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Characterizing of Bentonite with Chemical, Physical and Electrical Perspectives for Improvement of Electrical Grounding Systems

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The application of bentonite as electrical grounding improvement material (GIM) has been investigated. Bentonite is a type of clay which has high tendency to absorb and retain water, and swells. This property makes it desirable for applications in grounding system improvement as they could result in lowering as well as minimizing the fluctuation of ground resistance over a long period of time. However, these properties depend on the type of bentonite. Commercially, there are two types of available bentonite; namely sodium bentonite and calcium bentonite. Several experiments were conducted to determine the chemical composition, water absorption rate, swelling capability; density and resistivity of calcium bentonite since such information are not available in the literature

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Keywords: Bentonite; Electrode; Backfill material; Grounding; Chemical composition

1. INTRODUCTION

An electrical grounding system serves many purposes with the primary one being discharging the immense amount of lightning charge to mother earth within as short a time as possible. An extensive discussion on issues of grounding practices was made in Lim et al. [1]. The efficiency of an electrical grounding system in performing such function is highly dependent on the low frequency grounding resistance. The grounding resistance in turn depends on the soil resistivity as well as the geometry of grounding electrode. General practices to achieve low grounding resistance include deep-driving of electrodes, installation of Ufer ground as well as backfilling with grounding improvement material (GIM) [3-5]. The first option may not be viable when the layer of soil, which houses a grounding system, is very thin. Under such circumstances, backfilling is the more preferable alternative.

In order to maximize the benefits of backfilling, the GIM in use should possess the following characteristics [2]:

1. Compactable and soil-compacting
2. Naturally inert
3. Have low and stable resistivity
4. Able to maintain low grounding resistance with minimal fluctuation for long period of time
5. Does not leaches with time
6. Economically viable

In several studies the term Low Resistivity Material (LRM) has been used [6]-[8] instead of GIM which will be used throughout this report. The authors prefer the term GIM because apart from having low resistivity, the backfill material should also have all of the above characteristics. Therefore, the term GIM describes a certain backfill material used for electrical grounding purpose more accurately.

GIM has to be both compactable and able to compact soil so as to maximize the contact surface area between the grounding electrode and the surrounding soil, thus lowering the grounding resistance. The material must also be naturally inert to prevent corrosion of grounding electrodes. It has to possess low and steady resistivity so that the overall effective soil resistivity (including bentonite itself) does not increase as both soil resistivity and geometry of grounding systems are highly influential on the grounding resistance. It must also be able to sustain low grounding resistance with as little variation as possible over a distant period of time. Huge fluctuations of grounding resistance is highly detrimental especially towards high voltage transmission towers as it will cause back-flashovers which in turn will inflict a costly damage to the utility side if improper insulation coordination was practiced. The GIM should also be able to adhere permanently to the surface of grounding electrodes regardless of the surrounding environmental condition. Otherwise, extra costs will be incurred to replenish the lost quantity of GIM. Last but not least, the material to be used should have reasonable implementation cost.

To date, many materials have been researched in terms of their applicability as GIM [9 -15]. Yet, the most superior is still one of the earliest used GIM which is bentonite. There are some literatures dedicated to investigating the effectiveness of bentonite as GIM [2, 6, 16-18]. There is also a research conducted on the effectiveness of mixture of bentonite with some chemicals such as Na_2SO_4, Na_2CO_3, $MgSO_4$ and $MgCO_3$ as GIM [19]. However, there is no in-depth explanation of why bentonite appears to be good GIM. Likewise, there is also no detailing of the influence of type of bentonite used on its effectiveness as GIM. In addition, the shortcomings of bentonite as GIM were also only briefly described in the literature [2]. Therefore, this investigation is conducted to find why certain properties of bentonite make it highly applicable as GIM, and also some critical issues of using bentonite as GIM.

2. EXPERIMENTAL PART

2.1. Measurement of long-term ground resistance and soil resistivity

This section detailed the experimental procedures which yield results of interest here as reported in [20]. Steel cages encased in concrete mixed with various proportions of bentonite were installed in 8 pits at a site. The first pit was steel cage encased in pure concrete with standard ration 1(cement):2(sand):4(gravel). For the second pit, 10% of cement was replaced with bentonite. The sequence continues with 20% replacement for pit 3, 30% for pit 4 up to 70% for pit 8. Fig.1 illustrates the setup for a pit which was taken from [20].

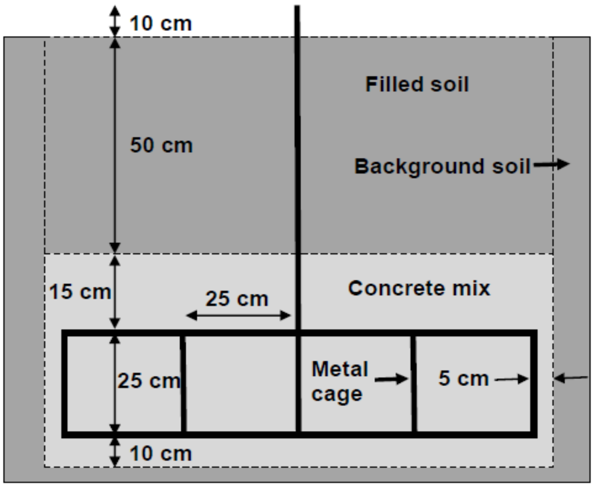

Figure 1. Setup for each pit [20]

Weekly measurements of the grounding resistance for up to 1 year were taken consistently using KYORITSU MODEL4105A. The measurement was based on Fall of Potential method. The potential probe (B) was placed 7m away from the measured grounding steel rod (A) and the current probe(C) a further 7m away. Both probes and the measured rod must be in a straight line as illustrated in Fig. 2.

