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Influence of Amang (Tin Tailing) on Geotechnical Properties of Clay Soil

(Pengaruh Amang Timah Terhadap Sifat Geoteknik Tanih Lempung)

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ABSTRACT

Amang or tin tailing is commonly found in the vicinity of disused mining area and responsible in downgrading the water quality, landscape and mechanical behaviour of soils. It was generated from extraction process of separating valuable metal from particular ore. This paper presents the geotechnical characteristics of amang-contaminated clay soil. The geotechnical properties of uncontaminated soils were studied in order to compare to that of amang-contaminated soils. The base soil used in this study represents completely weathered horizon of metasedimentary rock. Meanwhile, tin tailing sample was taken from the disused mine at Sungai Lembing, Pahang. The geotechnical characterisations of base soil and contaminated soils were determined based on consistency index, compaction behaviour, hydraulic conductivity and undrained shear strength (UU tests). Contaminated soil samples were prepared by adding 5, 10 and 20% of tailing, based on dry weigh of the studied base soil. The results from the particle size distribution analysis showed that residual soil from metasedimentary rock comprised 42.6% clay, 32.2% silt and 25.2% sand whilst tailing was dominated by 98% of sand fraction. XRD analysis indicated the presence of quartz, kaolinite and muscovite minerals in the studied soil. The specific gravity of soil used is 2.67 and the pH is 3.88. Tailing found to have higher specific gravity of 3.37. The consistency index of contaminated soils showed that liquid limit, w_L and plastic limit, w_P decreased with the increase in the percentage of tailing added to the soil samples. The value of maximum dry density, $\rho_{dry\ max}$ increased while optimum moisture content decreased due to the increase in tailing content in soil sample. The permeability of contaminated soil also increased with the increase in tailing contents ranged from 19.8 cm/hr to 23.8 cm/hr. The undrained shear strength, C_u, of contaminated soil decreased from 646 kPa (5% of tailing) to 312 kPa (20% of tailing) suggesting that the presence of tailing has influenced the geotechnical properties on the studied soil.

Keywords: Amang (tin tailing); compaction; geotechnical characterisation; residual soil; shear strength

ABSTRAK

Amang atau tahi lombong biasa ditemui di sekitar kawasan lombong terbiar dan bertanggungjawab dalam menurunkan kualiti air, lanskap dan sifat mekanik tanih. Ia terhasil daripada proses pengekstrakan bagi memisahkan logam bernilai daripada sesuatu bijin. Kertas ini membentangkan sifat-sifat geoteknik tanih lempung tercemar amang. Ciri-ciri geoteknik tanih tidak tercemar telah dikaji bagi membandingkan dengan tanih-tanih tercemar amang. Tanih asas yang digunakan dalam kajian ini mewakili bahagian tanih yang terluluhawa sepenuhnya bagi batuan metasedimen. Sementara itu, sampel amang telah diambil dari kawasan bekas lombong di Sungai Lembing, Pahang. Pencirian geoteknik tanih asas dan tanih tercemar ditentukan berdasarkan indeks ketekalan, kelakuan pemadatan, keberkonduksian hidraulik dan kekuatan ricih tak bersalir (ujian UU). Sampel-sampel tanih tercemar telah disediakan dengan menambahkan 5, 10 dan 20% amang berdasarkan berat kering tanih asas yang dikaji. Keputusan daripada analisis taburan saiz partikel menunjukkan tanih baki daripada batuan metasedimen terdiri daripada 42.6% lempung, 32.2% lodak dan 25.2% pasir manakala amang didominasi oleh 98% pasir. Analisis XRD menunjukkan kehadiran kuarza, mineral kaolinit dan muskovit dalam tanih yang dikaji. Graviti spesifik tanih yang digunakan adalah 2.67 dengan pH 3.88. Amang mempunyai graviti spesifik yang lebih tinggi iaitu 3.37. Indeks kekonsistenan tanih tercemar menunjukkan had cecair, w_L dan had plastik, w_P berkurangan dengan peningkatan dalam peratusan penambahan amang kepada sampel tanih. Nilai maksimum ketumpatan kering $\rho_{dry\ max}$ telah meningkat manakala kandungan lembapan optimum menyusut akibat daripada peningkatan dalam kandungan amang dalam sampel tanih. Ketelapan tanih tercemar juga bertambah dengan peningkatan dalam kandungan amang berjulat daripada 19.8 cm/j hingga 23.8 cm/j. Kekuatan ricih tak bersalir, C_u tanih tercemar berkurangan daripada 646 kPa (5% amang) hingga 312 kPa (20% amang) mencadangkan bahawa kehadiran amang mempengaruhi sifat-sifat geoteknik tanih yang dikaji.

Kata kunci: Amang (tahi lombong); pencirian geoteknik; pemadatan; kekuatan ricih; tanih baki

INTRODUCTION

Tin mining activity in Malaysia started in the 1600's, situated mainly in Kedah, Perak and Selangor. The rise in demand for tin led to the extensive exploration and extraction to other states in Malaya at that period. Tin mining has been a major activity of Malaysia since 1848. Since then tin mine industries rapidly grew in order to fulfil the world's demand for that raw material. Malaysia became the largest tin producer in 1883. In 1979, tin production of Malaysia is equivalent to 31% of world's tin production. Tin mine used to contribute between 80 and 90% of the total mineral export of Malaysia (Yip 1969). Mining industry has been responsible in the development of basic infrastructures such as road and railway system in order to establish network system among principal towns. It has given a massive impact on the initial rural development in Malaysia. Scarce of old tin mine activity can be seen until nowadays and some have been developed for settlement, township or recreation projects.

