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Studies on Contaminated Mine Soil and Its Remediation using Soil Washing Technique: A Case Study on Soil at Kolar Gold Fields

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P A P E R   I N F O

A B S T R A C T

Uncontrolled mining and the tailings produced can cause significant environmental impacts such as water, air, and soil pollution. In the present study, a contaminated soil of gold mines located in the Karnataka state of India was studied to know the geotechnical behavior of this soil as a foundation material and to suggest a suitable soil remediation technique to avoid contamination of surrounding water bodies. The in-situ dry unit weight of soil at the selected locations varied from 15.71 to 18.75 kN/m^3. The effective shear strength parameters determined from Triaxial test results were in the range of 4.8 – 8.2 kN/m^2 and $19.4^0 – 29.8^0$, respectively, for the cohesion and angle of internal friction. The soil samples were analyzed for bearing capacity and settlement using GEO5 software tool, and the economical dimensions of the footings were estimated. It was observed that the soil has sufficient bearing capacity, and the settlements are within the allowable range. The chemical analysis of the soil samples showed that there are considerable amounts of heavy metals present in the mine soil. Though the strength of the soil is good, the contaminants in the soil may cause groundwater contamination and damages to the footings. Hence, the soil washing technique as a remediation technique was also studied through column leaching tests using different leaching solutions and found that diluted hydrochloric acid (HCl) with Ethylenediamine-tetraacetic acid (EDTA) can effectively remove the heavy metals from the soil.

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1. INTRODUCTION

In most of the mining areas around the world, the presence of poisonous metals was observed in soil and water which caused environmental damage. The widespread metal pollution happened due to mining and smelting activities at the site may lead to multiple environmental problems [1-3]. The waste products from the mining process which are called tailings primarily consist of sand, silt, and clay sized materials with chemicals and process water. The mineralized rock from the mines is processed and reduced in size to recover the economic mineral. A significant volume of tailings produced from mining and processing is generally left as permanent features of the landscape after the mining ceases [4]. These tailings hold minerals such as chlorite, mica, quartz, etc. and also contain micronutrients [5-6]. The ecological restoration of dumps can be made using these mill tailings containing the nutrients and the effective method of stabilization of mine wastes is by growing a vegetation cover over the dumps [7-8]. The long-term stability, aesthetic view and low maintenance are possible by using native species for the vegetation cover. To assess the suitability of different species of plants, the tailings can be mixed with the soil in different proportions and their effectiveness can be studied [7]. Apart from the metal extraction, the mining activities are also common to extract thermal water which will be used for power generation and medical spa treatments [9].

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The mining activities in Kolar Gold Fields (KGF) were started around 2000 years back and has produced more than 800 tons of gold from the ore material of quantity 51 million tons. The quantity of gold yielded per ton of ore material has decreased gradually with time due to the exhaustion of the high-grade ore store. This has increased the processing costs and led to the closure of mining activities at this site for a few years. As the inferior quality of ore material was processed for yielding the gold, a huge quantity of mill tailings had generated and loaded in massive piles at KGF [10]. Around 32 million tons of tailings dumped in 15 locations along a stretch of 8 km in the mining area [11]. Effective management of these sites requires complex site characterization and selection of suitable remedial technology [12]. Rao and Reddy [5] studied the properties of the tailings at the KGF site to predict the effect of cyanide and its migration due to acid drainage. During the cyanidation process of gold extraction, there is a possibility of renaissance of cyanide in the leached solution and the factors influencing this regeneration are pH, time and temperature [13]. The concentrations of cyanide in the tailings will degrade naturally due to volatilization, leaching, and bacterial action [14].

The mining activities, which cause serious environmental threats, also cause problems to human health as the pollutants may enter directly or indirectly into human bodies through the food chain. As the industrial growth and economy of a country depend on the mining, it is very important to find the solutions to rectify the environmental problems associated with mining. Proper soil remediation techniques need to be identified and implemented at the site to avoid the problems associated with soil contamination. Soil washing with diluted chemical agents is effective in the removal of crystallized metal pollutants from the soil [15, 16]. Diluted acids such as EDTA and disodium ethylene diamine tetraacetate salt (Na_2-EDTA) have the capability to wash out the metal pollutants from the soil [17-20]. But, to protect the ecosystem from contamination, the efluent collected after soil washing must be treated before releasing into the environment as it contains the metal pollutants [21]. Plantation in the mining area will reduce the soil erosion and bring other ecological benefits. [5] Studied the nature of mill tailings in the study area for vegetation purpose and identified that species such as Babool, Neem, Eucalyptus and Gulmohar are apposite for the soil conditions in the study area.