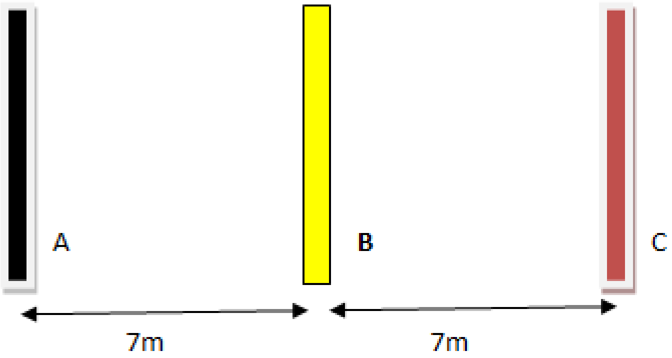

Figure 2. Grounding resistance measurement setup

In parallel, the soil resistivity (ρ) of the site was measured using the earth tester MEGER DET4TCR2 and setup is based on Wenner 4 pin method as shown in Fig. 3[4]. The four stakes were distanced *a* meters away from each other and the value of *a* should be at least equivalent to 20 times of the depth of the buried stakes *b*. The output measured at a certain inter-stake separation is the average soil resistance for the soil of equivalent depth and the soil resistivity can be approximated by equation:

$\rho = 2 \times \pi \times a \times R$ (1)

Where

a = distance between two consecutive ground stakes.

R = the soil resistance measured from the test instrument

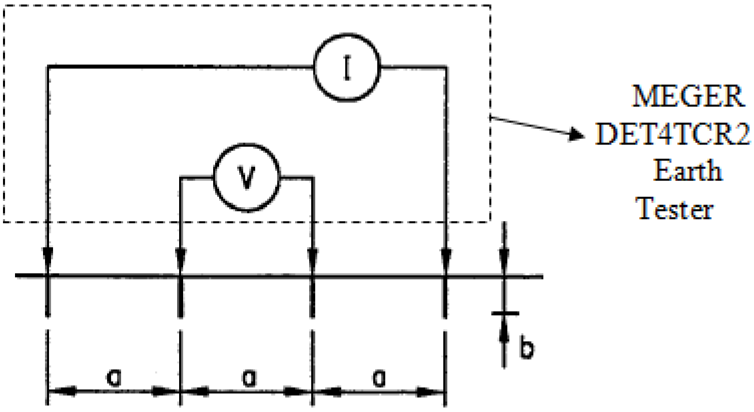

Figure 3. Soil resistivity measurement setup

Results of the first 5 weeks of measurements were published in Lim et. al [20] but one complete year of measurements are presented and discussed in the upcoming section.

2.2. *Measurement of physical properties of bentonite*

An experiment was conducted on a sample of calcium bentonite powder imported from Indonesia and 2 other samples from Pakistan whereby 1 of them is specified by the manufacturer as sodium bentonite while the other is not known. The objectives of the experiment are to determine their water absorption rate and swelling capacity at room temperature and pressure. The sodium bentonite from Pakistan shall be known as B1, the unknown sample as B2 and calcium bentonite from Indonesia as B3. Initially, 100 cm^3 of B1 powder was poured into a measuring beaker. Its corresponding mass was weighted. Then, 200 cm^3 of water was poured into it and the mixture was stirred until it is evenly mixed. The stirred mixture is then left for 1 day at room temperature and pressure and is again weighted to determine the hydrated density. Rate of evaporation is assumed to be insignificant as experiment only took 1 day at room temperature. The aforementioned steps were repeated for B2 and B3 respectively.

2.3. Measurement of electrical properties of bentonite

The electrical property of interest in this study is the resistivity of bentonite. The following procedures to measure the resistivity of all 3 samples were adopted from [13]. A cubical box made of Perspex without the top lid with dimensions of 10cmx10cmx10cm was first constructed. Two opposite sides of the box were pasted with aluminum foil to provide a conductive surface for measurement purpose. The empty box is then weighed using digital weight scale with maximum weighing capacity of 30kg to obtain its mass. The box is then filled up completely with B1 and pressed with a 4.7kg iron cast bar sitting on top of a 9.6cmx9.6cm wood block for 30 minutes. This is to ensure a uniformly flattened and compressed form of sample inside the box. By achieving this, the packing density of the sample in powder form under known pressure can be deduced. Density of powder varies with different applied pressure.

Then the weights are removed and the mass of the box filled with B1 is weighed again. The difference of weight corresponds to the weight of the sample and by dividing it with the volume of the box, the packing density can then be calculated. After the weighing procedures, the sample's resistivity can be measured by clipping the 2 probes of an LCR meter to the 2 sides pasted with aluminum foil of the box. The LCR meter was first used to measure the resistance of a known resistor in order to verify its functionality before being used for this experiment. Also, since the resistance of the Perspex is measured to be more than 10MΩ, the resistance measured can be approximated to be equal to the resistance of the mixture only. The resistance value displayed at the meter is then used to calculate the resistivity of dry bentonite (sample 1 then sample 2) by using the widely accepted formula:

$$R = \frac{\rho l}{A} \quad (2)$$

To measure the resistivity of wet bentonite, the sample inside the box is transferred to another container. Then, the cubical box is fully filled with water. Next, the water is poured into the container which was filled with dry B1 and the mixture was stirred until there were no traces of powder left. Finally the mixture was transferred back to the Perspex box as and the procedures of measuring mass and resistance as described previously were repeated. Last but not least, the entire procedures were replicated with samples B2 and then B3.

2.4. Analysis of chemical composition of bentonite

Energy Dispersive X-ray spectroscopy was performed to characterize and quantify the chemical elements exist within each sample. The machine used was EDX Thermo Scientific which runs with NORAN System 6 X-ray Microanalysis System as the software. Scanning Electron Microscope (SEM) with model number Hitachi S-3400N was used to produce topological images of the samples. This machine has maximum resolution of 30000 times and can scan images up to 50nm in size.

