Sara MOTWANI
1st year student MEng Engineering and Architectural Design
Material, Mechanics & Making Course – Geotechnics

GEOTECHNICS LAB REPORT

1. INTRODUCTION

This report aims to discuss the Oedometer Test, the Shear Box Test and the Triaxial Test and outlines their respective apparatus as well as evaluate the results obtained and their implications on the soil samples tested.

2. OEDOMETER TEST

2.1 Apparatus (Diagram 1)

The consolidation cell: It consists of a confining ring placed circumferentially around the sample to restrict the lateral displacement. Due to this there is no horizontal strain (ε_h), so volumetric strain = vertical strain ($\varepsilon_{vol} = \varepsilon_v + 2\varepsilon_h$). A loading cap transfers the load to the soil specimen. It is surrounded by a water bath that ensures that the soil remains essentially saturated. Porous Filters (stones) at the top and bottom of the sample are several orders of magnitude more permeable than typical samples of fine-grained soil. They allow water to flow into or out of soil without loss of soil particles i.e., allow soil to compress. Since the oedometer allows the water from the soil to move both from above and below the drainage path is half of the height of the sample. Sometimes a filter paper is placed between stone and soil sample to prevent porous stones from clogging with the soil. **The Loading Frame:** The loading frame configuration is composed of a loading beam and dead weights that allows for a constant load to be maintained indefinitely. **Deformation Measurement Mechanism:** The vertical deformation measurements of the soil specimen is performed using a dial gauge (most often) or an electronic instrument.

2.2 Analysis

COMPRESSION: An Oedometer is used for the analysis of one-dimensional compression of a soil sample. As mentioned in the apparatus, the soil sample is horizontally confined in a rigid ring and so only a vertical stress is applied onto the sample (leading to only vertical compression). As the stress is increased, the water from the soil flows out of the porous layers. This carries on until the pore pressure has dissipated, i.e., $U = 0$ and the settlement is complete and $\sigma'v = \sigma v$. The graph 1 shows the void ratio vs the vertical effective stress. The line with a larger slope is the 1D normal compression line whereas the one with the smaller slope is the swelling line. The soil follows the 1D NCL before it has gone through any unloading i.e., it is experiencing the maximum stress it has ever experienced. When the soil is unloaded it follows the path of the swelling line. The graph 2 shows a plot between the void ratio and log10 of the vertical stress $\sigma'v$ for a natural and a reconstituted sample with identical load increments applied to both. The graph presented is linear for reconstituted sample and curved for natural sample with a negative slope/gradient indicating a decreasing void ratio with increasing vertical stress. The gradient of this line can be used to evaluate the compression index (Cc) for the soil samples. For the reconstituted sample a constant compression index is calculated Cc = -0.54 kPa^{-1}. However, since the natural sample does not have a linear graph the Cc is non-constant and has a value that increases slowly with increase in stress from about Cc-initial = -0.051 kPa-1 to Cc-final = -0.539 kPa^{-1} (almost parallel to reconstituted for higher stresses). This shows that the natural sample is harder to compress that the reconstituted sample. This is also supported by the fact that a larger amount of force is required to cause an initial change in void ratio in the natural sample when compared to the reconstituted sample. This leads us to believe that the natural sample of soil is in fact sturdier and denser than the reconstituted sample and needs more force to compress i.e., reduce void ratios. Finally, we also observe that the NCL for the natural sample does not converge with the NCL of reconstituted sample, instead, it becomes parallel to it making it a fabric dominated soil (not easily rearranged).

CONSOLIDATION: The oedometer is used to determine consolidation characteristics. Consolidation is the change in volume that occurs with time as pore pressure dissipates. The graph 3 shows a plot of the settlement with the square root of time which initially shows linear behavior and then curves towards a horizontal asymptote. The time till which the graph behaves linearly is called the critical time (t_c) and is the time at which the pore pressure of the sample reaches the base. For this graph $t_c \sim 2$ minutes. Following this point the graph curves towards the asymptote and the pore pressure change occurs at the base until the pore pressure is 0 and final settlement is reached which is at an infinite time. The factor 'consolidation coefficient (C_v)' helps determine the time taken for the soil to settle (i.e., all water to drain out). Extrapolating a straight line to Settlement U_t = 1 (settlement at infinite time) we get t_{100} which is used to calculate C_v = 1.9 m^2/year. This means that the rate at which the water drains out of the given soil sample is 1.9 m^2/year. Hence, the time to reach settlement can be calculated using the consolidation coefficient (from the oedometer test) and the drainage path length.

