International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 3.45 (SJIF-2015), e-ISSN: 2455-2584
Volume 3, Issue 06, June-2017

Improvement of Unstable Slopes Using MICP Treatment

Dr. S. S. Pusadkar[1], Rewati Tawalare[2] Dr. A. I. Dhatrak[3]

[1] *Head of Civil Engineering Department, Government College of Engineering, Jalgaon ,Maharashtra, India.*
[2] *PG Student, Department of Civil Engineering, Government College of Engineering, Amravati, Maharashtra, India.*
[3] *Associate Professor, Department of Civil Engineering, Government College of Engineering, Amravati, Maharashtra, India*

Abstract—*Microbial-induced calcite precipitation (MICP) is new upcoming method of ground improvement to increase strength and stiffness of soil. The improvement in soil occurs due to natural biogeochemical processes by introducing bacteria and cementation solution. This paper describes the application of eco-friendly MICP technique for improving unstable slopes. In the present study, unstable slopes (1H: 1V and 0.67H: 1V) were treated using bacteria (S. Pasteurii) and cementation solution ($CaCl_2$ + Urea) at 2M concentration. The treated slopes were tested in a laboratory by conducting a model load test on slopes. The slope was treated by injecting MICP in a grid pattern of 50 mm x 50 mm. These unstable slopes were allowed to cure for the incubation period of 14 and 28 days. The results indicated that the unstable slope can be made stable after MICP treatment.*

Keywords – Slopes, Biogeochemical, Cementation, MICP, Incubation Period

I. Introduction

The unstable slope may fail and it make difficult to escape during failure if it occurs near a residential area. The sudden collapse of slope results in loss of several people and property. The possibility of slope failure is increased when slopes are naturally unstable or slope may become unstable by change of loading condition or under cutting of slopes. Some slopes are considered unstable due to their inclination and unconsolidated material. Unstable slopes are prone to failure in the form of rock falls, rock flows, plane shear or rotational shear. Fig. 1 shows failure of natural slope.

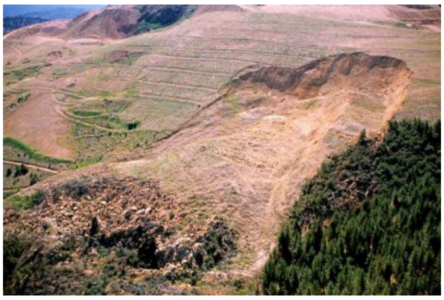

Fig. 1: Natural Slope failure

The various conventional methods to improve the stability of slope and prevent it from failure are partial replacement; root or geosynthetic reinforcement and grouting. Use of cement kiln dust and soil nailing with a surface grillage is also effective to enhance the stability of old fill slopes. Most of these methods are expensive, disturbing urban infrastructure and involve chemicals with significant environmental impact.

Due to the disadvantages of current slope stability methods, interest in the use of biological technologies in geotechnical engineering has been rising over the past few years. Microorganisms and biochemical processes are active in almost every environment on earth. One technology that has shown some promise is the use of bioactivity in sand cementation via calcium carbonate precipitation, namely, microbially induced calcite precipitation (MICP). Microbial Induced Calcite Precipitation (MICP) has recently emerged as a sustainable technique for soil improvement.

The bacteria type that is suitable for MICP is usually urease positive bacteria. S. *Pasteurii* is a more common type of bacteria used to precipitate calcium carbonate through the conversion of urea to ammonia and carbon dioxide. The soil cementation materials are mostly carbonates, silicates, phosphates, sulphides and hydroxides. When supplied with suitable substrates, micro-organisms can catalyze chemical reactions in the subsurface resulting in precipitation of inorganic minerals, which change the mechanical soil properties.

In cohesionless soils, MICP improves the shear strength after introducing bacteria and cementation material into the soil through soil particle binding. Calcium carbonate (calcite) is the most common element formed due to MICP because calcite formation is commonly found in nature. In this investigation, an attempt has been made to find natural solution for making unstable slope stable using Microbial Induced Calcite Precipitation (MICP).