3. RESULTS & DISCUSSION

3.1. Steady state earth resistance and soil resistivity

As mentioned earlier, this field work was already reported in [20]. However, only the first 5 months worth of measurements were available in [20]. Fig. 4 depicts the grounding resistance variation of the bentonite mixed concrete encasing metal cages for 1 year. The soil resistivity of the experimental site was approximately 100Ωm. Table.1 illustrates the mean and fluctuation of resistance for each pit for 1 year.

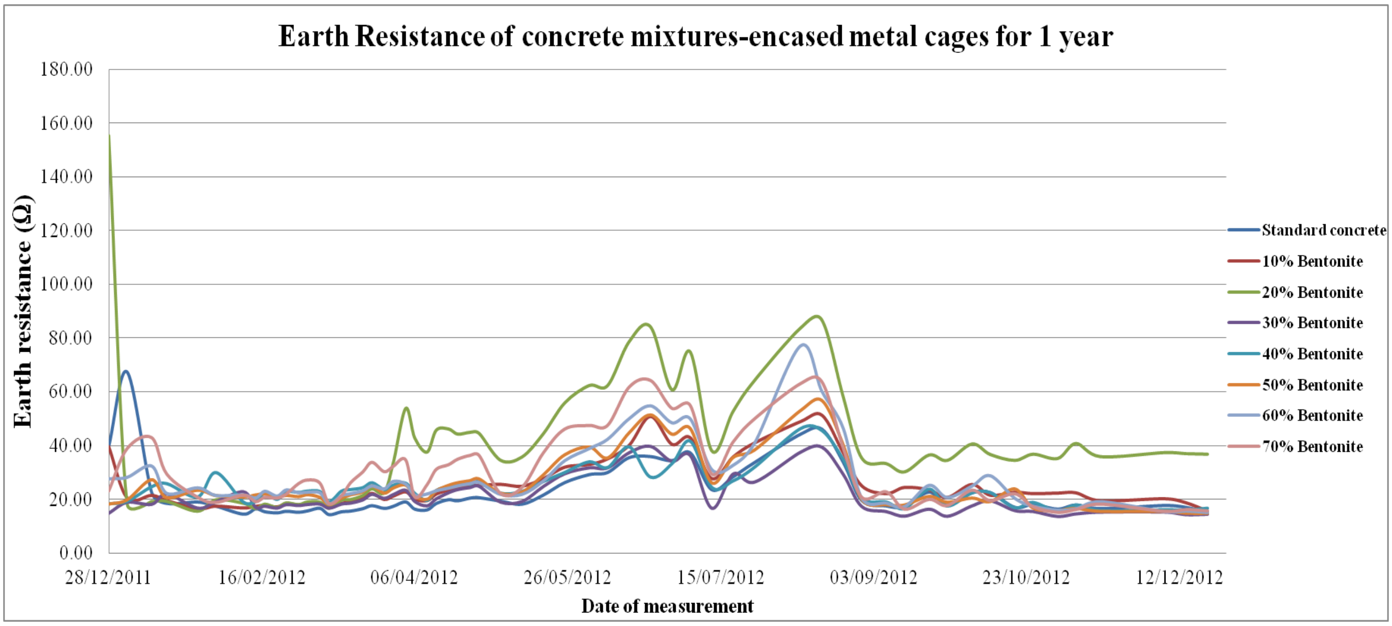

Figure 4. Grounding resistance of bentonite-mixed concrete encased metal cages for 12 months

Table 1. Mean and fluctuation of resistance for each pit

Pit	Average(Ω)	Standard Deviation(Ω)
1	22	10
2	25	9
3	40	24
4	21	7
5	24	7
6	25	10
7	27	12
8	30	13

3.2. Physical properties

Table 2. depicts the physical properties of interest of the 3 samples. It was observed that 1 day later, only 40g of water is left at the top of the swollen and solidified layer of bentonite B1 at the bottom of the beaker. This means that 100g (weight of 100 cm^3 of B1) can absorb 160g of water. Also, initial volume of dry 100g of B1 was $100cm^3$. However, after complete hydration, the volume of calcium bentonite has increased to $220cm^3$. This implies that the swelling capacity of B1 is approximately 220%. In terms of density, the density of dry B1 is $1000kg/m^3$. When swollen or completely hydrated, its density increased to $1295kg/m^3$.

Table 2. Absorption capability and swelling capacity of B1, B2 and B3

Type of Bentonite	Dry density (kg/m^3)	Absorption capability (%)	Swelling capacity (%)	Hydrated density (kg/m^3)
B1	1000	160	220	1295
B2	1000	130	180	1194
B3	800	125	150	1133

3.3. Electrical properties

Under dry and wet conditions, the resistivity of sodium bentonite was found in the literature to be approximately 18 Ωm and 3 Ωm respectively [2,13,19,21]. Table 3. shows the measured results of the three variations of bentonite.

Table 3. Resistivity of B1,B2 and B3

Bentonite	Packing Density(kg/m^3)	Dry resistivity (Ωm)	Wet resistivity (Ωm)
B1	1080	70	0.9
B2	1070	130	0.7
B3	1050	225	16

On the other hand, the resistivity of B3 which is calcium bentonite was measured to be 16Ωm when in full wet condition.

3.4. Chemical composition

Fig. 5 shows the morphology of the B3 which was obtained from Scanning Electron Microscopy (SEM). It can be observed that it has agglomerated due to the presence of water in the atmospheric condition. This demonstrates the hygroscopic nature of bentonite. Similar images were observed for those of B1 and B2 which were not shown here.