3. SHEAR BOX TEST

3.1 Apparatus (Diagram 2)

The apparatus for the Shear Box Test essentially resembles that of an oedometer (but it is usually square not circular) wherein the sample is placed in a rigid confinement restricting horizontal displacement but with a split that can apply a shear load (F_s) by pushing the top half with respect to the bottom half causing shearing. A vertical force (F_v) is applied with a loading hanger. It is submerged in a water bath keeps soil saturated, and the porous stones allow water to flow into or out of soil without loss of soil particles. F_s is measured by a proving ring that measures the displacement of the metal ring which is proportional to the force. Dial gauge is used to measure vertical and shear displacements.

3.2 Analysis

The graph 4 shows a plot of the ratio Shear Stress/Normal Stress against the Shear Strain to get two curves for the dense and loose samples respectively. It can be noted that the dense sample has a much larger curve than the loose sample. This is because the dense sample has peak strength and is strain softening leading us to believe it is over consolidated, whereas the loose sample does not have peak strength and is strain hardening leading us to believe it is normally consolidated. In the dense sample, shearing causes dilation (grains move apart). The peak strength for the dense sample from graph 4 is 0.83 which helps determine the friction angle φ' = 39.7°. In the loose sample, shearing causes compression (grains move closer). Towards the end of the graph, it can be observed that the lines representing dense and loose samples merge in a region where the shear/normal stress ration is between 0.75-0.8. This region of stabilisation is known as the critical state wherein the shear stress is constant, and the volumetric strain is constant while the shear strain increases. Graph 5 is a plot of the volumetric strain against shear strain. It can be observed that the graph for the dense sample ascends from values 0-2.5% of shear strain and small positive values for volumetric strain after which it begins descending to negative values for volumetric strain till it reaches volumetric strain between -1 and -1.5% and shear strain of about 18-20%. Graph 6 is a plot of the void ratio against shear strain, and it can be observed that for the dense sample the void ratios decrease to 0.65 at about 2.5% shear strain (as in graph 5) before it starts ascending. This negative value indicates dilation which links to the peak strength. Conversely, the graph 5 for loose sample shows an increase in volumetric strain with shear strain and graph 6 shows the void ratio for the loose sample decreases with increase in shear strain. Since these are positive values it indicates compression.

4. TRIAXIAL TEST

4.1 Apparatus (Diagram 3)

The triaxial test, being more reliable, has a more advanced apparatus. Like the first two it also is surrounded by water pressure around it to allow isotropic loading. A cylindrical sample placed is surrounded by a latex rubber membrane to prevent entry of water into the sample. A top platen provides an additional axial load through the loading arm. A pair of O-rings seal the membrane to the platen and base. Under the sample is a porous disk with a drainage tube with a tap under it to allow controlled outflow of water.

