© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Characterization of Eggshell and Natural Chloride Stabilized Soil Using Geophysical Techniques

Amit Kumar[1*], Dharmender Kumar Soni[1]

[1]Civil Engineering Department,
National Institute of Technology, Kurukshetra, 136119, INDIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2021.13.04.021
Received 17 May 2020; Accepted 27 February 2021; Available online 30 April 2021

Abstract: Although many techniques are available for the evaluation of soil parameters, but a quick and efficient method is always welcome. To avoid the hassle calculation and tedious procedures of testing; practitioners seek a fast method for site implementation of laboratory results. In the recent era of development and technology, it has been necessary to adopt the advanced techniques to evaluate the geotechnical parameters. In the present study, correlations between geophysical and compaction tests results have been derived. Eggshell powder (ESP), a waste material along with sodium chloride (NaCl) and polypropylene fiber (PPF) was used to stabilize the soil. Design of experiments was done by Taguchi technique using Minitab 17 software. A series of non-destructive geophysical tests i.e., Ultrasonic pulse velocity (UPV) and Electrical resistivity (R_e) tests was carried out on 21 days aged soil specimens. Not only software based analytical results showed ESP as the dominating factor for attaining improvement in packing of soil particles and make soil resistive but also the results confirmed the same. UPV of the stabilized soil was found increased up to 69%-122% with respect to an increase in dry density of about 1.16%-1.74%. The utility of the present study can be found in places where dense soil and electric resistive properties meets such as transmission lines and railway electric poles etc. and for the purpose seismic and resistivity mapping methods can be used

Keywords: Eggshell, sodium chloride, fiber, geophysical, Taguchi, optimization

1. Introduction

Strength parameters are essential check before constructing geotechnical structures involving roads, bridges buildings etc. on soil. Physical mapping of soil with the help of geophysical methods like R_e and UPV tests can be done for time and effort saving practices. The velocity of ultrasonic waves (UW) was found directly proportional to compactive efforts during compaction tests and inversely proportional to the plasticity and clay content present in the subjected soils. Propagation of UW depends on the condition of soil present and remains increased until optimum moisture content (OMC) reached. Electrical resistivity was found lower corresponding to high water content or dense packing of soil particles. Highly plastic or clayey soil symbolized lower electrical resistivity [1]. Bryson and Bathe [2] used some advanced data acquisition and control systems equipped instruments to evaluate the soil properties of sand-clay mixtures and found very promising results. The relationship between void ratio and conductivity encompassed some scattering and the conductivity was found as a function of ionic behave of pore fluid, while the decreasing pattern of electrical resistivity reported by Long et al. [3] was based on the function of salinity present in different samples of marine clay. In 2014, Abidin et al. [4] examined the basic geotechnical properties with respect to the electrical resistivity value (ERV, ρ) and found that ERV was directly proportional to coarser soil, bulk dry density and inversely proportional to water content, fine soil and atterberg limits.

Jing et al. [5] made some experiments on unsaturated sand, loess and clay and found that electrical resistivity of sand was much greater than other two soils due to the dissimilarity in their mineralogy, particle arrangement and sort of

*Corresponding author: amit_6160040@nitkkr.ac.in

impurities inherent within soils. Osman et al. [6] advocated that electrical resistivity is highly affected by ion exchange between clay minerals and high temperature of soil increase the mobility of ions of soil and consequently decrease the electrical resistance. Kumar et al. [7] reported that lime and phosphogypsum increased the compaction and strength properties which decreased the swell index appreciably and the results can be used for poor subgrade reclamation. Silt may absorb more water, so produce less electrical resistivity, while sand being a non-plastic type soil, has high electrical resistivity. So, inherent water molecules of soil play an important role in electrical conductivity and resistivity [8]. Some minerals like Mg, sulphates, Ca, Na etc. put effects on the electric resistance. So, the quantity and quality of the abovesaid minerals may also be check, if the electrical resistivity is a prime concern at mineral rich site. The sulphate ions react with available alumina and helps to create a dense hydrate structure to promote the strength in soil [9], [10].

