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The Effect of Salt and Sulfuric Acid on the Resistivity Value of Bentonite Mixed with Calcium Carbonate Soil under DC Voltage

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Abstract. Mountainous areas are characterized by high soil resistivity, which may interfere with the grounding system and safety. Therefore, Ground Enhancement Material (GEM) is needed so that the resistivity value of the soil is following the grounding resistance standards regulated by General Electrical Installation Requirements or PUIL 2000. Bentonite as Ground Enhancement Materials (GEM) has been widely used, but studies on bentonite mixed with calcium carbonate using various stages of salts and acids for reducing soil resistivity are still few. This paper presents research conducted on bentonite mixed with calcium carbonate ($CaCO_3$) as a test soil, with salt (NaCl) and sulfuric acid (H_2SO_4) under DC voltage. In this research, laboratory experiments have been carried out. From the experiments, it was found that the average resistivity value of the soil in dry conditions was 57096.39 Ωm, then there was a decrease in resistivity of 99.96% with the lowest average resistivity value being 20.9 Ωm in the application of 18% NaCl solution. Whereas in the application of 18% H_2SO_4 the average resistivity value is 259.6 Ωm with a resistivity reduction percentage of 99.55%. The use of NaCl is more effective in reducing soil resistivity than H_2SO_4.

Keywords: *bentonite; calcium carbonate; ground enhancement materials; soil resistivity; salt variation; sulfuric acid variation.*

1 Introduction

The addition of space requirements for residence and infrastructure development causes land expansion to be unavoidable. This is also the case in the Bandung Regency area [1]. The total area of Bandung Regency is 176,238.67 Ha, and most of Bandung's area is between the hills and mountains that surround Bandung Regency [2]. Mountainous areas, for example, the northern slope of Mount Malabar, have soil characteristics with a resistivity value of up to 1438 Ωm according to the research conducted by Asep Harja, et.al in [3].

For residential buildings, a grounding system is one of the most important things to be considered. Electrical grounding must be installed to prevent fires, damage to electronic devices, or even fatalities due to lightning strikes to building structures. For the grounding system, the resistivity value of the soil in the mountainous area does not meet the requirements. The standard value of earthing resistance following the General Electrical Installation Requirements or PUIL 2000 is less than 5 Ω [4]. Conditioning of the soil, where the ground rod must be installed, should be done by adding Ground Enhancement Materials (GEM) to reduce soil resistivity [5]. Bentonite soil and calcium carbonate ($CaCO_3$) can be used as GEM materials by treating the soil with a chemical solution [6].

Research on the characteristics of bentonite and $CaCO_3$ soils to be used as GEM, respectively, has been carried out in [5], [7]. However, studies on the characteristics of bentonite mixed with $CaCO_3$ soil are still few. This paper reports a study on how to reduce resistivity values in a mixture of bentonite soil and $CaCO_3$ soil, which was treated with salt solution (NaCl) and sulfuric acid solution (H_2SO_4) under DC voltage. This study uses DC voltage variations to see the ground impedance value determined from pure resistance at zero frequency (dc).

2 Ionization Propagation Model

When a sufficiently high electric field is applied to the ground, the air voids are ionized. The ionization zone will increase in the form of several paths that propagate away from the energized electrode, as illustrated in Figure 1 [8]. Soil texture can affect variations in soil resistivity values. The finer the texture of the soil, the higher conductivity of the soil with a lower resistivity value, and vice versa when the grain of the soil is coarser [9].

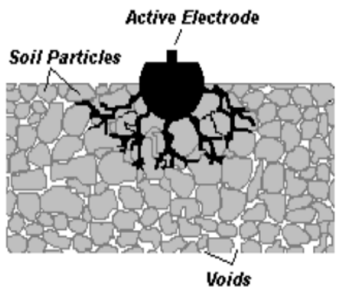


Figure 1 Ionization propagation model [8].