Year of 1983 was the starting point of significant drop in world's demand for tin. It was recorded that only 63 mines were operating in 1996 in Malaysia (Mohsein et al. 2008). The main reason was the increase in cost of operation. Disused tin mines can be a source of environmental related problems. Chiras (2001) mentioned that mining activity was responsible in the reduction of natural habitat, soil erosion and air and water pollution. It was estimated that about 200,000 hectare of ex-mine lands was found throughout Malaysia after 115 years of mining activity (Shamsuddin 1990). A common practice during that time was to dump the mines' waste products on ground surface. The waste might be shifted to nearby water courses and degraded the water quality in terms of physical and chemical aspects. The waste material consists of unstable minerals that can be purified for other valuable minerals.

Reduction in tin mining activity and the price of world's tin, had shifted the activity toward processing the tin by-product (tin tailing or amang) for other minerals (Ismail et al. 2003). Amang is also known as tailing sand literally and used by mining community to depict a mixture of tin ore, sand and mineral initially discarded by miners (Azlina et al. 2001; Ismail et al. 2003; Mohsein et al. 2008). Valuable minerals extracted from amang are such as illmenite, zircon, monazite, xenotime, columbite and struvirite. These minerals have a high demand in the production industry (Redzuan et al. 2002). However, these minerals are radioactive and may contaminate other associated minerals. Large volume of water was used in amang processing stages has contributed to the environmental pollution of soil and water systems. As amang mixed up with soil system, it changed the soil quality and also altered the mechanical behaviour of the contaminated soil. Because of the many abandoned tin mine land, the vast amount residual soils might be used for construction materials and/or site for foundation of engineering structures.

A few cases of tailing dam failures were recorded such as Merriespruit and Omai gold tailing dams in South Africa and Guyana in 1994 and 1995, respectively. Failure of Merriespruit gold tailing dam in South Africa was unusual and never happen before in such a catastrophic fashion (Fourie & Papageorgiou 2001). In Omai tailing dam failure, 2.9 million m^3 of mill effluent containing 25ppm total cyanide reached the Omai River (Vick 1997). It was not only confined to the issue of environmental degradation of nearby river system but the design itself elicited to the failure of the dam (Davies 2002). This issue has led to the fundamental studies on the engineering behaviour of tailing material in contributing on liquefaction problem. It was established acknowledge that silty sands are the most common type of soil involved in static and earthquake liquefaction (Yamamuro & Lade 1998). Therefore, this study aimed to investigate some engineering characteristics of amang or tailing-contaminated soil. However the presence of radioactive elements was beyond the scope of this study and further information was referred to previous studies (e.g. Ismail et al. 2003; Mohsein et al. 2008). The results from the engineering behaviour of tailing-contaminated soils were compared with that of uncontaminated soil for reference. It is useful to establish the information regarding to mechanical behaviour of contaminated soil since the disused mine land or soils will be redeveloped or recycled for other engineering practices such as embankment and foundation.

MATERIALS AND METHODS

SAMPLE COLLECTION AND PREPARATION

Sampling of base soil and amang (tin tailing) used in this study were carried out at Sungai Lembing disused mine area (Figure 1). A bulk soil sample from completely weathered profile (grade VI) was collected from weathered metasedimentary rock's outcrop (Figure 1(a). Similarly, a bulk sample of amang sample was collected at nearby abandoned plant. All disturbed samples were collected using auger at 30cm below the ground surface. Undisturbed soil samples were collected and preserved for shear strength tests. Soil and amang samples were dried at room temperature for a few days. Soil samples then were divided into 4 subdivisions to represent the different contents of amang contamination. Amang was added to soil sample based on 0, 5, 10 and 20% of the soil dry weight. The mixture of base soil and amang was thoroughly mixed and the mixture was permitted to cure in airtight container at ambient temperature for 14 days prior to testing.

EXPERIMENTAL PROCEDURES

Sample characterisations was performed on uncontaminated base soil and amang used in this study. Seven uncontaminated base soils were analysed for index properties and classified as per unified soil classification scheme. Standard methods adopted in order to determine the basic and geotechnical