In the current study, an effort is made to study the impact of dumping the mine tailings on the geotechnical characteristics of the study area. To study the geotechnical behavior of the soil at the site, four locations, namely, CN hill, Marikuppam, Champion reef and Coromandel were selected. The soil samples which were collected at the selected locations from a depth of 0.5 m were examined to know the changes in their geotechnical properties. It was found that there was not much variation in the index properties apart from the variation in specific gravity indicating the existence of heavy metals. The quality of ground water collected from the bore wells of the study area was also checked to know the level of water contamination at the site. The water tests on the samples showed that the water is slightly alkaline. To predict the suitability of these dumping areas for constructing the buildings, bearing capacity and settlement analyses were carried out with respect to each location at the study area. The geotechnical properties of the soil samples are taken as input for software to analyze its bearing capacity as well as settlement. The analyses were carried out with assumption of footing size and loads. The economical sizes of the footings at different sites were also estimated using the GEO5 software tool. It was observed that the soil is having sufficient bearing capacity and the settlements are within the allowable range. Even though the soil is having sufficient strength to take the structural loads, a contaminated soil still poses threats like water contamination when migrate into nearby water bodies. The heavy metals even enter into food chain through plants grown on this land. The soil remediation at the study area is required to remove the contaminants from the soil. Hence, the soil washing technique as a remediation technique was studied through column leaching tests. The column leaching tests were conducted with different leaching solutions and the effective leaching solution was identified. The percentage removal of metals with each solution were identified with respect to various metals presented in the soil. These results are useful to remediate the soil at the study area to remove the contaminants from the soil.

1. 1. Study Area   To study the effect of mining on soil properties, a gold mine area located at Kolar district in Karnataka state of India was selected, which is shown in Figure 1. The mining details of this area are specified in Table 1. Figure 2 shows the photographs of four locations in to study the effect of mining on soil properties, a gold mine area located at Kolar district in Karnataka state of India was selected, which is shown in Figure 1. The mining details of this area are specified in Table 1. Figure 2 shows the photographs of four locations in the study area. As the transportation of mined soil/tailings required a good infrastructure facility at the study area, it is required to conduct a survey as suggested by Ezirim and Okpoechi [22].

2. MATERIALS AND METHODS

The research methodology of the current research work is shown in the flow chart (Figure 3).

TABLE 1. Mining Details of the Study Area

Sites under consideration: CN hill, Marikuppam, Champion reef and Coromandel			
Mine starting year:	1880	Technique of gold extraction:	Cyanidation
Mine closure year:	2001	Volume of ore milled:	51.124 million tons
No. of mining shaft locations:	12	Volume of tailings generated:	32 million tons
No. of tailing dump sites:	15	Gold produced:	800.3 tons
Deepest mine: Location and shaft:	Champion reef Gifford shaft	Depth of the deepest mine:	3.2 km below ground surface
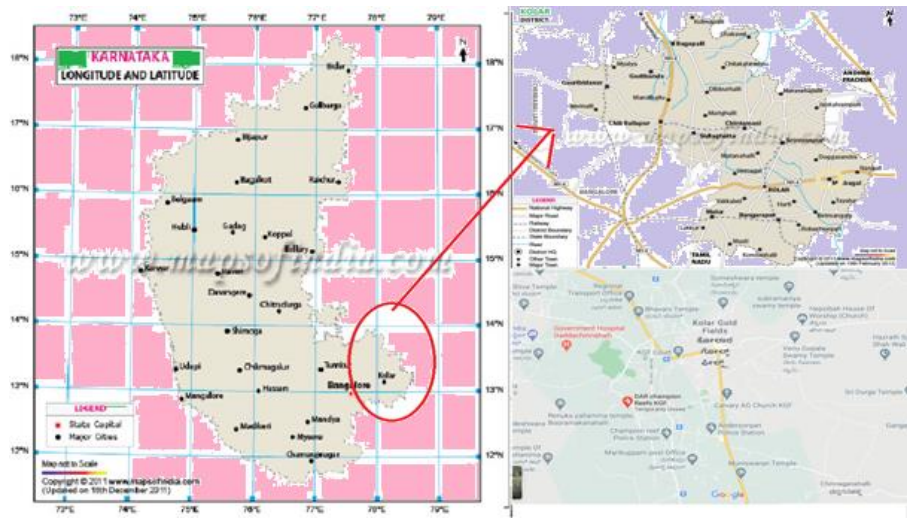
Figure 1. Study Area

(a) Marikuppam site

(b) Cyanide Hill (CN hill)

(c) Coromandel Site

(d) Champion reef- Gifford shaft dump site

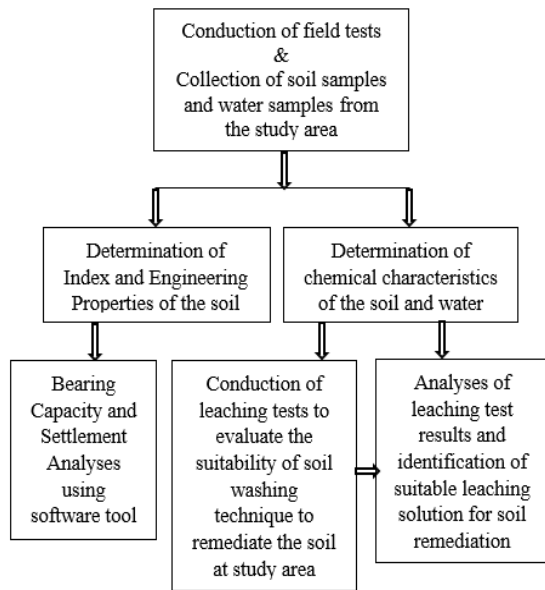**Figure 2.** Photographs at the Selected Locations of Study Area

Figure 3. Flowchart of the research methodology

2. 1. Mine Soil Samples   The disturbed and undisturbed samples of soil were collected from four major dump sites, i.e., Marikuppam (Residential-oldest dumpsite), Cyanide hill (CN hill), Coromandel and Champion reef- Gifford shaft. The properties of the collected soil samples such as specific gravity, plasticity characteristics, soil classification, compaction characteristics, density and permeability are determined according to the procedures given in various Indian Standard Codes [23-27] which are specified in Table 2.

