

Electric Conductivity Probes to Study Change in Degree of Saturation - Bench Top Laboratory Tests

Hadi Kazemiroodsari^{1,*}, Mishac K. Yegian², Akram N. Alshawabkeh², Seda Gokyer³

¹ Department of Civil engineering, Wentworth Institute of Technology, Boston, MA, USA

² Civil and Environmental Engineering Department, Northeastern University,, Boston, MA, USA

³ Geocomp corporation, Acton, MA, USA

Abstract. Sand characteristics such as liquefaction susceptibility can be affected as a result of change in degree of saturation of sand. New liquefaction mitigation technique by inducing partial saturation in sands is introduced by Yegian et al in 2007[1]. This technique requires to monitor changes in degree of saturation of sand. By nature, changes in degree of saturation of sand can lead in changes in its electric conductivity. Electric conductivity is the property of a material that represents its ability to conduct electric current. Fully saturated sand can conduct electric current better than sand with lower degree of saturation. Therefore, the change in measured electric conductivity can be used to calculate the change in degree of saturation of sand. In 1942, Gus Archie [2] expressed that the electric conductivity of soil is a function of its porosity, degree of saturation, tortuosity and electric conductivity of pore fluid. Using Archie's law electrical conductivity can be related to the degree of saturation in sands. Typically, electric conductivity probes and meters are instruments which are used to measure electric conductivity. Using electrical conductivity probes, sets of bench top tests were conducted on Ottawa sand to study the relation between degree of saturation and electric conductivity in sand. Partial saturation in sands were created by pouring dry sand into sodium percarbonate solution with a known initial concentration. By nature, sodium percarbonate in water, generates oxygen gas bubbles in time. The changes in electric conductivity in the specimen were measured using electric conductivity meters and probes. In addition, changes in degree of saturation of the specimen were measured using soil phase relations equations. Measured electric conductivity data and calculated degree of saturations were correlated to explore relation between electric conductivity and degree of saturation. This paper presents results of bench top tests, and suggests a relationship between, final degree of saturation of sand and initial concentration of sodium percarbonate solution

1 Introduction

1.1 Electric conductivity and its application:

Electric conductivity is a property of the material that represents its ability to conduct electric current. Electric conductivity of soils depends on soil properties including, porosity, degree of saturation, mineralogy, organic content, shape and size of particles and conductivity of the pore fluid [3]. Although it is very hard to define the type of a soil by just knowing its electric conductivity, electric conductivity measurement can be beneficial in understanding changes in soil properties. For instance, there are soil treatment techniques that include sending a chemical solution through a porous media where pore fluid's electric conductivity changes during the treatment and electric conductivity measurement can be a useful data to monitor the zone of treatment.

Eseller-Bayat et al in 2013 [5] proposed a new liquefaction technique by injecting sodium percarbonate solution into liquefaction susceptible soils. Sodium

percarbonate generates oxygen gas bubbles with time. Gas bubbles become trapped within sand pores and therefore decreases degree of saturation of the sand specimen. In addition, trapped gas bubbles decrease the electric conductivity of the pore fluid and soil. Therefore, changes in electric conductivity of soil can be related to the amount of trapped gas bubbles and changes in degree of saturation of soil. This paper presents the application of electric conductivity in calculating changes in degree of saturation of soil using Archie's law.

1.2 Archie's law:

Archie in 1942 expressed that electric conductivity of clean sand can be calculated using Equation 1.

$$\sigma = \frac{1}{a} \times \sigma_w \times \varphi^m \times S^n \quad (1)$$

In Equation 1, a is tortuosity of soil, which has a value typically between 0.5-1.5 [4], m is cementation exponent and is mostly in the range of 1.3 to 3 [3], n is

* Corresponding author: author@e-mail.org

saturation exponent, which has a value of 2 for clean sand, suggested by Archie, σ_w is electric conductivity of pore fluid, ϕ is porosity of soil and S is degree of saturation of soil.

Understanding Archie's law, when it is assumed that tortuosity, cementation exponent, pore fluid's electric conductivity and porosity of soil do not change during treatment, degree of saturation of a soil at any time during soil treatment can be calculated using Equation 2.

$$S_t = \sqrt{\frac{\sigma_t}{\sigma_i}} \times S_i \quad (2)$$

in which S_t is degree of saturation of soil at time t , σ_t is electric conductivity of soil at time t , σ_i is initial electric conductivity of soil and S_i is initial degree of saturation of soil.

Bench-top tests on Ottawa sand specimen is used to study the relations between changes in electric conductivity and degree of saturation of soil using Archie's law.

2 Specimen Preparation

Several soil specimens were prepared using Ottawa sand and sodium percarbonate solution to investigate the relationship between the change in electrical conductivity and degree of saturation. To prepare the specimen first an electric conductivity probe was placed inside a beaker. Sodium percarbonate solution with a desired chemical concentration was prepared by mixing sodium percarbonate powder in water. Ottawa sand was then poured in the sodium percarbonate solution. The specimen was assumed to be fully saturated at zero time when the soil was poured. Gas bubble generation resulted in change in electric conductivity as well as accumulation of water on top of the specimen as gas bubbles displaced pore water. These changes were recorded with time during the experiment. Data collection continued until no changes in measured data was observed. To measure electric conductivity Milwaukee electric conductivity probes and meters [6] were used. Figure 1 represent a typical bench top experiment.



