Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Laboratory Assessment of Clogging Potential using Soil Drilling Test

Arya S. Babu[1] and Sayida M. K.[2]

[1] College of Engineering Trivandrum, 695016, Kerala, aryasbabu95@gmail.com
[2] College of Engineering Trivandrum, 695016, Kerala, sayidamk@rediffmail.com

Abstract. The equipment used for soil excavation is subjected to the phenomenon of clogging. Clogging is the process of adhering of soil to the surface of the equipment. This can lead to certain economic as well as technical issues to soil drilling activities. In this paper a semi empirical and physical stimulation approach is adopted to determine the clogging potential of Thonnakkal soil. The analysis were done with the help of Atterberg limit test and a drilling equipment developed in the laboratory. In order to analyze the influence of swelling clay on clogging potential, soil mixtures were prepared by combining bentonite and Thonnakkal soil at different percentages and tests were performed. The drilling equipment was used to study the effect of penetration rate on the clogging potential. The changes in clogging potential at different water contents were also assessed.

Keywords: Clogging potential, Bentonite, Drilling equipment, Atterberg limits.

1 Introduction

The increasing demands of the growing population for buildings, transportation and other utilizes has triggered the need for tunnelling as well as other soil excavation activities. Clogging is one of the major troubles encountered by the various machines involved in the soil boring works [1]. It leads to economic losses, extension of span of the work and even standstills in the project [4]. Clogging is a phenomenon where the parts of the equipment gets plugged by the soil. The equipment irrespective of their size i.e., a small hammer used for compaction to a massive tunnel boring machines are subjected to clogging. Clogging potential is the property of a soil by virtue of which the soil adheres to a foreign surface and thereby clog an equipment.

The process of clogging involves a combination of the mechanisms of cohesion and adhesion of the soil. The clogging potential of a soil can be evaluated by analytical approach, semi- empirical approach or physical stimulation approach. In analytical approach the adhesive and cohesive forces are determined to indirectly predict the clogging potential. The conventional as well as modified vane shear, direct shear apparatus [1] [12] [16], and other tests using pistons [2] [15], cones etc. were performed to assess the adhesive and cohesive forces in soil. The semi-empirical approach make use of water content and Atterberg limits data of a soil to predict the clogging behavior of the soil. A clogging potential diagram was developed by Thewes (1999) and this diagram was further updated by Hollman and Thewes (2013). The diagram helps in clogging classification based on the liquid limit, plastic limit and water content of a soil [4] [14].

For physical simulation approach, the actual drilling process in the field is stimulated in the laboratory. Sass and Burbaum (2008) developed an apparatus in the laboratory to replicate the conditions of the cutting wheel of a tunnel boring machine [13]. Feinendegen et al. (2010) devised an equipment and performed a cone pull out test to evaluate the clogging potential [3]. Zumsteg and Puzrin (2012) used a Hobart mortar mixture and a novel shear plate device to determine the stickiness potential of clay pastes [17]. Kang et al. (2018) devised an equipment which facilitates soil drilling process and studied the effect of rotational velocity, penetration rate and size of drill bit on clogging potential [10]. In the field certain soil conditioners are applied to modify the soil properties and thereby reduce the clogging risks. The commonly used conditioners are water, foam, polymers, soap solution and salt solutions [1] [10] [11].

In this paper the clogging potential of Thonnakkal soil is assessed by means of a laboratory soil drilling test. The research focuses on the analysis of influence of bentonite clay, water content and penetration rate of the drill bit on the clogging potential of Thonnakkal soil.

2 Experimental Studies

2.1 Material

The soil used for the study was collected from Thonnakkal region of Thiruvananthapuram district, Kerala. The natural water content was determined by conducting the test according to IS 2720 (Part 2) 1973 [5]. The grain size analysis was performed as per IS 2720 (Part 4) 1985 [7]. The soil belongs to clayey sand with silt category. The specific gravity of the soil was tested as per IS 2720 (Part 3) 1980 [6]. The results of various soil tests conducted on Thonnakkal soil are listed out in Table 1. The bentonite clay used for the study was collected from a dealer based on Kutch region, Gujarat. The properties of the sodium bentonite used is presented in Table 2.