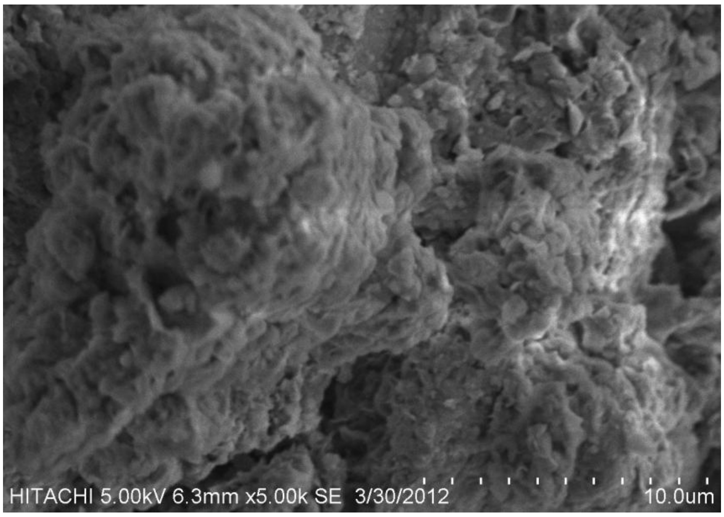

Figure 5. Morphology of calcium bentonite powder

Fig 6, 7 and 8 show the spectrum of bentonite as obtained using an energy-dispersive X-ray spectrometer (EDS) which is attached to a SEM. There are traces of Sodium ions in both B1 and B2 which indicates that both the known B1 and the unknown B2 are types of sodium bentonite. The presence of Calcium ions in B3 as indicated in Fig. 4 confirms that the sample is calcium bentonite with chemical elemental composition as shown in Table. 2. The quantity of calcium ions is not shown in Table. 4 because its weight is too low compared to the total weight of the elements. The K and L represent the energy-level shells of each element.

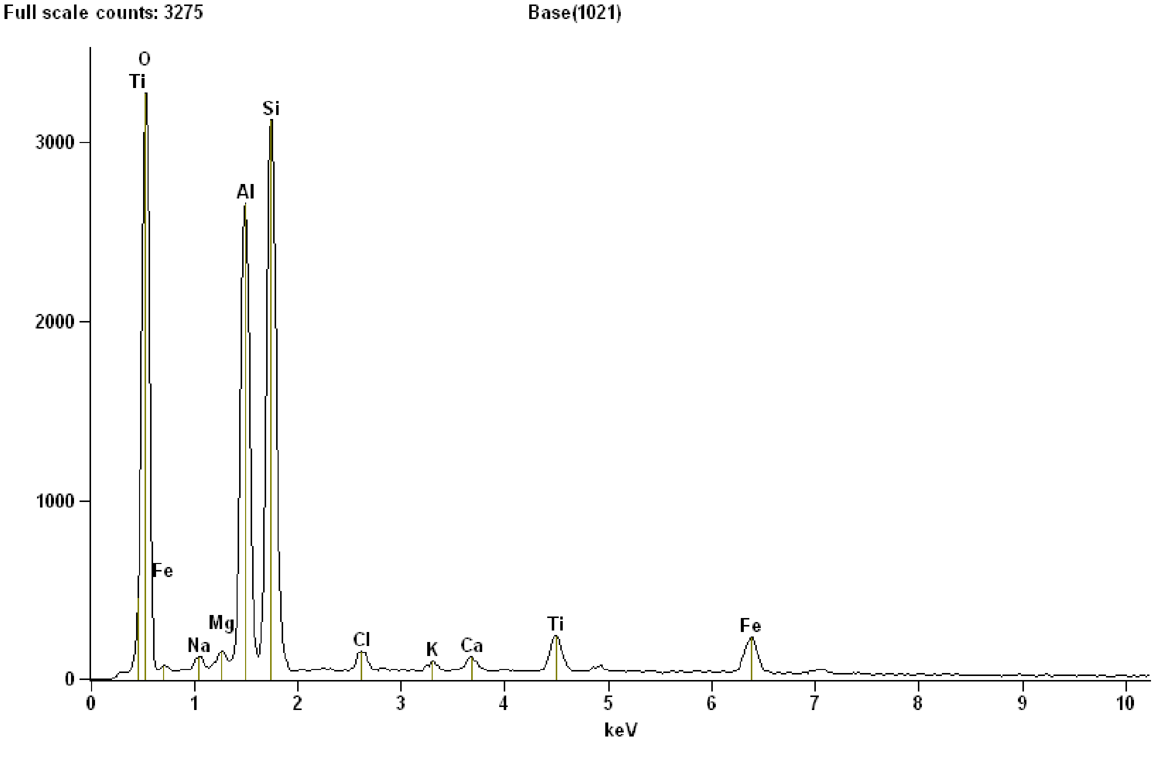

Figure 6. Spectrum of B1

Table 4. Composition of each element present in B1

Element Line	Weigh (%)	Weight Error (%)	Atom (%)	Atom Error (%)	Compound %	Normalized Compound (%)
O K	4.99S	---	9.11	+/- 0.07	---	---
Na K	1.15	+/- 0.08	1.46	+/- 0.11	1.15	1.15
Mg K	0.9	+/- 0.08	1.08	+/- 0.09	0.9	0.9
Al K	27.36	+/- 0.26	29.62	+/- 0.28	27.36	27.36
Si K	44.46	+/- 0.36	46.25	+/- 0.38	44.46	44.46
Si L	---	---	---	---	---	---
Cl K	2.24	+/- 0.10	1.85	+/- 0.08	2.24	2.24
Cl L	---	---	---	---	---	---
K K	0.84	+/- 0.08	0.63	+/- 0.06	0.84	0.84
K L	---	---	---	---	---	---
Ca K	---	---	---	---	---	---
Ca L	---	---	---	---	---	---
Ti K	6.45	+/- 0.26	3.94	+/- 0.16	6.45	6.45
Ti L	---	---	---	---	---	---
Fe K	11.61	+/- 0.33	6.07	+/- 0.17	16.6	16.6
Fe L	---	---	---	---	---	---
Total	100		100		100	100