Strip footing load test was used to evaluate the stability of slope. The strip footing of 75 mm was resting on slope crest after injection of bacteria and cementation solution and allowing sufficient curing time for developing the strength. The load test was conducted only on treated slopes as untreated slopes were unstable at the initial condition. The various parameters considered for present study were the slope angle, incubation period under vertical point load.

II. LITERATURE REVIEW

Zornberg[1] *et al.* (1998) conducted a centrifuge testing program to investigate the failure mechanisms of geosynthetic reinforced soil slopes and to evaluate the assumptions in their design. Scaling laws were established so that factors of safety in the models would be identical to those in prototype structures. The moment of failure was defined by a sudden change in the rate of settlements at the crest of the slope. The test results showed that overlapping reinforcement layers contribute to stability as they failed. The experimental results also indicated that stability of the reinforced slopes was governed by the peak shear strength and not by the critical state shear strength of the backfill soil.

Sawwaf[2] (2006) studied the potential benefits of reinforcing a replaced layer of sand constructed on near a slope crest. Model tests were carried out using model footing of 75mm width and geogrids. Several parameters including the depth of replaced sand layer and the location of footing relative to the slope crest were studied. Test results indicated that the inclusion of geogrid layers in the replaced sand not only significantly improved the footing performance but also leads to great reduction in the depth of reinforced sand layer required to achieve the allowable settlement.

Shahriar[3] *et al.* (2013) conducted the experimental work and numerical simulation to evaluate the effect of plants roots on sloping ground stability. The study also included tensile strength of the grass roots. Based on results from the tensile and direct shear tests, slope stability analyses were performed to demonstrate the grass soil-binding capabilities Variations in factor of safety of the slopes with and without root reinforcement subjected to different root diameters and different depths were investigated for the collected plants. Results concluded that the roots contributed to the stability of sloping ground and the best condition might probably be reached near the slope surface, which was equivalent to the soil erosion prevention.

Chu[4] *et al.* (2012) studied the use of *Bacillus sp*., which was isolated from tropical beach sand, to perform MICP either on the surface or in the bulk of sand. After six sequential batch treatments with suspension of urease-producing bacteria and solutions of urea and calcium salt, the permeability of sand was reduced to 14 mm/day in both cases of bulk and surface MICP. The stiffness of the MICP treated sand also increased considerably.

Zhao[5] *et al.* (2014) conducted laboratory study to investigate the influence of various factors on engineering properties of MICP-treated soil catalyzed by bacteria and ureases. The experiments of MICP catalyzed by Sporosarcina pasteurii (ACTT 11859) and urease (0.25M, 0.5M, 1.0, 1.5M) were conducted in similar conditions. The results of unconfined compression test showed that the experimental factors had a significant impact on the MICP process and engineering properties of sand treated by both bacteria and urease, whereas the curing conditions had a small effect.

Lin[6] *et al*. (2015) conducted triaxial and confined compression tests with embedded shear and compression wave (S-wave and P-wave) sensors on two MICP-treated silica sands. Triaxial compression tests were conducted at three different confining pressures (25, 50, and 100 KPa). Tests were also performed at calcium chloride ($CaCl_2$) concentrations of 0.1 and 0.3M. Results shown that the peak deviator stress of the Ottawa 20/30 sand and the Ottawa 50/70 sand increased by an average of 93 and 171%, respectively, compared with their corresponding untreated specimens. The MICP-treated specimens are less compressible than untreated specimens. As the $CaCO_3$ content increases, the compressibility of the treated soil specimens decreases.

Feng and Montoya[7] (2015) investigated the monotonic mechanical response of MICP cemented sand systematically using four cementation levels (untreated, lightly treated, moderately treated, and heavily treated) and three levels of effective confining pressure (100, 200, and 400 KPa). S. Pasteurii ATCC 11859 was used for study. The results indicated that the stiffness, peak shear strength, and dilation increased with an increase in calcite content at a given effective confining pressure and the dilation was suppressed with an increase in effective confining pressure.