Table 1. Properties of Thonnakkal soil

Property	Value
Natural water content (%)	20.4
Clay (%)	48
Silt (%)	14
Sand (%)	38
Liquid limit (%)	46
Plastic limit (%)	27
Plasticity index (%)	19
Specific gravity	2.5
MDD (g/cc)	1.8
OMC (%)	17

Table 2. Properties of Bentonite

Property	Value
Liquid limit (%)	310
Plastic limit (%)	40
Plasticity index (%)	270
Specific gravity	2.86
MDD (g/cc)	1.22
OMC (%)	32.6

2.2 Testing apparatus

Two different tests were performed which are Atterberg limit tests and laboratory drilling test. The liquid limit was tested within a cone penetrometer test apparatus. In order to conduct the laboratory drilling test, a small scale soil drilling equipment was fabricated. The photograph of the device is shown in Fig.1.

Fig. 1. Laboratory drilling test set up

The different parts of the equipment are electric power supply unit, drill bit, a rotational velocity controller and a motor. A high carbon steel drill bit with 50 mm diameter and 28mm height was used. The drill bit is hollow cylindrical with its one end open. The open end of the drill bit has teethed edges. The whole set up is mounted on the loading frame of a tensile testing strength equipment. The penetration rate can be adjusted by changing the gears in the tensile strength testing equipment. The equipment facilitates the change in penetration rate, shape and size of drill bit as well as rotational velocity during the test.

2.3 Methodology

The dry Thonnakkal soil and bentonite was mixed at various proportion by weight to get soil mixtures M0, M20 and M40. The proportion of the two soils in these mixtures is presented in Table 3. The desired amount of water was added to these dry mixtures to prepare the samples. The Atterberg limit test was carried out as per IS 2720 (Part-5) 1985 [8].

Table 3. Proportions of the soil mixture

Mixture	Thonnakkal soil (%)	Bentonite (%)
M0	100	0
M20	80	20
M40	60	40

The laboratory drilling test was carried out using a cylindrical mould of 10cm diameter and 11.5 cm height. The soil sample was filled in the mould as per IS 2720 (Part-7) 1980 [9]. The tests were conducted at three different water content which lies between plastic limit and liquid limit for all the soil mixtures. The penetration rates used in the test are 20, 40 and 80 mm/min and the rotational velocity was 30 rpm. The mould containing the soil was placed on the apparatus below the drill bit and the drill bit was allowed to penetrate into the soil. The penetration as well as rotation happens during the working of the machine. The drill bit was pulled out of the soil once a particular depth of penetration was achieved. The drill bit was disconnected from the device and the soil adhering to the inside of the bit was scrapped out and weighed. The clogging potential is expressed in terms of a parameter WSDB (weight of soil sticking to drill bit). WSDB is the ratio of the weight of soil sticking to the drill bit to the cross sectional area of the drill bit.

3 Test Results and Discussion

3.1 Atterberg limit tests

The effect of bentonite content on the LL, PL and PI of Thonnakkal soil was studied. The LL, PL and PI of the three soil mixtures are shown in Table 4. A rapid spike in LL happens when bentonite is introduced into Thonnakkal soil. The swelling nature of the bentonite leads to increased water absorption, which in turn favors LL increment. Researches in the past suggested that the soil with higher LL and PI has more chance of clogging. Hence it can be concluded that bentonite has the tendency to increase the clogging potential of Thonnakkal soil.

Table 4. LL, PL and PI values of soil mixtures

Mixture	LL (%)	PL (%)	PI (%)
M0	46	27	19
M20	105	31	74
M40	154	34	120

3.2 Results of laboratory drilling test

The influence of parameters like water content, penetration rate of drill bit and bentonite content on the clogging potential was analyzed.