TABLE 2. Index Properties of Mine Soil Samples

Location	Marik-uppam	CN hill	Coromandel	Champion reef
Specific Gravity	2.76	2.42	2.72	2.89
Liquid limit (%)	51.50	38.64	32.29	27.69
PL (%)	28.42	22.70	22.31	18.78
SL (%)	9.23	14.23	19.95	18.42
I_p (%)	23.08	15.94	9.98	8.91
% Gravel	9.7	14.85	0.75	0.7
% Sand	68.7	66.30	67.05	69.95
% Fines	21.6	18.85	32.2	29.35
Cu	10.12	3.51	4.42	2.86
Cc	1.4	0.68	1.77	1.36
Soil type as per IS classification	SW-SC	SC	SM	SM
In-situ bulk unit weight (kN/m³)	16.75	14.32	13.4	12.87

In-situ water content	21.63	10.27	2.19	1.52
In-Situ dry unit weight (kN/m³)	13.78	13	13.12	12.67
In-situ void ratio	0.965	0.83	1.03	1.24
Maximum dry unit weight from compaction test (kN/m³)	15.71	18.60	18.40	18.75
OMC (%)	20	14.8	14.2	15
Coefficient of permeability, k (cm/s)	2.04×10^{-3}	1.19×10^{-3}	2.32×10^{-4}	1.19×10^{-4}

2. 2. Water Samples at the Study Area   The ground water recharge characteristics of mining areas will vary as the backfill material properties differ from the original topsoil characteristics. The quality of ground water may also get affected as the backfill material may produce leachates of chemicals after mixing with the rain water. To analyze the quality of ground water in the study area, water samples at the selected locations of the study area were collected. The test results of the water samples are given in Table 3. The pH of natural water at study area ranges between 4–9 and the majority of the water samples are slightly alkaline. The presence of carbonates and bicarbonates of calcium and magnesium ions in the water show that the water is unsuitable for domestic purposes. Hardness can be removed by adopting some of the methods such as, addition of chemicals like lime/soda, using an ion exchange process such as resin etc.

2. 3. Direct Shear Tests on Soil Samples of Study Area   The direct shear tests were carried out using the guidelines given by soil testing methods (IS BIS 2720) [28] to know the shear strength parameters of test samples. To carry out the experiments, the oven dried soil

TABLE 3. Characteristics of Water Samples

Characteristics of water sample	Marikuppam	CN site	Coromandel	Champion reef
Acidity	0	0	0	0
Alkalinity (mg/l of CaCO₃)				
Phenolphthalein alkalinity	0	0	0	0
Methyl orange alkalinity	345.33	394.67	298.78	274.67
Total Hardness (mg/l of CaCO₃)	1185	1168	956	668
pH	7-7.5	6.5-7.5	6.5-7.5	6.5-7.5

sample was tamped in the shear box and the dry density was determined. The normal stress was applied through loading frame and shear stress through an electric motor. The normal stress was maintained constant and the shear load was applied till failure. The stress – strain curves were plotted to find the maximum shear stresses corresponding to the normal stresses applied. The normal and shear stresses of the samples tested were plotted on a graph and the shear strength parameters of soils were assessed. The parameters, thus estimated are as shown in Table 4.

2. 4. Triaxial Tests on Mine Soil Samples   To estimate the effective shear strength properties of mine soil samples, the triaxial test procedures and soil testing methods (IS BIS 2720) [29] were adopted. The diameter and length of test samples are 3.8 cm and 7.6 cm, respectively, which were compacted to their maximum density. The soil samples were subjected to vertical and lateral pressures to find the principal stresses corresponding to failure. The shear strength parameters of soil were obtained by plotting Mohr circles using these principal stresses. The pore pressures developed in the soil samples during testing were also noted to determine the effective values of stresses and shear parameters. The shear strength parameters, thus estimated are presented in Table 4.

2. 5. Consolidation Tests on Mine Soil Samples The consolidation tests on the soil samples were carried out as per the provisions in soil testing methods (IS BIS 2720) [30]. In the current investigation, these experiments were conducted to analyze the variations in consolidation properties such as compression index (Cc) and coefficient of consolidation (Cv). The normal stress applied on the soil samples was in the range of 50 to 800 kPa. The dial gauge readings (R) corresponding to different time periods (t) and pressure increments (σ^1) were noted and their corresponding voids ratio (e) were calculated. The e-log σ^1 plot was prepared and the slope of compression curve was taken as Cc. The R vs. log t plot was also prepared and Cv was estimated. The results

of consolidation tests and the estimated properties are arranged in Table 5.

2. 5. Leaching Tests on Soil Samples   The soil samples were tested with diluted chemical acids such as HCl, EDTA and combination of these two. The soil samples were subjected to a continuous supply of diluted acid solution and the effluent concentrations were measured with time. With this, the metals leached out with respect to each chemical acid were measured and the effective agent was identified [31].

3. RESULTS AND DISCUSSION

3. 1. Geotechnical Characteristics of Contaminated Soil Samples in The Study Area The physical and chemical characteristics of the soil of selected locations were studied in detail. The soil is sandy soil and the index properties are not affected much due to the contamination happened during the process of mining. The specific gravity is slightly higher than the normal soil, which indicates the existence of heavy metals in the mine soil. The shear parameters (C&Ø) are relatively not affected, indicating that the effect of contamination on shear strength is negligible. To assess the bearing capacity as well as the settlement characteristics of this soil, GEO5 software tool is used.