Intrusion of natural fibres like coir fibres also proved their efficacy in improves the strength properties. The stress-strain behaviour was found better than reference mix for 28 days cured specimens [11]. Controlled moisture content i.e., 30% based model was developed by Qazi et al. [12] and the model was inter-relate with soil's physical, chemical and strength parameters. The model also gesticulated that moisture content have influence on electrical resistance of soil. Eggshell powder improved the hardness, toughness, and impact energy, tensile and compressive strength in both uncarbonized and carbonized form of the aluminium matrix [13]. Other investigators like Jusoh and Osman [14] also affirmed this statement and confirmed with some statistical approaches, which comprises regression equation and high value of co-efficient of determination. Mostafa et al. [15] reported that if calcium contained soils experienced some electric charge; then the magnitude of resistivity can be control by maintaining the fineness and water content value. Experimental study conducted by Liu et al. [16] on an expansive soil made a hypothesis that expansibility of the soil can be judge by the resistance potential of the soil.

Other notable findings by Vincent et al. [17] used cement as a stabiliser in the soil and found an identical trend for UCS and R_e at same level of cement content. Pozzolanic reaction of cement lowers the void ratio and resists the electric charge in the matrix. Grounded blast furnace slag also improved the soil properties and verified using UPV technique. The results satisfied the specifications for road pavement [18]. The velocity of UW was found to be increase until OMC achieved [19]. Razali et al. [20] claimed that a Peat stabilised by Vinyl Acetate-Acrylic copolymer (VAAC) in an amalgam of sand, lime and cement may produce satisfactory results. An alkali activated flyash stabilised soil also demonstrated high UCS value after 28 days curing [21].

Altlomate et al. [22] tried to develop and compare a general equation with respect to UPV value of concrete specimens. In their finding, authors claimed to have some general equations applicable for rough estimation of compressive strength. Recently, nano-materials have also been found cheap and compatible materials for the production of different types of concrete. These materials can improve the sustainability of the product material and withstand against harsh environmental conditions [23]. Ibrahim et al. [24] investigated the various properties of mortar mix made up of cement, sand and coal bottom ash at different proportions. Overall study found the coal bottom ash as an effective alternate material for cement. From the literature study, it can be concluded that geophysical tests could be helpful to judge the behavior of material at site irrespective of tedious lab procedures. The motivation of the present study is to correlate soil properties to the non-destructive geophysical tests and to find out their feasibility in the field. The possible reason for the changes in the UPV and resistance has been given on the basis of laboratory results and previous studies. Use of cheap and easily available materials in this study made it economical. A possible eggshell menace solution also encourages the study.

2. Materials and Methods

2.1 Materials

Soil was procured from an excavated borrow pit at Srinagar, Jammu and Kashmir (India). As the Himalayan soil contains stone pebbles, vegetation roots etc. so, the soil was processed to clean from impurities before using for laboratory purpose. The subjected soil was found low plasticity silt (ML) as per plasticity chart proposed by Indian Standard Classification (ISC) system and other index properties of soil were (specific gravity 2.6; liquid limit 34%; plastic limit 29%; OMC 19.3% and MDD 1.72 g/cm^3). Being a waste, eggshell was used in powdered form in this study and its typical chemical compositions properties are CaO 99.83%; Cl 0.009%; Al_2O_3 0.001% and SiO_2 0.001% [25]. To maintain the uniformity of ESP during whole testing, ESP was sieved through 425µ and used. NaCl (white crystal form) was procured from a local chemical seller. PPF of length 12 mm and triangular in shape was used to strengthen the soil in randomly distributed manner. ESP, NaCl and PPF have been shown in Fig. 1(a), (b) and (c), respectively.

(a) (b) (c)

Fig. 1 - (a) Eggshell powder, (b) Industrial NaCl, and (c) Polypropylene fiber

2.2 Design of Experiments

Additives and their dosage percentages have been given in Table 1. Experiments were designed by Taguchi technique using MINITAB 17 software. Design of experiments in the form of orthogonal array (OA) has been given in Table 2, in which each row signifies experimental conditions with alternative additive dosage [26], [27]. Comprehensive details on Taguchi technique can be found in notable books of pioneer authors [28]-[30].