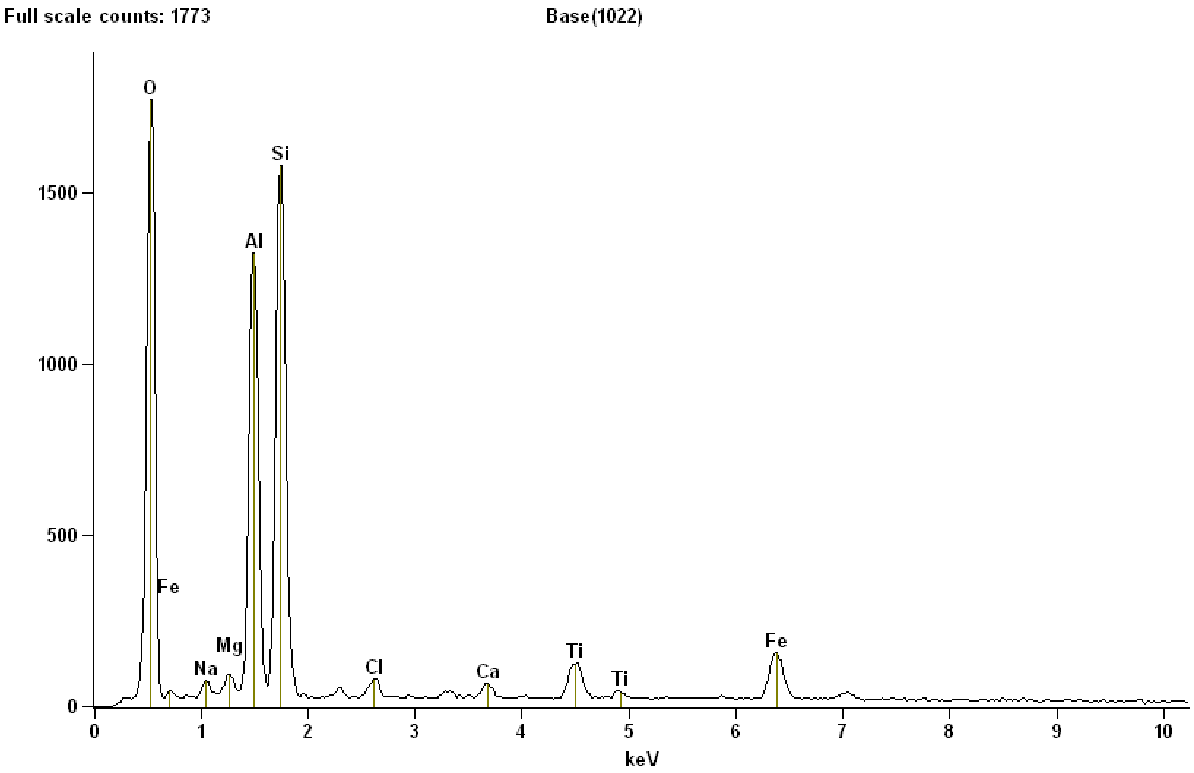

Figure 7. Spectrum of B2

Table 5. Composition of each element present in B2

Element Line	Weigh (%)	Weight Error (%)	Atom (%)	Atom Error (%)	Compound (%)	Normalized Compound (%)
O K	6.37S	---	11.66	+/- 0.11	---	---
Na K	1.3	+/- 0.12	1.65	+/- 0.15	1.3	1.3
Mg K	1.31	+/- 0.12	1.58	+/- 0.15	1.31	1.31
Al K	26.1	+/- 0.34	28.31	+/- 0.37	26.1	26.1
Si K	41.58	+/- 0.47	43.33	+/- 0.49	41.58	41.58
Si L	---	---	---	---	---	---
Cl K	2.33	+/- 0.23	1.93	+/- 0.19	2.33	2.33
Cl L	---	---	---	---	---	---
Ca K	---	---	---	---	---	---
Ca L	---	---	---	---	---	---
Ti K	6.19	+/- 0.36	3.78	+/- 0.22	6.19	6.19
Ti L	---	---	---	---	---	---
Fe K	14.83	+/- 0.50	7.77	+/- 0.26	21.2	21.2
Fe L	---	---	---	---	---	---
Total	100		100		100	100