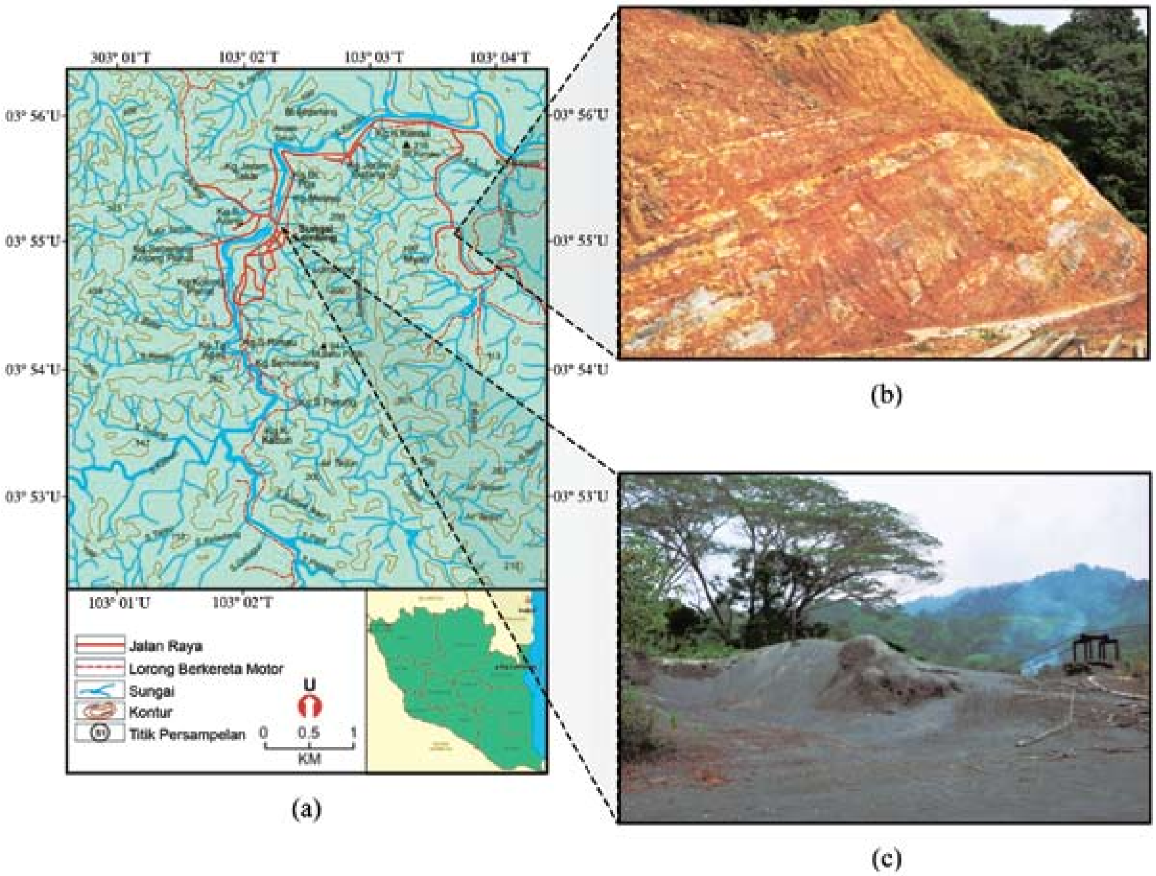


FIGURE 1. (a) The location of soil sampling at Sungai Lembing area, (b) Base soil collected at top of weathered metasedimentary rock and (c) amang or tin tailing openly dumped near to Sungai Lembing river

characterisations for the studied soil were referred to the British Standard Institution 1377 (1990a; 1990b; 1990c; 1990d) Part 2, 4, 5 and 7. The soil characterisation analysis performed on uncontaminated base soil consisted of particle size distribution, x-ray diffraction (XRD) analysis, specific gravity, pH, consistency index (liquid and plastic limits), compaction, permeability and undrained shear strength. Particle size distribution was carried out based on dry sieving and pipette techniques. The presence of dominant clay minerals was determined from the XRD analysis. A Phillip x-ray diffractometer equipped with Ni-filtered CuK$_\alpha$ radiation generate at 30kV and 30mA with a scan speed of $4^o 2\theta$ min^{-1}. Soil samples were powdered prior to analysis in order to determine the minerals present in the studied soil. A pycnometer bottle method was applied to determine the soil specific gravity. Similarly a simple amang characterisation was also performed in this study. The amang samples were studied in terms of particle distribution, XRD and specific gravity.

In order to establish the effects of amang contamination on the base soil, the amang-contaminated soils were prepared and tested in terms of geotechnical characteristics. Data from the amang-contaminated soil were compared to that of uncontaminated soils. Four contaminated soils were analysed including consistency index, compaction, permeability and undrained shear strength. Each set of contaminated soils consisted 5, 10 and 20% of amang contents. After curing period, the consistency index and compaction tests were carried out at different contents of added amang. The consistency index of liquid limit was determined by using the Casagrande cup techniques. Soil sample was placed in Casagrande cup and groove of 13 mm wide was made down to its centre. The metal cup then was repeatedly dropped until the groove closes and the number of blows was recorded. The representative moisture content at liquid limit is equivalent to 25 blows. The plastic limit was defined by rolling 3 mm diameter of soil thread or it started to crumble. The standard Proctor 2.5 kg compaction effort was used to determine the values of maximum dry density, $\rho_{dry\ max}$ and optimum water content, w_{opt}. For each amang content, about 2.5 kg of contaminated soil was used to perform the test. The soil samples were compacted with 2.5 kg rammer at high of 30 cm into three uniform thickness in a standard cylinder mould. Twenty five blows were applied on to each layer. At the end of test, sample was collected and oven dried to determine the moisture content. A similar procedure was repeat to the same soil for four times with higher moisture content samples. The compaction curves delineated from the dry density and moisture content values wold be used to determine the values of $\rho_{dry\ max}$ and w_{opt} for each fraction of amang-contaminated soil. The permeability of contaminated soils was determined by a flling head permeameter method. The unconsolidated undrained tests for contaminated soils were performed for each percentage of added amang. For each test of particular added amang content, three samples were prepared at maximum dry density, $\rho_{dry\ max}$ and optimum moisture content, w_{opt}. Therefore, nine samples were prepared in standard compaction mould. Prior to shearing, confining stresses of 140, 280 and 420 kPa were imposed to the samples under cell pressure, σ_3. Samples were sheared at constant strain rate of 1.00 mm min^{-1}.

