Behaviour of a New Material that Improves Ufer Grounding Practice

1. Introduction

Electrical grounding is a vital mechanism that dissipates undesired charge to ensure the safety of human as well as equipments. Power system maloperation may happen due to poorly designed and improperly implemented grounding system. Substations and telecommunication towers being built on highly resistive site are very common due to space restriction constrain. In arid environment such as deserts and sub-deserts, rocky hill terrains and dry sand pits, implementing a grounding system with reasonably low ground resistance is very challenging as moisture is scarce in such soil. Under such circumstances, application of Bentonite slurry or ufer grounding is highly recommended [1]. The problem with using Bentonite slurry as grounding improvement material is that it could be a very costly material for importing countries. In addition Bentonite may leach away if the environing soil is corrosive such as those in the petrochemical industrial zones [2]. On the other hand, the practice of ufer grounding has its own issues as well [1]. The major issue of ufer grounding is its high resistivity when moisture content is low. Therefore Bentonite has been recommended to be introduced into the concrete mix to possibly prolong moisture retention capability of concrete as well as lowering its resistivity [2]. The inspiration came from the fact that Bentonite and cement have common physical and mechanical properties up to some extent. Both cement and Bentonite get fast-hydrated in the presence of moisture content forming a paste which has improved conductivity.
Previous work has determined the ideal composition to be Bentonite: Cement : Sand : Gravel (0.3:0.7:2:4) by volume [2-3] (hence named “best mix”). "Best mix" means the optimum bentonite-concrete mixture proportion which was found in previous study to be 30% Bentonite: 70% cement [2-3]. Also, in the study reported in [2], it was done on only 1 site with the same soil resistivity. Further study on its performance at soil with high resistivity confirmed its effectiveness in relative to several other conventional setups which include bare driven copper rod, pure bentonite slurry and pure concrete mix[4].

For the engineering applications, an empirical formula which correlates the ground resistance and the soil resistivity will be of high convenience. Such correlation can then be used to aid engineers in estimating the ground resistance obtainable if the grounding system using the proposed “best mix” is installed in the site with certain given resistivity. To enhance the validity of the correlation which is to be formulated, ground resistance measurements at as many sites with different soil resistivity as possible need to be conducted.

In addition, it is of interest to quantify the effectiveness of the “best mix” as compared to a standard concrete mix. In current work, the aforementioned correlation was determined for the “best mix” at a fixed dimension. The proposed empirical formula can be used for sizing of ufer grounding system to achieve a pre-determined value of ground resistance, once the soil resistivity in the area is provided as an input parameter. Hence, the present study would complement the previous studies in [2-4] as the correlation is formulated after considering a few sites of different soil resistivity.

2. Methodology

This field work commenced with selection of sites before the predesigned grounding systems were installed. Once done, concurrent measurement of localized soil resistivity and ground resistance were performed from 27th July 2013 until 24th December 2013.

2.1. Selection of sites

The sites are selected by considering the construction space availability, soil stability and resistivity. Upon weighing such factors, the sites identified are:
- Site 1 used in [3]
- Site 2 with huge trees and rocky soil [5]
- Site 3 used in [4]
- Site 4 with filled land[5]

Two pits (One each for best mix and standard concrete mix) were installed at Site 1 with an average soil resistivity of 115 Ωm. Site 1 was also the same site used in determining the optimum composition of bentonite-concrete mix as detailed in [3]. Fig. 1 shows the map of site 1.

Four pits were installed at Site 2 as shown in Fig. 2 with two of them close to large trees while the other two on the rocky part of the site. Previous study on the same site had shown that ground resistance of copper rods planted close to both locations were significantly different [5]. Average soil resistivity at B1-B2 and C1-C2 were 961 Ωm and 902 Ωm.
respectively [5]. Site 3 was located in the same site used in [5] as shown in Fig. 3. It is also one of the highest points in the research campus. A location much closer to the slope which exhibits a very high soil resistivity, averaging at 2.7 kΩm, was selected for the installation of experimental set up. The pits were designated as D1 and D2. The slope was about 45° and 15 m high. The final site 4 was situated at a landfill as illustrated in Fig. 4. The average soil resistivity was measured to be 257 Ωm which is approximately twice of that in Site 1.

The designations A1, B1, C1, D1 and E1 refer to pits with the best mix while the designations A2, B2, C2, D2 and E2 refer to pits with pure concrete encasing steel cage.

