ISSN 1996-3343

Asian Journal of Applied Sciences

http://knowledgiascientific.com

Knowledgia SCIENTIFIC
A Place to Publish Outstanding Research

Asian Journal of Applied Sciences 3 (4): 237-249, 2010
ISSN 1996-3343

Geotechnical Characteristics of Oil-Contaminated Granitic and Metasedimentary Soils

Z.A. Rahman, U. Hamzah and N. Ahmad
Faculty of Science and Technology,
School of Environmental and Natural Resource Sciences,
Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia

Abstract: This study was designed to investigate the geotechnical properties of oil-contaminated soil for two different residual soils originally developed from *in situ* weathering of granitic and metasedimentary rocks. The physical characterisations of the soil were determined including particle size distribution, specific gravity test and X-Ray Diffraction (XRD). The engineering parameters for the contaminated and uncontaminated soils were Atterberg limits, compaction and soil shear strength. The amounts of hydrocarbon added to soil were varied at 0, 4, 8, 12 and 16% of dried weight of soil samples. The results from the particle size distribution analysis showed that residual soil from granitic rock comprises 38% sand, 33% silt and 4% clay while metasedimentary soil consists of 4% sand, 43% silt dan 29% clay. The mean values of specific gravity for the granitic and metasedimentary soils are 2.56 and 2.61, respectively. The types of minerals present in granitic soil sample are quartz, kaolinite and gibbsite while metasedimentary soil consists of quartz and kaolinite. The Atterberg limits value decreased as a result of increasing amount of added hydrocarbon into the soil. A similar behavior was observed with the values of maximum dry density and optimum water content with increasing hydrocarbon content. The maximum deviator stress, q_{max} for granitic and metasedimentary soils ranged between 6-28 kPa and 8-27 kPa, respectively. The overall unconsolidated undrained shear strength, C_u showed a decreasing trend with the increase in hydrocarbon content.

Key words: LNAPL, hydrocarbon, contaminated soil, geotechnical parameter

INTRODUCTION

Oil spill usually occur during transportation and has posed a major environmental hazard due to its difficulty and costly in order to remove and clean the contaminated sites. There are several potential sources of oil leakage to surrounding ecosystem are through damage pipeline, tanker accidents, discharges from coastal facilities, offshore petroleum production and natural seepage (Habib-ur-Rehman *et al.*, 2007). The spillage of oil into the ground has just not affected the ecosystem but to the safety of the civil engineering structures (Shroff *et al.*, 1998). The cleaning up of the hydrocarbon-contaminated soil is a complicated job by virtue of high cost and limitations in disposing the excavated soil (Shah *et al.*, 2003).

Corresponding Author: Z.A. Rahman, Faculty of Science and Technology,
School of Environmental and Natural Resource Sciences,
Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia

The lacks of proper management of diused oil and illegal dumping of other hydrocarbon components in many developed countries have contributed to the problem in tackling the environmental issue.

The spillage of hydrocarbon liquid moves downward under gravity partially saturating the soil in its pathway toward groundwater level (Pamukcu and Hijazi, 1992). For LNAPL components, they float and spread horizontally within the capillary zone. A further saturation of soil by hydrocarbon is expected to change the engineering behavior of soil. The fabric and mineralogy are among factors that control the mechanical properties besides stress history and initial density (Brenner *et al.*, 1997). The presence of various kinds of clay minerals which are chemically active can interact differently with pore fluid. The change in engineering behavior can be related to the change of its fabric (Pamukcu *et al.*, 1990; Tuncan and Pamukcu, 1992). Generally, hydrocarbon is more viscous than water therefore, it relatively moves slower within the groundwater body. Some of hydrocarbon might be trapped and clogged, reducing pore volume led to a reduction in hydraulic conductivity of contaminated soils (Khamehchiyan *et al.*, 2007).

Much researches have been carried out in order to investigate the effects of hydrocarbon on engineering characteristics of oil-contaminated soil. The change in hydraulic conductivity of particular soil can be associated with the change in fabric when the molding pore fluid and permeation pore fluid are water. As a result of soil contamination, various liquids interact with chemically active soil of clay particles, altering their behavior (Habib-ur-Rehman *et al.*, 2007). Alsanad *et al.* (1995) and Alsanad and Ismail (1997) performed a series of laboratory tests in order to determine the influence of oil contamination and aging effect on geotechnical properties of Kuwaiti sand. The amounts of added oil to the sand were varied and the parameters of shear strength, compressibility, permeability and compaction were determined. Meanwhile, Aiban (1998) examined the effects of temperature on contaminated soil strength, porosity and compaction with samples collected from East Saudi Arabia. The compressibility and deformation of oil-contaminated sand increased as the temperature increased above room temperature. The shear strength found to be independent of testing temperature when samples compacted to their maximum dry densities. Evgin and Das (1992) performed a series of triaxial tests on contaminated and uncontaminated clean sands. The results showed that the oil saturated samples drastically reduced the friction angle for loose and dense samples. In other hand, it apparently increased the volumetric strain. This findings also suggested that settlement of footing would increase as a result of oil contamination. Shin and Das (2001) studied the load capacity for oil partially saturated sand at oil content ranged between 0 and 6%. The results indicated that the load capacity dropped with the increase of oil content. Khamehchiyan *et al.* (2007) investigated the effect of crude oil on geotechnical properties of sandy-soil and clay. The results showed that the Atterberg limits decreased with the increase in oil percentage. The increasing of oil content in the soil samples also caused the decreasing of maximum dry density, optimum water content, porosity and shear strength.