From the literature survey, it was observed that there were several limitations of conventional methods used for improvement of performance unstable of slope. To overcome this drawback one should look for natural alternative. MICP showed improvement in soil properties and no work had been observed on performance of unstable slope using microbially induced calcite precipitation (MICP). It was therefore decided to conduct study on unstable sand slope reinforced with MICP.

III. MATERIAL

A.

B. *Sand*

For the load tests, cohesionless, dry Kanhan sand was used. This sand is available in Nagpur region of Vidharabha, Maharashtra. The test sand has angular shape, uniform yellow colour with small proportion of flint stone of black colour. Table I shows the index properties of sand used for the test.

TABLE I: Index Properties of Sand

Properties	Values
Specific gravity	2.69
γ_{max} (kN/m^3)	17.11
γ_{min} (kN/m^3)	15.82
Relative Density (%)	40
Angle of internal friction(φ)	47.00
Cohesion (kN/m^2)	0.00
Coefficient of uniformity(C_u)	2.125
Coefficient of curvature(C_c)	1.204
IS classification	SP

C. *Bacteria*

The test tube of Bacillus Pasteurii (NCIM 2477) bacterial culture was obtained from National Collection of Industrial Microorganism (NCIM), Pune, as shown in Fig. 2. The purely natural culture was stored under the 30^0 C in the laboratory. It is the most common bacteria which are used for the Microbial Induced Calcite Precipitation (MICP).

Fig. 2: Culture of Bacillus Pasteurii (NCIM 2477)

D. *Cementation Solution*

Cementation solution was made by adding urea and $CaCl_2$ at 2M concentration in distilled water.

E. *Test Box-*

The test boxes were made of 12 mm thick plywood to accommodate the slope of 1H: 1V and 0.67H: 1V. The size of box was 1000 mm x 425 mm x 400 mm and is as shown in Fig. 3.

Fig. 3: Test box

E. Strip Footing- The strip footing was fabricated by using mild steel plate having dimensions 380mm x 75 mm and 15 mm. The footing had a little groove at the centre for application of load. The model footing is as shown in Fig. 4.

Fig. 4: Strip footing

IV. METHODOLOGY

The model sand slopes with slope 1H: 1V and 0.67H: 1V were prepared by using compacting sand in layers of 50 mm thick by marking the inner surfaces of the test box at 50 mm intervals to prepare the sand bed in layers. It was observed that, 1H: 1V and 0.67H: 1V both are unstable slopes as they failed as soon as the support was removed from the face. The process of filling the test box was continued by compacting the sand layer by layer until the height of the slope was reached. The great care was taken to make the slope face near the support so that the relative density remains same throughout the bed.

The MICP solution was made by mixing of cultivated bacteria solution and 2M concentration of cementation solution (i.e.$CaCl_2$ and urea dissolved in distilled water). The MICP solution was then injected into the slope in a grid pattern of 50 mm x 50 mm at toe, sloping surface and up to the distance 4B from slope crest. Then the slopes were allowed to incubate for 14 and 28 days by covering a polythin sheet over the surface.

The test box with MICP induced slope was brought under a loading frame after removing the support to conduct the laboratory load test. A strip footing was placed on the slope crest. The load was applied on strip footing in intervals until failure occurs. The load and corresponding settlement was measured during the entire test at various intervals. The load settlement curve was plotted for each MICP treated slope test and ultimate bearing capacity of strip footing was obtained. Fig. 5 and Fig. 6 show slope injected with bacteria and cementation solution and experimental setup for strip footing load test conducted on incubated slope. Fig. 7 shows slope after failure occurred.

Fig. 5: Injected test slope

Fig. 6: Experimental setup

Fig. 7: Slope failed after test

V. RESULT AND DISCUSSION

The experimental investigation were carried out on a strip footing by conducting a load test on MICP treated sand slope of angle 1H:1V and 0.67H:1V with footing placed at crest. Fig. 8 and Fig. 9 shows the load settlement curve of MICP treated slope of angle 1H: 1V and 0.67H: 1V with 14 and 28 days incubation respectively. The incubation period was given to develop the strength due to MICP. The results of treated sand slope were compared with respect to incubation period. The load test was not conducted on untreated sand slope as both the slopes were unstable.