Table 1 - Additives and their degree

	Additives		
Degree	**ESP (%)**	**PPF (%)**	**NaCl (%)**
1	3	0.05	2
2	6	0.10	4
3	9	0.15	6

Table 2 - Experimental mix design (Orthogonal Array)

Mix Designation	Additives		
	ESP (%)	**PPF (%)**	**NaCl (%)**
R1	3	0.05	2
R2	3	0.10	4
R3	3	0.15	6
R4	6	0.05	4
R5	6	0.10	6
R6	6	0.15	2
R7	9	0.05	6
R8	9	0.10	2
R9	9	0.15	4

2.3 Test Procedure

Doing first things first, the index properties of the subjected soil i.e., ISC, plasticity characteristics and specific gravity were determined in laboratory. Afterwards compaction characteristics were also determined to corelate with the geophysical tests results. Whole testing was done accordance to Indian standards of soil testing. UPV and ER tests on UCS sized samples (38 mm x 76 mm) were performed accordance to IS 13311 (Part I): 1992 and two electrodes method, respectively. UPV tests were conducted using Through Transmission or Direct Transmission technique. To determine electrical resistivity, two copper plates of 1mm thickness each were used as electrodes and soil sample was sandwiched between them. Wet squeegees were also put on both sides of the sample to assure good electrical path around the soil samples and to allow the free migration of water [31]. To maintain the repeatability of results, each test was performed in duplicity too. Responses obtained by performing the experiments were analyzed by Taguchi technique using MINITAB 17 software. Signal to Noise (S/N) ratio, Analysis of variance (ANOVA) and response graph are the main parts of Taguchi technique. Where S/N ratio means the ratio of preferred to invaluable response. This ratio has three categories: (a) larger the better, (b) smaller the better, and (c) nominal the better. ANOVA enables one to see the other statistical terms like means of square, sum of square, percentage contribution of a particular factor etc. Response graphs empower to read the level of additive at which optimized condition possibly occurs. Although velocity of ultrasonic pulse and electric resistance should be high for the treated soil, so in this study S/N ratios were calculated as larger the better for both cases.

3. Results and Discussion

In the present study consequences of ESP, PPF and NaCl on subjected soil's compaction and geophysical properties were observed through UW and electric charge. A correlation was also derived between both parameters. Typical UPV and R_e testing setup are shown in Fig. 2 and Fig. 3, respectively. The findings were reported in the form of velocity at which UW passes and resistance calculated for the samples.