2.2. Installation of Grounding Systems

Steel cages with the same dimension (12 mm diameter) as in [4] and shown in Fig. 5 but encased in 0.5 m x 0.5 m x 0.3 m of materials were installed at the five sites, one each for standard concrete and the proposed mix. The thickness of the mix/concrete was further reduced to 0.3 m as the main governing factor of the resistivity of the entire chunk is the resistivity of the cage since its resistivity is significantly lower than mix/concrete. Fig. 6 illustrates the dimension of each grounding pit. Also, by further reducing the thickness so that the mix/concrete is just thick enough to envelop the cage, the total mass and hence the cost and transportability shall be improved via a respective reduction and enhancement.

Different approaches were used in constructing the steel cage encasement in Bentonite mixed concrete chunks. In [3-4], the concrete and Bentonite were mixed at the installation site itself. However in current work, the Bentonite mixed concrete chunks were first precast or made in a cubical mould. Wooden moulds of dimensions 0.5 m x 0.5 m were first constructed. Then, 0.1 m of the mix of interest were poured into the moulds and left for hardening. About two hours later, the steel cage was placed on top of the hardened layer and moulds were filled up to 0.3 m height. Once they have sufficiently hardened as shown in Fig. 7, they were then transported to be planted at the selected sites. A backhoe was used to compress the soil on the refilled pits in order to shorten soil compaction time. This new method was adopted with the view of developing a readymade electrode that can easily be commercialized. This precast approach is more cost and time efficient as all the installations were completed within half a day compared to five days in the work in [3] and two days in the work described in [4]. The method of on-site mixing as employed in previous works [3-4] is susceptible to rain disruption hence causing slight delays in completing the said constructions. PVC tubes were used to cover all protruding electrodes.
to minimise dust intrusions once installation completes. Such protruding electrodes were to be clamped on for measurement of ground resistance.

![Fig. 5. Steel cage [4]](image)

![Fig. 6. Dimension of grounding pit](image)

![Fig. 7. Concrete mix encased steel cage](image)

2.3 Measurement of Ground Resistance and Localized Soil Resistivity

Localized soil resistivity at several locations spread around the same site was found to be significantly different from the average soil resistivity of the relevant site [6]. This observation was also highlighted in [5]. Therefore the localized resistivity of up to the burial depth of 1 m was monitored on a daily basis at the vicinity of each pit for the first 60 days followed by weekly measurements up to five more months. Measurements were taken in a cross-direction (as shown by the blue arrows in Fig. 1) with the protruding electrode as the center for each pit and the average was considered as the final reading. The measurement of localized soil resistivity was done by employing Wenner 4 pole method as illustrated in Fig. 8. Separation distance between the consecutive probes was kept at 1 m as only localized resistivity of up to the burial depth was of interest.

Similar procedure as employed in [3-4] was replicated in order to measure the ground resistance. The measurement setup is depicted in Fig. 9. Kyoritsu Model 4105 which operates based on Fall of Potential method was used in this work. Separation distance between the probes were kept at 7 m as it was the distance which yields the value closest to the average of a series of measurement for distances of 5, 6, 7, 8, 9 and 10 m. Measurements were conducted on a daily basis for up to 60 days followed by weekly measurement for up to five months and were done simultaneously with soil resistivity measurement.
4. Results

Fig. 10 to Fig. 14 depicts the respective localized soil resistivity at each of the ten grounding pits for a period of 5 months from 27th July until 24th December. As discussed in [6], the variation of localized soil resistivity or rather the average resistivity of soil layers up to a specific depth is highly significant. Table 1 shows that the amount of fluctuation represented by the standard deviation is generally higher at sites with higher average localized soil resistivity. Fig. 15 to Fig. 19 depicts the ground resistance of each installed grounding pit for the same aforementioned period. Table 1 also shows the average and fluctuation of the corresponding ground resistance.
Table 1: Summary of localized soil resistivity and ground resistance