RESULTS AND DISCUSSION

CHARACTERISTICS OF UNCONTAMINATED SOIL

Amang was dominated by sand fraction of 98% whilst silt and clay were represented by 0.6 and 1.4%, respectively. Meanwhile the base soil of completely weathered metasedimentary rock can be classified as clay texture. The base soil comprised more than 50% of fine grain of clay and silt fractions (Table 1). The particle size distribution curves for both materials are shown in Figure 2. The specific gravity (G_s) for soil sample and amang used in this study was 2.67 and 3.37. The pH of soil was 3.88 which considered very acidic based on classification odopted by Leper (1964). The results from the XRD analysis of base soil showed the presence of quartz, kaolinite and muscovite. Quartz minerals are usually resistant to chemical weathering while feldspar group tends to change to clay minerals. The clay mineral of kaolinite is dominant in studied soil and probably has affected its G_s value. The presence of kaolinite can also be an indicator that the soil has at final phase of weathering process (Siti Nurshakiren 2010). Menawhile, the XRD analysis of amang samples indicated the presences of arsenopyrite, realgar, chalcopyrite, pyrite, hematite and quartz minerals. Arsenopyrite (FeAsS) can slowly oxidise, releasing arsenic into water system. Realgar (α-As_4S_4) known as arsenic sulfide is soft with specif gravity of 3.5. Chalcopyrite ($CuFeS_2$) usually darker yellow and its occurences is often massive. Pyrite (FeS_2) is a common sulfide minerals and is usually associted with other sulfides or oxides in quartz vein, sedimentary rock and metamorphic rocks. Reaction of pyrite with oxygen and water generates sulfate which attribute acid mine drainage (AMD).

The consistency indexs of liquid limit and plastic limit for uncontaminated soils are 55.5% and 29.6%, respectively (Table 1). These values gave plasticity index of 25.9. The plotting of the fines on the Casagrande plasticity chart classified the soil as CI (inorganic clay) material (upper A-line) under the unified soil classification scheme (Figure 3). The values of $\rho_{dry\ max}$ and w_{opt} of the uncontaminated soils were determined from compaction curves achieved from the standard Proctor compaction test. The mean values of $\rho_{dry\ max}$ and w_{opt} were 1.65 gcm^{-3} and 14.9%, respectively. Permeability tests of uncontaminated base soil gave 14.5 mm/hr. The results of unconsolidated undrained triaxial tests were performed on uncontaminated soil is shown in Table 1. The undrained soil strength, C_u of the uncontaminated samples was 646 kPa.

GEOTECHNICAL CHARACTERISTICS OF CONTAMINATED SOILS

The effect of hydrocarbon contamination has clearly seen on the geotechnical properties of the studied soils. The results from the consistency index tests of amang-contaminated soils is shown in Table 2(a) and graphically presented in Figure 4. Plasticity index, I_P represents the difference in water content, w between liquid limit, w_L and plastic limit. It can be seen that the w_L and w_P decreased

TABLE 1. The soil characteristics of uncontaminated soil of base soil (completely weathered metasedimentary rock) and amang

Properties of Materials	Base Soil	Amang (tailing sand)
Particle Size Distribution (%)		
Sand	25.2	98.0
Silt	32.2	0.6
Clay	42.6	1.4
Mean Specific Gravity, G_s	2.67	3.37
XRD analysis	Quartz, kaolinite, muscovite	Arsenopyrite, realgar, chalcopyrite, pyrite, hematite, quartz
Consistency Index		
Liquid limit, w_L (%)	55.5	-
Plastic limit, w_P (%)	29.6	-
Plasticity index, I_p (%)	25.9	-
Compaction Test		
Max. dry density, $\rho_{dry\ max}$ (gm^{-3})	1.65	-
Opt. water content, w_{opt} (%)	14.9	-
Permeability, k (mm/hr)	14.5	-
Undrained strength, C_u (kPa)	646.0	-