This study aimed to investigate the effects of hydrocarbon on engineering properties of residual soils developed from granitic and metasedimentary rocks. These earth materials are readily available and have a wide distribution in Peninsular Malaysia. Most of residual soils have been commonly used in engineering practices such as embankment, foundation, liners and base material for landfill and roads. However, not many studied have been conducted to understand their engineering behavior whenever the soils have been contaminated by oil. In addition, soil mechanics models have been developed whether in fully or partially saturated of water rather than oil. The occurrence of oil is expected to change the physical and chemical interaction between soil particles. In terms of site remedition, the geotechnical knowledge is essential in order to understand their behavior and to design proper approaches for removal and cleaning oil-contaminated soil schemes. Stabilization of oil-contaminated soil indicated improvement in some engineering behavior such as Unconfined Compressive Strength (UCS), cohesion and angle of internal friction ude to addition of lime, fly ash and cement (Shah *et al.*, 2003). Therefore, in this study, it was vital to simulate the hydrocarbon contamination using artificially oil-contaminated soils in terms of engineering behavior and comparison has been made between contaminated and uncontaminated soils.

MATERIALS AND METHODS

Study Area

The soil samples used in this study were collected in 2008 from two sites representing residual soils developed from *in situ* weathering of granitic rock and sedimentary rock. The selected sites were situated in District of Hulu Langat Selangor. The granitic soil samples were taken from Semenyih area (Site 1) as shown in Fig. 1a. The site was cleared for construction of residential purpose and located close to the Jalan Semenyih. The lithology of this area predominantly consists of granitic rocks of late Triassic-Createaceaous which part of the Main Range Granite. Meanwhile, the later type of soil was collected at construction site for new buildings Faculty of Sciences and Technology in Universiti Kebangsaan Malaysia Campus, Bangi Selangor Malaysia (Site 2) (Fig. 1b).

Sample Preparation and Soil Characterisation

A hand-auger was used to obtained disturbed samples at depth 10 cm below the ground surface and kept in plastic bag. Approximately 30 kg of samples were collected for each type of soil and were air dried and pulverized in order to break down the soil aggregations. The samples then were divided into 5 portions, weigh 5 kg each. The physical characterizations of both soils were carried such as particle size distribution, specific gravity and X-Ray Diffraction (XRD).

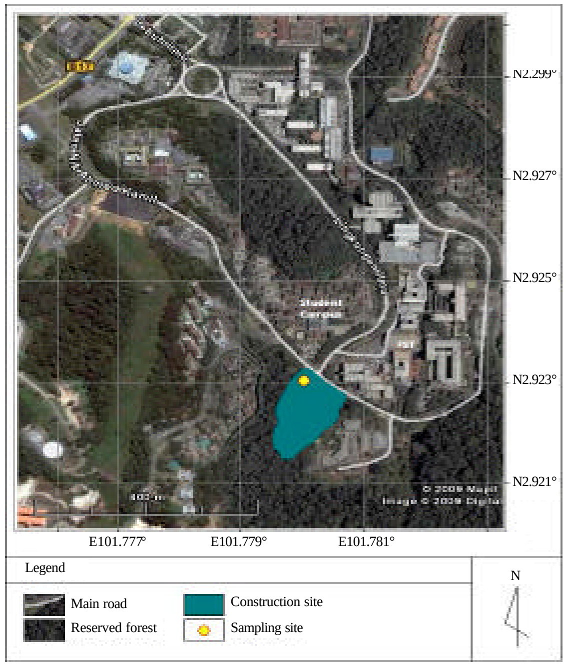
The engine oil was used in this study to represent one of the hydrocarbon components of LNAPL. Each portion of soil sample was mixed thoroughly with engine oil at different percentage of 0, 4, 8, 12 and 16% to the dry weight of soil. The samples were kept in airtight container for 2 weeks to attain a homogeneous mixture. These samples then were used to determine the engineering properties of the soils. The tests were generally carried out on the soil samples in accordance with the procedure outline by British Standard Institution (1990).

