Shear Strength of Remoulding Clay Samples Using Different Methods of Moulding

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Abstract. Shear strength for clay soil was required to determine the soil stability. Clay was known as a soil with complex natural formations and very difficult to obtain undisturbed samples at the site. The aim of this paper was to determine the unconfined shear strength of remoulded clay on different methods in moulding samples which were proctor compaction, hand operated soil compacter and miniature mould methods. All the samples were remoulded with the same optimum moisture content (OMC) and density that were 18% and 1880 kg/m³ respectively. The unconfined shear strength results of remoulding clay soils for proctor compaction method was 289.56kPa with the strain 4.8%, hand operated method was 261.66kPa with the strain 4.4% and miniature mould method was 247.52kPa with the strain 3.9%. Based on the proctor compaction method, the reduction percentage of unconfined shear strength of remoulded clay soil of hand operated method was 9.66%, and for miniature mould method was 14.52%. Thus, because there was no significant difference of reduction percentage of unconfined shear strength between three different methods, so it can be concluded that remoulding clay by hand operated method and miniature mould method were accepted and suggested to perform remoulding clay samples by other future researcher. However for comparison, the hand operated method was more suitable to form remoulded clay sample in term of easiness, saving time and less energy for unconfined shear strength determination purposes.

Keywords: Soft soil, ground modification, shear strength.

1. Introduction
The construction development on clay soil cannot be avoided because of the lack land space. Clay is a fined grained soil known as a very complex natural formations with high compressibility and low shear strength [1]. Soil in its remoulded state was commonly referred to as unstructured, and differences in mechanical behavior between a soil in its natural and remoulded states are considered to be the result of structure [2]. The fabric of soil is progressively disrupted when the soil was remolded and the behavior of the soil was altered. Depending on the size and strength of the soil particle the arrangement may alter the water retention and mechanical behavior of the soil and make it different from that of undisturbed soil of the same mineralogy [3]. There have been a lot of studies on developing constitutive models that consider the structure of the soil, such as those proposed by Nova...
and Gens, Liu et al. and Tanaka et al. [4, 5, 6]. They suggested new constitutive model for structured clays where its parameters can be readily determined in the laboratory.

The remoulded samples was very important to study because its very challenging and very hard to obtain undisturbed samples of soft soil at the site. Alshamib [7], state that to obtained the undisturbed samples was impossible due to the process of boring, driving the coring tool, raising and withdrawing the coring tool and extruding the soil specimens that can contributed some disturbance in the structure of the soft clay (Whitlow) [8]. Due to these problems, the remoulded samples was very important to study and understanding to overcome the difficulty process of taking undisturbed soil at the site.

2. Materials and Methods

2.1 Remoulding Sample

The disturbed clay soils from this study were collected at RECESS, UTHM, Batu Pahat, Johor. The disturbed clay was then remoulding through three different methods that were proctor compaction, hand operated and miniature mould. In this study, the proctor compaction method used as the based method for other methods that were hand operated method and miniature mould method. From the proctor compaction, the value of maximum dry density was 1525 kg/m$^3$ and the optimum moisture content (OMC) was 18 %. Then, the bulk density obtained was 1880 kg/m$^3$. Thus, to form the same density for all remoulded clay, 162 gram mass were kept constant. Then, the remoulded clay soils for all methods were formed with the specimens sizes 38 mm diameter and 76 mm of height. The procedure of samples preparation for proctor compaction method was according to (BS 1377: Part 8: 1990).

2.2 Remoulding Clay by Using Ordinary Proctor Compaction Method

Proctor test was designed to determine the dry density and moisture content relationship for compaction of soil based on BS 1377: Part 4: 1990. Figure 1 (a and b) shows the ordinary proctor compaction apparatus during and after soil was compacted. A cylindrical mould 1 liter or 1000 cm$^3$ volume filled with three layers of soil. This cylindrical mould has 105 mm internal diameter 115.5 mm effective height with removable extension collar. Each layer of soil were stamped with 25 blows per layer with a standard rammer 2.5 kg and a drop distance of 300 mm for each impact. The optimum moisture content was determined to be used in all other methods for mixing the soil.