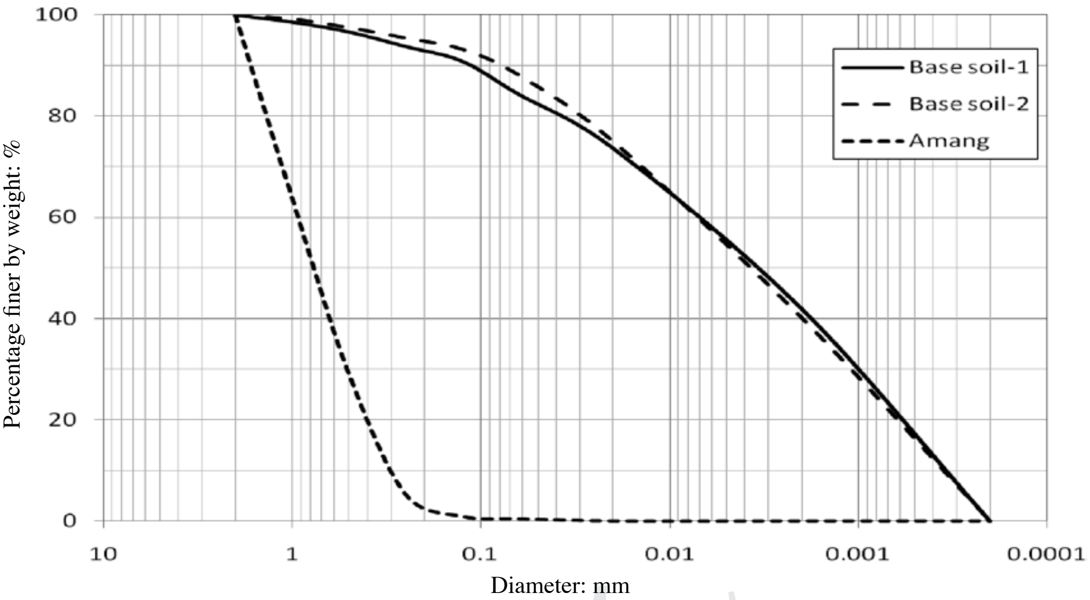
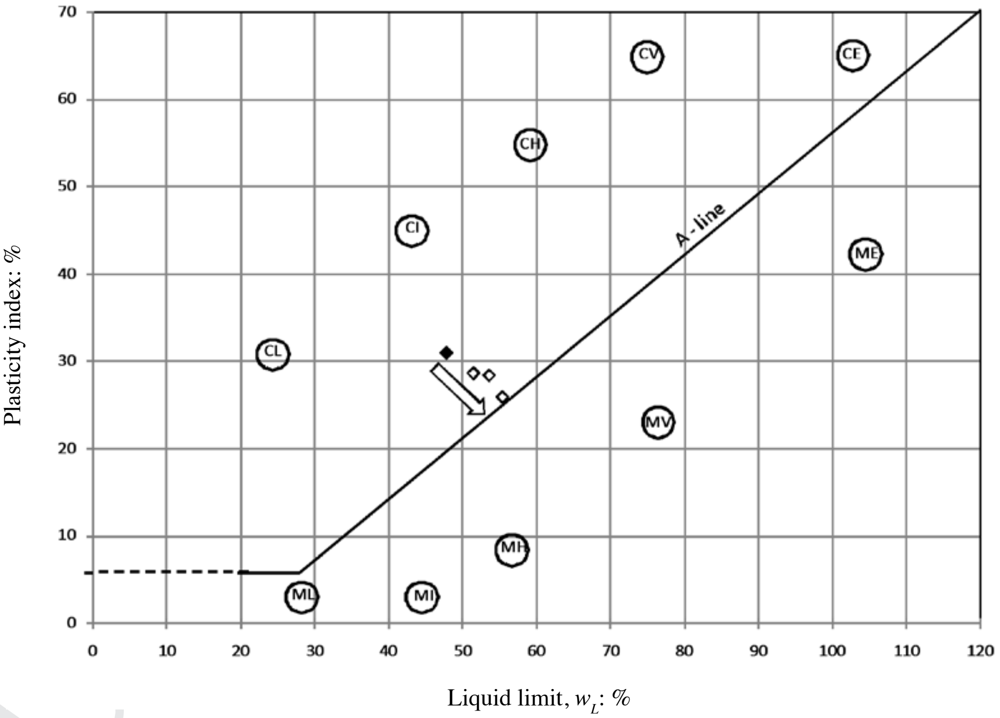


FIGURE 2. Particle size distribution of the base soil and amang used in this study



(Notes: Fine material: C=clay; M=silt. Plasticity: L=low; I=intermediate; H=high; V=very high; E=extremely high)

FIGURE 3. Casagrande plasticity chart of the uncontaminated (black symbol) and amang-contaminated soils (blank symbols). Arrow shows the direction of increasing amang contents in soil samples

with the increase in amang content. However, the plasticity index, I_p, increased with added amang contents. The drop in w_L and w_P values were 13.7% and 35.5%, respectively. Meanwhile the increase in I_p was represented by 11.2%. The results indicated that an increase in amang contents has lowered the soil ability to hold water. The lower the plastic limit value, the closer the soil to liquid behaviour. From the Casagrande plasticity chart, the increase in added content of amang has dragged the points toward A-line (Figure 3). This indicated that the presence of amang has changed the contaminated soil from clay to silty soil.