Fig. 1. Typical bench top test on Ottawa sand

3 Theoretical Basis, Results and Discussion

2.1. Theoretical Basis:

Using the specimen preparation method described in earlier section 2, multiple sand specimen were prepared. Specimens were assumed to be fully saturated with sodium percarbonate solution. Sodium per carbonate solution between sand pores generates oxygen gas bubbles. Oxygen bubbles replace pore fluid in sand and push the water out of the sample. Degree of saturation of sand decreased as a result of the replacement of pore fluid with gas bubbles. The volume of water accumulated on top of the specimen during the test is equal to the volume of gas generated by solution. Therefore, at any time during the experiment, the difference between the volume of solution used at the beginning of specimen and the volume of solution accumulated on top of the specimen represents the volume of solution inside the pores. The total volume of solution used at the beginning of the experiment represented the total volume of voids inside the specimen. Knowing the volume of solution inside the specimen at any time and total volume of voids of the specimen, one can calculate degree of saturation of soil at any time during the test. At any time, degree of saturation can also be calculated using Equation 2 using electrical conductivity measurements. Degree of saturation determined from electrical conductivity measurements was then compared with degree of saturation calculated using phase relations equations.

2.2 Results:

Figure 2 presents the measured electric conductivity data as well as calculated degree of saturation as a function of time for four tests. Sodium percarbonate solutions with mass concentration of 0.5%, 1%, 1.2%, 1.4% and 4% were used to prepare specimens in these five tests. Degree of saturation is calculated as a function of time using Equation 2 and phase relations equations. It should be noted that in all tests' initial degree of saturation, which is shown as S_i in Equation 2 is assumed to be 100%.

It was noticed that some gas bubbles tend to escape from the specimen when the concentration of solution was more than 1.2%. The volume of the escaped gas was replaced with chemical solution and therefore sudden rise in electric conductivity readings were observed. The escape of gas bubbles occurred more often around the probe as the smooth surface area around the probe created an easy path for bubbles to escape. Therefore, a change in degree of saturation was not calculated based on electric conductivity after the bubble escape was observed in data, while generally this escape of bubbles was not significant enough to affect the overall degree of saturation of the specimen calculated based on phase relations.

3 Conclusion

It can be observed from Figure 2 that the degree of saturation calculated based on electric conductivity data and phase relations equations match reasonably. The degree of saturation calculated based on electric

conductivity is slightly larger than degree of saturation calculated based on phase relations which can be due to inaccurate measurements of small volume changes during the test and escape of gas bubbles locally around the probes.