![Figure 1](a) During Compaction.  (b) After Compaction.

Figure 1. (a and b) Ordinary Proctor Compaction During and After Compaction

2.3 Remoulding Clay by Using Hand Operated Soil Compactor Method

In this method, the soils were mixed with 18% of water content. Then, 162 gram of soils were transferred to a 38 mm diameter and 76 mm height a split mould and compacted in 4 layers of 40 g
each layer used hydraulic hand operated compressor. The top of each layer was compacted properly to make sure the soil were bond together neatly. Then, the specimen was extracted out from the mould and marked to determine its orientation. Tang [9], state these method include tapping and static compaction where it’s suitable to form the samples due to repeatability, workability and lower probability of soil sample to failure.

![Figure 2. Hand Operated Soil Compactor.](image)

2.4 Remoulding Clay by Customade Miniature Compaction (Miniature Mould)
Based on past researcher Mokhtar [10], the miniature mould apparatus was used in preparing remoulded samples for testing Unconfined Compression Strength test (UCS). In this method, the remolded clay soil was mixed with 18 % of water content and mixed well thoroughly with a spoon. Then, 162 gram mass of mixed soil was transferred to 38 mm diameter and 76 mm height of split mould and then compacted in 4 layers where 40 g for each layer. Each layer were tamped and compacted with customade miniature compaction tools: first tamped with Tool A for 40 times followed with Tool B for 40 times. Then, the specimen was extracted out from the mould and marked to determine its orientation. Mokhtar [10] stated that the determination of orientation was needed to standardize the orientation of top and bottom of the specimens during the tests and ensure exact duplicity in the specimens. Figure 2 shows the apparatus of hand operated soil compactor. The tools and compaction mould set was shown in Figure 3. The top of each layer of compacted properly before placing the following layers to improve the bonding between each layers. Then, the specimen was slid out from the 38 mm diameter and 76 mm height of the mould.

![Figure 3. Customade Miniature Compaction (Miniature Mould) Equipment.](image)
2.5 Unconfined Compression Strength Test

Unconfined compression strength test was accepted test to determine strength of more robust tropically weathered materials [11]. The purpose of unconfined compression strength test was to determine the unconfined shear strength of saturated clays quickly [12]. The procedure of unconfined compressive strength test was defined as cylindrical specimen of cohesive soil where a steadily increasing axial load was subjected to the soil specimen until failure [13]. The main purpose of this test was to determine the unconfined compressive strength \(q_u\), which is then used to calculate the unconfined shear strength \(c_u\) value for all the methods. The reconstituted clay specimen for all methods were properly prepared and placed between the top and lower platens in the unconfined compression strength test machine that show in Figure 4. An axial load was then applied vertically at a standard strain rate of 1 mm per minute until the soil specimen was failed. Then the reading was taken and analysis.

![Figure 4. Unconfined Compression Test Apparatus.](image)

3. Results and Discussions

3.1 Clay Properties

The index properties of RECESS clay soil was 73.80 % of natural water content, liquid limit was 56 %, plastic limit was 37.19 % and specific gravity of clay soil was 2.6. The result of index properties was in the range with past previous study that shown in Table 1.

| Author | Moisture Content (%) | Liquid Limit (%) | Plastic Limit (%) | Specific Gravity |
|--------|----------------------|------------------|-------------------|-----------------|
| Ibrahim and Chan [14]; Ho and Chan [15] | 73.8 | 56.0 | 37.19 | 2.6 |
| Alshamib [7] | 80.5 | 68.0 | 31.7 | 2.62 |
| Mohd Yusof [16] | - | 60.0 | 32.27 | 2.6 |

Table 1. Physical Properties of Typical RECESS Clay
3.2 Stress-Strain Behavior of Combination Method