The maximum dry density, $\rho_{dry\ max}$ and optimum moisture content w_{opt}, from the compaction tests are shown in Table 2(b). Compaction curves of contaminated and

TABLE 2. Variation of (a) consistency index and (b) compaction tests values of contaminated soils

a. Consistency tests

Amang ctt. (%)	Liquid limit, w_L (%)	Diffr.$^{\Psi}$ (%)	Plastic limit, w_P (%)	Diffr.$^{\Psi}$ (%)	Plasticity Index, I_P (%)	Diffr.$^{\Psi}$ (%)
0	55.5	13.7	29.6	35.5	25.9	11.2
5	53.7		25.3		28.4	
10	51.5		22.9		28.6	
20	47.9		19.1		28.8	

$^{\Psi}$Diffr. - Different values (in %) of w_L or w_p or I_p at (0-20%)

b. Compaction tests

Amang ctt. (%)	Max. Dry density, $\rho_{dry\ max}$ (gm^{-3})	Diffr.$^{\Psi}$ (gm^{-3})	Opt. water content, w_{opt} (%)	Diffr.$^{\Psi}$ (%)
0	1.66	0.1	14.0	3.5
5	1.62		14.5	
10	1.59		16.0	
20	1.56		17.5	

$^{\Psi}$Diffr. - Different values of w_L or w_p or I_p at (0-20%)

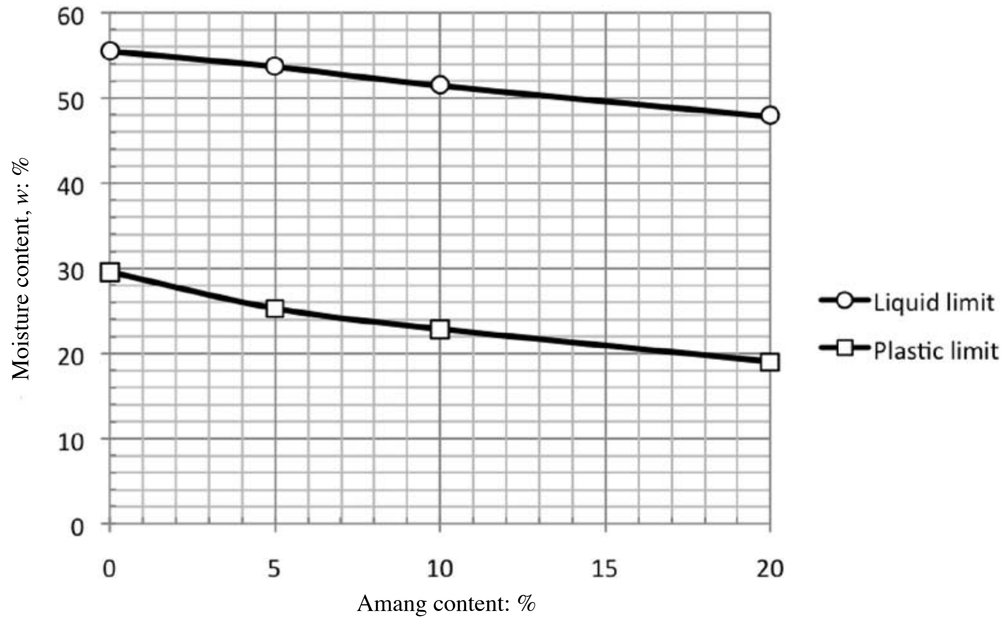


FIGURE 4. The relationship between liquid limit and plastic limit values with amang contents in the soil mixture

uncontaminated soils were presented in Figure 5. It is shown that the compaction curves for contaminated soils moved to the right side of the uncontaminated curve. The effect of amang content in contaminated soils was clearly seen in Figure 6. The $\rho_{dry\ max}$ decreased from 1.65 to 1.55 gcm^{-3} as added amang content in soils were increased from 0% to 20%. While the w_{opt}, increased from 14.9% to 18.3% when the amang content increased. This suggested that the studied soil requires a higher w_{opt} in order to achieve maximum dry density as the soil becomes contaminated with amang. An addition of amang which dominated by sandy size particles has formed larger inter-particle pore. Subsequently more water would be needed to achieve the maximum dry density of contaminated soil. These results indicated that amang-contaminated soils are difficult to be compacted to maximum dry density and require higher water content if compared to that of uncontaminated soils.

The permeability of the studied soil was investigated in order to establish the capacity of soil to permit the water flow within the soil media. It was found that the permeability of contaminated soil increased with the increase in amang content (Figure 7). The permeability of uncontaminated soil was 14.49 cm hr^{-1} and increase up to 23.81 cm hr^{-1} when 20% of added amang content. The permeability of uncontaminated soil was considered

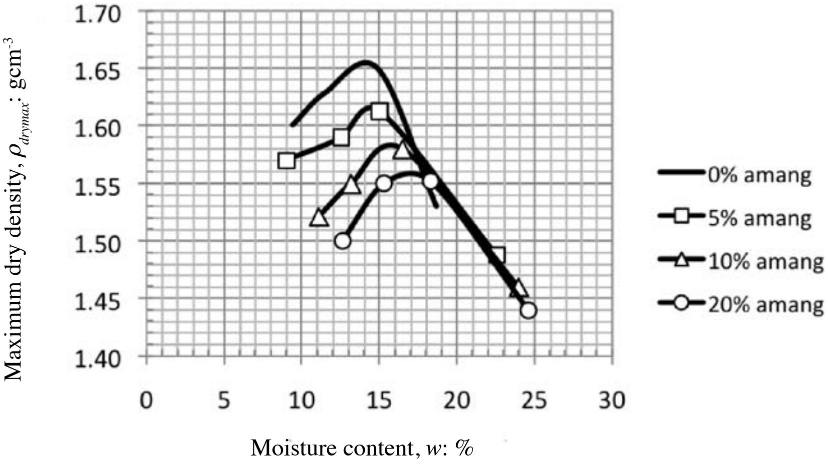


FIGURE 5. The compaction curve pattern of uncontaminated versus amang-contaminated soils