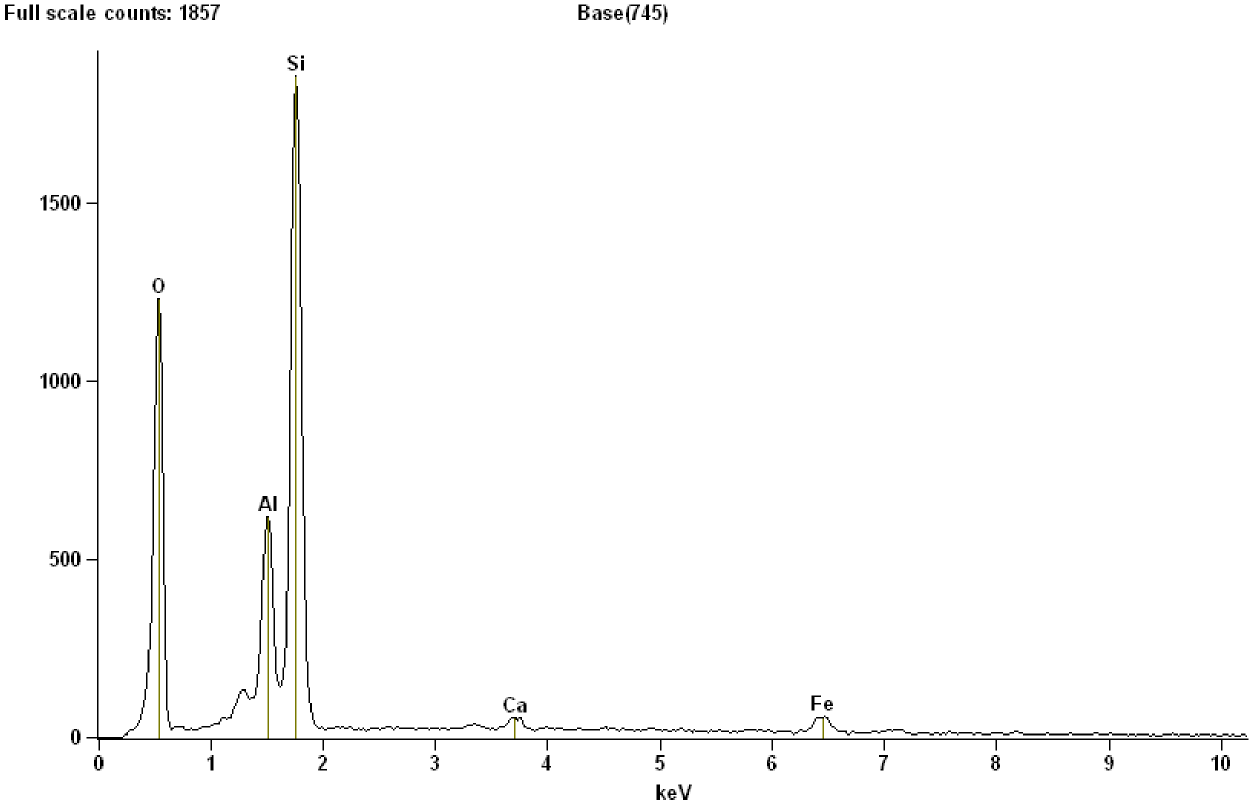

Figure 8. Spectrum of B3

Table 6. Composition of each element present in B3

Element Line	Weigh (%)	Weight Error (%)	Atom (%)	Atom Error (%)	Compound %	Normalised Compound (%)
O K	4.09S	---	7.25	+/- 0.08	---	---
Al K	15.13	+/- 0.43	15.91	+/- 0.45	15.13	15.13
Si K	71.28	+/- 0.75	72.01	+/- 0.76	71.28	71.28
Si L	---	---	---	---	---	---
Ca K	---	---	---	---	---	---
Ca L	---	---	---	---	---	---
Fe K	9.51	+/- 1.06	4.83	+/- 0.54	13.6	13.6
Fe L	---	---	---	---	---	---
Total	100		100		100	100

3.5. Properties of Bentonite

Bentonite is a type of material with smectite as its main composition and also having its physical properties to be dictated by the smectite minerals [22]. It is a montmorillonite and hygroscopic clay which is characterized by an octahedral sheet of aluminum atoms being infixed between two tetrahedral layers of silicon atoms [23]. It has net negative electric charge due to the isomorphic substitution of Al^{3+} with Fe^{2+} and Mg^{2+} in the octahedral sites and Si^{4+} with Al^{3+} in the tetrahedral sites and is balanced by the cations such as Na^{+} and Ca^{2+} located between the layers and surrounding the edges [24]. Natural bentonite, when hydrated with water, is alkaline with pH of 8 to 10 [25]. It is hydrophilic in nature as it is strongly hydrated by water [26]. This explains why bentonite has great water absorption capability. Water absorption of bentonite occurs by means of diffusion and capillary suction [27]. In addition, it also able to retain water or rather moisture content for a considerable period of time at atmospheric pressure. Once water is absorbed, it can expand up to several times of its original volume. However, this water retention and swelling capacity of bentonite is dependent on temperature and pressure [28].

Bentonite also has great cation exchange capacity, bonding capacity, plasticity and strong tendency to react with organic compounds [29]-[30]. Due to all of the mentioned properties, bentonite finds many applications in various fields which include pelletization of iron ore, feedstock, oil drilling, cosmetics, pharmaceuticals, sealants, farming and hydraulic containment [31]-[37]. When treated with acid, bentonite powder has great ionic adsorption capacity and thus can be used as adsorbent in catalyst, bleaching earth, and also in the preparations of organoclay, and nanocomposites [23], [38-40]. Another field which has been increasingly using natural bentonite is waste water treatment whereby it is used to remove heavy metallic ions such as cadmium, plumbum , copper and zinc [41]-[44]. It should be noted also that all of the aforementioned properties varies with the type of bentonite namely Sodium bentonite and Calcium bentonite. This important point was not at all discussed in the past literatures on application of bentonite as GIM.

3.6. Types of Bentonite

Commercially, there are two major types of bentonite namely Calcium bentonite and Sodium bentonite. The type of bentonite is dictated by the type of external cation that is adsorbed onto the surface layer of bentonite particle either by natural means (during the natural process of mineral formation) or by chemical treatment [45]. For most of the applications, Sodium bentonite is preferred over calcium bentonite due to its superior swelling capacity as well as its extremely low hydraulic conductivity to water [46]. The latter advantage makes Sodium bentonite more widely utilized in various hydraulic containment applications whereas the former which is of concern here, renders Sodium bentonite to be a better GIM than Calcium bentonite. Note that the conclusion drawn regarding Sodium bentonite being a better GIM is only a theoretical assumption. No research has been done yet to ascertain such assumption although such assumption has been verified in experiments conducted on other applications of bentonite.