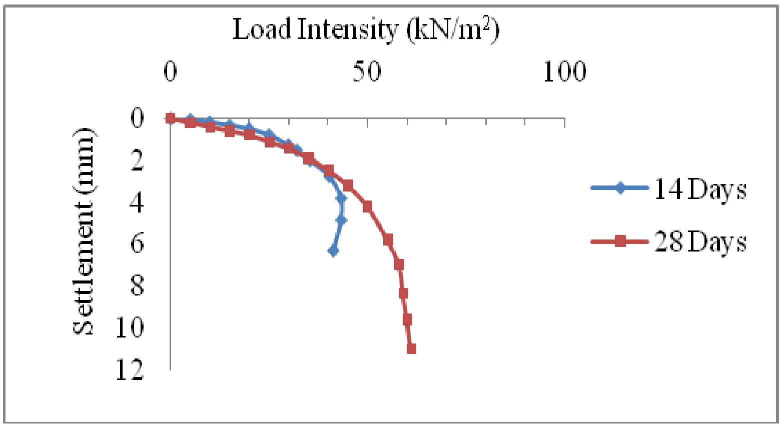

Fig. 8: Load settlement curve for footing on treated sand slope of angle 1H:1V

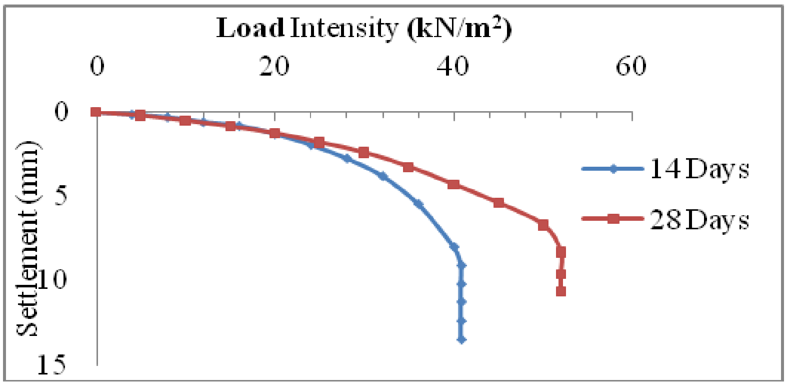

Fig. 9: Load settlement curve for footing on treated sand slope of angle 0.67H: 1V

The model tests results obtained from laboratory tests were analysed and discussed. The ultimate bearing capacity (UBC) of footing at crest for each slope and both incubation periods is given in table Table II. Initially the bearing capacities of both the untreated slopes were considered as 0 kN/m^2.

TABLE II: UBC of Strip Footing on MICP Treated Slope

Location of Footing	UBC (kN/m^2) (for untreated slopes)	Slope			
		1H: 1V		0.67H: 1V	
		UBC (kN/m^2) (Incubation Period in Days)		UBC (kN/m^2) (Incubation Period in Days)	
		14	28	14	28
At crest	0	43.8	54.8	40.8	52.0

The effect of some important parameters of slope and MICP such as effect of slope angle and effect of incubation period were studied.

A. *Effect of Slope Angle*

The test was carried out on two unstable slopes with slope as 1 H: 1V and 0.67 H: 1V. The tanks were filled with sand at desired relative density and after injecting MICP, box was allowed to remain under cover with polythine for 14 and 28 days as incubation period i.e. period for development of strength. It was observed that the treated slopes were stable and withstand without any support. The slope was tested by load test and bearing capacity of strip footing was determined. Fig. 10 shows the ultimate bearing capacity of strip footing for both 14 and 28 days of incubation. From results it was observed that the ultimate bearing capacity of footing decreased with increasing the slope angle for both incubation periods. However, unstable slope was able to withstand and carry load in terms of footing.