Effect of water content on WSDB

The tests were carried out at three different water contents between PL and LL for all the three mixtures. The analysis was carried out using the parameter consistency index. The consistency index corresponding to a particular water content was calculated as I_C = (LL-w)/(LL-PL), where LL is the liquid limit, w is the water content, and PL is the plastic limit. The water content and corresponding consistency index of the various mixtures are presented in Table

Table 5. Water content and consistency index of various mixtures

Mixture	Water content (%)	Consistency Index
M0	25	1.11
	35	0.58
	45	0.05
M20	35	0.95
	65	0.54
	95	0.14
M40	40	0.93
	90	0.54
	140	0.12

The variations of M0, M20 and M40 mixtures is shown in Figs. 2, 3 and 4. For all the mixtures, WSDB increases then reaches a peak value and then decreases, when consistency index is reduced. The highest consistency value is when water content is near PL while lowest consistency value occurs when water content is near LL. The peak WSDB value for all the three soil mixtures lies in the consistency index range of 0.4- 0.5. The peak value is nearer to the LL, but changes in WSDB values are rapid in between water content corresponding to peak WSDB value and PL. It can be infered that the clogging can be controlled by maintaining a higher consistency.

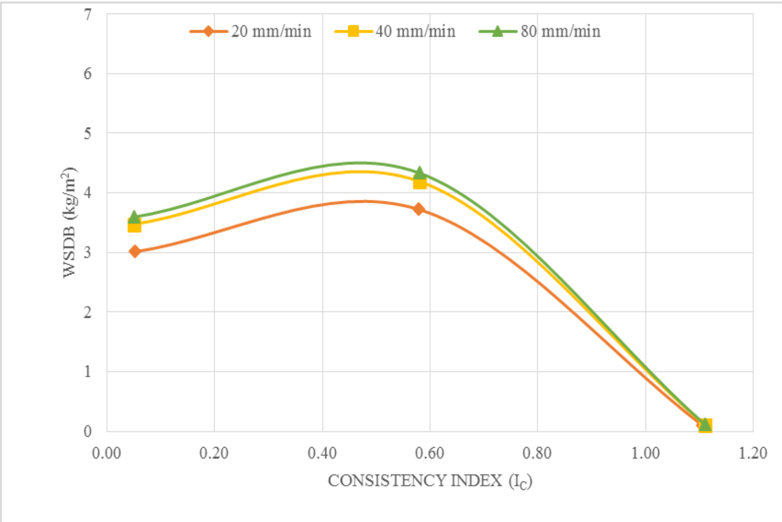

Fig. 2. Variation in WSDB with consistency index of M0 mixture

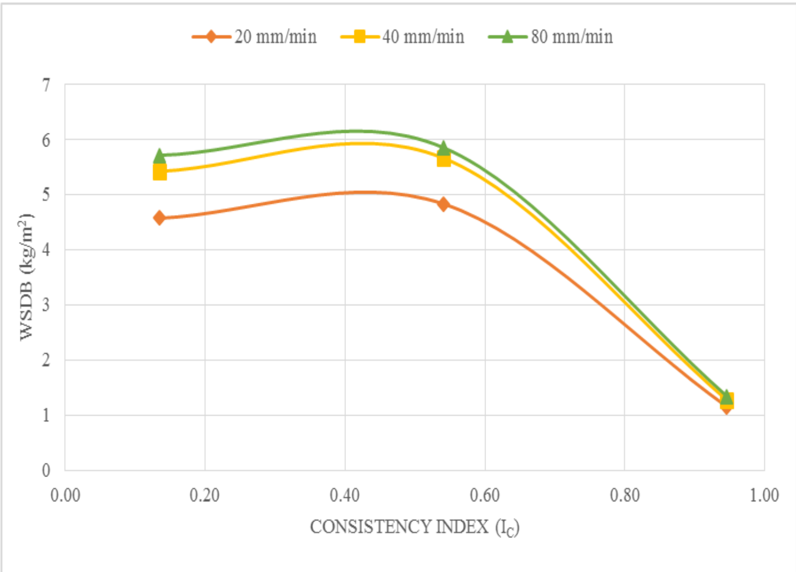

Fig. 3. Variation in WSDB with consistency index of M20 mixture

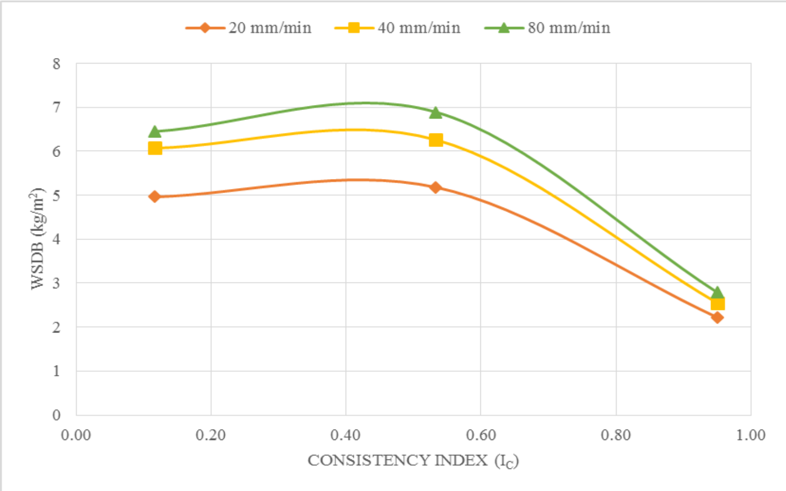

Fig. 4. Variation in WSDB with consistency index of M40 mixture

Effect of penetration rate on WSDB

The effect of penetration rate on WSDB of M0 mixture or Thonnakkal soil) is shown in Fig. 5. At I_C = 0.58 and 0.05, when the penetration rate is increased from 20 to 80 mm/min, an initial gradual increase followed by a constant WSDB value is observed. But when I_C = 1.11, WSDB values is constant (approx. zero) irrespective of the penetration rate.

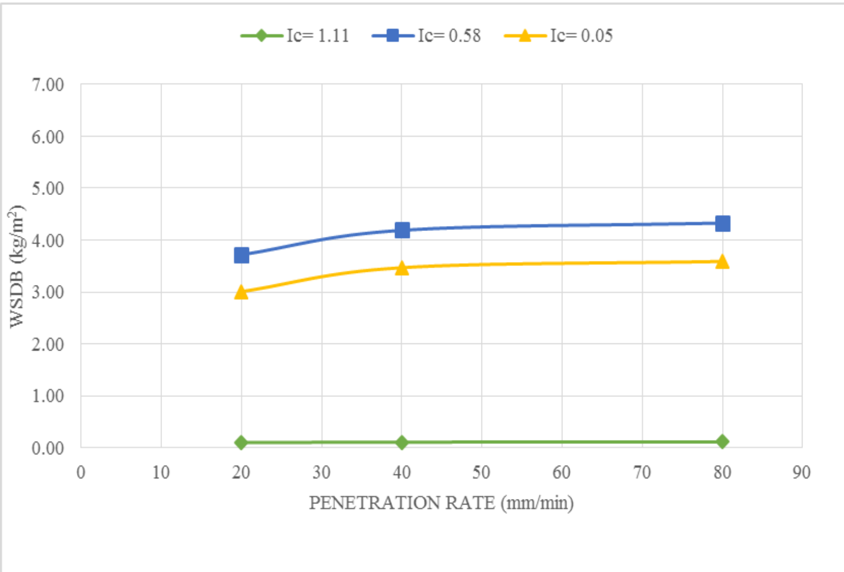

Fig. 5. Variation in WSDB with penetration rate of M0 mixture

The trend shown by M20 mixture (Fig. 6) is similar to that of M0 mixture, except that when the I_C value is highest the WSDB value is not zero but it is between 1-1.4 kg/m^2. In M40 mixture (Fig. 7), initially an increase happen and after a certain point the rate at which the increase happen gets slowed down for I_C = 0.53 and 0.12. When I_C = 0.53 and 0.12, the WSDB growth rate is 33% and 30% respectively. For I_C = 0.95, a 26% increase is observed when penetration rate is increased from 20 to 80 mm/min.