The high sorption ability of bentonite towards dissolved cations in the environing pore water is attributed to its net negative electrical charge [47]. The theoretical cause of difference in swelling capacity between Sodium bentonite and Calcium bentonite was soundly explained in [45]. The term electrical double layer or diffuse double layer (DDL) was used to describe a clay particle (bentonite) being surrounded by layers of water and adsorbed ions [48]. DDL is a measure of how resistive clay is towards penetration of water through it. The more resistive it is, the higher the amount of swelling. DDL is quantified by another scientific quantity called the Debye length (λ) which is governed by equation [45]:

$$\lambda = \sqrt{\frac{\varepsilon_r \varepsilon_o RT}{2F^2 I}} = \sqrt{\frac{(3.924\times10^{-6}\,\frac{mol.nm^2}{L.K})\varepsilon_r T}{I}} \quad (3)$$

Where the constants are:
ϵ_o = vacuum permittivity
R = ideal gas constant
F= Faraday's constant
While the variable parameters are:
T = absolute temperature
I= ionic strength of the soil water
ϵ_r = relative permittivity of the DDL

Likewise, the ionic strength is governed by equation:

$$I = \frac{1}{2}\sum z_i^2 C_i$$

Where
Zi = valence
Ci = molar concentration of ionic species i.

Now, Sodium ion in Sodium bentonite has a valence of +1 whereas Calcium ion in Calcium bentonite has a valence of +2. This implies that the ionic strength of sodium bentonite is weaker than that of calcium bentonite. This also means that the Debye length of sodium bentonite is larger. Thus, sodium bentonite swells more and the more it swells, the thicker is the layer of electrolyte surrounding the grounding electrodes. The significance of this layer of electrolyte will be discussed in the next section.

It was observed that sodium bentonite can absorb up to 5 times of its original weight in water and swell up to 13 times its dry volume [25]. However, there are many different manufacturers of Sodium as well as Calcium Bentonite and even mixture of Sodium and Calcium Bentonite thus it is safe to say that each will exhibit different water-absorbing capability and swelling capacity. On the other hand, the absorption rate of water of calcium bentonite was not available in the literature. Therefore, the experiment as described in section 2.2 was conducted and the results were as displayed in Table. 2.

By analyzing Tables. 2, 4, 5 and 6, one can infer several interesting noteworthy highlights. B1 and B2 which are variations of sodium bentonite absorbs water at a higher rate than B3 which is calcium bentonite. This suggests that sodium bentonite is yet again better than calcium bentonite as a GIM owing to its superior water absorption capability. The swelling capacity of sodium bentonite is confirmed to be superior than that of calcium bentonite when one refers to Table. 1. However, the 2 different samples of sodium bentonite experimented here only swells to a much lesser extent with average of 200% compared to 1300% as reported in literature [24]. This clearly indicates that the swelling capacity of bentonite varies even among the various produce of sodium bentonite alone. Thirdly, the weight proportion of sodium ions does not directly translate into greater water absorption and swelling rate which can be observed from Tables. 4 and 5. Although B2 has higher amount of sodium ion (1.30%) compared to B1(1.15%), it only swells at 180% and absorbs 130% of water compared to 200% and 160% of B1 respectively. The higher concentration of Magnesium ion may also be the possible cause the reduction of swelling capacity of B2. It is also worth mentioning that calcium bentonite has higher initial water absorption rate than sodium bentonite [49].

3.7. Steady state resistance

The conclusion drawn by Lim et al [1] based on the five month measurements was not optimistic as bentonite-mixed concrete yielded higher grounding resistance value than pure concrete encased steel cages leading to the assumption that bentonite cannot be mixed well with concrete [20].. However, such assumption seems to be wrong when considering the readings taken in long-term. Fig. 4 illustrates the grounding resistance for the first 12 months of measurement. It can be observed that for the first 7 months, the assumption made in Lim et.al [1] was valid [20]. Beyond that period, it seems that 30% bentonite-mixed concrete consistently produced the lowest grounding resistance value. In addition, measured values of other mixtures with the exception of 20% bentonite seem to approach the grounding resistance value of pure concrete encased metal cage beyond that stipulated 7 months. The only anomaly was 20% bentonite because during construction, the steel cage was slightly damaged which is possibly the reason why its readings are as such. To summarize, 30% bentonite mixed concrete is a promising grounding improvement material based on the 12 months readings. Although there is no clear relation between volume of bentonite and the grounding resistance value, 30% by volume is the ideal proportion when mixing bentonite with concrete.

As shown in Table. 1, pit 4(30% bentonite) gives the lowest average grounding resistance and also the second lowest in terms of fluctuation of readings over 1 year period. As aforementioned, a GIM should also be able to minimize the extent of fluctuation of steady state grounding resistance over a long period of application. Both pit 4 and 5 produced similar amount of fluctuation but the former is chosen as the best ratio as it recorded lowest resistance and lower implementation cost since less bentonite is required for installation.

3.8. Suitability as backfill material

As previously mentioned, there are six requirements that a material has to reasonably satisfy in order for it to qualify as an effective GIM. Bentonite can bind together huge amount of soil in the presence of moisture which is why it was extensively used for soil stabilization by means of grouting. Therefore, the first requirement was fulfilled. Bentonite is also insignificantly corrosive even for a long period of time [2], [13]. In fact, Bentonite is even used in cathodic protection of steel in concrete [50].

Having low resistivity is also another important criterion of a backfill material. As shown in Table. 3, bentonite regardless of types are exhibit much lower resistivity under wet condition compared to dry condition. Sodium bentonite (B1 and B2) clearly showed lower resistivity than calcium bentonite (B3) under both conditions. Presence of moisture is again proved to be vital for bentonite to function as GIM.

The fourth characteristic which is of utmost importance as a GIM is the material has to be able to maintain low grounding resistance for where possible, an infinite amount of time. Numerous researches have demonstrated the superiority of bentonite in sustaining low grounding resistance with minimal fluctuations for a distant period of time [7], According to various literatures, this capability of bentonite was due to formation of an electrolyte when bentonite is ionized by water [2]. This layer of electrolyte is formed due to both bentonite’s ability of absorbing and retaining water by swelling. Theoretically, sodium bentonite would be better than calcium bentonite in this aspect. This electrolyte layer which envelopes the grounding electrode serves as pathway for dispersion of lightning charge. In other words, this conductive layer aids ionic conduction or dispersion of lightning current to the surrounding soil. As long as there is moisture in the soil, this electrolyte will remain enclosing the buried grounding electrode. This implies that under typically neutral soil, the layer of electrolyte will not get washed away. Hence, there will not be a need for replenishing of bentonite.

