Effect of the oil spill on the soil friction angle

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Abstract. There are many factors governs the soil stability, and strength is one of the most important aspects. In the event of soil contamination by oil spills, the soil characteristic and its physical properties will change due to the intrusion of oil in the subsurface. This changes mainly related to the viscous properties of the oil in comparable to natural groundwater. As the soil friction angle is one of the main components of the soil shear strength, the viscosity of the oil will affect the soil friction angle. In this study, three types of typical sand were used to mix with water and oil, and the soil friction angle is determined using direct shear test on these samples under dried condition, 50% of soil saturation and at optimum moisture content. The three sand is classified as Sandy clay, Silt clay with sand and Silt with sand. It is found all samples followed soil compaction principal when the sample mixed with water or oil, except for Sandy clay soil. For sandy clay, as the soil friction angle supposed to increase when reaching the optimum moisture content ($\phi = 38.7^\circ$), the soil friction angle is continued to reduce ($\phi = 34.2^\circ$). This may due to less than 60% coarse grain of the grain size distribution in sandy clay. As coarse grain is the main factor for the grain angularity function that provides the interlocking between particles.

1. Introduction
Most oil spill cases happened in unexpected situation in the land and sea during transfer of the oil or leakage of storage tanks. However, there are oil spill cases happened intentionally as what occur in 1991 at Persian Gulf War [1], [2]. Quick action for remediation of the contaminated land is crucial as it will not just contaminate the ground but also affect the geotechnical properties of the soil. A better understanding of the effect of soil contaminated with hydrocarbon may be of help in assessing the recovery potential of a soil [3].

Soils might be contaminated by oil due to the leakage of the oil. Major tasks are required for reclamation and recovery of the contamination area [4]. Oil products such as heavy fuel oil, diesel oil or gasoline are the most common chemical spills occurred [5]. Other than that, in heavily industrial places, oil pollution is common where careless operators do not take consideration about the environmental issues. Such places include fuel depots and army polygons [6].

Benzene, toluene, ethylbenzene and xylene (BTEX) are one of the compositions in the fuel oil's contents which are hazardous materials subject to regulations in many parts of the world [7], [8]. Transportation of oil from one place to another by pipeline or vehicle is increasing the potential of an oil spill accident. Oil spill that occurred on land will affect the structure above ground because the soil structure and stability changed due to different physical and chemical characteristic of the oil.

The ground stability, mainly related to shear strength, is one of the most important key aspects to ensure the stability of civil engineering structure and infrastructure. As the soil friction angle is one of
the main components of the soil shear strength, the viscosity of the oil will affect the soil friction angle. Therefore, this study is focused on the effect of the oil spill on the soil friction angle.

2. Method and Laboratory Tests
The focus of this research is to understand the effect of oil spill on the soil friction angle. Three typically sand used for construction at Penang, Malaysia was used in this research. The soil was classified before it mixed with the oil. The oil used was diesel and the properties are; density of 0.850 g/cm³, kinematic viscosity of 1.5 – 5.8 mm²/s at 40 °C, and vapor pressure of < 1hPa at 20 °C.

The soil samples are oven dried for 24 hours to disperse off all water from the samples. Samples need to be oven dried to control moisture content for each test. If the soil is partially dry, it will affect the result of the tests since it going to be mixed with diesel. Specific gravity is defined as the ratio of the unit weight of a given material to the unit weight of water. The small pycnometer method is used in this laboratory testing.

Sieve analysis test used to determine particle size distribution of larger diameter. To obtain the grain size distribution of soils, there are two separate procedures; mechanical sieve size for particle bigger than 63 μm and hydrometer analysis for smaller than 63 μm. The mass retained are recorded and the test is performed in accordance with BS 1377: Part 2: 1990 [9].

Liquid limit is the minimum water content at which the soil will flow under a small disturbing force. It is the boundary between the plastic and semi-solid states. In this experiment, liquid limit test was carried out by using cone penetrometer method as in BS 1377: Part 2: 1990: Clause 4.3.1. This method covers the determination of the liquid limit of a sample of soil in its natural state, or of a sample of soil from which material retained on a 425 μm test sieve has been removed.