Fig. 2- Typical UPV test setup

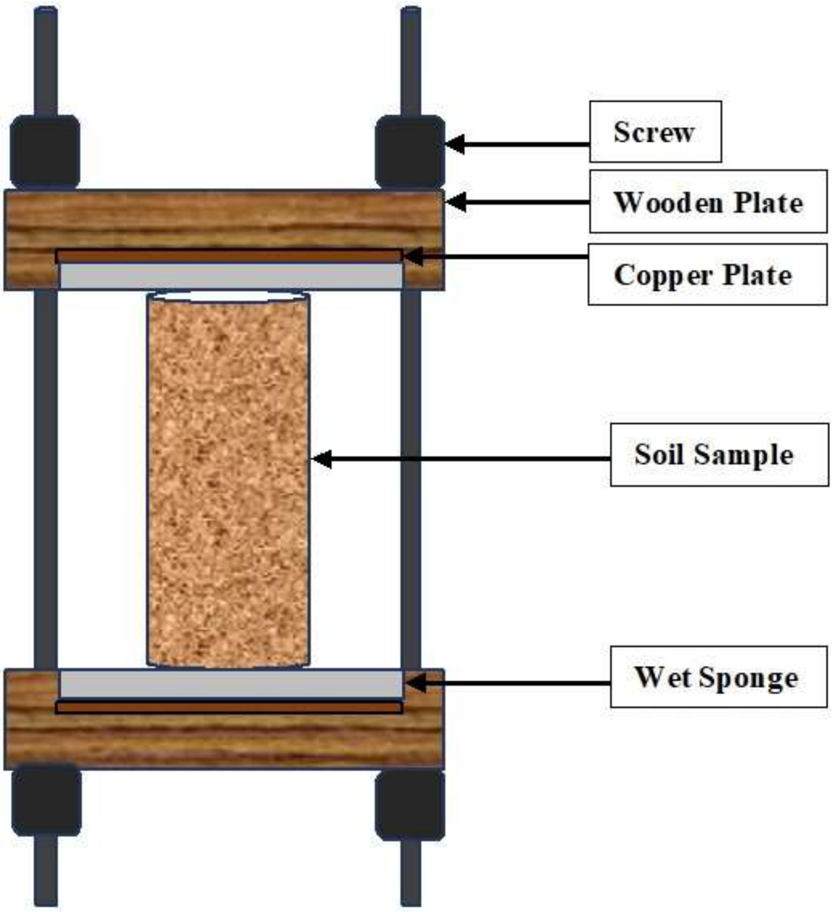

Fig. 3 - Typical R_e test setup

Fig. 4 and Fig. 5 show the laboratory results for compaction and geophysical properties corresponding all mix designs as well as for parent soil sample (R0). Analysis of Fig. 4 showed that high UPV corresponds to higher MDD. The probable reason behind this is to have linear function relation between density and velocity. ESP (density 2.47 g/cm^3 approx.) is capable to modify the density of soil from low to high. It is well known fact that dense materials can surpass the velocity easy and fast than the loose one. The findings were corresponding to previous studies of notable researchers [32], [33].

From the observation of Fig. 5, it can be seen that moisture and additives affect the electrical resistance and conductance significantly. It is time tested that sodium and chloride ions play a vital role in relation with electrical resistance and conductance. Sodium and chloride represent the positive and negative ion charge, respectively. So, being an ionic charged substance, sodium chloride has an ability to carry electric charge too. That's why in the context of the present study, all the designed mixes showed lower electrical resistance than parent soil sample (R0). Moreover, silt has propensity to absorb moisture and that was triggered due to the presence of NaCl. Consequently, lowered the resistance [8]. Thus, it can also be concluded that NaCl may charge the conductance in the soil, if exist naturally or otherwise.