3 Methodology

3.1 Tested Soil

Mineralogically, bentonite is composed of smectite with the chemical formula ((Na, Ca)(Al, Mg)$_6$(Si4O10)$_3$(OH)$_6$-nH$_2$O) [10]. It has a layered structure with the swelling ability and has movable cations. The bentonite used in this study comes from the village of Sarimanggu, Karangnunggal, Tasikmalaya, Indonesia, and the type is Ca-bentonite. The $CaCO_3$ rock was obtained from a mining company located at PT Batu Wangi, Padalarang, West Java. Rocks need to be processed to get a smooth texture. The soil texture for this study can be seen in Figure 2. Bentonite soil has a coarser texture than $CaCO_3$ soil.

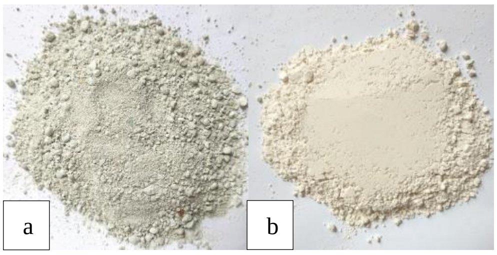
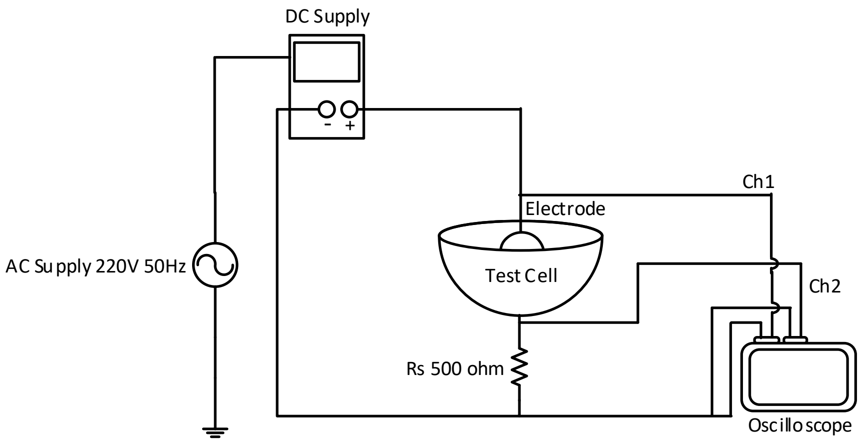


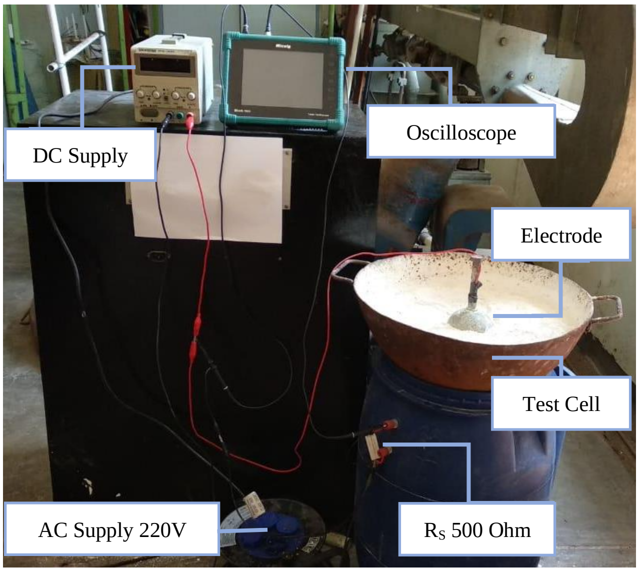
Figure 2. Soil texture of (a) bentonite and (b) $CaCO_3$

3.2 Test-Set Up`

Test-set up used in our experiment is illustrated in Figure 3. DC power supply was generated using a GW Instek SPS-1230 DC power supply with an input of 220 VAC 50 Hz, which produces an output voltage range between 0-11.5 VDC. The voltage from the DC supply flows to the tested ground through a ball-shaped aluminum electrode with a diameter of 10 cm. The soils tested were bentonite and $CaCO_3$ stored in an iron hemispherical test cell with a diameter of 46 cm. Measurements were made using a Micsig TO1102 tablet oscilloscope. Channel 1 (Ch1) probe is used to measure the voltage injected into the electrode while the resulting potential difference is measured with a channel 2 (Ch2) probe. A shunt resistor Rs of 500 Ω was used as a link between the test cell and the negative pole of the circuit, whose main function is to create a smaller resistance path for the flow of current.