Engineering Properties of Soils

Atterberg Limits

Atterberg limits are important in for fine material of soils and have been used extensively in geotechnical engineering for identification, description and classification of soils and as a basis for the preliminary assessment of their mechanical properties (Khamehchiyan *et al.*, 2007). The tests are used to establish empirical information of the soil reaction to water. It can be used to assess the mechanical behavior of soils in natural and remolded states. Therefore, the contamination of hydrocarbon in particular soils might modify the soils engineering behavior. This parameter aims to determine the minimum water contents at which soil begins to deform as a plastic or liquid, respectively (Lee and Baraza, 1999). Liquid limit was determined using the Cassagrande method where the paste of soil was located in the cup and subjected to shallow drops. The water content for plastic limit was

(a)



(b)

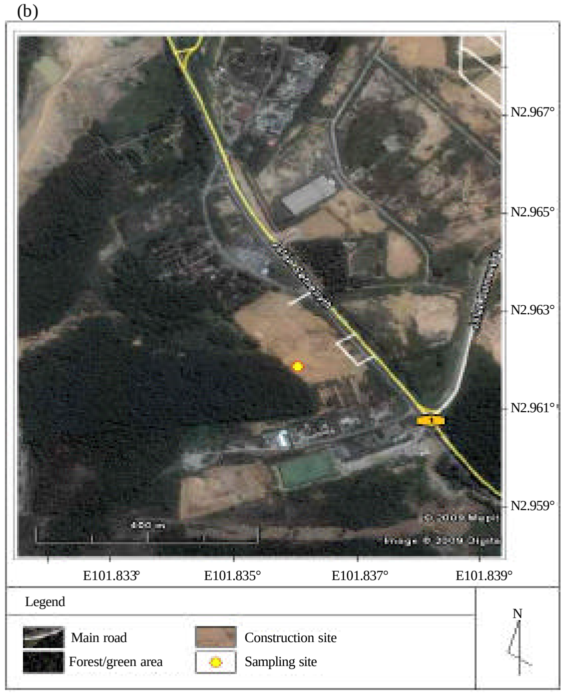


Fig. 1: The locations of the sampling sites for the residual soils (a) UKM Bangi Campus and (b) Semenyih area. Source: Google Map 2009

determined by rolling the soil thread until its stated crumble at about 3 mm long. The plasticity index, I_p is defined the difference between liquid limit and plastic limit. The Atterberg limits are usually presented on a plasticity chart, plotting the data between the plasticity index and the liquid limit. This chart was used to classify the soil based on different behaviors.

Compaction Test

Compaction tests were performed based on a Proctor Standard compaction method (2.5 kg rammer) in order to achieve the relationship between moisture content and dry density of the soil samples. Soil samples were compacted in steel mould in three equal layers using the rammer, each layer being given 27 blows evenly distributed over the mould area. The dry maximum density (MDD) and Optimum Moisture Content (OMC) were derived from the compaction curve. A similar procedures were repeated for oil-contaminated soil samples at different hydrocarbon contents.

Triaxial Test

The shear strength of the soils was studied using the Unconsolidated Undrained (UU) conventional triaxial tests. It is a quick test to achieve shear strength parameters coarse and fine soils in either undisturbed or remoulded state. The UU test is different from the Unconfined Compressive Strength (UCS) test because the ground stress applied to the soil can be simulated by water in triaxial cell. A detail procedure of the test is described by Head (1998). All samples were prepared from the compaction tests device. Samples were prepared with 36 mm in diameter and 76 mm high were extruded from the compaction mould. Three different confining pressures of 140, 280 and 420 kPa would be applied to the samples. Therefore three samples were prepared for each percentage of hydrocarbon addition. The rate of strain was 2% min^{-1} which is equivalent to a starin of 1.5 mm min^{-1}. The shearing of each sample was continued until the sample had failed or until 20% of strain was achieved.

RESULTS AND DISCUSSION

Soil Characterisation

Particle size analysis showed that the granitic soil samples consisted of 64% sand, 34% silt and 2% clay while metasedimentary soil samples consisted of 34% gravel, 37% sand, 27% silt and 2% clay. It is clearly seen that the granitic soils are higher in sand percentage if compared with the metasedimentary soils. The proportions of gravel and sand in metasedimentary soils are close while granitic soils showed the highest percentage of sand. Both soil samples showed small amount of clay proportion. The particle size distribution of both soil samples is shown in Fig. 2. Based on the texture classification, granitic and metasedimentary soils could be classified as sandy loam and silty clay loam, respectively. The results from the XRD analysis on the granitic soils indicated the presence of quartz, kaolinite and gibbsite. Meanwhile, the metasedimentary soils predominantly consisted of minerals quartz and kaolinite. Quartz minerals present in both soils and are resistant to chemical weathering. While kaolinite minerals are the resultant of chemical weathering of feldspar minerals. Gibbsite minerals are directly formed from primary minerals or alteration from kaolinite. This is caused by the unstable nature of kaolinit in wet conditions. Specific gravity values for granitic and metasedimentary soils were 2.56 and 2.6, respectively.