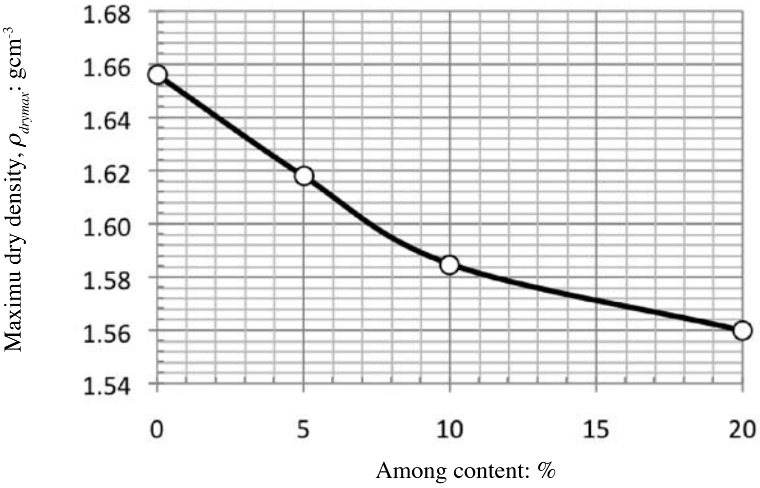


FIGURE 6. Effect of amang contents on the MDD and OMC values of amang-contaminated soils relative to uncontaminated soil

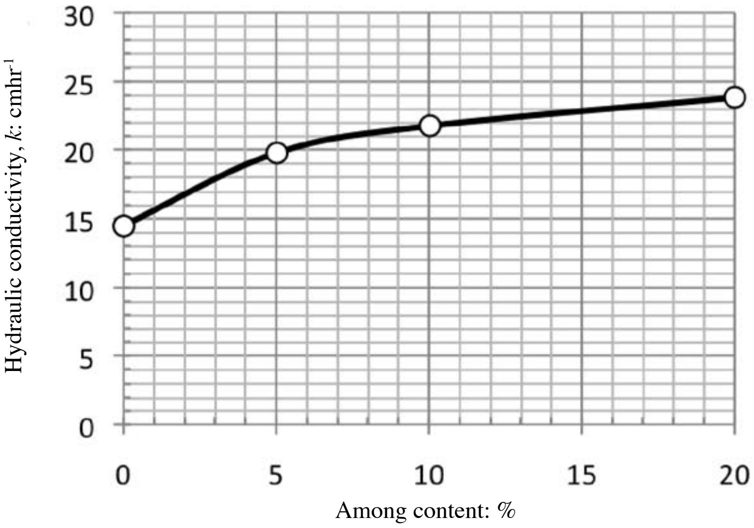


FIGURE 7. Effect of amang contents on the permeability parameter of amang-contaminated soils relative to uncontaminated soil

fast as it consisted of 42.6% of sand fraction. Meanwhile amang is dominated by sand size particles. As expected by adding increased amount of amang to the base soil has increased the occurrence of inter-particle pore spaces of the studied soil. Therefore, the contaminated soils have a higher permeability if compared to that of uncontaminated soil. It also found that the change in permeability was larger at 5% amang content but steadily reduce when amang contents were increased to 10 to 20%. It could be assumed that the increment in permeability value would steadily dropped with higher amang content, however this could not be prove due to limited data.

A series of unconsolidated undrained triaxial test was performed in order to establish the influence of amang contents on shear strength of the studied soil. The effect on shear strength was observed based on the apparent cohesion, C_u value. The maximum deviatoric stresses, q_{max} for particular applied confining stress, σ_3 at different amang contents were shown in Table 3. The C_u values were extracted from the Mohr circles, with assumption that friction angle, $\phi_u = 0$.

