate of test 2 using the prototype under normal water immersion conditions showed that the increase in the daily corrosion rate of the concrete was influenced by a decrease in the resistance of the concrete, the number of days also decreased, and the possibility of the corrosion rate increasing. Expressed as the corrosion rate of concrete 2 on the last day is 0.00022 m/year.

4) Sensor Validation

In this study, validation testing was carried out by comparing tests using a prototype and a validator in the form of a multimeter. The results of the validation are as follows:

TABLE 3.
PROTOTYPE VALIDATION

No.	Prototype (kΩ)		Digital Multimeter (kΩ)		Correction	
	Salt Water	Normal Water	Salt Water	Normal Water	Salt Water	Normal Water
1	51.43	25.72	48.5	26.4	-2.9	0.68
2	51.35	25.68	50	25.7	-1.4	0.02
3	51.32	25.66	51.1	25.6	-0.2	-0.06
4	51.24	25.62	52.2	24.2	1.0	-1.42
5	51.15	25.53	53.4	22.5	2.3	-3.03
∑	256.49	128.21	255.2	124.4	-1.29	-3.81
$\bar{X}$	51.298	25.642	51.04	24.88	-0.258	-0.762

Based on the measurement results in Table 3, it can be seen that the data to determine the characteristics of the measurements carried out for 5 days are as follows:

- Sensivity

$$Sensitivity = \frac{\Delta output}{\Delta input} = \frac{O_{max} - O_{min}}{I_{max} - I_{min}}$$

$$= \frac{5.4-22.5}{51.43-25.53}$$

$$= \frac{30.9}{25.9} = 1.193\Omega$$

- Accuracy

$$A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right|$$

$$A = 1 - \left|\frac{26.4 - 25.72}{26.4}\right|$$

$$A = 1 - 0.025$$

$$A = 0.975$$

$$A(\%) = 0.975 \times 100\% = 97.5\%$$

- Error

Error = 1-Accuracy
= 1-0.975
= 0.025
Error (%) = 0.015 × 100% = 2.5%

This results in the following static characteristics:

Range : 25.53 – 51.43kΩ
Span : 25.9
Sensivity : 1.193Ω
Accuracy : 97.5%
Error : 2.5%

IV. CONCLUSION

Based on the manufacture of system monitoring corrosion in concrete using an IoT-based concrete resistivity test, there are the following conclusions:

- A corrosion rate monitoring system in concrete has been designed using a resistivity test based on the Internet of Things so that it can be used as a preventive measure to determine the corrosion rate in reinforced concrete and minimize the cost of restructuring a concrete-structured building by knowing the corrosion rate early.
- The monitoring system designed can work by detecting current and voltage using the INA219 sensor and the NodeMCU ESP8266 microcontroller so that the concrete resistivity can be calculated where the data can be processed to calculate the corrosion rate of concrete with an interface in the form of an application on Blynk.
- In the concrete corrosion rate monitoring system using the resistivity test, the uncertainty value is expanded by ±5.86 with a 95% confidence level from the T-table student. The accuracy of the measuring instrument is 97.5% with a system response to show the corrosion rate in concrete 1 and 2 which can be concluded based on Table 2.1 that the corrosion rate in the concrete of this study is "SLOW" and based on Table 2.2 it can be said the corrosion rate in concrete 1 and 2 classified as "PASSIVE".

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