(a) Schematic diagram



(b) Laboratory setting

Figure 3 Test set-up (a) schematic diagram and (b) laboratory setting

3.3 Experiment

A mixture of 5 kg of bentonite and 5 kg of $CaCO_3$ was used in this experiment, so the total soil used was 10 kg for each chemical treatment. The soil in the test cell was compacted to get a better measurement.

The salt used in this experiment used crystalline salt dissolved in tap water with a concentration of 35% or 0.6 M while the H_2SO_4 solution used was a concentration of 24.5% or 4.4 M. Considering the proportion of the solution stages given to the soil to be 0%, 6%, 12%, and 18%. The percentage of a solution is calculated for 10 kg of soil mass. The percentage of 0% solution is the soil in dry conditions and the percentage of solution used is 6%, which means that as much as 600 ml of solution is given to the soil being tested, and so on. The process of administering NaCl and H_2SO_4 solutions was carried out in a short time to minimize the effects of water settling and drying. To calculate the percentage solution in ml use equation (1).

$$Solution\ (ml) = \frac{6}{100}(10\ kg) = 600\ ml \tag{1}$$

The NaCl solution was sprayed using a sprayer and stirred to get an even distribution of the solution throughout the soil. While the H_2SO_4 solution was not sprayed for safety considerations, so the acid solution was poured carefully from the bottle container on the soil surface and mixed manually. For experiments with acids, it is required to wear protective equipment, i.e. masks, gloves, safety shoes, and safety glasses.

Variations in the DC voltage applied to the soil for each percentage of solution are as many as 22 voltage variations in the range of 1-11.5 VDC, with a voltage difference of 0.5 VDC. The measured output voltage is then calculated by *Ohm's* law equation (2) to get the resistance value *R*:

$$R = \frac{Vin - Vout}{I} \tag{2}$$

Where *Vin* is the voltage injected into the electrodes, *Vout* is the output voltage measured by the oscilloscope, and the current *I* calculated from equation (3):

$$I = \frac{Vout}{Rs} \tag{3}$$

Rs is a shunt resistor. The resistivity value ρ is calculated using the formula in equation (4) from similar research that has been conducted in reference[10]:

$$\rho = \frac{2\pi R}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right)} \tag{4}$$

Where ρ is the soil resistivity, r_1 and r_2 are the radii of the electrode and test cell in meters.

4 Result and Discussion

4.1 Effect of NaCl Solution Percentages Variation to the Magnitude of Soil Resistivity

Table 1 shows the injected voltage and the measured voltage by the oscilloscope. The 0% condition is when the soil condition has not been given a NaCl solution, with an initial voltage of 1-1.5 VDC, causing the distribution of ionization in the soil to be not wide enough and the measured voltage is also very small, with an average voltage of 0.03 VDC, as tabulated on Table 1. The greater percentage of NaCl solution given to the soil, the measured voltage is closer to the initial injected voltage. The best maximum measured voltage value was obtained when the NaCl solution percentage of 18% was added to the soil. For instance, when the injected voltage is 11.5 VDC, then the measured voltage is 10.86 V indicating that 94% of the energized voltage is discharged to the ground.