TABLE 4. Shear Strength Parameters of Soil Samples

Location	Marikuppam	CN hill	Coromandal	Champion reef
Direct Shear Test				
Cohesion, C (KPa)	12.8	14.6	15.4	16.8
Angle of internal friction, Ø	24.1	23.6	18.4	16.7
Triaxial Test				
Effective cohesion, C^1 (KPa)	8.2	7.7	5.9	4.8
Effective Angle of internal friction, $Ø^1$	29.8	26.2	21.7	19.4

TABLE 5. Consolidation Properties of the Soil in Study Area

Sample location	Bulk unit weight, kN/m³	Natural Moisture Content, %	Consolidation characteristics				
			Compression Index (Cc)	Swelling Index (Cs)	Pre-consolidation pressure (Pc), kN/m²	Coefficient of compressibility (a_v) cm²/kg	Coefficient of consolidation (Cv) m²/year
CN Site	14.32	10.27	0.12	0.009	176.52	0.12-2.48	0.69-4.87
Marikuppam	16.75	21.64	0.24	0.014	176.52	0.02-0.16	1.32-5
Champion Reef	12.87	1.52	0.21	0.015	147.1	0.08-0.51	1.27-3.05
Coromandel	13.4	2.19	0.19	0.011	98.07	0.1-1.71	2.51-9.09

3. 2. Ground Water Characteristics at The Study Area   The Acidity for all the water samples was found to be zero, which concludes that the water contains very minimal or nil hydrogen ions. Alkalinity for water samples from Marikuppam, CN site and Champion reef was found to be 345.33 mg/l of CaCO₃, 394.67 mg/l of CaCO₃ and 274.67mg/l of CaCO₃, respectively, which are within the permissible limit (600 mg/l of CaCO₃). But the lower values of alkalinity indicate that the water contains heavy metals (IS 10500-1991). Hardness of water in Marikuppam, CN site and Champion reef was found to be 1185 mg/l of CaCO₃, 1185 mg/l of CaCO₃ and 668 mg/l of CaCO₃ respectively, which is greater than the permissible limits (600 mg/l of CaCO₃). The pH of the water in the 3 selected study area is in the range of 7 to 7.5 which specifies the soil is slightly alkaline.

3. 3. Bearing Capacity Analysis of Soils in The Study Area   The The results of laboratory experiments were provided as input to the software and the bearing capacity was analyzed for a footing of size 1.6 m x 2 m placed at 1.5 m depth. The vertical load on the footing was taken as 300 kN with a service load of 214.29 kN. The footing details and soil properties are shown in Figure 4 (for Marikuppam soil). From the analysis, the bearing capacity of the Marikuppam soil was estimated as 1001.97 kPa and the factor of safety corresponding to a contact pressure of 112.89 kPa was found as 8.88 which is relatively high. Hence, to get an economical section using the inbuilt functions of the software, the footing size was revised. The revised size, thus obtained from Marikuppam soil is 0.7 x 0.7 m (Figure 5). The CN hill soil was studied in the similar
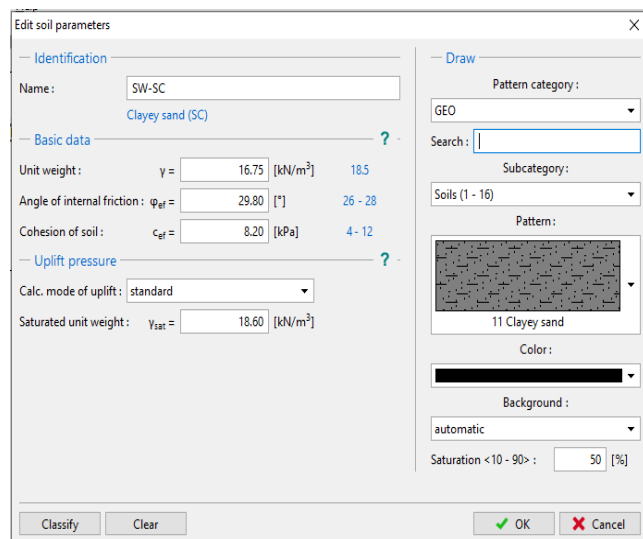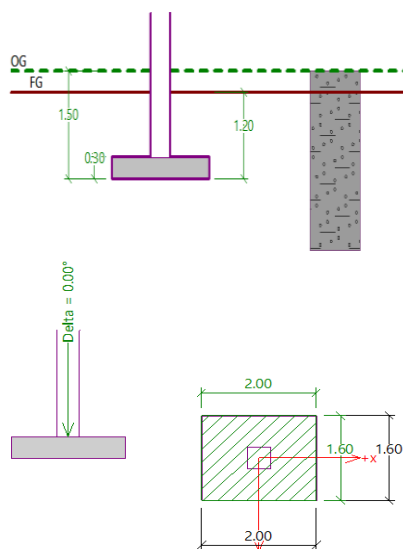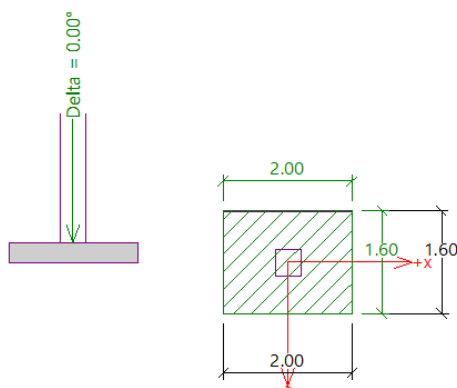