<table>
<thead>
<tr>
<th>Soil Resistivity (Ωm)</th>
<th>Average</th>
<th>Standard Deviation (X)</th>
<th>Ground Resistance (Ω)</th>
<th>Average</th>
<th>Standard Deviation (Y)</th>
<th>Y/X</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>82</td>
<td>21</td>
<td>A1</td>
<td>31</td>
<td>10</td>
<td>0.50</td>
</tr>
<tr>
<td>A2</td>
<td>126</td>
<td>55</td>
<td>A2</td>
<td>79</td>
<td>51</td>
<td>0.97</td>
</tr>
<tr>
<td>B1</td>
<td>695</td>
<td>228</td>
<td>B1</td>
<td>249</td>
<td>90</td>
<td>0.44</td>
</tr>
<tr>
<td>B2</td>
<td>494</td>
<td>153</td>
<td>B2</td>
<td>180</td>
<td>74</td>
<td>0.53</td>
</tr>
<tr>
<td>C1</td>
<td>1417</td>
<td>299</td>
<td>C1</td>
<td>136</td>
<td>78</td>
<td>0.35</td>
</tr>
<tr>
<td>C2</td>
<td>741</td>
<td>170</td>
<td>C2</td>
<td>177</td>
<td>54</td>
<td>0.39</td>
</tr>
<tr>
<td>D1</td>
<td>4254</td>
<td>1160</td>
<td>D1</td>
<td>1405</td>
<td>399</td>
<td>0.23</td>
</tr>
<tr>
<td>D2</td>
<td>3266</td>
<td>790</td>
<td>D2</td>
<td>1188</td>
<td>341</td>
<td>0.32</td>
</tr>
<tr>
<td>E1</td>
<td>484</td>
<td>109</td>
<td>E1</td>
<td>123</td>
<td>44</td>
<td>0.42</td>
</tr>
<tr>
<td>E2</td>
<td>369</td>
<td>78</td>
<td>E2</td>
<td>114</td>
<td>20</td>
<td>0.40</td>
</tr>
</tbody>
</table>
Fig. 20 depicts the variation in ground resistance against variation in localized soil resistivity for the best mix and pure concrete mix respectively. Upon curve fitting, it was found that there exists a linear correlation between the two parameters for both setups as given by:

\[ R = 0.30\rho \text{ (best mix)} \]  \hspace{1cm} (1)
\[ R = 0.35\rho \text{ (concrete mix)} \]  \hspace{1cm} (2)

The Pearson squared coefficient of determination are 0.88 and 0.92 respectively.

5. Discussions

Previous work has found that the localized soil resistivity significantly varies on a daily basis at each site [6]. This is reflected by the data obtained during the initial two months as given in Fig. 10 to Fig. 14 where daily measurements were taken. However as measurement period extends beyond the first two months, except for Site 1, similar trend of significantly fluctuating localized resistivity were observed. This further justifies the claim in [5] that localized soil resistivity is significant even at daily basis especially at sites with medium to high resistivity. As expected, the fluctuation is highest at site with highest soil resistivity namely D1 as shown in Table 1.

Although B1, B2, C1 and C2 were buried in the same land lot, their respective localized soil resistivities were significantly different from each other. In terms of fluctuation per average soil resistivity, B1 and B2 were found to be higher than C1 and C2 most possibly due to the proximity of a large tree. This is consistent with the conclusion in [5] that presence of large trees may contribute to significantly higher ground resistance which in turn was caused by an increase in the soil resistivity of the soil near to the tree. In fact, the localized resistivity of C1 still remains approximately double (after five months of measurement) that of C2 although they are just 5 m apart. It took approximately one month
for the soil surrounding A2 to achieve maximum soil compaction as indicated by the abrupt collapse of soil resistivity after the stipulated period. C1, C2, D1 and D2 were purposely located at rocky sites to evaluate the performance of the best mix under high soil resistivity condition.

By observing Fig. 15 to Fig. 19, one commonality can be noticed which is the ground resistance of all pits are generally declining initially before reaching a relatively stable level. The decline in resistivity in A2 as aforementioned also translated to an abrupt decline in the measured ground resistance at the same instance thus suggesting the possibility of a linear correlation between ground resistance and soil resistivity. In site 3 of D1 and D2, the change in resistivity could reach 1 kΩm on two consecutive days of measurement [6]. However the effect of this change is very much reduced in the presence of concrete and best mix as they are able to stabilize the ground resistance to a significant extent. This would not be the case if the approach of driven copper rods was used as discussed in [4].