Table 1 Voltage measured at each voltage variation using various NaCl solution percentages

Voltage (VDC)	Measured Voltage (VDC)			
	NaCl 0%	NaCl 6%	NaCl 12%	NaCl 18%
1.05	0.001	0.22	0.72	0.81
1.50	0.002	0.51	1.16	1.26
2.00	0.01	0.67	1.60	1.78
2.50	0.01	0.90	2.01	2.22
3.00	0.01	1.12	2.39	2.70
3.50	0.02	1.28	2.81	3.18
4.00	0.02	1.52	3.16	3.62
4.50	0.02	1.71	3.61	4.07
5.00	0.03	1.88	4.14	4.54
5.50	0.03	2.13	4.50	5.02
6.00	0.04	2.33	4.98	5.44
6.50	0.04	2.54	5.31	5.97
7.00	0.04	2.76	5.90	6.46
7.50	0.04	2.98	6.33	6.93
8.00	0.04	3.20	6.86	7.38
8.50	0.05	3.42	7.27	7.88
9.00	0.05	3.63	7.70	8.31
9.50	0.05	3.86	8.10	8.82
10.00	0.06	4.06	8.64	9.31
10.50	0.06	4.26	9.07	9.77
11.00	0.06	4.49	9.50	10.39
11.50	0.07	4.66	9.90	10.86
Avg.	0.03	2.46	5.26	5.76

Table 2 shows the results of soil resistivity using the NaCl solution. The average resistivity at 0% soil conditions is 57096.39 Ωm. When the value of the input voltage increases, the resistivity value will decrease correspondingly. At the addition of 6% solution, the soil began to react with the NaCl solution to reduce the resistivity value significantly with a decrease of 99.40% from the initial condition. Then, the solution was added twice (from 6% to 12%), and the average resistivity decreased to 43.59 Ωm or decreased by 99.92%. Likewise, from 6% to 18% (the solution becomes 3 times) there is a decrease of 99.96%. For all test voltages used in this measurement when the NaCl solution was 18%, the average resistivity is 20.9 Ωm, which is the lowest average soil resistivity acquired compared to other NaCl solution percentages used.

Table 2 Magnitude of soil resistivity versus voltage variation in with various NaCl solution percentages

Input Voltage (VDC)	**Resistivity (Ωm)**			
	NaCl 0%	**NaCl 6%**	**NaCl 12%**	**NaCl 18%**
1.05	347701.60	739.56	88.00	57.31
1.50	158256.80	394.29	59.50	37.85
2.00	57976.93	374.54	49.71	25.32
2.50	45004.89	355.59	48.81	25.01
3.00	42504.15	337.87	51.33	22.14
3.50	36579.13	348.97	49.02	20.41
4.00	38584.38	328.87	53.11	21.07
4.50	37276.79	327.48	49.48	21.21
5.00	34645.27	332.25	41.69	20.34
5.50	34296.81	318.05	44.60	19.19
6.00	34109.18	315.70	41.11	20.66
6.50	35251.29	312.11	44.98	17.82
7.00	35640.87	307.97	37.42	16.78
7.50	36248.35	305.12	37.10	16.51
8.00	36292.54	301.85	33.35	16.86
8.50	35342.19	298.87	33.96	15.79
9.00	35219.20	296.92	33.89	16.67
9.50	35307.15	293.27	34.69	15.47
10.00	34888.95	293.65	31.59	14.88
10.50	35219.20	294.00	31.64	15.00
11.00	35524.88	291.01	31.69	11.78
11.50	34250.00	294.61	32.44	11.83
Avg.	57096.39	340.25	43.59	20.90

Figure 4 depicts the curve of the injected voltage versus the soil resistivity value using different NaCl solution percentages. It is seen that with 0% NaCl the resistivity curve is quite steep when a voltage in the range of 1-1.5 VDC is injected into the soil. This indicates that the soil used in this test was not dry enough, in other words, the soil still contains moisture. In this measurement, the propagation of the voltage injected to the electrode is affected by soil moisture causing a decrease in the resistivity value at each applied voltage.