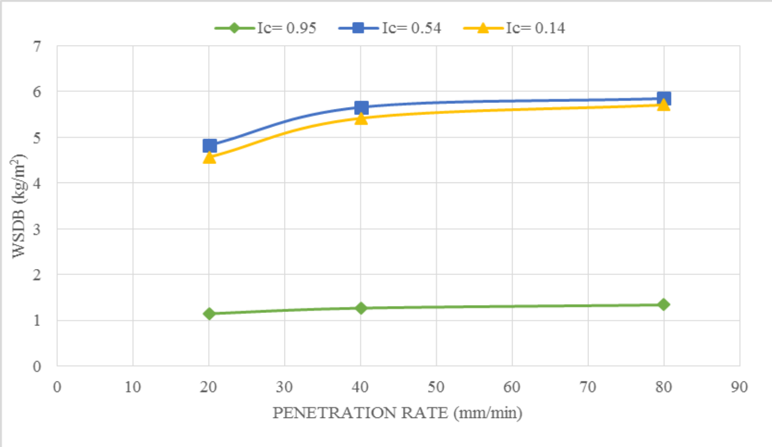

Fig. 6. Variation in WSDB with penetration rate of M20 mixture

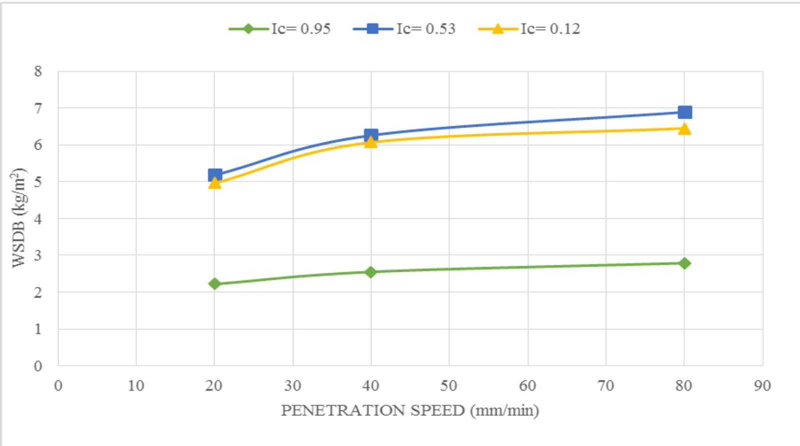

Fig. 7. Variation in WSDB with penetration rate of M40 mixture

In all the mixtures, the the highest WSDB value occurs at 80mm/min while lowest is at 20mm/min, but the changes occuring in WSDB values are more evident in between 20 and 40 mm/min range.

Effect of bentonite content on WSDB: The effect of bentonite content on WSDB is analysed at different consistency indices and penetration rates. The variations happening at 20mm/min penetration rate is shown in Fig. 8. The change in WSDB at

40mm/min and 80 mm/min are depicted in Figs. 9 and 10 respectively. It is clear from these figures that at a particular consistency, when the bentonite content is increased the WSDB value also increases. The WSDB value of Thonnakkal soil is low when compared to bentonite and Thonnakkal soil mixtures. It shows that presence of bentonite considerably change the clogging nature of Thonnakkal soil.

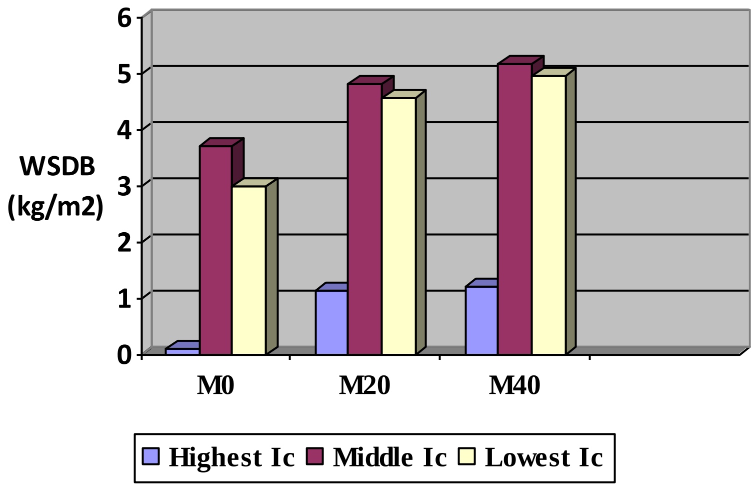

Fig. 8 Variation in WSDB with change in bentonite content at 20 mm/min penetration rate