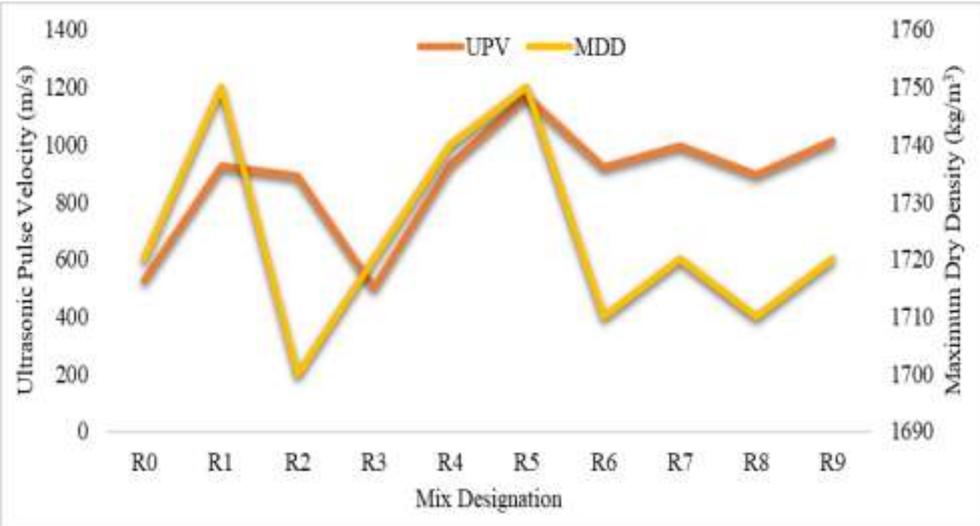

Fig. 4 - Comparative graph between UPV and MDD

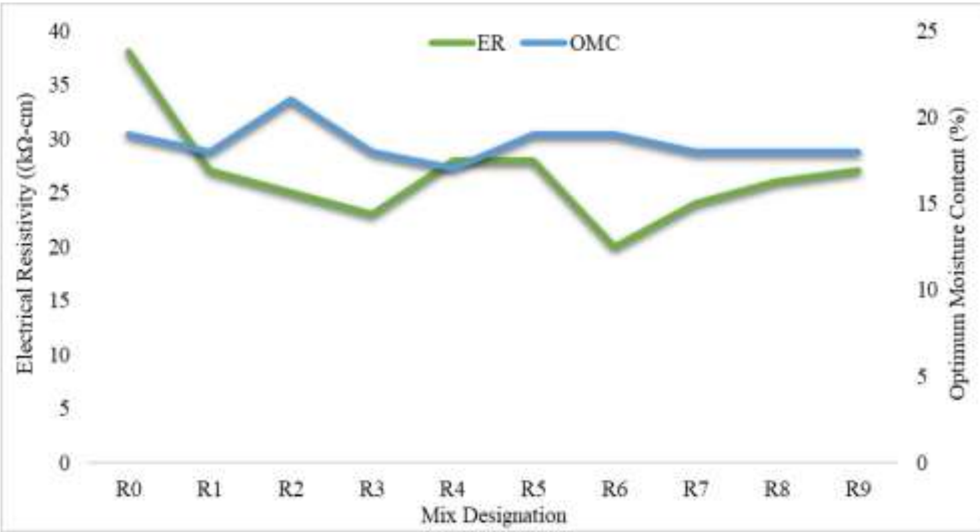

Fig. 5 - Comparative graph between R_e and OMC

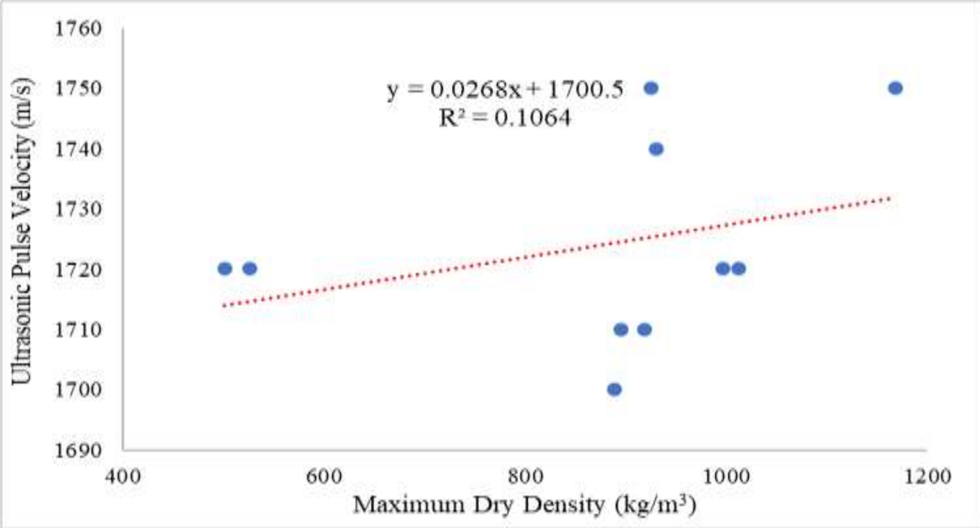

Fig. 6 - Correlation graph between UPV and MDD

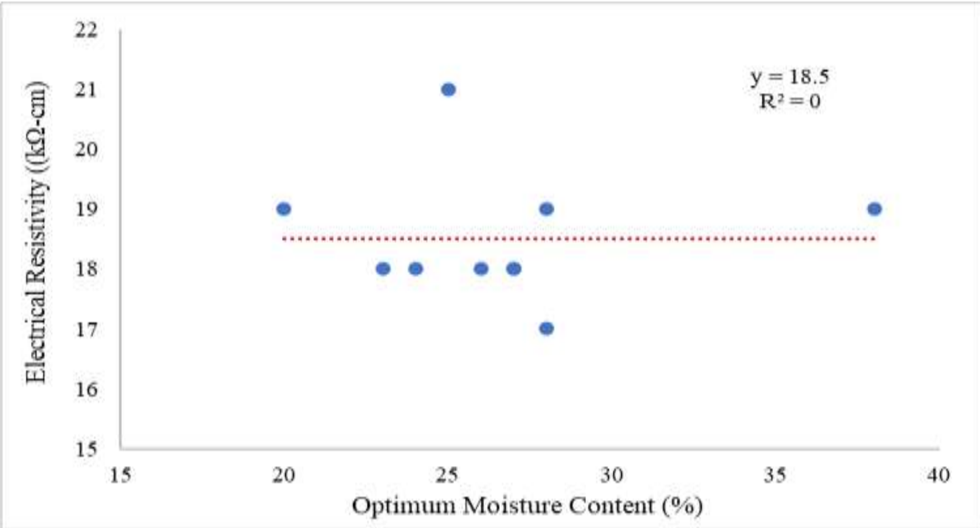

Fig. 7 - Correlation graph between R_e and OMC

Correlation graphs for UPV vs. MDD and R_e vs. OMC have been given in Fig. 6 and Fig. 7. Graphs proved that there is no correlation between compaction and geophysical properties. The reason for this may be said the asymmetry of the design of experiments.

S/N ratios (larger the better) for the responses obtained from UPV and R_e tests have been given in Table 3. In S/N ratio delta means the difference between higher and lower S/N ratio and ranking shows the hierarchy of dominating factor for obtaining high UPV and R_e. Analyses of variance of UPV and R_e tests results have been given in Table 4.

Table 3 - S/N ratio for UPV and R_e

Level	S/N ratio for UPV (m/s)			S/N ratio for R_e (kΩ-cm)		
	ESP	PPF	NaCl	ESP	PPF	NaCl
1	57.43	59.56	59.21	27.82	27.00	27.27
2	60.00	58.13	57.83	25.37	26.67	26.21
3	59.70	59.45	60.10	27.45	26.97	27.15
Delta	2.57	1.43	2.28	2.45	0.34	1.05
Rank	1	3	2	1	3	2

Table 4 - Analyses of variance for UPV and R_e

Additives	DOF	ANOVA for UPV (m/s)				ANOVA for R_e (kΩ-cm)			
		Seq. SS	Adj. MS	Adj. SS	Contribution (%)	Seq. SS	Adj. MS	Adj. SS	Contribution (%)
ESP	2	95085	47542	95085	37.51	65.554	32.777	65.554	65.88
PPF	2	16562	8281	16562	6.53	1.936	0.968	1.936	1.95
NaCl	2	62245	31112	62245	24.55	14.497	7.249	14.497	14.57