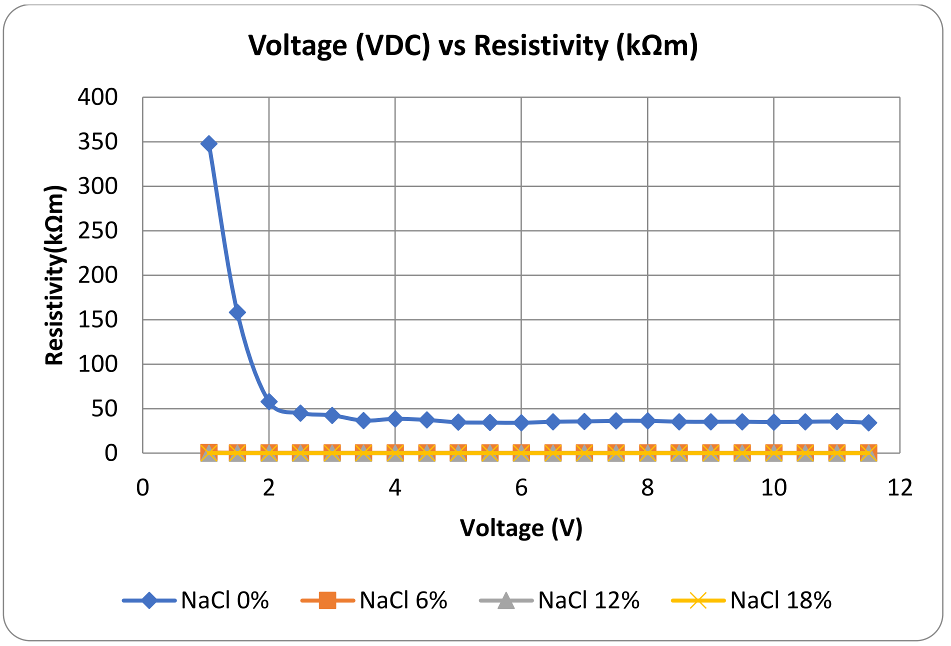


Figure 4 Graph of input voltage versus soil resistivity magnitudes with all various NaCl solution percentages

The ionization zone will spread out and is assumed to be like a current path that propagates away from the electrode that is being applied to the voltage. The speed of current propagation is very dependent on the applied voltage and the soil conductivity [8].

To clarify the graph of the decrease in resistivity in the application of 6%, 12%, and 18% NaCl can be seen in Figure 5. Figure 5 shows that any increase in the NaCl solution percentage level will cause a decrease in soil resistivity. This phenomenon might result in a change in the chemical composition of the soil. Moisture in the soil has an initially small conductivity, but when it reacts with a NaCl solution, the conductivity value becomes higher and the resistivity value decreases. With an 18% NaCl solution added to the soil, the soil tested and the ionization is more uniform compared to the other percentage stages used in this experiment. Therefore, the use of chemical compounds, such as NaCl, added to the bentonite and $CaCO_3$ soil can greatly help to reduce the soil resistivity value.

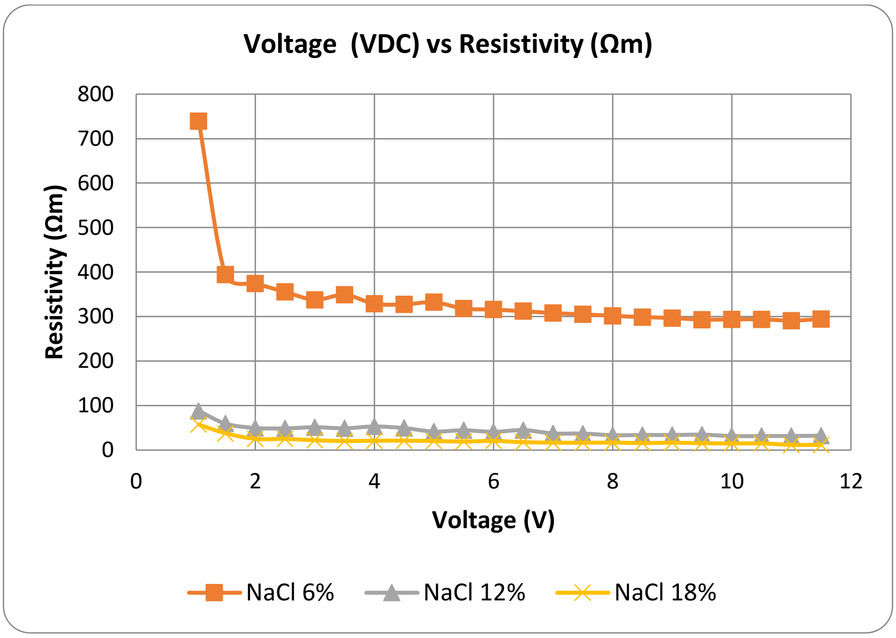


Figure 5 Graph of input voltage versus resistivity value with 6%, 12%, and 18% NaCl solution percentages