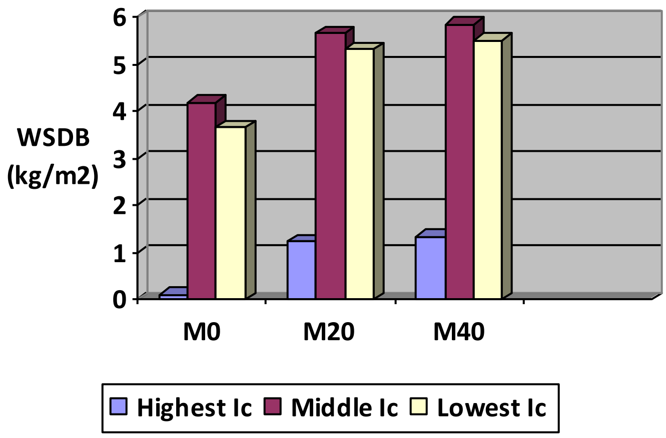

Fig. 9 Variation in WSDB with change in bentonite content at 40 mm/min penetration rate

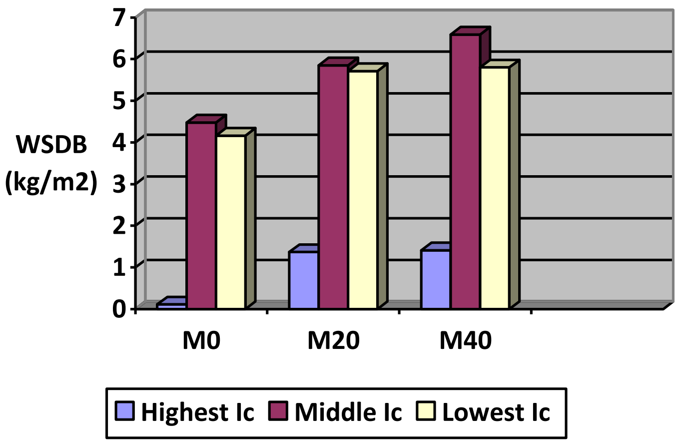

Fig. 10. Variation in WSDB with change in bentonite content at 80 mm/min penetration rate

The variation in peak WSDB value due to the introduction of bentonite into Thonnakkal soil is visible in Fig. 11. There is a rapid change in peak WSDB when the bentonite content is between 0 to 20% and the increase becomes gradual in 20 to 40% range.

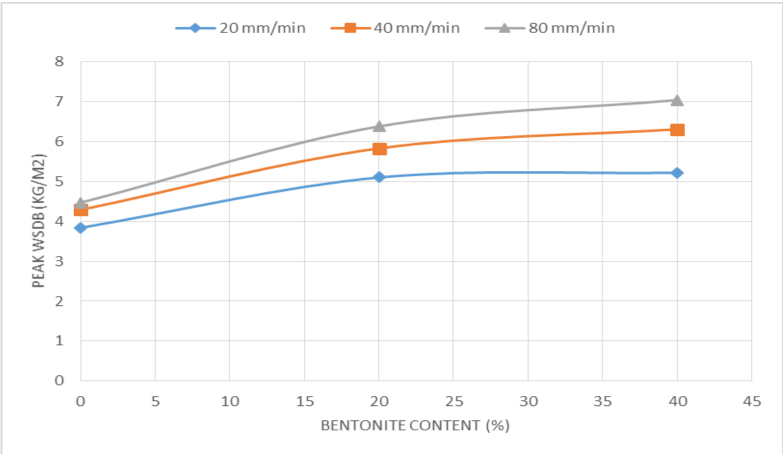

Fig. 11. Variation in peak value of WSDB due to bentonite content

4 Conclusions

1. The Atterberg limits value can be considered as an indicator of clogging potential. Higher the LL and PI, higher is the tendency of the soil to clog.

2. The Atterberg limits of Thonnakkal soil is not much high, but this is not the case once bentonite is added into this. The LL and PI of the soil mixture other than M0 is very high.
3. The data obtained from the laboratory drilling test is more informative compared to the Atterberg limit test. A wide range of parameters which influence the clogging potential can be analyzed.
4. Water content is a factor which influence clogging potential. The WSDB value increases from a water content near to PL and reaches a peak value and then it starts reducing towards LL. The clogging can be limited by maintaining a higher soil consistency.
5. The increase in WSDB with increase in bentonite points out that bentonite content can also elevate the tendency of Thonnakkal soil to clog.
6. The changes in peak WSDB value is more predominant in the bentonite range of 0 to 20%. There is increase in WSDB value in between 20 to 40% bentonite content also but this increase is very gradual.
7. The penetration rate of the drill bit is another factor affecting clogging potential. The increase in penetration rate increases the clogging potential of the soil.