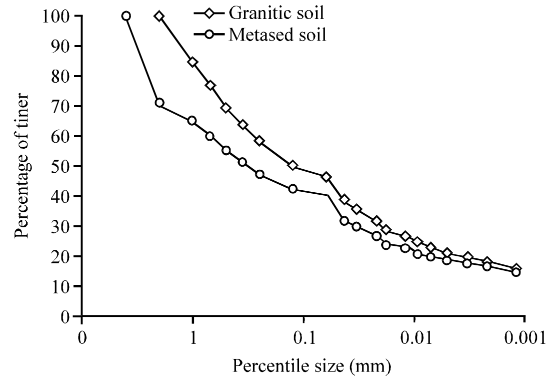


Fig. 2: The particle size distribution curves for both types of soils

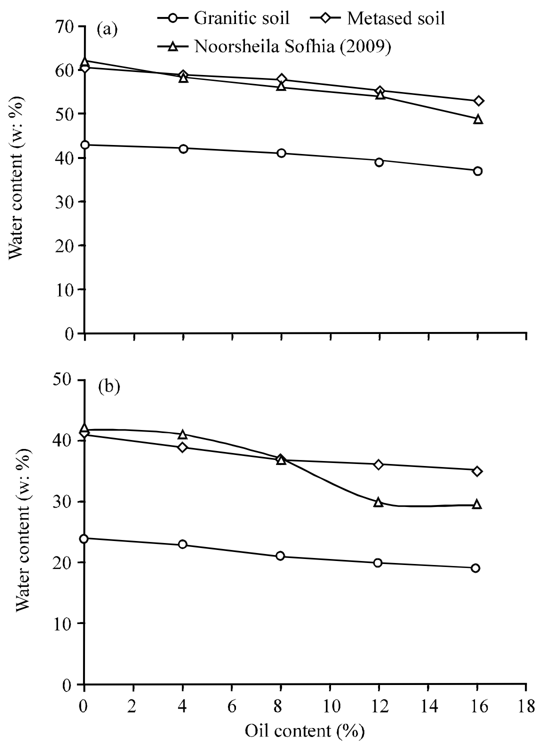


Fig. 3: Results of the Atterberg's limit tests on granitic and metasedimentary soils (a) liquid limit and (b) plastic limit

Geotechnical Properties

Atterberg Limits

The results from the liquid limit and plastic limit tests for the granitic and metasedimentary soils are shown in Fig. 3a and b. The results of this study were also compared with the data obtained from the basaltic soils by Ithnin (2009) in order to look the influence of hydrocarbon on different soils. The addition of hydrocarbon into the studied soils has clearly affected the engineering properties of the contaminated soils. The increasing in the hydrocarbon contents in soils caused the reduction of the water content at the liquid limit and plastic limit. A similar picture was also seen by Khamehchiyan *et al.* (2007) based on their study on sandy soils. The presence of hydrocarbon which is non-polarised liquid has caused the reduction in thickness of water film around the clay minerals. Hydrocarbon relatively makes first contact with clay minerals instead of water. Since, water is a binding agent between clay minerals and its orientation around the clay mineral provides the plasticity characteristics. This is not happen if clays surrounded by hydrocarbon. In addition, the trend of reduction of the water content at Atterberg limits with increasing hydrocarbon contents is best represented by a clear straight line as shown in Fig. 3.

For the granitic soils the water contents at plastic limit and liquid limit are always below the metasedimentary soils. The metasedimentary soils seemed very close to the pattern showed by the basaltic soils studied by Ithnin (2009). The high value of liquid limit for the metasedimentary soils indicated that they have a higher water absorption capability if compared to the granitic soils.

The plastic index plots at different content of hydrocarbon for the granitic and metasedimentary soils are shown in Fig. 4a. The plasticity index values for the granitic

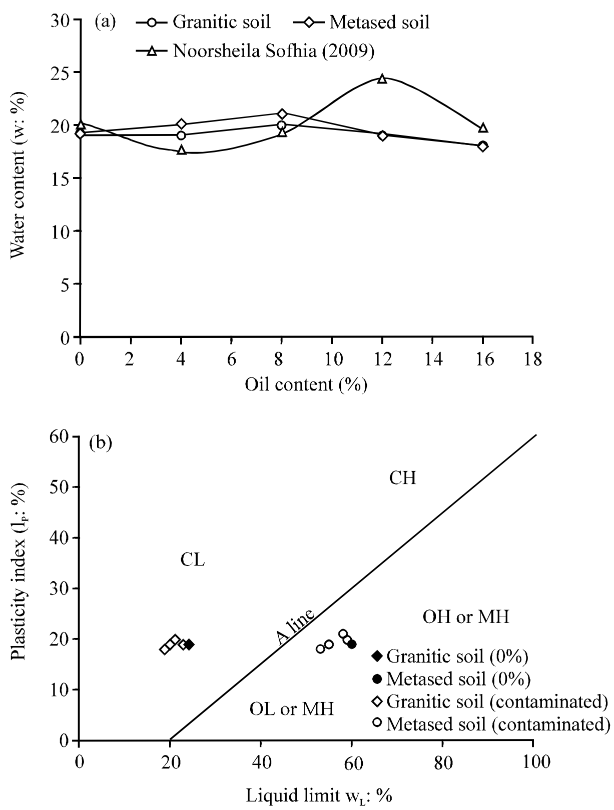


Fig. 4: (a) The trends of plasticity index (w%) and (b) data points on the plasticity chart, taken from Unified Soil Classification System. CH: inorganic clays of high plasticity; CL; inorganic clays of low to medium plasticity