4.2 Effect of H_2SO_4 Percentages Variation to the Magnitude of Soil Resistivity

From Table 3, the maximum voltage value is obtained in the soil when the 18% H_2SO_4 solution is added to the soil under test. For instance, when the injected voltage to the ground electrode is 11.5 VDC, then the measured voltage is 5.59 VDC indicating that 49% of the injected voltage (11.5 VDC) at the ground electrode is discharged to the ground.

However, the ratio between the energized voltage to the measured voltage in the test using H_2SO_4 solution is still relatively small, for example when the soil is given a voltage of 10 VDC through the electrodes, the voltage measured at each addition of 6%, 12% and 18% H_2SO_4 respectively are 0.22 VDC, 2.30 VDC, 4.73 VDC. This means bentonite mixed with $CaCO_3$, using 4.4 M H_2SO_4 solution to conduct electric current is still not effective.

In addition, the soil resistivity value can be affected by the concentration of the chemical solution. In a concentrated solution, the movement of ions is more difficult so the conductivity becomes lower. And conversely, in a dilute solution, the ions in the solution move easily so that the conductivity is greater.

Table 3 Voltage measured at each voltage variation using various percentages of H_2SO_4 solution

Voltage (VDC)	Voltage Measured (VDC)			
	H_2SO_4 0%	H_2SO_4 6%	H_2SO_4 12%	H_2SO_4 18%
1.05	0.001	0.003	0.11	0.31
1.50	0.002	0.01	0.21	0.56
2.00	0.01	0.01	0.33	0.77
2.50	0.01	0.01	0.43	1.05
3.00	0.01	0.02	0.55	1.28
3.50	0.02	0.03	0.65	1.50
4.00	0.02	0.04	0.78	1.93
4.50	0.02	0.04	0.91	1.98
5.00	0.03	0.05	1.01	2.20
5.50	0.03	0.07	1.14	2.45
6.00	0.04	0.08	1.26	2.68
6.50	0.04	0.10	1.38	2.94
7.00	0.04	0.11	1.51	3.18
7.50	0.04	0.13	1.64	3.44
8.00	0.04	0.15	1.77	3.67
8.50	0.05	0.16	1.89	3.96
9.00	0.05	0.18	2.02	4.17
9.50	0.05	0.20	2.16	4.45
10.00	0.06	0.22	2.30	4.73
10.50	0.06	0.24	2.42	4.98
11.00	0.06	0.27	2.59	5.26
11.50	0.07	0.27	2.74	5.59
Avg.	0.03	0.11	1.36	2.87

From Table 4, when added 6% H_2SO_4 solution, the average resistivity decreased by 63%. Then, the solution was added twice (from 6% to 12%), and there was a decrease in resistivity of 98.55%. Likewise the addition of 6% to 18% (the solution becomes 3 times) there is a decrease of 99.55%. It is seen that the lowest average resistivity value was achieved when the percentage for the H_2SO_4 used is 18%. The average resistivity, in this case, is 259.6 Ωm, which is the lowest average resistivity, obtained compared to other H_2SO_4 solution percentages used in this experiment.