In this paper, the maximum percentage of bentonite introduced into Thonnakkal soil was 40%, but the effect of higher percentages of bentonite should also be analyzed in future studies. Similarly the effect of size and shape of drill bit on clogging potential should also be studied.

References

1. Alberto-Hernandez, Y., Kang, C., Yi, Y. and Bayat, A.: Mechanical Properties of Clayey Soil Relevant for Clogging Potential. International Journal of Geotechnical Engineering 12 (6), 529- 536 (2017).
2. Amir, K. B., Ali, M., Mohammad, G., and Akbar, C.: Assessment of the adhesion potential of kaolinite and montmorillonite using a pull-out test device. Bulletin of Engineering Geology and the Environment 76 (4), 1507-1519 (2017).
3. Feinendegen, M., Ziegler, M., Spagnoli, G., Fernandez-Steeger, T. and Stangek, H. (2010). "A new laboratory test to evaluate the problem of clogging in mechanical tunnel driving with EPB shields." ISRM International Symposium- EUROCK 2010, Switzerland, pp. 429- 432.
4. Hollmann, F. and Thewes, M.: Assessment method for clay clogging and disintegration of fines in mechanised tunnelling. Tunnelling and Underground Space Technology 37, 96-106 (2013).
5. IS 2720 -Part 2: Methods of Test for Soils- Determination of Water Content, Bureau of Indian Standards, New Delhi (1973).
6. IS 2720 -Part 3: Methods of Test for Soils- Determination of Specific Gravity, Bureau of Indian Standards, New Delhi (1980).
7. IS 2720 -Part 4: Methods of Test for Soils- Grain Size Analysis, Bureau of Indian Standards, New Delhi (1985).
8. IS 2720 -Part 5: Methods of Test for Soils- Determination of Liquid and Plastic Limit, Bureau of Indian Standards, New Delhi (1985).

9. IS 2720 -Part 7: Methods of Test for Soils- Determination of Water Content-Dry Density Relation Using Light Compaction, Bureau of Indian Standards, New Delhi (1980).
10. Kang, C., Bayat, A., and Yi, Y.: Performance evaluation of TBM clogging potential for plain and conditioning soil using a newly developed laboratory apparatus. International Journal of Geotechnical Engineering 14(5), 463- 472 (2018).
11. Kang, C., Bayat, A., Yi, Y., and Wu, Y.: Assessment of the clogging potential of two clays. Applied Clay Science 178, 76- 83 (2019).
12. Littleton, I. (1976). "An experimental study of the adhesion between clay and steel." Journal of Terramechanics, 13 (3), pp. 141- 152.
13. Sass, I. and Burbaum, U. (2008). "A method for assessing adhesion of clays to tunneling machines." Bulletin of Engineering Geology and the Environment, 68, pp. 27–34.
14. Thewes, M. (1999). "Adhäsion von Tonbödenbeim Tunnelvortriebmit Flüssigkeitsschilden (Adhesion of clay soil during tunneling with liquid shields)", PhD thesis, University of Wuppertal, Institute of Soil Mechanics and Foundation Engineering, Wuppertal, Germany.
15. Thewes, M. and Burger, W., (2005). "Clogging of TBM drives in clay–identification and mitigation of risks". International World Tunnel Congress and the 31st ITA General Assembly, Turkey, pp. 737–742.
16. Yao, Y. S. and Zeng, D. C. (1990). "Investigation of the relationship between soil-metal friction and sliding speed." Journal of Terramechanics, Science Direct, 27 (4), pp. 283-290.
17. Zumsteg, R. and Puzrin, A. M. (2012). "Stickiness and adhesion of conditioned clay pastes." Tunnelling and Underground Space Technology, 31, pp. 86–96.