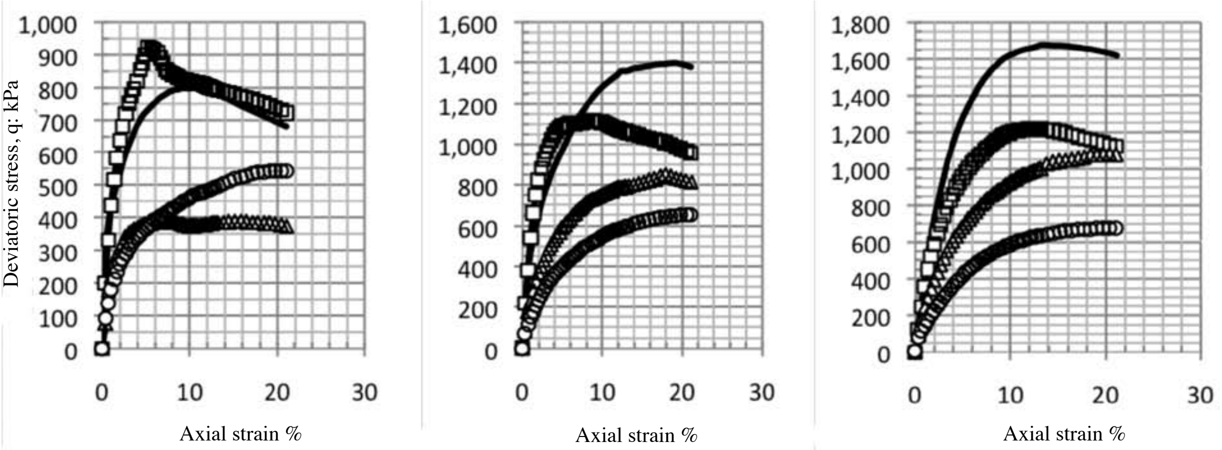
Stress-strain curves for the tests were shown in Figure 8. It is clearly seen from stress-strain curves, all samples showed a drastic linear increase in deviatoric stress, q up to 2% of axial strain. Then q increases at lower increment up to peak value before the samples collapsed. The soil samples indicated a stress-dependant behavior with brittle type of failure. The effect of amang contents on the stress-strain curves is clearly seen at different applied confining stresses (σ_3 = 140, 280 and 420 kPa). At σ_3 of 140 kPa, the effect of amang content was not clear but at higher σ_3 of 280 and 420kPa, the maximum deviatoric stress, q_{max} achieved increased with the decrease in amang content (Figure 8(b) & Figure 8(c). Figure 9 shows the relationship between C_u and the amang contents. The C_u value decreased from 646 kPa (0%) to 312kPa (20% amang content). An addition of 10% amang content has significantly dropped the undrained shear strength from 646 kPa to 312 kPa. This can be described that the presence of amang content has increased the possibility of soil inter-particles sliding when shearing applied to the contaminated soils.

CONCLUSION

The influence of amang content on the geotechnical properties of contaminated soil is clearly observed. The Atterberg limits of contaminated soils were lowered than that of uncontaminated soils and the decreases in plastic and liquid limits correspond to the increase in amang contents. Addition of amang to uncontaminated soils shifted the uncontaminated soil to A-line suggesting that the presence of amang has changed uncontaminated

TABLE 3. The maximum deviatoric stresses (q_{max}) and applied confining stresses (σ_3) for the uncontaminated and amang-contaminated soils

Amang content, (%)	Applied confining stress, σ_3 (kPa)	Maximum deviatoric stress, q (kPa)		
		140	280	420
0		799.3	1398.8	1677.4
5		923.3	1116.4	1218.9
10		388.9	851.5	1080.8
20		543.0	653.2	675.0



(a) (b) (c)

FIGURE 8. Stress-strain curves for uncontaminated and amang-contaminated soils at different applied confining stress, σ_3 of (a) 140 kPa; (b) 280 kPa; (c) 420 kPa

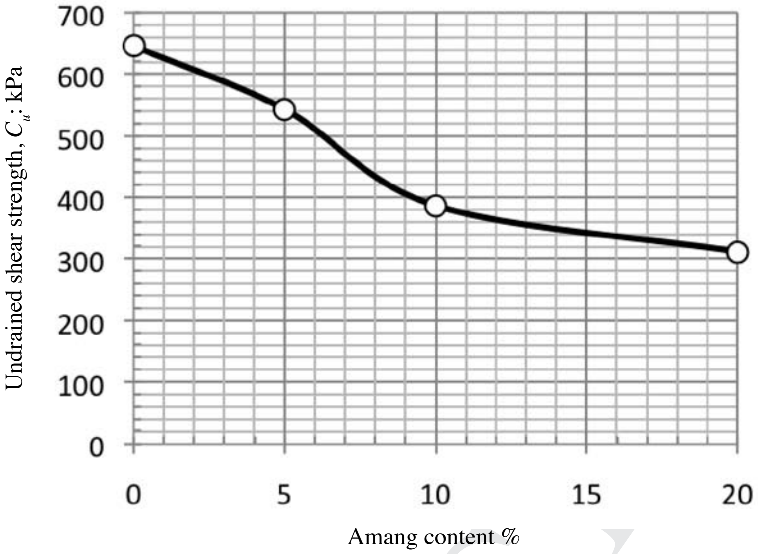


FIGURE 9. Relationship between C_u and amang contents in contaminated soils

soils from clay to silty soils. Similarly, the maximum dry density was also dropped with the increase in amang contents and more water would be required in order to compact the amang-contaminated soils. It was expected that the permeability of contaminated soil increased with the increase in amang content due to the presence of inter-particle pore spaces as soil contaminated with amang. The undrained shear strength was decreased with the increase in amang content in contaminated soils. Presence of amang could allow the inter-particle sliding when contaminated soils were sheared. It is useful to have geotechnical properties of amang-contaminated soils since it would assist/benefit engineers or decision makers in recycling of contaminated soils for other soil engineering purposes.

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