Behaviour of shear strength envelope mixing with usable cooking oil using consolidated drained triaxial test

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Abstract. Awareness of peoples towards environmental impact assessment to sustainable development have been progressively increase from time to time. For that reason, this research is focusing on the effect of the usable daily cooking oils to the shear strength of soil which easily thrown into the soil in the backyard of the houses. Due to that, the mixing of oil with water in the soil may lead to reduction in shear strength and thus will lead to failure in a foundation of structures. This study was carried out to investigate the effect of shear strength of soil when mixing with usable cooking oil with 5% and 10% and compared it with the soil without mixing with usable cooking oil using single stage triaxial consolidated drained test. Finding reveal that there is significant reduction in shear strength for control specimens with the mixing of 5% and 10% of usable cooking oil. For control specimens, the shear strength was at 26° of effective friction angles whereas for specimens mixing with 5% and 10% was at 22° and 20° respectively. The shear strength was deduced for about 6° for specimens in natural and mix with 10% of usable cooking oil. In the end, results show that reduction in shear strength will continuously decreased with the increase of the quantities of usable cooking oil and thus will reflect towards the failure of a foundation.

1. Introduction

Oil can come from many sources such as fossil fuels which are from geological formation from beneath of earth or also known as crude oil and that comes from plantations sources such as palm and coconut plantations. There are many usages of oils which are in fuelling the vehicles to make people easy for travelling, in shampoos and soaps and for cooking purposes as well. In Malaysia, palm oil productions is one of the high contributors in economy aspects. Moreover, palm oil is very beneficial in terms of health and disease management due to its highly content in vitamin E. It really gives benefit to people in the food production especially such as cooking oil, margarines and others. As population increases, the demand of palm oil also increases since people use the palm in various type of usage in their daily life. However, the awareness among Malaysian on how to dispose oil properly especially waste cooking oil is extremely low. This can be shown based on a journal by some of the researchers. Based on their findings, the waste cooking oil is usually removed into the drain, sink, soil and trash which finally lead the oil to spill onto the soil at the end [1]. This condition made the soil become contaminated and give impacts to not only to human health but to soil properties as well.

Soil contamination through oil can be really problematic. It can affect the physically and chemically behaviour of soil. In terms of geotechnical engineering it can affect the characteristic of soil which give the information on coarse soil, fine soil and moisture content. The occurrences of high amount on soil also give impact on shear strength and bearing capacity. These parameters of soil are crucial as Malaysia is towards to development country where many new developments will rise and to
avoid the soil failing to perform its function which is to support building structures system as well. This situation can be seen in China where crude oil contamination causes the soil pH up to 8.0 and reduces available concentrations of phosphorus in soil. Moreover, in Malaysia, every day, soil is contaminated by oil. This is due to oil spills, oil which is removed into leakage drainage and also lack of awareness of people on disposing oil in a proper way. Most people in Malaysia dispose their waste cooking oil by removing it into the sink, trash and also pour it onto the soil at the back of their houses. It is not just because of the lack of awareness of people on oil management, it is also because of inadequate infrastructure, land expertise and land scarcity make the municipal waste management become an issue. The possibility of decreasing the shear strength of soil itself is really worrisome because it can cause a major disaster such as settlement or crack. Thus, this research is to investigate the effect of shear strength of soil due to waste cooking oil that infiltrates into the soil layers.

2. Literature Review

Previous study conducted by Ismail [1] revealed that in Asian countries like Malaysia, Indonesia, Thailand, Republic of China, etc, the waste of usable cooking oil estimated around 40,000 tonnes per year. With this substantial amount of usable cooking oil, the easier way to dispose is just throw it in the backyard of the houses or in the drainage system in a building. The awareness of recycle back usable cooking oil to produce such as recycle eco soap or alternative bio-diesel fuel is still lack [2]. The awareness of recycle back usage cooking oil have been a key factor which limited the activities of recycle back the usage cooking to the authority that handle these items [3]. According to the National Solid Waste Management Department under Ministry of Housing and Local Government, the rate of recycle items in Malaysia for the time being is about 5 % and this rate has been targeted to increase by 22 % in the year of 2020 [4].

Furthermore, Mahmud [5] mentioned that in his research study, to increase the awareness of society towards for better environmentally friendly, the culture of recycle must be address to the society so that the action of recycle can be one of the habits in lifelong learning. In order to achieve the habits of recycle, there are four aspects that need to taking into account which knowledge of recycle back the usage cooking oil, the proper way to dispose the usage cooking oil, habits to collect and restore in proper way of usage cooking oil and awareness towards environmental friendly [6]. Kiakalaieh et al. [7] found that the usage of cooking oil can be converted into bio-diesel fuel. If the usage of cooking oil can be recycled and transform into bio-diesel fuel, then the cost to produce biodiesel can be reduced up to 60 % to 90 % and this outcome can save the use of petroleum as a fuel consumption.

