A Study on Recycled Plastic Pins as Micropile in Stabilization of Cohesive Slope

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Abstract. Stabilization of cohesive slope is very important on large scale infrastructure projects as there is always an inherent tendency of slope failure causing threats to life and property. The aim of this research work is to utilize waste plastic for stabilization of earthen slope. For this, recycled plastic pins, made-up with recycled plastics, sawdust and fly ash is used as micropile. Experiments were conducted in a model cohesive slope with slope angle 30º made inside a steel tank of dimension 1mx1mx1m. Two different diameter (*d*) of micropiles, 22mm and 30mm are used in two lengths, 20*d* and 30*d* and at three different spacings 3*d*, 4.5*d* and 6*d*. Four number of micropiles are arranged in a row along the slope in an A-frame with inclinations 0º, 5º, 10º and 15º with vertical. The load-settlement behaviour of micropile groups are studied under static axial vertical compressive load. The ultimate load carrying capacity of micropile group under specific settlement are determined from experimental observations. Plaxis-3D models are also developed to validate the experimental results. It is observed that the load carrying capacity of a micropile group increases with the increase in diameter, length, spacing and inclination of micropiles.

Keywords: Recycled Plastic Pin, Micropile, Cohesive Slope, Load-Settlement, Plaxis-3D.

1 Introduction

Different approaches are used for stabilization of natural or man-made slopes. Some methods aim to increase the shear strength of soil to enhance its properties and factor of safety of the slope. The frequently used mechanical and chemical stabilization techniques include compaction, mixing, dewatering, lime, cement, fly ash, etc. Methods such as pre-stressed anchors, rock bolts, piles, micropiles, soil nailing, geosynthetic reinforcement, retaining walls etc. are used for structural support to increase the stability of the slope. The applicability of micropiles for slope stabilization projects are increasing due to some advantages as - simple construction process, requires small working area, can be installed easily in zones with restricted equipment admittance, requires less excavation in comparison with earth retaining systems, can be installed in all types of soil where installation of driven piles or drilled shafts may be difficult and costly, produce less noise and vibration during installation and improves aesthetics of the area [1]. Large-scale physical model tests were performed on different pattern of micropiles installed on earthen slopes to create an experimental database related to the spacing and micropile batter angle to enhance the prediction of limit loads for micropiles in slope stabilization works [2, 3]. Numerical and experimental study was performed on micropiles utilized to strengthen tall railway embankments [4]. Case studies are also available related to the application of micropiles in stabilization of slopes in different types of soils such as loose deposit of sandy soil, dense sand, stiff clay soil, c-ϕ soil, karstic limestone deposit, layered soil, hard rock etc. These includes location of the site and its general description, problem statement, approved remedial measures, technology adopted for boring / drilling holes, choice of gravity grouted / pressure grouted micropiles, its design (diameter, length, spacing, number etc.) and layout, instruments used for micropiling work, load testing procedures adopted for different types of loads etc. High strength micropile groups were used for the restoration of Cannon Place (1868), an ancient monumental structure in London [5]. Micropile and anchor system was applied to meet up environmental and technical challenges in the construction of Banjo Bill rock catchment basins situated on SR 89A in Oak Creek Canyon near Sedona, Arizona [6]. Micropiling was used for retrofitting of slope of an aqueduct in Manchester, UK as the retrofitting work were permitted with no direct loading and minimum vibration on the conduit or slope [7]. Micropiles were installed successfully for slope stabilization in inaccessible areas and under adverse climatic conditions, one in a ropeway station in high alpine mountain range in Europe and another in East-West gas pipeline over the mountain region of Western Ghats near Mumbai in India [8]. The reconstruction of Oak Hill Cemetery and restoration of a tall wall in Port Deposit, MD were done with A-frame micropiles [9]. Micropiles are also installed as a remedial measure to mitigate landslides. Some examples are: The Blue Trail Landslide project located on U.S. Highway between Alpine Junction and Hoback Junction, Wyoming; The SUM-271 project located on interstate 271 northbound in Richfield Township, Summit County, Ohio; The Littleville landslide project located on a section of US Route 43, Alabama [1].