metasedimentary soils ranged between 18-20% and 18-21% of water contents, respectively. The increase in hydrocarbon addition on both types of soils has not changed the plasticity index values since, the variable was calculated from the difference between liquid and plastic limits. The results of the Atterberg limits from the granitic and metasedimentary soils were also plotted on the plasticity chart (Fig. 4b). It is clearly seen that the increase in hydrocarbon content has moved the behavior of soils to the left of the plasticity chart, reducing the water contents at liquid limits for the granitic and metasedimentary soils. For the granitic soils, the samples fall within the Clay Ljanuary 11, 2010ow (CL) plasticity region, suggesting that they behave as in inorganic soils of low to moderate plasticity. Meanwhile for the metasedimentary soils, data points located below the A-line, within silt high plasticity (MH) zone, represented behavior of inorganic silts with high compressibility.

Compaction Characteristics

Standard proctor compaction test were performed on uncontaminated and contaminated samples from granitic and metasedimentary soils. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) values at different hydrocarbon contents for both types of soils are shown in Fig. 5a and b.

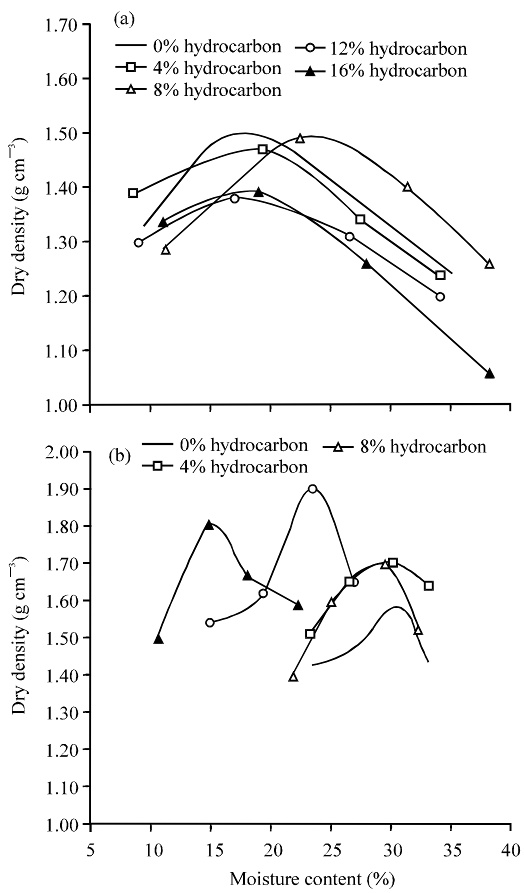


Fig. 5: Compaction curves for the (a) granitic soil and (b) metasedimentary soil at different contents of hydrocarbon

The MDD value for granitic soil (0% hydrocarbon) is 1.50 g cm^{-3} at the OMC of 17.16%. As the hydrocarbon increased up to 4 and 8%, the compaction characteristics did not change much (Fig. 5a). The MDD values at 4 and 8% of hydrocarbon contents were 1.47 and 1.49 g cm^{-3} at OMC values of 19.39 and 22.46%, respectively. However, with increase of hydrocarbon contents to 12 and 16%, the compaction curves were shifted down to the left of the uncontaminated soil's curve (Fig. 5a). Therefore, the MDD values decrease to 1.38 and 1.37g cm^{-3}, respectively but no significant in OMC values. This indicated that too much hydrocarbon is presence in the contaminated granitic soil and most of the voids are probably occupied by hydrocarbon causing less reduction in moisture content in order to achieve the maximum dry density value of soil. Therefore, soil becomes difficult to be compacted due to the presence of hydrocarbon.

The MDD value for metasedimentary soil is 1.58 g cm^{-3} at the OMC of 21.9%. With the increase of hydrocarbon content to 4 and 8%, the MDD values are 1.71 and 1.70 g cm^{-3} and OMC values of 21.5 and 20.9%, respectively. However, with further increase of hydrocarbon contents to 12 and 16%, the compaction curves were dragged to the left of the plot with MDD values of 1.90 and 1.80 g cm^{-3} (Fig. 5b). Meanwhile, the OMC values are 15.8 and 8.5%, respectively. It is also clearly seen from Fig. 5b that the increase of hydrocarbon contents from 12 to 16% has slightly decreased the MDD value but still above the value of samples with lower hydrocarbon contents.