From the study of ANOVA table, it can be concluded that ESP had more contribution to attain a high UPV and electric resistance value for the subjected soil. The role of ESP in improving the resistance can be understood by the phenomenon of pozzolanic reaction, by which the soil-additive matrix got adhered by CSH (calcium silicate hydrate) gel formation. The gel bonded the soil particles and formed soil cluster those consequently resist the electric charge. The findings of the present study best suited with the results of Vincent et al. [17].

4. Conclusions

Present study interpreted the relation between soil engineering properties and non-destructive tests results. Primary conclusions of the above study are:

- Dense packing of soil particles is the prime reason for attaining high density and high UPV value.
- Pozzolanic reactions are responsible for the hydrous gel formation and make soil-additive matrix more tortuous to resist the electric charge.
- Sodium (Na^+) and chloride (Cl^-) ions were found root cause for the promotion of conductivity.
- Moisture content was also another factor to lose the resistance against electric charge.

Although, the present study showed results resembles to previous studies based on UPV and R_e tests. But it is also optional that, further studies may be done on other soils using different additives for more clarity in results.

Acknowledgement

This research is financially supported by Council of Scientific and Industrial Research (CSIR), New Delhi (Acknowledgement No. 141099/2K17/1).

References

[1] Zeyad, S. A. H., Craig, H. B., & Blotz, L. R. (1996). Electrical resistivity of compacted clays. Journal of Geotechnical Engineering, 122(5), 397-406

[2] Bryson, L., & Sebastian Bathe A. (2009). Determination of selected geotechnical properties of soil using electrical conductivity testing. Geotechnical Testing Journal, 32(3), 1-10. https://doi.org/10.1520/GTJ101632