Figure 4. Foundation and Soil Details as Input to GEO5 Software (For Marikuppam Site)

Verification of spread footing bearing capacity
Vertical bearing capacity check
Shape of contact stress : rectangle
Most unfavorable load case No. 1. (Load No. 1)
Design bearing capacity of found.soil R_d = 1001.97 kPa
Extreme contact stress σ = 112.89 kPa

Factor of safety = 8.88 > 1.50
Bearing capacity in the vertical direction is SATISFACTORY
Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
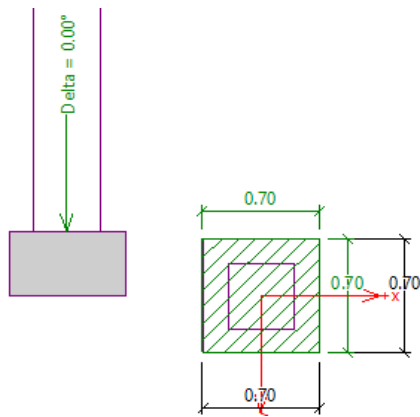Max. overall eccentricity e_t = 0.000<0.333
Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check
Most unfavorable load case No. 1. (Load No. 1)
Horizontal bearing capacity R_{dh} = 237.45 kN
Extreme horizontal force   H   =   0.00 kN

Factor of safety = 1000.00 > 1.50
Bearing capacity in the horizontal direction is SATISFACTORY

Verification of spread footing bearing capacity
Vertical bearing capacity check
Shape of contact stress : rectangle
Most unfavorable load case No. 1. (Load No. 1)
Design bearing capacity of found.soil R_d = 997.11 kPa
Extreme contact stress σ = 630.47 kPa

Factor of safety = 1.58 > 1.50
Bearing capacity in the vertical direction is SATISFACTORY
Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
Max. overall eccentricity e_t = 0.000<0.333
Eccentricity of load is SATISFACTORY
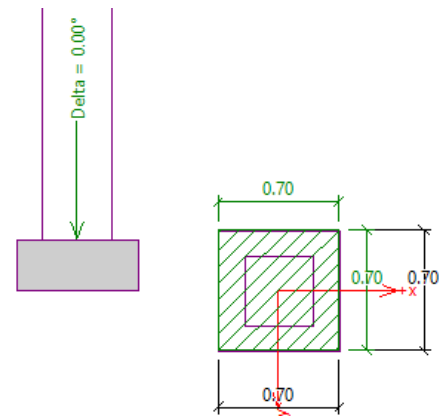
Horizontal bearing capacity check
Most unfavorable load case No. 1. (Load No. 1)
Horizontal bearing capacity R_{dh} = 183.30 kN
Extreme horizontal force   H   =   0.00 kN

Factor of safety = 1000.00 > 1.50
Bearing capacity in the horizontal direction is SATISFACTORY

Figure 5. Bearing Capacity Analysis of Marikuppam Soil

way and found that the footing dimension of 0.7 x 0.7 m was not sufficient (Figure 6). The revised dimension of 0.9 x 0.9 m yielded an economical design with a factor of safety of 1.55 and bearing capacity of 600.53 kPa. The economical footing dimensions obtained for Coromandel

and Champion Reef soils were 1.2 x 1.3 m and 1.5 X 1.5 m, respectively (Figures 7 and 8). The bearing capacities obtained for Coromandel and Champion Reef soils corresponding to these dimensions were estimated as 327.32 kPa and 240.45 kPa, respectively.

Verification of spread footing bearing capacity
Vertical bearing capacity check
Shape of contact stress : rectangle
Most unfavorable load case No. 1. (Load No. 1)
Design bearing capacity of found.soil R_d = 599.66 kPa
Extreme contact stress σ = 627.82 kPa

Factor of safety = 0.96 < 1.50
Bearing capacity in the vertical direction is NOT SATISFACTORY
Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
Max. overall eccentricity e_t = 0.000<0.333
Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check
Most unfavorable load case No. 1. (Load No. 1)
Horizontal bearing capacity R_{dh} = 156.91 kN
Extreme horizontal force   H   =   0.00 kN

Factor of safety = 1000.00 > 1.50
Bearing capacity in the horizontal direction is SATISFACTORY

Verification of spread footing bearing capacity
Vertical bearing capacity check
Shape of contact stress : rectangle
Most unfavorable load case No. 1. (Load No. 1)
Design bearing capacity of found.soil R_d = 600.53 kPa
Extreme contact stress σ = 387.61 kPa