Soil Shear Strength

A series of unconsolidated undrained triaxial compression tests (UU) were performed on samples of granitic and metasedimentary soils with different ratios of hydrocarbon contents. The tests applied predetermined confining stresses, σ_3 and the effective stress in the sample remain unchanged regardless of the value of applied σ_3, with condition that sample is in fully saturated state (Craig, 1995). The results of the UU tests always expressed in terms of stress-strain curve and then the shear strength value, C_u of the soil is achieved from the Mohr circle plots.

The stress-strain curves for the studied soils at different hydrocarbon contents were shown in Fig. 6 and 7. It is clearly seen that the uncontaminated soils achieved a higher value of deviator stress, q if compared with that from contaminated soils. The stress-strain plots for all tests indicated a linear drastic increase in q as seen at early strain (below 1% strain). At low confining stress of 140 kPa, the rates of deviator stress change were significantly high if compared to the rates of samples sheared at higher confining stresses of 280 and 420 kPa. Then the deviator stress, q continued to increase at lower rate up to the maximum point before the soil samples failed. All samples failed in a brittle type of failure. It also suggested that the trend of stress-strain behavior is stress dependant. For the samples with 0% of hydrocarbon contents from the granitic soil samples, the maximum deviator stress, q_{max} is 26 kPa under confining stress, σ_3 of 140 kPa. The values of maximum q for the same hydrocarbon content (0%) at confining stresses, σ_3 of 280 and 420 kPa increased to 66 and 73 kPa (Fig. 6a-c). At higher confining stresses at particular hydrocarbon content have associated with the increase of maximum deviator stress, q_{max} value. It can be seen for granitic soil sample with 4% of hydrocarbon content sheared at σ_3 of 140 kPa achieved maximum q of 18 kPa. At higher confining stresses, σ_3 of 280 and 420 kPa, the maximum q for granitic soil samples with 4% hydrocarbon are 23 and 28 kPa, respectively. A similar pattern was also observed for metasedimentary soil samples (Fig.7a-c).

The influence of hydrocarbon on the granitic and metasedimentary soils was examined in terms of undrained shear strength value, C_u. The undrained shear strength values for

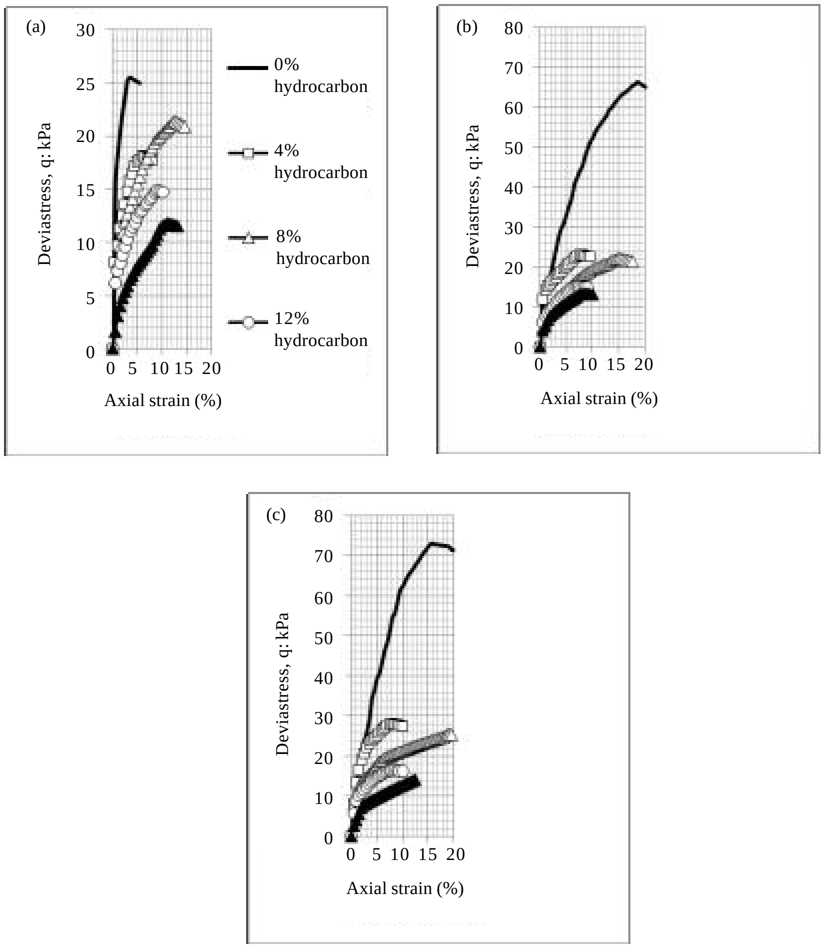


Fig. 6: Stress-strain curves for granitic soils at different hydrocarbon contents (a) σ_3 = 140 kPa (b) σ_3 = 280 kPa and (c) σ_3 = 420 kPa