Table 4 Magnitude of soil resistivity versus voltage variation in with various H_2SO_4 solution percentages

Voltage (VDC)	Resistivity (Ωm)			
	H_2SO_4 0%	H_2SO_4 6%	H_2SO_4 12%	H_2SO_4 18%
1.05	347701.58	77110.91	1696.94	483.69
1.50	158256.81	49977.50	1212.76	339.81
2.00	57976.93	36292.54	1015.73	318.60
2.50	45004.89	35640.87	966.22	279.46
3.00	42504.15	31490.79	886.18	270.44
3.50	36579.13	24888.40	880.05	267.62
4.00	38584.38	22737.90	824.64	266.14
4.50	37276.79	21304.24	794.01	256.14
5.00	34645.27	18383.81	791.93	256.08
5.50	34296.81	16033.42	765.94	249.13
6.00	34109.18	14852.75	752.04	249.32
6.50	35251.29	13111.88	747.42	242.44
7.00	35640.87	12808.45	731.60	240.69
7.50	36248.35	11203.43	719.99	237.40
8.00	36292.54	10797.25	704.42	236.81
8.50	35342.19	10330.52	700.53	230.11
9.00	35219.20	9670.41	692.67	232.48
9.50	35307.15	9381.06	683.69	227.78
10.00	34888.95	9091.55	673.09	223.63
10.50	35219.20	8654.27	669.07	222.48
11.00	35524.88	7976.48	650.42	219.03
11.50	34250.00	8223.37	641.39	212.20
Avg.	57096.39	20907.35	827.31	259.61

As depicted in Figure 6, the 0% H_2SO_4 curve means that the soil is still dry and has not been yet mixed with the H_2SO_4 solution. It is the same with the results obtained using the 0% NaCl solution, indicating that the soil is not yet contaminated with chemical solutions from external factors. So, the percentage of adding a solution below 12% using H_2SO_4 does not significantly affect the decrease in soil resistivity values compared to adding a solution above 12%. To clarify the graph of the decrease in resistivity in the application of 12% and 18% H_2SO_4 can be seen in Figure 7. As shown in Figure 7, the use of H_2SO_4 can reduce soil resistivity but the effect is not too significant, because the soil's capacity to exchange ion become lower. The use of chemical compounds to activate bentonite and $CaCO_3$ that are used as a grounding medium certainly affects the soil pH and chemical reactions in the soil, which triggers the corrosion reactions.

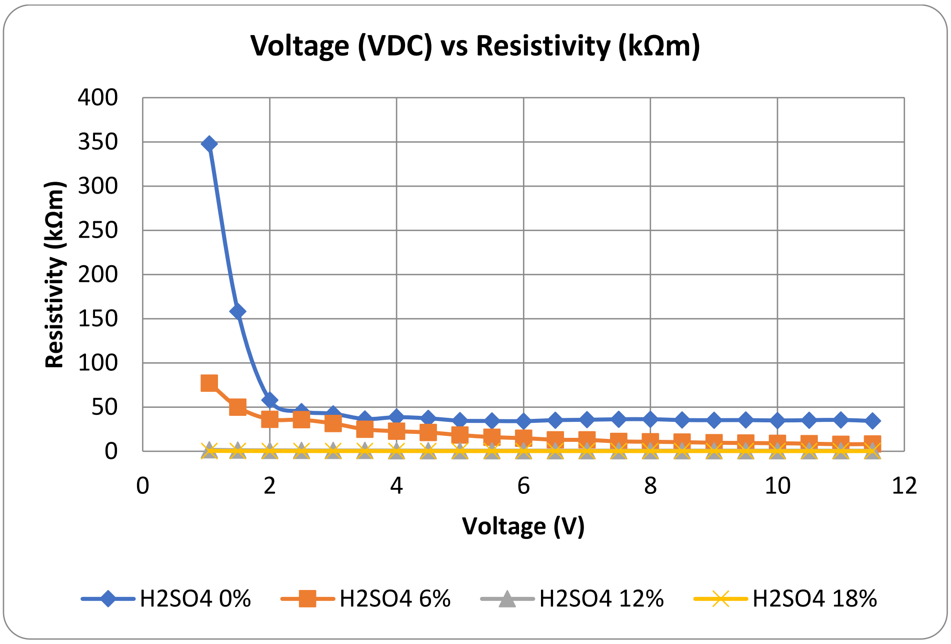


Figure 6 Graph of input voltage versus soil resistivity magnitudes with all various H_2SO_4 solution percentages