Factor of safety = 1.55 > 1.50
Bearing capacity in the vertical direction is SATISFACTORY
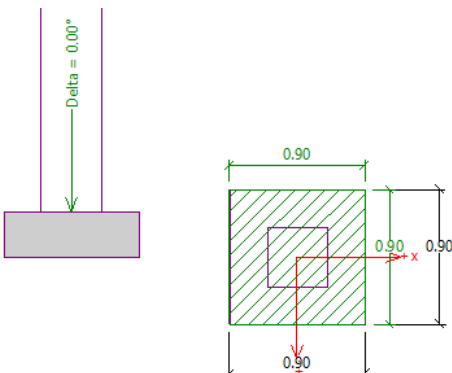**Verification of load eccentricity**
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
Max. overall eccentricity e_t = 0.000<0.333
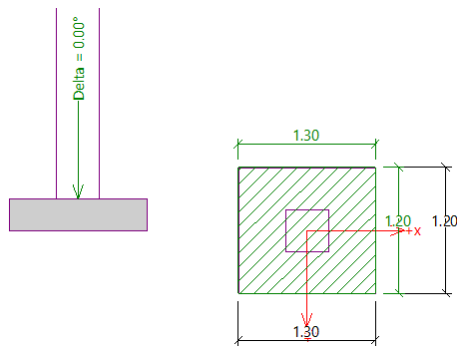Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check
Most unfavorable load case No. 1. (Load No. 1)
Horizontal bearing capacity R_{dh} = 162.99 kN
Extreme horizontal force   H   =   0.00 kN

Factor of safety = 1000.00 > 1.50
Bearing capacity in the horizontal direction is SATISFACTORY

Figure 6. Bearing Capacity Analysis of CN Site Soil

Verification of spread footing bearing capacity
Vertical bearing capacity check
Shape of contact stress : rectangle
Most unfavorable load case No. 1. (Load No. 1)
Design bearing capacity of found.soil R_d = 327.32 kPa
Extreme contact stress σ = 210.77 kPa

Factor of safety = 1.55 > 1.50
Bearing capacity in the vertical direction is SATISFACTORY
Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
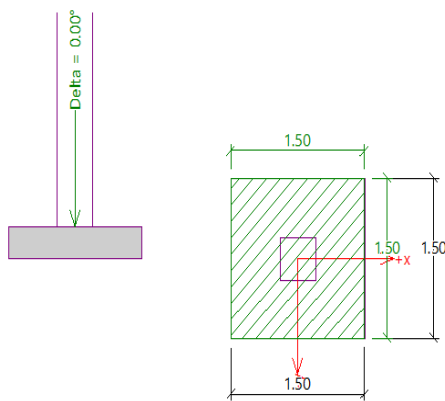Max. overall eccentricity e_t = 0.000<0.333
Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check
Most unfavorable load case No. 1. (Load No. 1)
Horizontal bearing capacity R_{dh} = 143.24 kN
Extreme horizontal force H = 0.00 kN

Factor of safety = 1000.00 > 1.50
Bearing capacity in the horizontal direction is SATISFACTORY

Figure 7. Bearing Capacity Analysis of Coromandel Site Soil

Verification of spread footing bearing capacity
Vertical bearing capacity check
Shape of contact stress : rectangle
Most unfavorable load case No. 1. (Load No. 1)
Design bearing capacity of found.soil R_d = 240.45 kPa
Extreme contact stress σ = 152.20 kPa

Factor of safety = 1.58 > 1.50
Bearing capacity in the vertical direction is SATISFACTORY
Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
Max. overall eccentricity e_t = 0.000<0.333
Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check
Most unfavorable load case No. 1. (Load No. 1)
Horizontal bearing capacity R_{dh} = 135.46 kN
Extreme horizontal force H = 0.00 kN

Factor of safety = 1000.00 > 1.50
Bearing capacity in the horizontal direction is SATISFACTORY

Figure 8. Bearing Capacity Analysis of Champion Reef Site Soil

3. 4. Settlement Analysis of Soils in the Study Area

The settlements that may occur at four locations of the study area were analyzed by taking the economical dimensions that were obtained from the bearing capacity analysis. The results of settlement analyses corresponding to four locations are shown in Figures 9-12. The estimated settlements respectively, for Marikuppam soil, CN site soil, Coromandel soil and Champion Reef soil are 13.5 mm, 10.5 mm, 7.4 mm and 6.1 mm which are less than the permissible settlement (25 mm). A parametric study was conducted to know the variations in the settlement values with the applied load. The settlements corresponding to vertical loads of 300 kN, 400 kN, 500 kN, 600 kN, 700 kN, 800= kN, 900 kN and 1000 kN were estimated with respect to each location of the study area (Table 6). From this table, it can be observed that the settlements corresponding to vetical load of 600 kN and above are above 25 mm. The effective dimensions of footings corresponding to these vertical loads to keep the settlements below 25 mm are given in Table 7.

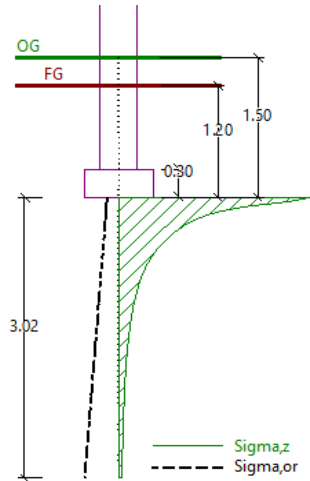**TABLE 6.** Settlements (mm) with different vertical loads