Detail design procedure of micropiles for soil slope stabilization is available [1], but the grout-to-ground ultimate bond strength value required to calculate the axial force to be resisted by the micropile below the potential slip surface is not available for soft cohesive soil. This type of deep-seated soft cohesive soil having high liquid limit (> 50%) and plasticity index (> 20%) is available in many parts of North-East India. So, in this paper an experimental and numerical approach has been adopted to study the load-settlement behavior of cohesive slope reinforced with A-pattern micropiles constructed with recycled plastic pin (RPP). Recycled plastic pins inserted through the embankment upstream face offers extra resistance that restrain the further movement of slip surface and thus increases the safety factor. However, experimental study is very limited on the potential use of RPPs in stabilization of cohesive slope.

2 Materials used in the Study and Properties

Material used for this research work are Recycled plastic pins and clayey soil.

2.1 Recycled Plastic Pin

Recycled Plastic Pin (RPP) is a lightweight material derived from the used plastic and waste materials like fly ash, sawdust and polymer [10]. It is chemically and biologically less reactive compared to some other underpinning elements. The use of RPPs in geotechnical applications can reduce the volume of waste plastic that are generally used in land filling work and also can increase its demand [11]. The different constituent of RPP are: high-density polyethylene (HDPE) (55–70%); low-density polyethylene (LDPE) (5–10%); polystyrene (PS) (2–10%); polypropylene (PP) (2–7%); polyethylene-terepththalate (PET) (1–5%); and additives like, sawdust, fly ash etc. (0–5%) [12]. Modulus of elasticity of plastic lumber can be increased sufficiently by adding glass and wood fibre as additives [13]. The material properties of RPP used for this experimental study is given in the Table 1 (as supplied by the vendor).

Table 1. Material properties of RPP

Property	Value	ASTM Standard
Density	0.93 gm/cm^3	ASTM D792
Tensile strength	16 MPa	ASTM D638
Shear strength	14.6 MPa	ASTM D638
Compressive strength	19.6 MPa	ASTM D695
Continuous service temp.	180^{o}C	N/A
Thermal co-efficient of expansion	0.00001/ ^{o}C	ASTM D696
Flexural modulus	685 MPa	ASTM D790
Modulus of elasticity	3000kPa	N/A

2.2 Soil

The soil used in the study is cohesive soil collected from the fields situated near National Institute of Technology Silchar campus, Assam. The physical properties of the soil were determined in the laboratory as per Bureau of Indian Standards code of practice and given in the Table 2.

Table 2. Properties of soil

Properties of soil	Value
Gravel (%)	0
Fine sand (%)	12
Silt + clay (%)	88
Plastic limit (%)	26.5
Liquid limit (%)	55
Plasticity index (%)	28.5
Maximum dry density, MDD (gm/cc)	1.422
Optimum moisture content, OMC (%)	23
Unconfined compressive strength, UCS (kPa)	49.64
Specific gravity	2.54
Soil classification	CH

3 Methodology for Experimental Investigation

3.1 Preparation of test tank

Small scale model tests were planned to perform in a steel tank of size 1m×1m×1m. Cohesive soil was collected from nearby fields and were crushed into fine powdered form and mixed properly with optimum moisture content. A polythene sheet was used to cover the steel tank to minimize the frictional drag between tank and soil. Soil was filled inside the tank by compacting with a hammer. The soil slope is made with an angle of 30^o as shown in Fig. 1.

Fig. 1. Preparation of test tank

3.2 Construction of micropile with recycled plastic pins

Micropiles of two different diameters (d) 22mm and 30mm as shown in Fig. 2. and two different lengths (l) 20d, and 30d were selected for testing. It was constructed along a single row 1 × 4 numbers having A-Pile configuration making inclinations (θ) of 0^o, 5^o, 10^o, 15^o with respect to vertical axis of loading. Each group was constructed with three different spacings (s) of 3d, 4.5d and 6d. At the specific locations of the micropiles, holes were made with hand auger to the required depth. Cement (43 grade) with water–cement ratio of 0.45 were used as grout. Total forty-nine tests were conducted as shown in Table 3.