The performance of best mix when measured in terms of fluctuation is better than that of pure concrete. This is deduced from Table 1 that the ratio of fluctuation in ground resistance with respect to fluctuation in localized soil resistivity is lower for best mix except for E1 and E2 which is comparable with each other. The ability of maintaining ground resistance with minimal fluctuation especially at sites with extreme soil resistivity is one of the main characteristic of an effective grounding improvement material (GIM) as defined in [2]. The existence of Bentonite in the concrete mix played a significant role in elevating the stability in ground resistance.

Based on equations (1) and (2), the best mix outperforms the concrete mix by about 14%. In other words, the best mix would exhibit ground resistance of 14% lower than the standard concrete mix if both were installed at the same site with the same localized soil resistivity. This suggests that the best mix is significantly more effective insites with extreme soil resistivity. When implemented at site of say 5 kΩm resistivity, the improvement in terms of ground resistance would be 250 Ω. This difference is huge especially for the case of lightning current which could easily reach kilo amperes. The product of both would be a difference in ground potential rise of the order of megavolts. Such voltage could give rise to dangerous step voltages which could put lives and integrity of electrical equipment at jeopardy.

It is worth to draw comparison between the proposed design and several others of comparable dimensions. For single vertical copper rod driven up to 1 m and considering the diameter of 12 mm, the correlation would be \( R=0.876\rho \) [7-8]. This shows that the proposed design is almost thrice more effective than single driven copper rod. The copper rod needs to be driven up to 3 m in order to have a comparable correlation with that of the proposed design. On the other hand for a copper plate of similar dimensions of 0.5 m x 0.5 m, the correlation would be \( R=0.63\rho \) [7]. Again this shows that the proposed design is twice more effective than grounding plate. Furthermore such plates are prone to corrosion which is not expected to be an issue in the proposed design as concrete offers protection against corrosion whereas bentonite is a naturally inert material [2],[9]. However further investigative works is warranted in order to completely dispel the threat of corrosion of Bentonite-concrete mix to metal bars.

One good potential application of the best mix is in the grounding of telecommunication towers. Many telecommunication (telco) towers face two main constrains from the
electrical grounding perspective namely space restriction and high soil resistivity. A typical grounding system design adopted for telco towers is as shown in Fig. 21 [10]. As can be seen, large space is required to implement the recommended design. Radial conductor stretching up to few hundred meters means that the site must be able to provide such space. Space limitation for installation of grounding system is a regular phenomenon as the towers are usually erected at cramped areas such as road sides and hilltops. The best mix had demonstrated an improvement of 14% over the standard concrete mix in terms of their correlations between ground resistance and soil resistivity. Therefore the best mix when being implemented as the foundation of the telco towers may be able to reduce the number of grounding conductors thus reducing the space requirement for grounding.

In addition, many issues to telco towers due to high soil resistivity were reported in the literature [11-12]. Many of them were built on rocks which have very large resistivity. A novel way of grounding to tackle such issues was proposed in as shown in Fig. 22. The tower site was encompassed by a layer of reinforced concrete [12]. Then the leg and foundation of the tower was connected to the reinforced concrete which was watered via a control mechanism to keep it moist. Apart from that, the fencing encircling the tower site should also be grounded with its own foundation before being connected to the main foundation. Significant improvements were reported in [12].

![Fig. 21. A typical grounding system for telco towers][10]

![Fig. 22. Proposed grounding design for telco on highly resistive soil][12]

**5. Conclusion**

An empirical formula ascribed to the proposed stand alone grounding pit of dimension 0.5 m x 0.5 m x 0.3 m for pure concrete and best mix was derived. These designs were found to be especially effective in sites with extreme soil resistivity which are typically either rocky or semi-desert characteristics in nature. The beneficial effect of introduction of Bentonite at 30% composition over standard concrete mix has been quantified to be about 14% in terms of its correlation between ground resistance and soil resistivity. A good application of the best mix would be in the grounding of telco towers built at sites with space limitation and high resistivity. However until further research on the mechanical strength of the best mix, the current best mix should best be applied as foundation of lighter structures such as fencing of the telco tower.

Future study on various dimensions of Bentonite-concrete chunks would be beneficial. Such information would allow the formulation of similar correlation as presented here for
bigger dimensions and eventually the expected performance of a building’s foundation made of the best mix. Soil resistivity of more extreme values extending up to 10 kΩm should be located and used for this additional works. Finally, the high frequency, high impulse voltage response of the best mix as employed in [13] should also be investigated to study the breakdown characteristic of such material.

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References