Vertical Load	Marik-uppam	CN hill	Coromandel	Champion reef
300	13.5	۱۰/۷	۷/۷	۶/۵
400	18.5	۱۴/۵	۱۰/۴	۸/۷
500	23.4	۱۸/۳	۱۳/۲	۱۱/۰
600	28.3	22.2	۱۶/۰	۱۳/۴
700	33.2	26.0	۱۸/۸	۱۵/۶
800	38.2	۳۰/۰	۲۱/۷	۱۸/۰
900	43.1	۳۳/۸	۲۴/۴	۲۰/۳
۱۰۰۰	۴۸/۲	۳۷/۸	۲۷/۳	۲۲/۸

TABLE 7. Effective sizes (m) of footings subjected to different vertical loads

Vertical Load	Marik-uppam	CN hill	Coromandel	Champion reef
۳۰۰	۰/۷x۰/۷	0.9x0.9	۱/۲x۱/۳	۱/۵x۱/۵
۴۰۰	۰/۷x۰/۷	0.9x0.9	۱/۲x۱/۳	۱/۵x۱/۵
۵۰۰	۰/۷x۰/۷	0.9x0.9	۱/۲x۱/۳	۱/۵x۱/۵
600	0.8x0.8	0.9x0.9	۱/۲x۱/۳	۱/۵x۱/۵
700	1.0x1.0	1.0x1.0	۱/۲x۱/۳	۱/۵x۱/۵
800	1.1x1.1	1.1x1.1	۱/۲x۱/۳	۱/۵x۱/۵
900	1.2x1.2	۱/۳x۱/۳	۱/۲x۱/۳	۱/۵x۱/۵
۱۰۰۰	۱/۵x۱/۵	۱/۴x۱/۴	۱/۴x۱/۴	۱/۵x۱/۵

Settlement and rotation of foundation - results

Foundation stiffness:
Average modulus of deformation E_{def} = 7.79 MPa
Foundation in the longitudinal direction is rigid (k=303.21)
Foundation in the direction of width is rigid (k=303.21)

Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.33
Max. eccentricity in direction of base width e_y = 0.000<0.33
Max. overall eccentricity e_t = 0.000<0.33
Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement   = 13.5 mm
Depth of influence zone = 3.02 m
Rotation in direction of x = 0.000 (tan*1000); (0.0E+00 °)
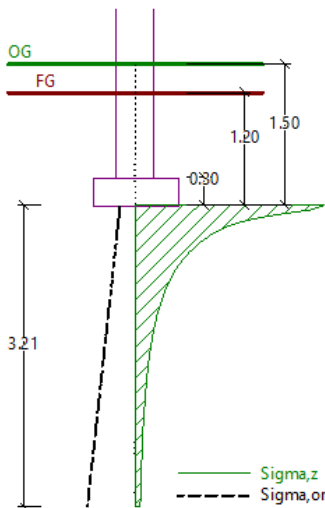Rotation in direction of y = 0.000 (tan*1000); (0.0E+00 °)

Figure 9. The Estimated Settlement of Marikuppam Soil

Settlement and rotation of foundation - results

Foundation stiffness:
Average modulus of deformation E_{def} = 7.79 MPa
Foundation in the longitudinal direction is rigid (k=142.66)
Foundation in the direction of width is rigid (k=142.66)

Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
Max. overall eccentricity e_t = 0.000<0.333
Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement   = 10.5 mm
Depth of influence zone = 3.21 m
Rotation in direction of x = 0.000 (tan*1000); (0.0E+00 °)
Rotation in direction of y = 0.000 (tan*1000); (0.0E+00 °)

Figure 10. The Estimated Settlement of CN Site Soil

3. 5. Results of Column Leaching Tests   The soil in the study area needs to be remediated to remove the contaminants and to avoid problems due to contamination. The initial concentrations of chromium, lead, nickel, copper and zinc in the soil samples, respectively, were 45.72, 27.33, 19.78, 9.49 and 6.99 mg/kg. The metal concentrations were almost same for all the four locations and hence the soil samples were mixed thoroughly and the leaching tests were conducted with different leaching solutions. The diluted acids were passed through the soil and the effluent concentrations were determined. From the effluent concentrations, the quantity of metals leaached were estimated and the percentage removal of metals were calculated. The metals leached out with respect to each leaching solution are given in Table 8. From this table it can be observed
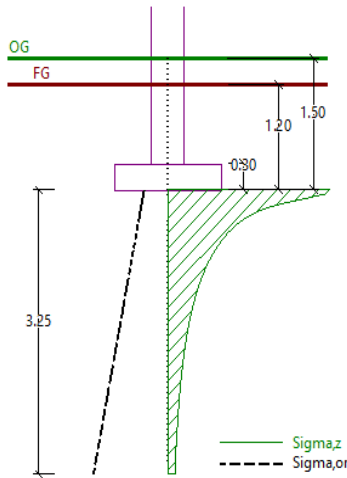
Settlement and rotation of foundation - results

Foundation stiffness:
Average modulus of deformation E_{def} = 7.79 MPa
Foundation in the longitudinal direction is rigid (k=47.34)
Foundation in the direction of width is rigid (k=60.19)

Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
Max. overall eccentricity e_t = 0.000<0.333
Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement = 7.4 mm
Depth of influence zone = 3.25 m
Rotation in direction of x = 0.000 (tan*1000); (0.0E+00 °)
Rotation in direction of y = 0.000 (tan*1000); (0.0E+00 °)