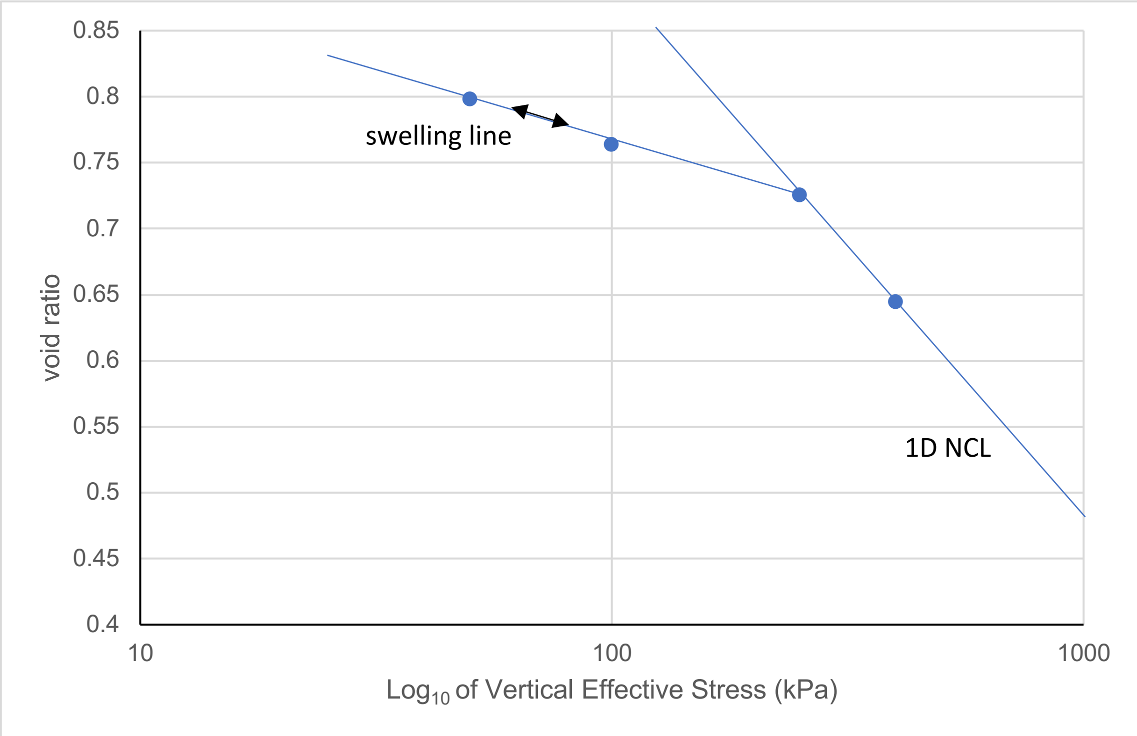
4.2 Analysis

The Graph 7 is a plot of the deviatoric stress (q') against total and effective stress (p and p') the **first shearing** of the 400 kPa sample for undrained shearing is analysed (dark blue and red). It can be observed that the graph bends towards the left i.e., further away from the actual path and hence pore pressure is increasing so, the sample is normally consolidated (using $\sigma' = \sigma - U$). This sample is then unloaded and sheared again with a total axial force of 600 kPa and the **second shearing** is analysed (light blue and orange). It can be observed that the effective shearing path bends towards the right due to which pore pressure decreases slightly hence proving the sample to be slightly over consolidated. It leads us to conclude that in the first shearing the sample was normally consolidated but in the second shearing it showed over consolidated behaviour. Further, it is observed that the gradient of the total stress path (p) for both normal and over consolidated clays is found to be 3 from its mathematical definition $p = (\sigma_a' + 2\sigma_r')/3$ and $p' = p - U$. The undrained shear strength (Su) of these two samples can be determined by extrapolating the critical state deviatoric stress (q_{cs}) and observing effective stress paths using $Su = q_{cs}/2$. This gives us Su(NC) = 71kPa and Su(OC) = 83.5 kPa. It is also analysed that the shear strength of the samples does not correspond as its supposed to (since they have the same specific volume). This is because the test for the first shearing was stopped too early not enabling the strains to reach the desired value.

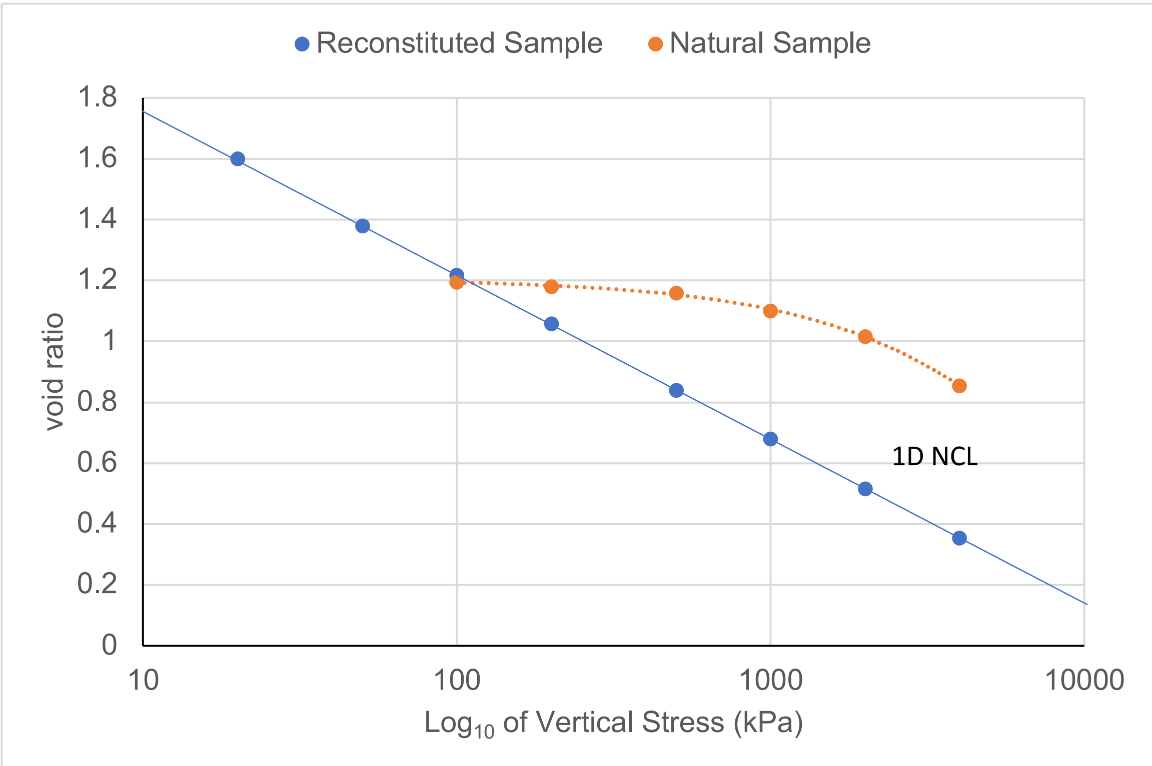
MOHR CIRCLES (Diagram 4&5) – The critical state stresses can be used to draw Mohr Circles (using the critical state deviatoric stress as diameter of the circle) which help define the critical state failure envelope from which the critical state shearing angle (φ_{cs}') can be calculated. It is conclusive to find that the failure envelope passes through the origin as solids tend to have no strength at no effective stress. We calculated φ_{cs}'(NC) = 19° which is lower than expected and φ_{cs}'(OC) = 26° which is higher than expected which is 22-23° for London clay as the first shearing was stopped early.