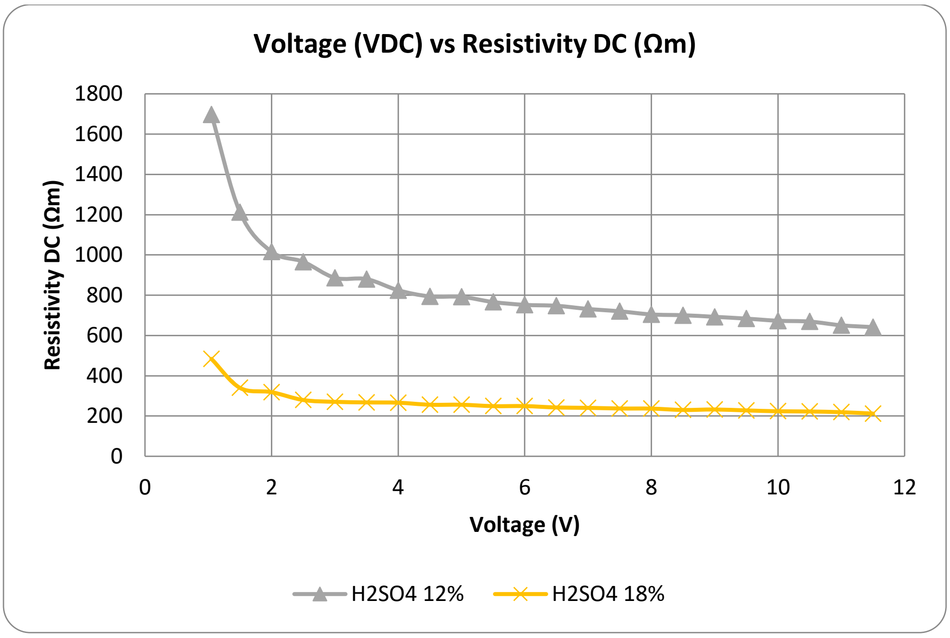


Figure 7 Graph of input voltage versus resistivity value with 12% and 18% H_2SO_4 solution percentages

Soils with high resistivity will reduce corrosion reactions. Thus, when only 6% H_2SO_4 is added, the corrosion reaction that occurs is small because the bentonite and $CaCO_3$ soils have high resistivity values. When the bentonite and $CaCO_3$ soils are mixed with 18% H_2SO_4, more soil particles are exposed to H_2SO_4, and the higher the corrosivity level will, in turn, make the resistivity gets smaller. The higher corrosivity of the soil, the greater the current flowing in the soil due to the low resistivity value, resulting in high conductivity. Therefore, the decrease in the soil resistivity using the H_2SO_4 is influenced by the corrosivity reaction and the change chemical properties of the soil [9] [11].

5 Conclusion

Laboratory experiments using a DC power supply to determine the resistivity value of the soil by adding chemical compounds in the form of H_2SO_4 and NaCl to the bentonite and $CaCO_3$ soil have been carried out in this research. In conclusion, the use of bentonite mixed with $CaCO_3$ can be used as ground enhancement materials (GEM), this material can reduce the resistivity value of the soil using an additional percentage of chemical solution. When the soil is dry (0%) without chemical solutions, the measured resistivity was 57096.39 Ωm. In the soil experiment tested with NaCl solution, the highest percentage level was 18%, and the average resistivity value decreased to 20.9 Ωm or decreased by 99.96%. With 18% H_2SO_4, the soil resistivity value is 259.6 Ωm or there is a 99.55% decrease. In a NaCl solution with a percentage of 6%, the average resistivity is 340.25 Ωm, whereas to achieve a resistivity value that is the same or close to that produced by 6% NaCl, it is necessary to add a solution of H_2SO_4 with a percentage of 18%. This shows that the percentage addition of the solution using NaCl solution to the soil has a 3-fold greater effect on reducing the resistivity than the H2SO4 solution. Based on the experimental results obtained in our study, when comparing the effectiveness of NaCl and H_2SO_4 in reducing grounding resistance, NaCl is more effective in reducing soil resistivity than H_2SO_4.

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