On the other hand, a research was conducted by Abousnina et al. [8] and found that the contaminated sand cause by oil leakages and from oil transfer pipes can cause increase in permeability and thus it will affect the density and reduce the stability of the soil. The change in behaviour of the sand will weaken the bearing capacity and can create an excessive settlement of a foundation. The finding evidence from Abousnina et. al., [8] has been supported by Rahman et. al [9] where from the findings, its reveal that the oil contamination was clearly observed on basaltic weathered soil of Grade V and VI and the oil contamination has furthered degrade the shear strength of the soil. Figure 1 and Figure 2 illustrate the shear strength of the contaminated oil with basaltic residual soil Grade V and VI mix at 4, 8,12 and 16% contaminated oil. Results shows that the shear strength of the soil keep reduce constantly when the percentage of the contaminated oil constantly increase [9].

Research done by Rahman and Zahari [10] indicate that the shear strength of the laterite soil continuously reduces due to increase in percentage of usable cooking oil under soaked condition for 14 days in the triaxial machine. Results also reveal that the specimens under soaking period of 14 days using multistage consolidated drained triaxial test, the shear strength reduce for about 9 % compared to control specimens without mixing with usable cooking oil. Figure 3 illustrate the shear strength of the control specimens with specimens that soaked with 14 days at different percentage of usable cooking oil.
Figure 1. Stress-strain response envelope for soil Grade V at different confining stress of (a) 140 kPa; (b) 280 kPa; (c) 420 kPa [9].

Figure 2. Stress-strain response envelope for soil Grade VI at different confining stress of (a) 140 kPa; (b) 280 kPa; (c) 420 kPa [9].

Figure 3. Mohr failure envelope for specimens at various percentage of usable cooking oil with soaking for 14 days at different confining stress pressures [10].
3. Research Methodology
This research study was conducted to investigate the effect of shear strength due to mixing with waste cooking oil in different percentage in the residual soil. The soil samples were taken from the construction site at Kolej Kenanga, Universiti Teknologi MARA, Shah Alam, Selangor. The samples were collected at the site location and place it in the polyethylene bag and bring to the laboratory for testing. The disturbed soil samples were tested for index properties test such as water content, specific gravity, plasticity properties and dry sieving test and for shear strength test, the remoulded specimens were tested for consolidated drained triaxial test series. About nine (9) remoulded specimens with size of 50 mm in diameter with 100 mm in height were used in the test. All the tested specimens were remoulded using the same amount of optimum water content which have been determined using compaction test procedures. This is to make sure that all the remoulded specimens were in identical condition so that the results output is in the best state.

In order to prepare for the nine (9) remoulded specimens mixing with 5% and 10% wasted cooking oil, the soil samples were weight for about 3 kg for compaction test procedure. With the used of 14% (420 ml) of optimum water content and 5% (150 ml) and 10% (300 ml) of usage cooking oil, the mixing process were done thoroughly and compacted according to the BS 1377: Methods of Test for Soils for Civil Engineering Purposes (1990) Parts 1 to 9. After that, the specimens were tested using consolidated drained triaxial test using different applied effective stress of 50, 200 and 300 kPa to investigate the shear strength behaviour of the specimens.

4. Results and Analysis
Table 1 tabulated the recorded data of effective internal friction angle at failure, $\phi'$ with transition shear strength at failure, $\tau'$ and transition effective stress at failure, $(\sigma-U_w)_t$, deviator stress at failure, cell pressure and pore water pressure for control, mix with 5% and 10% usage cooking oil specimens. Results shows that the internal friction angle at failure for control specimens without mix with any usage cooking oil was 27° with transition shear strength at 60 kPa and transition effective stress at 80 kPa. However, when the specimens are mix with usage cooking oil at 5%, the shear strength of the specimens significantly decrease for about 22° in internal friction angle with transition shear strength at 50 kPa and transition effective stress at 80 kPa. Moreover, when the specimens are mix with 10% of usage cooking oil, the results tremendously keep deduce to 20° in internal friction angle with transition shear strength at 50 kPa and transition effective stress at 73 kPa.

Table 1. Effective friction angle at failure, $\phi'$ for control, mix with 5% and 10% usage cooking oil specimens.

| Specimens         | Effective Stress, kPa | Condition of Failure | Shear Strength Parameters |
|-------------------|-----------------------|----------------------|---------------------------|
|                   | DS (kPa) | PWP (kPa) | CP (kPa) | $\phi'$ | $\tau'$ | $(\sigma-U_w)_t$ |
| Control           |          |           |          |         |         |  |
| 50                | 140      | 400       | 450      |         |         |  |
| 200               | 384      | 400       | 600      | 27°     | 60      | 80 |
| 300               | 542      | 350       | 650      |         |         |  |
| Mix with 5% usage |          |           |          |         |         |  |
| cooking oil       |          |           |          |         |         |  |
| 50                | 103      | 650       | 700      | 22°     | 50      | 80 |
| 200               | 288      | 400       | 600      |         |         |  |
| 300               | 402      | 400       | 700      |         |         |  |
| Mix with 10% usage|          |           |          |         |         |  |
| cooking oil       |          |           |          |         |         |  |
| 50                | 113      | 450       | 500      | 20°     | 50      | 73 |
| 200               | 281      | 500       | 700      |         |         |  |
| 300               | 371      | 400       | 700      |         |         |  |

* DS - Deviator Stress, PWP - Pore Water Pressure, CP - Cell Pressure
The stress-strain response of all the specimens need to be plotted in order to determine the internal friction angles. Figure 4 (a) illustrate the stress-strain response of the control specimens with effective stress of 50, 200 and 300 kPa where the maximum deviator stress has been recorded in order to plot the Mohr failure envelope. Meanwhile, in Figure 4 (b) shows the Mohr failure envelope with effective stress at 50, 200 and 300 kPa for control specimens without mix with usage cooking oil and the effective friction angle can be determine.