Fig. 2. Recycled plastic pins used as micropile of diameter 22 mm and 30 mm

Table 3. Summary of experimental programme

Diameter (d) (mm)	Length/dia. (l/d) of MP	Number (n) of MP	Spacing/dia. (s/d) of MP	Inclination of MP with vertical (θ)	Total Tests
	20	4	3, 4.5, 6	0^o, 5^o, 10^o, 15^o	12
22	30	4	3, 4.5, 6	0^o, 5^o, 10^o, 15^o	12
	20	4	3, 4.5, 6	0^o, 5^o, 10^o, 15^o	12
30	30	4	3, 4.5, 6	0^o, 5^o, 10^o, 15^o	12
Test conducted on soil without micropile					01
Total number of tests conducted					49

3.3 Experimental set-up and procedure

A steel plate was used as micropile cap. Small holes having diameter smaller than the micropile diameter were made on the steel plate at the specific spacing. The top portion of the micropile was tapered to smaller diameter so that it can be inserted into the hole and place in a fixed position. Two dial gauges were used to measure vertical displacement and placed at two corners of the cap. Pressure gauge and hydraulic jack was used to apply load on the steel plate and one proving ring was used to measure the applied load. The picture of experimental setup during a test in shown in Fig. 3. The load corresponding to settlement having 10% of micropile diameter used was assumed as the failure load for the embankment [14]. The maximum load corresponding to the maximum settlement obtained from different micropile configurations was observed and applied for base soil without having micropiles.

Fig. 3. Experimental setup

4 Numerical Analysis

Finite element analysis is a numerical technique used in geotechnical engineering for finding approximate solutions to actual problems as it can handle various types of materials, geometries and boundaries and can show the distribution of stresses and displacements. However, to validate the results, it should be supplemented by experimental investigation. Generally, more accurate results are obtained by finer meshes, but it increases the analysis time. In the study Plaxis-3D software were used to model the embedded micropile. The micropile was demonstrated by embedded beam elements that was connected with the cap. The slope stability was analyzed with a plain strain model using 15-noded elements. The standard fixities were used to define boundary conditions. The Mohr-Coulomb material model was used for undrained condition. Table 4 shows the different properties of soil and steel plate. Fig. 4. shows the generated numerical model in Plaxis-3D software.

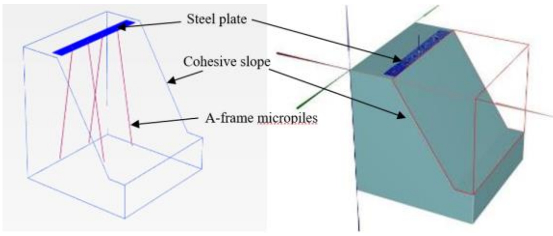


Fig. 4. Numerical model created in Plaxis-3D software

Table 4. Parameters assigned for numerical calculation in Plaxis-3D

Parameters	Soil	Steel plate
Material Model	Mohr-Coulomb	Elastic, isotropic
Drainage type	Undrained	Non-Porous
Unit weight above phreatic line(γ_{unsat})	16.5 kN/m^3	78 kN/m^3
Unit weight below phreatic line(γ_{sat})	18 kN/m^3	-
Young's Modulus(E)	1.25x10^3 kPa	200x10^6 kPa
Poison's Ratio(v)	0.45	0.3
Cohesion(c)	24.8 kPa	-
Friction Angle(Φ)	0^o	-

5 Results and Discussion

5.1 Results from experimental analysis

The load corresponding to the settlement equal to 10% of micropile diameter was assumed as the failure load for the embankment reinforced with micropile [14]. The diameter of micropiles used was known, so, load carrying capacity was recorded directly during the experiment from the proving ring reading corresponding to the settlement of the 10% of micropile diameter. So, load-settlement graphs were not plotted and the experimental results are tabulated in Table 5a and Table 5b for two different *l*/*d* ratios 20 and 30 respectively.

Table 5a. Load carrying capacity of micropile group for *l*/*d* ratio 20

Diameter (*d*), mm	Inclination of micro-pile with vertical (*θ*), °	Load carrying capacity, kN		
		s/*d* = 3	*s*/*d* = 4.5	*s*/*d* = 6
22	0	0.928	0.9915	1.104
	5	1.25	1.307	1.424
	10	1.2765	1.442	1.567
	15	1.4125	1.553	1.69
30	0	1.202	1.3055	1.3785
	5	1.3765	1.5405	1.595
	10	1.533	1.67	1.756
	15	1.657	1.8115	1.8665

Table 5b. Load carrying capacity of micropile group for *l*/*d* ratio 30

Diameter (*d*), mm	Inclination of micro-pile with vertical (*θ*), °	Load carrying capacity, kN		
		s/*d* = 3	*s*/*d* = 4.5	*s*/*d* = 6
22	0	1.127	1.157	1.236
	5	1.449	1.4725	1.556
	10	1.4755	1.6075	1.699
	15	1.6115	1.7185	1.822
30	0	1.401	1.471	1.5105
	5	1.5755	1.706	1.727
	10	1.732	1.8355	1.888
	15	1.856	1.977	1.9985

Variation of load carrying capacity of A-frame micropile group along with the degree of inclination of micropile with vertical are plotted for 22mm diameter micropile group for two different *l*/*d* ratios of 20 and 30 and shown in Fig. 5a. and Fig. 5b. respectively.