granitic and metasedimentary soils were plotted against the hydrocarbon contents as shown in Fig. 8. Based on the figure, the effect of hydrocarbon contents on the shear strength values is clearly shown. The shear strength values of both soils significantly dropped from 0 to 4% of hydrocarbon contents. For the granitic and metasedimentary soils, the C_u decreased from 28 to 15 kPa and 27 to 13 kPa, respectively when soil samples were mixed up with 4% of hydrocarbon. Beyond 4% of hydrocarbon content, the values of C_u slightly decreased from 13 kPa (at 8%) to 6 kPa (at 16%) for granitic soils. Meanwhile for the metasedimentary soils, the decrease in C_u values from 14 to 16% of hydrocarbon contents are from 12 to 8 kPa. It suggested that the higher the hydrocarbon in the soil, the lower the C_u soil strength. This can be described that the presence of hydrocarbon which has particular viscosity will partially or fully coat and leaving hydrocarbon blanket surrounding the soil particles. Therefore, by increasing the hydrocarbon content in the soils, the chance to inter-particle slippage will also increase, subsequently reduce the shear strength of the soil.

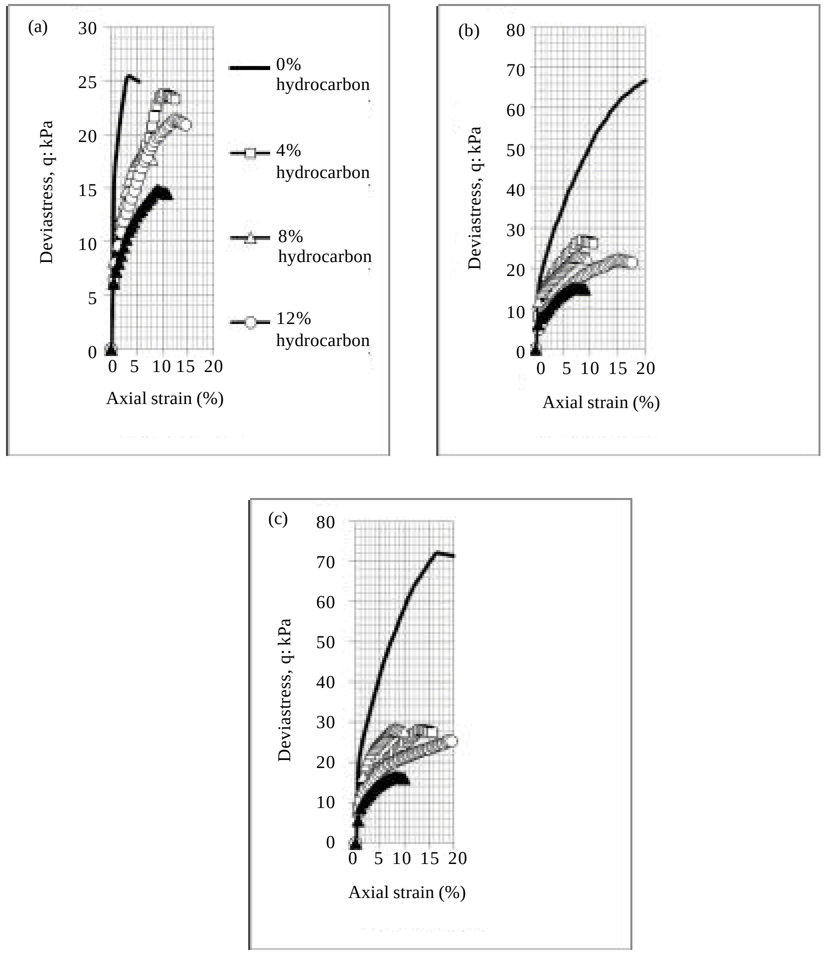


Fig. 7: Stress-strain curves for metasedimentary soils at different hydrocarbon contents (a) σ_3 = 140 kPa (b) σ_3 = 280 kPa dan and (c) σ_3 = 420 kPa

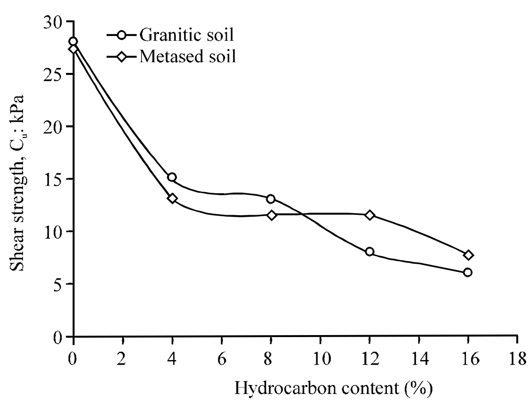


Fig. 8: Effect of hydrocarbon on the shear strength values at different hydrocarbon contents

A similar conclusion was also observed by Habib-ur-Rahman *et al.* (2007). Ithnin (2009) also observed a similar behavior with soil samples from the weathered basaltic soil of grade V and VI.