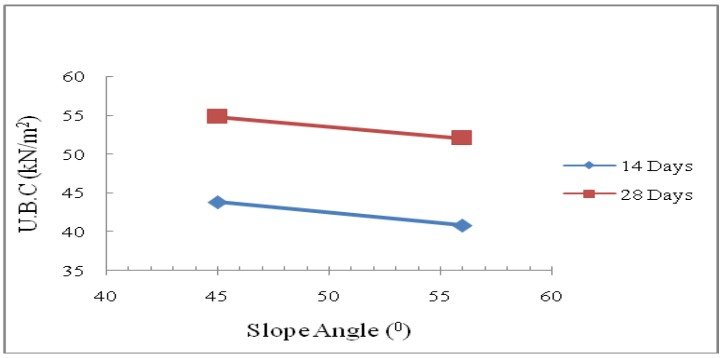

Fig. 10: Effect of slope angle on U.B.C.

B. *Effect of Incubation Period*

The effect of incubation period on performance of slopes can be seen in Fig. 11. It was found that the ultimate bearing capacity of footing increased with incubation period for each slope angle. The incubation period had significant effect on the load-settlement characteristics of MICP induced slope and hence further long term study is needed in this aspect.

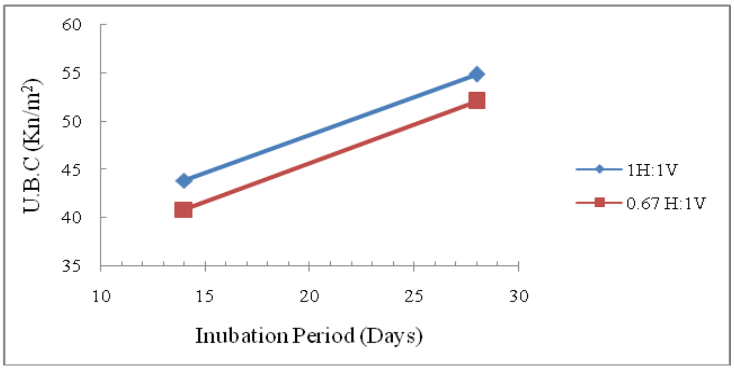

Fig. 11: Effect of incubation period on U.B.C. of Footing

VI. Conclusions

Based upon the experimental investigations carried out in the laboratory, the following conclusions are drawn:

1. The unstable slope i.e. the slope which could not withstand naturally can be made stable by treating soil by MICP.
2. The bearing capacity of footing on MICP treated sand slope at crest is significantly increased.
3. The behaviour of surface strip footing on MICP treated slope is greatly affected by the slope angle and incubation period.
4. The incubation period for treated sand slope may be taken as 28 days.

References

[1] Jorge G. Zornberg, Nicholas Sitar and James K. Mitchell, "Performance of Geosynthetic Reinforced Slopes at Failure", *Journal of Geotechnical and Geoenvironmental Engineering*, 124, 670-683.

[2] Sawwaf M. E. A. (2006), "Behavior of Strip Footing on Geogrid-Reinforced Sand over a Soft Clay Slope", *Geotextiles and Geomembranes*, Vol 25, 50–60.

[3] Minhaz M. Shahriar, Jay X. Wang, and William B. Patterson, "Contribution of Grass Roots on Enhancement of Slope and Embankment Stability", *Geo-Congress 2013*, 1339-1348.

[4] Chu J., Stabnikov V. & Ivanov V. (2012), "Microbially Induced Calcium Carbonate Precipitation on Surface or in the Bulk of Soil", *Geomicrobiology Journal*, Vol 29, 544–549.

[5] Zhao Q., Li L. and Zhang H. (2014), "Factor Affecting Improvement of Engineering Properties of MICP-Treated Soil Catalyzed by Bacteria and Urease", *J. Geotechnical and Geoenvironmental Engineering*, 04014094-(1-10).

[6] Lin H., Suleiman M. T., Brown D. J. and Kavazanjian E. (2015), "Mechanical behavior of Sands Treated by Microbially Induced Carbonate Precipitation" *Journal of Geotechnical and Geoenvironmental Engineering*, 04015066-(1-13).

[7] Feng K. and Montoya B. M. (2015), "Influence of Confinement and Cementation Level on the Behavior of Microbial Induced Calcite Precipitated Sands under Monotonic Drained Loading" *Journal of Geotechnical and Geoenvironmental Engineering*, 04015057- (1-9).