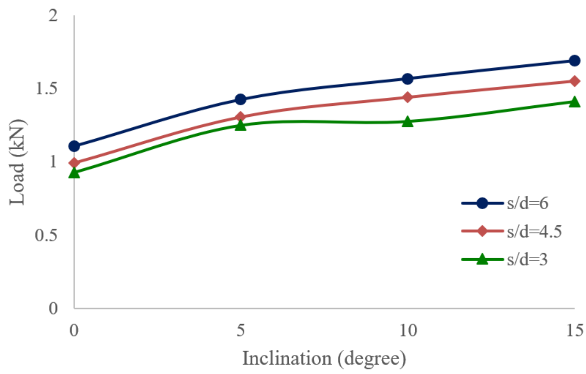


Fig. 5a. Load carrying capacity versus angle of inclination of micropile with vertical for *d* =22mm and *l*/*d* = 20

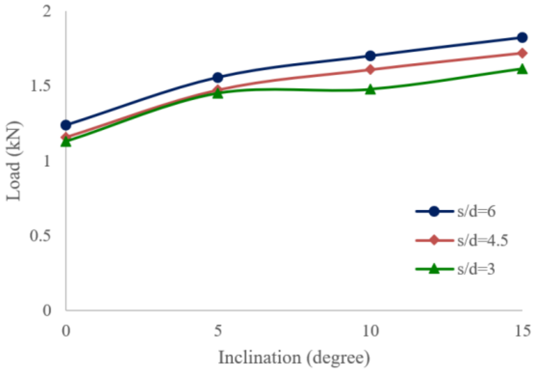


Fig. 5b. Load carrying capacity versus angle of inclination of micropile with vertical for *d* = 22mm and *l*/*d* = 30

Variation of load carrying capacity of A-frame micropile group along with the degree of inclination of micropile with vertical are plotted for 30mm diameter micropile group for two different *l*/*d* ratios of 20 and 30 and shown in Fig. 5c. and Fig. 5d. respectively.

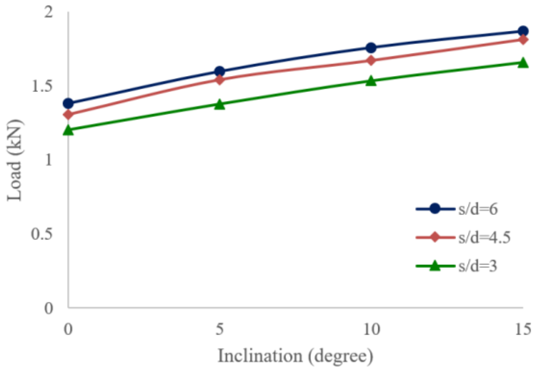


Fig. 5c. Load carrying capacity versus angle of inclination of micropile with vertical for *d* = 30mm and *l*/*d* = 20

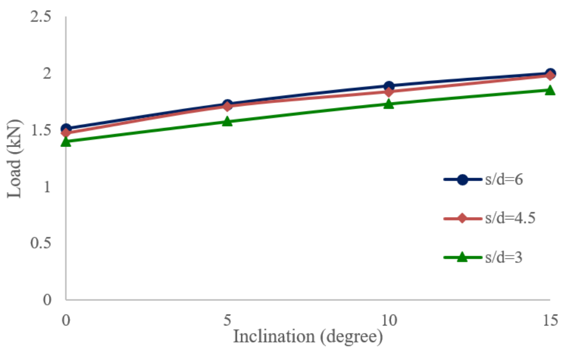
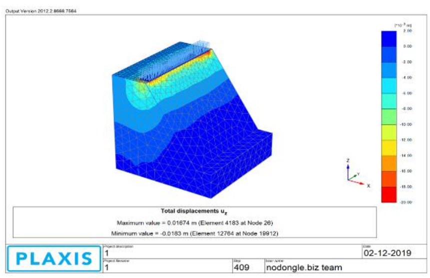


Fig. 5d. Load carrying capacity versus angle of inclination of micropile with vertical for *d* = 30mm and *l*/*d* = 30

It is observed from the Tables 5a-5b and Fig. 5a - Fig. 5d, that the load carrying capacity is more for larger diameter micropiles at same *l*/*d* ratio. For same diameter of micropile, capacity is more for larger *l*/*d* ratio. For same diameter of micropile, same *l*/*d* ratio and *s*/*d* ratio, capacity of group increases with the degree of inclination of A-frame micropile with vertical. Similarly, for same diameter of micropile, same *l*/*d* ratio and degree of inclination of micropile with vertical, capacity of group increases with the *s*/*d* ratio. However, optimum value could not be found out from this small-scale model test.