Figure 5 shows the average of the unconfined compressive strength and the axial strain between all methods was 495.04 kPa – 579.12 kPa and 3.9 % - 4.8 % respectively. In this graph, the unconfined compressive strength of remoulded clay for proctor compaction method has record the highest value of 579.12 kPa with the strain 4.8 %. While, the unconfined compressive stress of miniature mould method has recorded the lowest value of 495.04 kPa with the strain 4.4% followed by hand operated method 523.32 kPa with the strain 3.9 %. The proctor compaction method recorded the higher strain failure because of the technique compaction makes the soil particle bind well to other soil particles. Das [17], state that the compaction effort can affect the soil particle.

![Graph showing stress vs strain for different methods](image)

**Figure 5.** Axial Stress vs Axial Strain (All Three Methods).

Table 2 shows the average value of maximum unconfined compressive strength ($q_u$) and unconfined shear strength ($c_u$). The value of maximum unconfined compressive strength ($q_u$) for methods proctor compaction, hand operated and miniature mould were 579.120 kPa, 523.320 kPa and 495.040 kPa respectively. From this table, the lowest value of unconfined shear strength for miniature mould method was 247.52 kPa, followed by hand operated method, 261.66 kPa and the highest unconfined shear strength was by proctor method, 289.56 kPa. Based on the proctor compaction method, the reduction percentage of unconfined shear strength of remoulded clay soil for hand operated method was 9.66 %, and for miniature mould method was 14.52 %. This reduction percentage may cause from the type of methods conducted and the specimen handling manner. Yusoff et al [18], state the strength of soil specimen texture was affected since the samples was compacted. From these percentages, the hand operated method was more effective to form the remoulded clay samples because the percentage value of unconfined shear strength was lower than 10 %. However, the miniature mould method still can be accepted because it does not exceed than 15 %. Thus, it can be conclude that remoulding clay using hand operated method and miniature mould method were accepted and suitable to form the samples. However for comparison, the hand operated method was more suitable to form remoulded clay sample in term of easiness, saving time and less energy.
Table 2. The Average Value of Maximum Unconfined Compressive Strength and Unconfined Shear Strength.

| Method              | Unconfined Compressive Strength, q_u (kPa) | Unconfined Shear Strength, c_u (kPa) |
|---------------------|------------------------------------------|------------------------------------|
|                     | Sample 1       | Sample 2       | Sample 3       | Average       |                      |
| Proctor Compaction  | 589.187        | 574.079        | 574.079        | 579.120       | 289.56               |
| Hand Operated       | 524.443        | 522.757        | 522.757        | 523.320       | 261.66               |
| Miniature Mould     | 499.745        | 492.396        | 492.969        | 495.040       | 247.52               |

3.3 Types of Failure

Based on this study, failure mode of remoulding sample for proctor method is shearing as shown in Figure 6 (a). While failure mode on remoulding sample for hand operated method and miniature method are bulging as shown in Figure 6 (b) and (c) respectively. According to Das [17], the failure of soil specimens at the end of unconfined compression test are in two type that were shearing and bulging.

Conclusion

In this paper, the remoulded clay sample for proctor compaction method used as comparison for other method that are hand operated method and miniature mould method. The unconfined shear strength results of remoulded clay soils for three different methods that were 289.56kPa (proctor compaction method), 261.66kPa (hand operated method) and 247.52kPa (miniature mould method). The unconfined shear strength readings for all methods were still in the range because the different of percentages of unconfined shear strength of remoulding clay between hand operated and proctor compaction method was 9.66% and remoulded clay for miniature mould and proctor compaction method was 14.52%. These three methods shows unconfined shear strength within to the range method that was proctor compaction method, and its proved that all three methods were suitable to used to performed the soil samples. Thus, it can conclude that remoulding clay of hand operated method and miniature mould method are accepted to perform remoulded clay samples. However based on the easiness, saving time and less energy used in preparing the remoulded samples, the hand operated method was more suitable for shear strength determination purposes.

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