Figure 11. The Estimated Settlement of Coromandel Site Soil

Settlement and rotation of foundation - results

Foundation stiffness:
Average modulus of deformation E_{def} = 7.79 MPa
Foundation in the longitudinal direction is rigid (k=30.81)
Foundation in the direction of width is rigid (k=30.81)

Verification of load eccentricity
Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.000<0.333
Max. overall eccentricity e_t = 0.000<0.333
Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement = 6.1 mm
Depth of influence zone = 3.27 m
Rotation in direction of x = 0.000 (tan*1000); (0.0E+00 °)
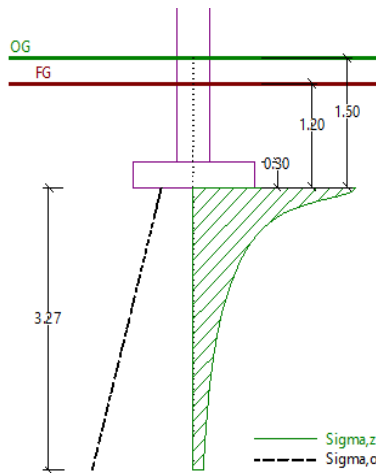Rotation in direction of y = 0.000 (tan*1000); (0.0E+00 °)

Figure 12. The Estimated Settlement of Champion Reef Site Soil

that the highest removal efficiency was achieved with 0.1 N HCl + EDTA. With this solution, the percentage removal of chromium, lead, nickel, copper and zinc in the soil samples were 66.17%, 77.84%, 83.74%, 88.74% and 93.44%, respectively. It was found that a combination of HCl and EDTA solution diluted to 0.1 normality has yielded the best results and it can be used as a leaching agent to implement the soil washing technique as remediation in the study area. The results are similar to the Indian reported data [31].

TABLE 8. Percentage removal of metals with different leaching solutions

Leaching Solution	Chromium	Lead	Nickel	Copper	Zinc
0.1 N HCl	23.35	33.54	50.35	62.93	57.30
0.1 N EDTA	44.72	57.51	61.33	84.47	81.58
0.1 N EDTA+HCl	66.17	77.84	83.74	88.74	93.44

4. CONCLUSIONS

The Geotechnical behaviour and remediation of soil in the mining area was studied in detail. The soil properties corresponding to four locations, namely Marikuppam, CN site, Coromandel and Champion reef were studied. It was observed that there were not much variations in the index properties The analyses of bearing capacity and settlement of soils were carried out using GEO5 software tool. From the analyses the minimum dimensions of the footings required at 1.5 m depth for Marikuppam, CN site, Coromandel and Champion reef soils were estimated to be 0.7 x 0.7 m, 0.9 x 0.9 m, 1.2 X 1.3 m and 1.5 x 1.5 m, respectively. A parametric study was also conducted to know the variations in the settlements with respect to different loading conditions. Though the soil is having sufficient strength to take the structural loads, it may cause contamination of nearby water bodies as it contains

considerable amounts of heavy metals. Hence, to remediate the soil, the soil washing technique was studied by conducting the column leaching tests with three leaching solutions. It was found that the soil washing technique can be effectively used as a remediation technique to clean up the site from heavy metals with a combination of diluted HCl and EDTA.

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Persian Abstract

چکیده

معادن کنترل نشده و باطله های تولید شده می تواند اثرات زیست محیطی قابل توجهی مانند آلودگی آب، هوا و خاک داشته باشد. در مطالعه حاضر، خاک آلوده معادن طلا واقع در ایالت کارناتاکا هندوستان برای شناخت رفتار ژئوتکنیکی این خاک به عنوان ماده پی و پیشنهاد یک روش اصلاح خاک مناسب برای جلوگیری از آلودگی آب های اطراف مورد مطالعه قرار گرفته است. وزن واحد خشک خاک در مکان های انتخاب شده از ۱۵.۷۱ تا ۱۸.۷۵ کیلونیوتن بر متر مکعب متغیر بود. پارامترهای مقاومت برشی مؤثر تعیین‌شده از نتایج آزمایش سه محوری به ترتیب در محدوده ۴۸ – ۸.۲ کیلونیوتن بر متر مربع و ۱۹.۴۰ – ۲۹.۸۰ درجه برای چسبندگی و زاویه اصطکاک داخلی بوده است. نمونه‌های خاک از نظر ظرفیت باربری و نشست با استفاده از نرم‌افزار GEO5 مورد تجزیه و تحلیل قرار گرفت و پی ها به لحاظ اقتصادی مورد ارزیابی قرار گرفتند. مشاهده شد که خاک دارای ظرفیت باربری کافی بوده و نشست‌ها در محدوده مجاز قرار دارند. تجزیه شیمیایی نمونه های خاک نشان داد که مقادیر قابل توجهی فلزات سنگین در خاک معدن وجود دارد. اگرچه استحکام خاک خوب است، اما آلاینده های موجود در خاک ممکن است باعث آلودگی آب های زیرزمینی و آسیب به پی ها شده باشد. از این رو، تکنیک شستشوی خاک به عنوان یک تکنیک اصلاحی نیز از طریق آزمایش‌های آبشویی ستونی با استفاده از محلول‌های لیچینگ مختلف مورد مطالعه قرار گرفت و مشخص شد که اسید هیدروکلریک (HCl) رقیق‌شده با اتیلن دی‌آمین تتراستیک اسید (EDTA) می‌تواند به طور مؤثر فلزات سنگین را از خاک حذف نماید.