5.2 Results from numerical analysis

Generally, the factor of safety value assumed to be 2 in the design of micropile [1]. So, safe load was calculated from the failure load (ultimate load) obtained from the experimental investigation. This safe load carrying capacity obtained from the experimental analysis was applied in numerical models constructed with different variables using Plaxis-3D software. The settlement under this load was determined and compared with the values obtained in the respective experiment. As for example, the generation of mesh and displacement (settlement) for slope without micropile and for 22mm diameter micropile group with *l*/*d* ratio 20, *s*/*d* ratio 4.5 and inclination of micropile of 15° with vertical are shown in Fig. 6a. and Fig. 6b. respectively. The results of numerical analysis are tabulated in Table 6a and Table 6b for two different *l*/*d* ratios 20 and 30 respectively.



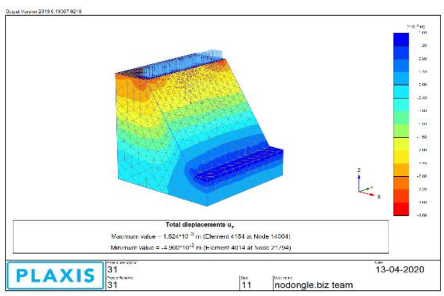


Fig. 6a. Displacement of slope without micropiles

Fig. 6b. Displacement of slope with diameter micropile 22mm, *l*/*d* ratio 20, *s*/*d* ratio 4.5 and inclination with vertical 15°

Table 6a. Settlement of micropile group for *l*/*d* ratio 20

Diameter (*d*), mm	Inclination of micropile with vertical (*θ*), °	Settlement, mm		
		s/*d* = 3	*s*/*d* = 4.5	*s*/*d* = 6
22	0	6.629	5.052	4.891
	5	5.358	5.008	4.866
	10	5.358	4.911	4.862
	15	5.161	4.9	4.858
30	0	4.828	4.721	4.686
	5	4.826	4.72	4.638
	10	4.8	4.712	4.555
	15	4.751	4.705	4.552

Table 6b. Settlement of micropile group for *l*/*d* ratio 30

Diameter (*d*), mm	Inclination of micropile with vertical (*θ*), °	Settlement, mm		
		s/*d* = 3	*s*/*d* = 4.5	*s*/*d* = 6
22	0	4.49	4.161	4.031
	5	4.483	4.157	4.031
	10	4.18	4.108	4.012
	15	4.164	4.067	4.004
30	0	4	3.827	3.583
	5	3.937	3.803	3.552
	10	3.868	3.749	3.499
	15	3.85	3.713	3.242

Variation settlement of A-frame micropile group along with the degree of inclination of micropile with vertical are plotted for 22mm diameter micropile group for two different *l*/*d* ratios of 20 and 30 and shown in Fig. 7a. and Fig. 7b. respectively.

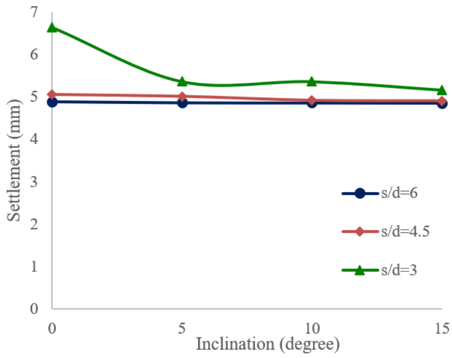


Fig. **7a.** Settlement plotted against angle of inclination of micropile with vertical for *d* = 22mm and *l*/*d* = 20