CONCLUSIONS

The weathered soils of granitic and metasedimentary rocks are dominated by silty sand and gravelly sand texture, respectively. The values of the Atterberg limits (liquid limit and plastic limit) decreased as a result of the presence of hydrocarbon in the soils. By increasing the hydrocarbon content, the compaction curves for both soils were shifted from the uncontaminated soils compaction curves. The MDD and OMC values for granitic and metasedimentary soils were decreased with the increased in hydrocarbon contents. The unconsolidated undrained tests suggested that all the samples are stress-dependent. The increased in an applied confining stress would increase the maximum deviator, q_{max} stress at particular hydrocarbon content. The effect of hydrocarbon contents on undrained shear strength value was clearly observed on granitic and metasedimentary soils. The shear strength values, C_u of both soils significantly dropped from 0 to 4% of hydrocarbon contents. Then, the shear strength values decreased slightly beyond 4% of hydrocarbon content in the soil samples. However, the overall trends are the decrease in the value of shears strength as the hydrocarbon content increased.

ACKNOWLEDGMENTS

We thank to Ministry of Sciences, Technology and Innovations (MOSTI) on the support of this research project under research grant 060102SF0276. Special thank also due to laboratory staff at School of Environmental and Natural Sciences, FST for the assistant and support in terms of field sampling, samples preparation and soil testing.

REFERENCES

Aiban, A., 1998. The effect of temperature on the engineering properties of oil-contaminated sand. Environ. Int., 24: 153-161.

Alsanad, H.A., W.K. Eid and N.I. Ismael, 1995. Geotechnical properties of oil contaminated Kuwait Sand. J. Geotech. Eng., 121: 407-412.

Alsanad, H.A. and N.F. Ismail, 1997. Aging effect on oil contaminated Kuwait sand. J. Geotech. Geoenviron. Eng., 123: 290-293.

Brenner, R.P., V.K. Garga and G.E. Blight, 1997. Shear Strength Behavior and the Measurement of Shear Strength in Residual Soils. In: Mechanics of Residual Soils, Blight, G.E. (Ed.). Balkema Press, Rotterdam, pp: 155-217.

British Standard Institution, 1990. Methods of Test for Soil for Civil Engineering Purpose. BSI, London.

Craig, R.F., 1995. Soil Mechanics. 5th Edn., Chapman and Hall, London.

Evgin, E. and B.M. Das, 1992. Mechanical Behavior of Oil-Contaminated Sand. In: Environmental Geotechnology, Usmen, M.A. and Y.B. Acar (Eds.). Balkema Publishers, Rotterdam, Netherlands, pp: 101-108.

Habib-ur-Rahman, S.N. Abduljauwad and T. Akram, 2007. Geotchnical behavior of oil-contaminated fine grained soils. Electron. J. Geotech. Eng., 12: 1-1.

Head, K.H., 1998. Manual of Soil Laboratory Testing. 2nd Edn., John Wiley and Sons, London.

Ithnin, N.S., 2009. Pencirian sifat fizik dan geoteknik tanah basalt tercemar hidrokarbon di Bulatan Bunga Cengkih, Kuantan, Pahang. B.Sc. Thesis, Universiti Kebangsaan Malaysia.

Khamehchiyan, M., A.M. Charkhabi and M. Tajik, 2007. Effects of crude oil contamination on geotechnical properties of clayey and sandy soils. Eng. Geol., 89: 220-229.

Lee, H. and J. Baraza, 1999. Geotechnical characteristics and slope stability in the gulf of Cadiz. Marine Geology, 155: 173-190.

Pamukcu, S., T. Mustafa and H.Y. Fang, 1990. Influence of Some Environmental Activities on Physical and Mechanical Behaviour of Clays. In: Physico-Chemical Aspects of Soils and Related Materials ASTM STP 1095, Hoddinott, K.B. and R.O. Lamb (Eds.). American Society for Testing and Material, America, pp: 91-107.

Pamukcu, S. and H. Hijazi, 1992. Grouting/soil Improvement and Geosynthetics. Geotechnical Special Publication, New York, pp: 345.

Shah, S.J., A.V. Shroff, J.V. Patel, K.C. Tiwari and D. Ramakrishnan, 2003. Stabilization of fuel oil contamination soil - A case study. Geotech. Geological Eng., 21: 415-427.

Shin, E.C. and B.M. Das, 2001. Bearing capacity of unsaturated oil-contaminated sand. Int. J. Offshore Polar Eng., 11: 220-227.

Shroff, A.V., D.L. Shah and S.J. Shah, 1998. Characterisation of fuel oil contaminated soil and remedial measures-a case study. Proceedings of Indian Geotechnical Conferences, Dec. 18-20, New Delhi, pp: 49-51.

Tuncan, A. and S. Pamukcu, 1992. Predicted mechanism of crude oil and marine clay interactions. Proceedings of the Environmental Geotechnology, May 25-27, Cesme, Turkey, Taylor and Francis, pp: 205-212.