Soil compaction Proctor test is carried out to determine the optimum moisture content and maximum dry density of a compacted specimen. In this standard Proctor test, the sample is compacted in a mould that has volume of 1000.98 cm³. The diameter and height of the mould are 105 mm and 115.6 mm respectively. 4-6 % of water is added, and the soil is mixed evenly. In this test, 4 % increment of water is being added to the soil. In this study, soil strength tested using direct shear test is intended to determine the shear strength of soil based on BS 1377: Part 7: 1990 [10]. Preparation of the samples is based on soil under clause 4.4.

3. Results and discussion
In this research, three typical sand used for construction in Penang, Malaysia was collected to be used to study the soil friction angle changes due to oil spill. Each sample has a different percentage of particle size. The percentage of gravel, sand, silt and clay can be determined from the particle size distribution. The ranges for the percentage of particle size are tabulated in Table 1. Sample A have higher composition of clay compared to sample B and sample C.

The soil Atterberg limits are determined at which the moisture content at the point of transition from semisolid to plastic state is the plastic limit (PL), and from plastic to liquid state is the liquid limit (LL). Liquid limit determined by the moisture content at 20 mm cone penetration. From experiments carried out liquid limit obtained from the graph of penetration resistance to moisture content for all three samples. Based on the graph, the liquid limit for sample A is 49.97%, sample B is 58.67% and sample C is 38.39%. Plastic index (PI) for all three samples were determined using the formula PI = LL – PL. Plastic index for sample A is 22%, sample B 29% and sample C 13%. The Atterberg limits result and soil classification is shown in Table 2.

Based on the results obtained, the soil can be classified according to the American Association of State Highway and Transportation Officials (AASHTO) Classification System. Sample A is classified as Sandy clay, sample B as Silt clay with sand and sample C as Silt with sand.

Based on Unified Soil Classification System (USCS). For sample A, the soil is classified as poorly graded sand with clay (SP-SC) because PI > 7 and plots above “A” line of Casagrande’s Plasticity Chart [11]. However, for both sample B and sample C, the soil is classified as well graded sand with clay (SW-SC).
Table 1: Percentage of Gravel, Sand, Silt and Clay.

| Particle | Standard | Particle Name (Size, mm) | Sample A | Sample B | Sample C |
|----------|----------|--------------------------|----------|----------|----------|
| Gravel   | BS 1377  | Fine Gravel (2 – 6 mm)   | 0.6      | 20.6     | 22.0     |
|          | AASHTO   | Gravel (2 – 75 mm)       |          |          |          |
|          | ASTM     | Coarse Sand (2 – 4.75 mm)|          |          |          |
|          | USCS     | Coarse Sand (2 – 4.75 mm)|          |          |          |
| Sand     | BS 1377  | Sand (0.060 – 2 mm)      | 57.2     | 50.2     | 57.6     |
|          | AASHTO   | Sand (0.075 – 2 mm)      | 56.4     | 48.9     | 56.5     |
|          | ASTM     | Sand (0.075 – 2 mm)      |          |          |          |
|          | USCS     | Sand (0.075 – 2 mm)      |          |          |          |
| Silt     | BS 1377  | Silt (0.002 – 0.060 mm)  | 9.2      | 20.4     | 20.4     |
|          | AASHTO   | Silt (0.005 – 0.075 mm)  | 7.1      | 15.5     | 17.2     |
|          | ASTM     | Silt (0.005 – 0.075 mm)  | 43.0     | 30.5     | 21.5     |
|          | USCS     | Fines (< 0.075 mm)       |          |          |          |
| Clay     | BS 1377  | Clay (< 0.002 mm)        | 33.0     | 8.8      | 0        |
|          | AASHTO   | Clay (< 0.005 mm)        | 35.9     | 15       | 4.3      |

Table 2: Soil Atterberg Limits and Soil Classification

|                    | Sample A | Sample B | Sample C |
|--------------------|----------|----------|----------|
| Specific Gravity   | 2.67     | 2.65     | 2.63     |
| Liquid Limit       | 49       | 58       | 38       |
| Plastic Limit      | 27.2     | 29.8     | 25.6     |
| Plastic Index      | 22       | 29       | 13       |
| AASTHO Classification | Sandy clay (A-6, A-7-6) | Silt clay with sand (A-1-b) | Silt with sand (A-1-B,A-2-4, A-2-5, A-2-7) |
| USCS Classification | Poorly Graded Sand with Clay (SP-SC) | Well Graded Sand with Clay (SW-SC) | Well Graded Sand with Clay (SW-SC) |

Proctor tests were performed on each sample to determine the optimum moisture content and maximum dry density of the soil. Optimum moisture content for Sandy clay, Silt clay with sand and Silt with sand are 19.7%, 15.3% and 13.4% respectively. The compaction curve of the proctor test for all samples is shown in Figure 1.
Figure 1. Compaction curve for all proctor test.