[3] Long, M., Donohue, S., L'Heureux, J. S., Solberg, I. L., Rønning, J. S., Limacher, R., O'Connor, P., Sauvin, G., Rømoen, M., & Lecomte, I. (2012). Relationship between electrical resistivity and basic geotechnical parameters for marine clays. Canadian Geotechnical Journal, 49, 1158-1168. https://doi.org/10.1139/T2012-080

[4] Abidin, M. H. Z., Saad, R., Ahmad, F., Wijeyesekera, D. C., & Baharuddin, M. F. T. (2014). General relationship between field electrical resistivity value (ERV) and basic geotechnical properties (BGP). International Journal of Integrated Engineering, 6(1), 23-29

[5] Hong Jing, J., Shunqun, L., & Lin, L. (2014). The relationship between the electrical resistivity and saturation of unsaturated soil. Electronics Journal of Geotechnical Engineering, 19, Bundle O, 3739-3746

[6] Osman, S. B. S., Fikri, M. N., & Siddique, F. I. (2014). Correlation of electrical resistivity with some soil parameters for the development of possible prediction of slope stability and bearing capacity of soil using electrical parameters. Pertanika Journal of Science & Technology, 22(1), 139-152

[7] Kumar, S., Dutta, R. K., & Mohanty, B. (2014). Engineering properties of bentonite stabilized with lime and phosphogypsum. Slovak Journal of Civil Engineering, 22(4), 35-44. https://doi.org/10.2478/sjce-2014-0021

[8] Hazreek, Z. A. M., Aziman, M., Azhar, A. T. S., Chitral, W. D., Fauziah, & A., Rosli, S. (2015). The behaviour of laboratory soil electrical resistivity value under basic soil properties influences. IOP Conf. Series: Earth and Environmental Science, 23, 1-9. https://doi.org/10.1088/1755-1315/23/1/012002

[9] Samui, P., & Kim, D. (2016). Determination of electrical resistivity of soil based on thermal resistivity using RVM and MPMR. Periodica Polytechnica Civil Engineering, 60(4), 511-515. https://doi.org/10.3311/PPci.8206

[10] Dutta, R. K., & Kumar, V. (2016). Suitability of flyash-lime-phosphogypsum composite in road pavements. Periodica Polytechnica Civil Engineering 60(3), 455-469. https://doi.org/10.3311/PPci.7800

[11] Tilak, B. V., Dutta, R. K., & Mohanty, B. (2015). Effect of coir fibres on the compaction and unconfined compressive strength of bentonite-lime-gypsum mixture. Slovak Journal of Civil Engineering, 23(2), 1-8. https://doi.org/10.1515/sjce-2015-0006

[12] Qazi, W. H., Osman, S. B. A. B. S., & Memon, M. B. (2016). Prediction of soil engineering properties using electrical resistivity values at controlled moisture content - a conceptual paper. ARPN Journal of Engineering and Applied Sciences, 11(6), 3684-3689

[13] Anjali, Malik, R., Bhandari, S., Pant A., Saxena, A., Seema, Kumar, N., Chotrani, N., Gunwant, D., & Sah, P. L. (2017). Fabrication and mechanical testing of eggshell particles reinforced Al-Si composites. International Journal of Mathematical, Engineering and Management Sciences, 2(1), 53-62. https://dx.doi.org/10.33889/IJMEMS.2017.2.1-005

[14] Hisyam Jusoh, H., & Osman, S. B. S. (2017). The correlation between resistivity and soil properties as an alternative to soil investigation. Indian Journal of Science and Technology, 10(6), 1-5. https://doi.org/10.17485/ijst/2017/v10i6/111205

[15] Mostafa, M., Anwar, M. B., & Radwan, A. (2017). Application of electrical resistivity measurement as quality control test for calcareous soil. HBRC Journal, 1-6. https://dx.doi.org/10.1016/j.hbrcj.2017.07.001

[16] Liu, S., Chu, Y., Wang, F., Du, Y., & Zha, F. (2017). The expansibility prediction of expansive soil with electrical resistivity method. Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul, 1055-1058

[17] Vincent, N. A., Shivashankar, R., Lokesh, K. N., & Jacob, J. M. (2017). Laboratory electrical resistivity studies on cement stabilized soil. International Scholarly Research Notices, Hindawi, 1-15. https://doi.org/10.1155/2017/8970153