![Figure 4](image)

**Figure 4.** (a) Stress-strain response envelope for control specimens at effective stress at 50, 200 and 300 kPa; (b) the internal friction angle at failure for control specimens at effective stress of 50, 200 and 300kPa.

Furthermore, Figure 5 (a) represent the stress-strain response of the specimens when mix with 5 % of usage cooking oil corresponded to effective stress of 50, 200 and 300 kPa where the maximum deviator stress has been recorded in order to plot the Mohr failure envelope and in Figure 5 (b) shows the Mohr failure envelope with effective stress at 50, 200 and 300 kPa for specimens that mix with 5 % usage cooking oil. On the other hand, results also revealed that there is a significant reduction in term of effective friction angle at failure, $\phi_f$ by 2° between samples that mix with 5 % and 10 % usage cooking oil. Figure 6 (a) illustrate the stress-strain response of the specimens when mix with 10 % of usage cooking oil corresponded to effective stress of 50, 200 and 300 kPa where the maximum
deviator stress has been recorded in order to plot the Mohr failure envelope and in Figure 6 (b) shows the Mohr failure envelope with effective stress at 50, 200 and 300 kPa for specimens that mix with 10 % usage cooking oil.

**Figure 5.** (a) Stress-strain response envelope for specimens mix with 5 % usage cooking oil at effective stress of 50, 200 and 300 kPa; (b) the internal friction angle at failure for specimens mix with 5 % usage cooking oil at effective stress of 50, 200 and 300kPa.
There is a significant reduction in the shear strength for all the specimens when mix with usable cooking oil compared to the control specimens. Results reveal that there is a significant reduction of 22.7 % in shear strength from control specimens compared with mix with 5 % of usage cooking oil. In the meantime, there is slightly different in shear strength of 10 % from specimens that mix with 5 % usage cooking oil compared with specimens that mix with 10 % usage cooking oil. Figure 7 (a) and (b) illustrate the summary of all the specimens for stress-strain response and failure criterion for Mohr failure envelope of all the specimens. Overall, the shear strength of the specimens from control specimens compared to 5% mix with usage cooking oil, the shear strength keeps reduce to 35 %. This value gives a great significant outcome to shows that the shear strength of the specimens is keep reducing when the amount of usage cooking oil keeps increase daily.

**Figure 6.** (a) Stress-strain response envelope for specimens mix with 10 % usage cooking oil at effective stress of 50, 200 and 300 kPa; (b) the internal friction angle at failure for specimens mix with 10 % usage cooking oil at effective stress of 50, 200 and 300 kPa.
Figure 7. (a) Stress-strain response envelope for control, mix with 5 % and 10 % usage cooking oil at effective stress of 50, 200 and 300 kPa; (b) the internal friction angle at failure for control, mix with 5% and 10 % usage cooking oil at effective stress of 50, 200 and 300 kPa.

The results of this study indicate that the higher effective friction angle at failure, \( \phi' \), is at control specimens without adding any usage cooking oil while the lowest friction angle at failure, \( \phi'' \), is at 10 % mix with usage cooking oil specimens. It shows that the bigger amount of usage cooking oil being dumping at the soil surface, the worsen condition of the soil will become in term of shear strength of the soil. Thus, when raining occurs, the rainwater will bring along the dumping usage cooking oil to seep through inside the soil layer and thus will weaken the bonding between soil inter-particle beneath the soil sub-surface.

5. Conclusion
A series of laboratory study using consolidated drained triaxial test was carried out to investigate the behaviour of shear strength of usage cooking oil when mixing with the residual soil in different
percentage. Output of the research reveal that when the soil is mixing with usage cooking oil, there is a significant reduction in effective friction angle at failure, $\phi'$, for all the specimens. Moreover, when the proportion of the usage cooking oil increase, the shear strength of the soil also keeps decrease gradually. Results indicate that the shear strength of soil will keeps decreases when the amount of disposal usage cooking oil keep increases and thus will create an excessive settlement to the related foundation system especially in shallow foundation. This will become the worst-case scenario when rainwater mix with usable cooking oil and infiltrated deep beneath the subsoil.

As for recommendation, in order to investigate the real behaviour of shear strength when mix with usage cooking oil, the soaking effect and time of soaking might be the best option. Nevertheless, the percentage of usable cooking oil also play an important role on decreasing the shear strength. Due to that, the percentage of usable cooking oil also needs to be study through in order to determine the optimum value that may affect the shear strength of the particular soil.

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