Direct shear test done was to determine the friction angle of soil and soil cohesion. Direct shear test is carried out on all three samples to get the friction angle of soil. Soil condition tasted in dried condition, 50% of soil saturation and optimum moisture content. The influence of moisture content on both shear strength parameters is very significant. As can be seen from the Figure 2, increases in the moisture content in the soil has caused a decrease in the internal friction angle but at optimum moisture content, the friction angle value increasing for all three samples is sandy clay, silt clay with sand and silt with sand.

Figure 2. Effect of moisture content sample mix water

When the soil is in dry state, it is shown that the friction angle has highest value for all three samples. The value of friction angle, $\phi$ for sandy clay at dry condition is 40.8°, silt clay with sand is 38.5° and silt with sand is 37.9°. Similar condition found by sadek et. al (2011) when a dry sandy soil demonstrates a higher soil friction angle and shear strength compared to moist and wet sandy soil.
When the dry soil matrix in contact with water, water will start to fill the available void. Water also might replace the solid (soil) matrix volume into a water volume. When moisture content increased as a result of the existence of water, the distance between particles increased significantly. This cause a significant reduction of friction angle when compared to dry condition.

As the amount of water increases, water became as lubricant for soil particle to glide in between particle void and rearrange to obtain the most compact particle packing. In the process, the soil friction angle increased gradually. The most compact particle packing can be achieved when the soil is at optimum moisture content. As at optimum moisture content, the soil can also achieve the maximum dry density. This is also the condition where the highest soil strength can be achieved.

In considering for sandy soil, major component of soil shear strength is obtained mainly from the soil friction angle rather than soil cohesion. Thus, at maximum dry density, it is considered the highest soil friction angle value could be reached for the tested sandy soil. In accordance with compaction curve behaviour and principle, as the dry density would reduce if the soil is subjected to further moisture increment after the optimum moisture content, the soil friction angle should also be reduced.

Similar condition also occurs when the dry soil is in contact with oil. As shown in Figure 3, when the dry soil matrix in contact with oil, oil will start to fill the available void. With the increases in the moisture content of oil in the soil has caused a decrease the soil friction angle. When the oil content increase after the dry condition, both Silt clay with sand and Silt with sand exhibits a similar behaviour as the increasing of water content after the dry condition.

![Figure 3. Effect of Moisture Content sample mix oil](image)

Sandy clay soil, however, shown an opposite behaviour as the soil friction angle will be kept reduce even at the point of reaching the optimum moisture content. Main reason of the behaviour is since both Silt clay with sand and Silt with sand has the main grain size distribution from coarse grain (gravel and sand); about 70% to 80%. Unlike the sandy clay, less than 60% of the grain size distribution is from coarse grain. As coarse grain is the main factor for the grain angularity function that provides the interlocking between particle, the soil that contains abundance coarse grain may not be affected by the increase of oil content. In sandy clay soil, there is a possibility for the clay fraction instead it is acted as a filler inside a coarse grain particle, it may start to flocculate and becoming a larger clump when the clay fraction in contact with the oil. Such condition may cause the reduction of soil friction angle as the soil particle may not be able to rearrange its position to reach the maximum packing condition.
4. Conclusion

The soil friction angle is one of the most important components in soil strength. The effect of soil contaminated with diesel has been chosen for this study. Three types of typical sand have been chosen, and one of the sands is having slightly higher clay content. The soil friction angle is determined from the direct shear test. For all three samples, the soil friction angle is very high when it is in dry condition. Soil friction angle decrease when moisture content of water in the soil increase from the dry state; but friction angle increased at optimum moisture of water. A similar condition occurs when the oil content increase from the dry state towards the optimum moisture content for silt clay with sand and silt with sand. In contrast for sandy clay sample, the soil friction angle keeps reducing even when the oil content reaching the optimum moisture content value.

Acknowledgement

The authors wish to express sincere appreciation for the support and encouragement provided by the School of Civil Engineering, Universiti Sains Malaysia in making this project a success. The research work was funded by the Department of Higher Education, Ministry of Education Malaysia under the Fundamental Research Grant Scheme with grant number FRGS/1/2018/TK01/USM/03/4.

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