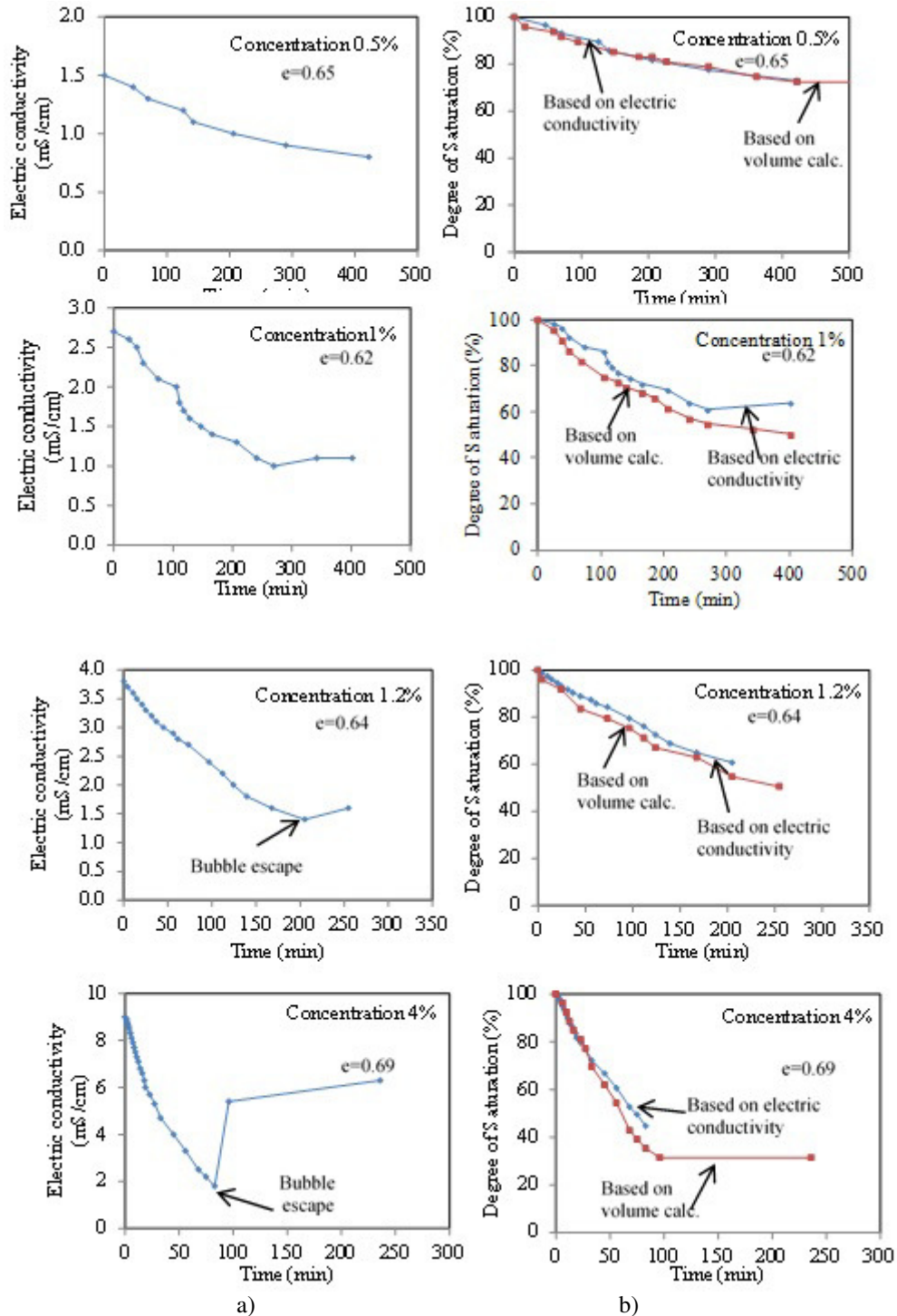


Fig. 2. a) - Measured electric conductivity data by time, b) calculated degree of saturation by time

Figure 3 shows final degree of saturation calculated for different concentration of solution both based on electrical conductivity measurements and phase relations. It can be observed from Figure 3 that when the concentration of solution is more than 1.5%, degree of

saturation does not decrease lower than 40%. This can be attributed to the fact that with very low degree of saturation, the volume of gas bubbles is more than the pore fluid causing escape of gas bubbles and hence suggesting a lower bound of saturation using electrical

conductivity probes. Electric conductivity probes can detect the escape of gas bubbles from the specimen. Changes in degree of saturation due to escape of gas bubbles can be calculated using same method introduced in this paper. Since the escape of the bubbles can be detected by the electrical conductivity probes, it is suggested that instrumenting the site with multiple electric conductivity probes would be useful to detect the escape of bubbles during in situ treatment.

It should be noted that this paper does not recommend using Figure 3 to estimate in situ degree of saturation of treated soil. However, it can be concluded that the changes in degree of saturation of sand can be calculated using electric conductivity measurements. This method can be used to monitor the effectiveness of the treatment and estimate final degree of saturation of the treated site.

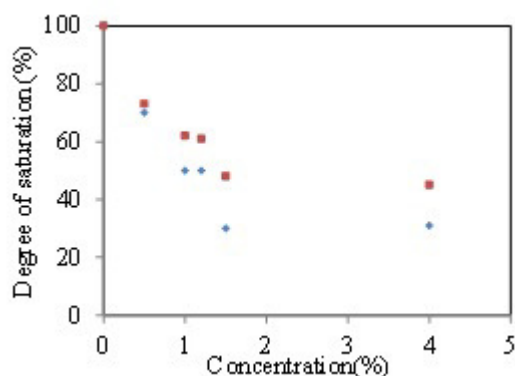


Fig. 3. Final degree of saturation based on electric conductivity and volume calculation for solution concentrations of 0.5%, 1%, 1.2%, 1.5% and 4%

Acknowledgements

We would like to thank National Science Foundation (NSF) for supporting this research as a part of a larger research project titled “Induced Partial Saturation (IPS) through Transport and Reactivity for Liquefaction Mitigation”. In addition, we would like to thank our colleague Dr. Fritz Nababan for his support and help in this project.

References

1. Yegian, M. K., E. Eseller-Bayat, As Alshawabkeh, and S. Ali. Induced-partial saturation for liquefaction mitigation: experimental investigation. *Journal of Geotechnical and Geoenvironmental Engineering* 133, no. 4 (2007): 372-380.
2. Archie, Gustave Erdman. Electrical resistivity an aid in core-analysis interpretation. *AAPG Bulletin* 31, no. 2 (1947): 350-366.
3. James K. Mitchell, Kenichi Soga *Fundamentals of Soil Behavior*, John Wiley & Sons Inc., Hoboken, NJ (2005), 577 pp., US \$130.00, ISBN 0-471-46302-7." (2005): 275-276.
4. Winsauer, Weldon Otto, H. M. Shearin Jr, P. H. Masson, and M. Williams. *Resistivity of brine-*

5. Eseller-Bayat, E., Yegian, M. K., Alshawabkeh, A., and Gokyer, S. (2013). Liquefaction response of partially saturated sands. I: Experimental results. *J. Geotech. Geoenviron. Eng.*, **139**(6), 863-871.
6. MW302 electric conductivity meter manufactured by Milwaukee Instruments available: (<http://www.milwaukeeinstruments.com/site/products/products/standardportable->)