However, in the author’s opinion, there is another complementary explanation of why bentonite can reduce and maintain grounding resistance for a long time. It is possible that the electrolytic layer formed as a result of addition of bentonite into soil could serve as buffer zone which has the ability to trap charges.

3.9. Critical issues

The theoretical assumption that bentonite does not leach out holds true only if the environing soil is noncorrosive. In contaminated soil, the electrolyte or rather the “swollen layer of hydrated bentonite” may actually shrink and crack due to the attack of contaminant ions such as chloride. This problem is more chronic for sodium bentonite compared to calcium bentonite [45]. In other words, calcium bentonite is more resistant to corrosion than sodium bentonite.

In addition, it was mentioned in literature that under natural condition bentonite would not shrink or leaches away [2]. Assuming that that condition only applies for sodium bentonite since most likely the literature was referring to sodium bentonite, the behavior of swollen calcium bentonite was monitored for a few days. It was discovered that after one week, the thickness of the swollen calcium bentonite had actually shrunk by 20% although it is still in moist condition and under room temperature and pressure.

Cost-wise, bentonite may be a burden especially for developing countries to employ as GIM because not many countries produce bentonite, hence incurring extra importation costs. This is why numerous researches have been conducted in order to find replacement for it. Industrial waste such as mud and iron powder and also agricultural waste such as palm kernel nut were experimented [11], [13], [18]. Although palm oil kernel cakes (derived from palm kernel nut) was claimed to be able to satisfy all six requirements of an ideal GIM, unlike bentonite, there is only one research done on it. More experiments need to be conducted to compare bentonite’s performance with palm oil kernel cake. All in all, there is still no better backfill material discovered thus far. In the long run, the heavy investment on using bentonite may actually be worth it especially in tropical countries whereby the prevalence of lightning strikes is high.

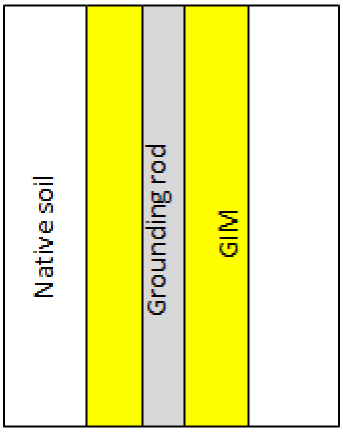

Figure 9. Augured-hole method for GIM-based grounding system [8]

Another issue which should probably be investigated in future researches is the effect of bentonite on the soil ionization phenomena. In the event of lightning strike, the air-filled voids within the soil may breakdown and become temporarily conductive hence lowering the overall grounding resistance for typically μs [51]. From the perspective of electrical grounding protection, soil ionization is beneficial. However, what happens when bentonite is added is not known. It is possible that ionization of bentonite will further reduce the overall grounding resistance within a short time. The incorporation of soil ionization effect is vital in order to optimize the design of grounding system with the application of GIM.

When employing GIM into the design of grounding system, there are typically two types of configuration namely augured-hole method and pit method. In augured-hole method, the grounding electrode is completely enveloped by GIM as shown in Fig. 9.

On the other hand, the embedment of grounding electrode in GIM in a pit is as illustrated in Fig.10.

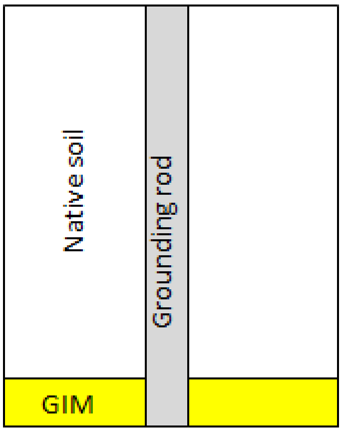

Figure 10. Pit method for GIM-based grounding system [8]

In both methods, the amount of GIM required is an issue itself. This is because an optimum volume safeguards both the economical and safety aspect of grounding. Backfilling with too little amount of bentonite may be insufficient in order to lower the grounding resistance so that ground potential rise is minimized and hence guaranteeing human safety and protection of highly sensitive electrical and electronic equipment. On the contrary, backfilling with too much bentonite will incur high material costs to the party concerned. It has been discussed that in the pit design, there is a certain saturation value of the volume of GIM at which the grounding resistance is not reduced in a significant manner once that value is exceeded [8]. Therefore, proper consideration of the amount of bentonite required is vital to ensure both feasibility and safety of a grounding system design using bentonite as backfilling material.

3.10. The way forward

The next phase of research will be to compare the performance of 30% bentonite mixed concrete encased steel cage with two other proposed settings namely steel cage encased in pure bentonite and steel cage encased in pure native soil. The selected site will consist of soil with much higher soil resistivity than the site of discussion here. The rationale is that based on literature, the effectiveness of bentonite as GIM is most significant under extremely high soil condition. This information will be made available to the literature in few months time. Another point worth investigating in the future is the incorporation of effects of ionization of bentonite in overall grounding system performance.

4. CONCLUSIONS

Applicability of bentonite as GIM has been investigated in detail in this report. The results of several experiments conducted on both sodium and calcium bentonite confirmed that sodium bentonite indeed is better than calcium bentonite in terms of functionality as GIM. However, these experiments should be replicated in real grounding system installation, in order to further verify the conclusions. Several issues of using bentonite as GIM have also been discussed with critical analysis. Future application of bentonite as backfill material should take into account such issues. An innovative experiment on introducing bentonite into concrete mixture to encase steel cage was presented and 30% bentonite ratio is a promising grounding improvement material which will be further verified through future studies.

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