[18] Vinay, A., & Pradeepkumar, A. V. (2017). Ultrasonic pulse velocity assessment of GGBS stabilized soils. International Conference on “Recent Trends in Environmental Science and Engineering” (RTESE’17), APSCE, Bangalore, India, 140-145

[19] Bhange, N. A., & Pritiradheshyamnandagawali (2018). Engineering characterization of clayey soil by ultrasonic pulse velocity tests. The International Journal of Engineering and Science (IJES), 21-26

[20] Razali, S. N. M., Zainorabidin, A., Bakar, I., & Mohamad H. M. (2018). Strength changes in peat-polymer stabilization process. International Journal of Integrated Engineering: Special Issue 2018: Innovations in Civil Engineering, 10(9), 37-42. https://doi.org/10.30880/ijie.2018.10.09.007

[21] Elkhebu, A., Zainorabidin, A., Bakar, I. Hj., B. K. H., B., Abdeljouad, L., & Dheyab, W. K. (2018). Alkaline activation of clayey soil using potassium hydroxide & fly ash. International Journal of Integrated Engineering: Special Issue 2018: Innovations in Civil Engineering, 10(9), 84-89. https://doi.org/10.30880/ijie.2018.10.09.016

[22] Altlomate, A., Shahidan, S., Alatshan, F., Elkher, M., Hannan, N. I. R. R., Zuki, S. S. M., Khalid, F. S., & Ibrahim, M. H. W. (2018). Evaluate the expressions of compression strength and UPV relationship. International Journal of Integrated Engineering, 10(8), 33-37. https://doi.org/10.30880/ijie.2018.10.08.008

[23] Kewalramani, M. A., & Syed, Z. I. (2018). Application of nanomaterials to enhance microstructure and mechanical properties of concrete. International Journal of Integrated Engineering, Special Issue 2018: Civil & Environmental Engineering, 10(2), 98-104. https://doi.org/10.30880/ijie.2018.10.02.019

[24] Ibrahim, A. H., Keong, C. K., Johari, M. A. M., Rashid, M. R. M., & Ariffin, K. S. (2019). Influence of coal bottom ash on properties of Portland cement mortar. International Journal of Integrated Engineering, 11(2), 069-077. https://doi.org/10.30880/ijie.2019.11.01.008

[25] Adogla, F., Yalley, P. P. F., & Arkoh, M. (2016). Improving compressed laterite bricks using powdered eggshells. The International Journal of Engineering and Science, 5(4), 65-70

[26] Kumar, A., & Soni, D. K. (2018). Significance of pH in fine grained soil. ICSWMD 2018, Lecture Notes in Civil Engineering, 21, 264-272. https://doi.org/10.1007/978-3-030-02707-0_32

[27] Singh, H., Garg, P., & Kaur, I. (2019). Proceedings of the 1st International conference on sustainable waste management through design 2018, Lecture Notes in Civil Engineering, © Springer Nature Switzerland AG 2019. https://doi.org/10.1007/978-3-030-02707-0

[28] Logothetis, N. (1992). Managing for total quality from Deming to Taguchi and SPC. New York: Prentice Hall International Ltd

[29] Roy, R.K. (2001). Design of experiments using the taguchi approach. New York: Wiley Interscience

[30] Rahman, Z., & Talib, F. (2008). A study of optimization of process by using Taguchi’s parameter design approach. The Icfai University Journal of Operations Management, 7(3), 6-17

[31] Yao, X., Fang, L., Qi, J., & Yu, F. (2017). Study on mechanism of freeze-thaw cycles induced changes in soil strength using electrical resistivity and X-Ray computed tomography. Journal of Offshore Mechanics and Arctic Engineering, 139, 1-9. https://doi.org/10.1115/1.4035244

[32] Sheeran, D. E., Baker, W. H., & Krizek, R. J. (1967). Experimental study of pulse velocities in compacted soils. Highway Record No. 177, Highway Research Board, 226-238

[33] Yesiller, N., Inci, G., & Miller, C. J. (2000). Ultrasonic testing for compacted clayey soils. Advances in Unsaturated Geotechnics, 54-68. https://doi.org/10.1061/40510(287)5