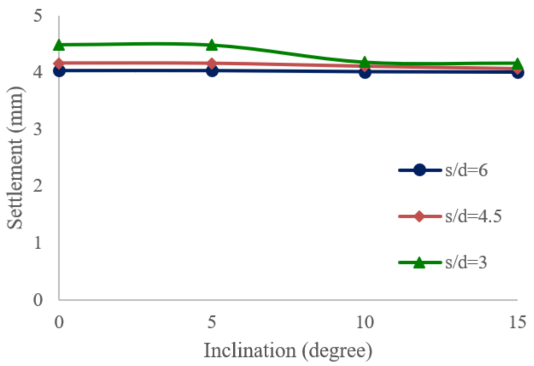


Fig. **7b.** Settlement plotted against angle of inclination of micropile with vertical for *d* = 22mm and *l*/*d* = 30

Variation Settlement of A-frame micropile group along with the degree of inclination of micropile with vertical are plotted for 30mm diameter micropile group for two different *l*/*d* ratios of 20 and 30 and shown in Fig. 7c. and Fig. 7d. respectively.

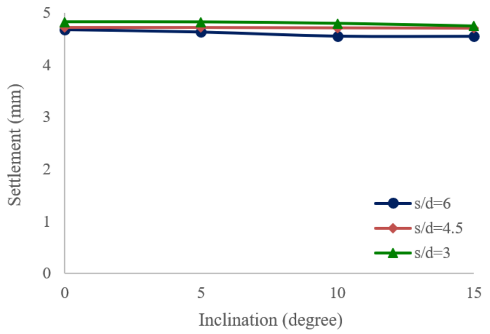


Fig. **7c.** Settlement plotted against angle of inclination of micropile with vertical for *d* = 30mm and *l*/*d* = 20

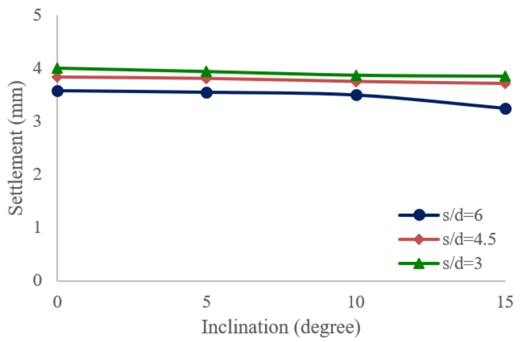


Fig. **7d.** Settlement plotted against angle of inclination of micropile with vertical for *d* = 30mm and *l*/*d* = 30

It is observed that the A-frame micropile group with diameter 30mm, length 30*d*, spacing 6*d*, and placed at an inclination of 15^o with vertical shows least group settlement. This may be due to the less overlapping of stress zone inside the group due to the large spacing.

6 Conclusions

This paper presents the experimental results of load tests conducted on cohesive model slope with unconfined compressive strength value around 50 kPa reinforced with A-frame micropile groups. Slope was made inside a steel tank of dimensions 1m×1m×1m. Half the load obtained from experimental investigation corresponding to settlement of 10% of micropile diameter was applied to the numerical models made with Plaxis-3D software and the settlement resulted from numerical analysis was cross validated. Based on the experimental and numerical analysis, the following conclusions are drawn.

The load carrying capacity of a A-frame micropile group observed to be higher for higher diameter micropile. For an illustration, capacity of vertical (θ=0°) micropile group with *l*/*d* ratio 20 and *s*/*d* ratio 4.5 increases to 31.6%, when the diameter is increased from 22mm to 30mm. The load carrying capacity of a micropile group observed to be higher for higher length of the micropile. For an example, the capacity of vertical micropile group with diameter 22mm and spacing 3*d* increases to 21.4%, when the length is increased from 20*d* to 30*d*. The load carrying capacity of a micropile group increases with the spacing also. As an instance, capacity of micropile group with diameter 22mm, *l*/*d* ratio 20 and placed at an angle 15° with vertical (θ) increases to 20%, when the spacing increases from 3*d*-6*d*. The load carrying capacity of a micropile group increases with the increase in the inclination angle with vertical (θ). For an illustration, capacity of micropile group placed vertically (θ = 0°) with *l*/*d* ratio of 20 and *s*/*d* ratio of 4.5 increases to 56.6%, when the inclination is increased from 0^o to 15^o. Settlement of a micropile group under the ultimate load in experimental investigation is less compared to that of numerical analysis. This may be due to the resistance offered by lateral confining action of steel tank. For an illustration, the settlement of vertical micropile group of 22mm diameter with *l*/*d* ratio 20 and *s*/*d* ratio 3, is obtained 6.629mm (instead of 2.2mm) under the same load of 0.928 kN in the numerical model.

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