5. GRAPHS AND DIAGRAMS

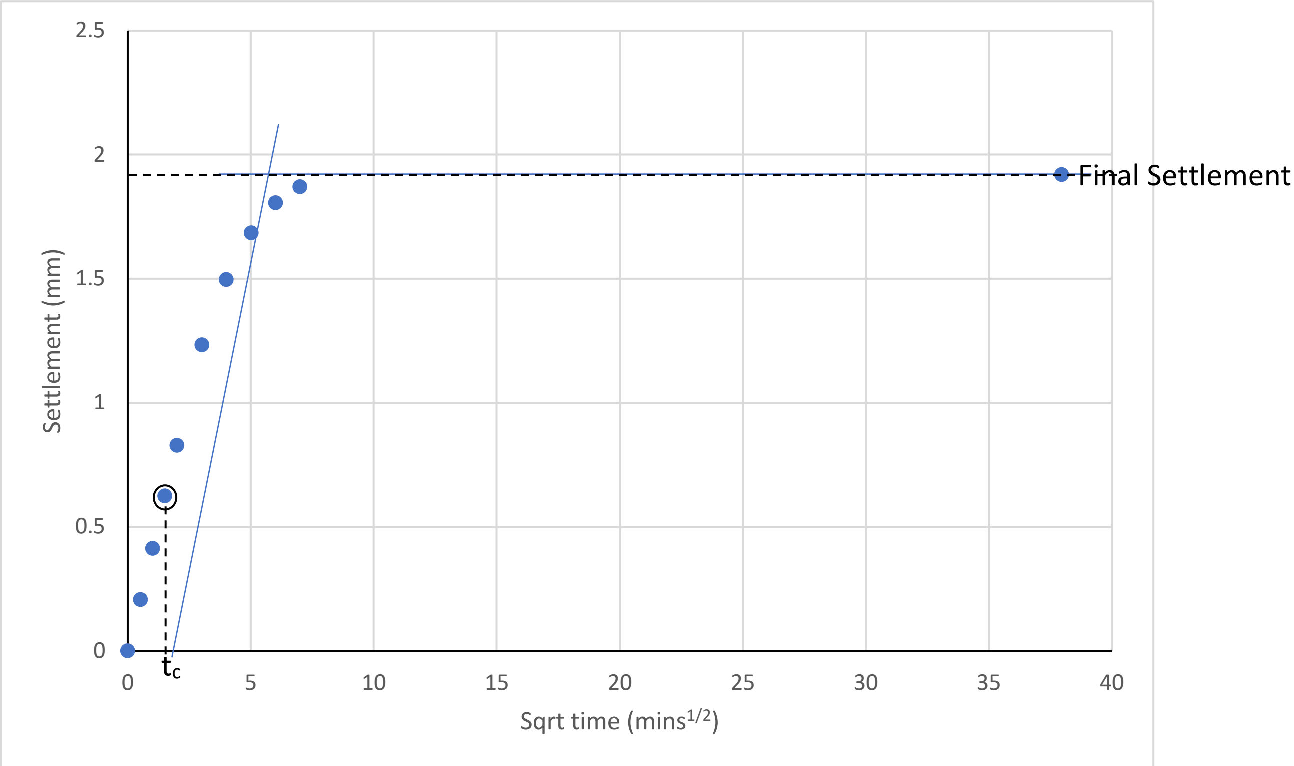
5.1 Graph 1 – Void ratio against Vertical Effective Stress for Reconstituted sample



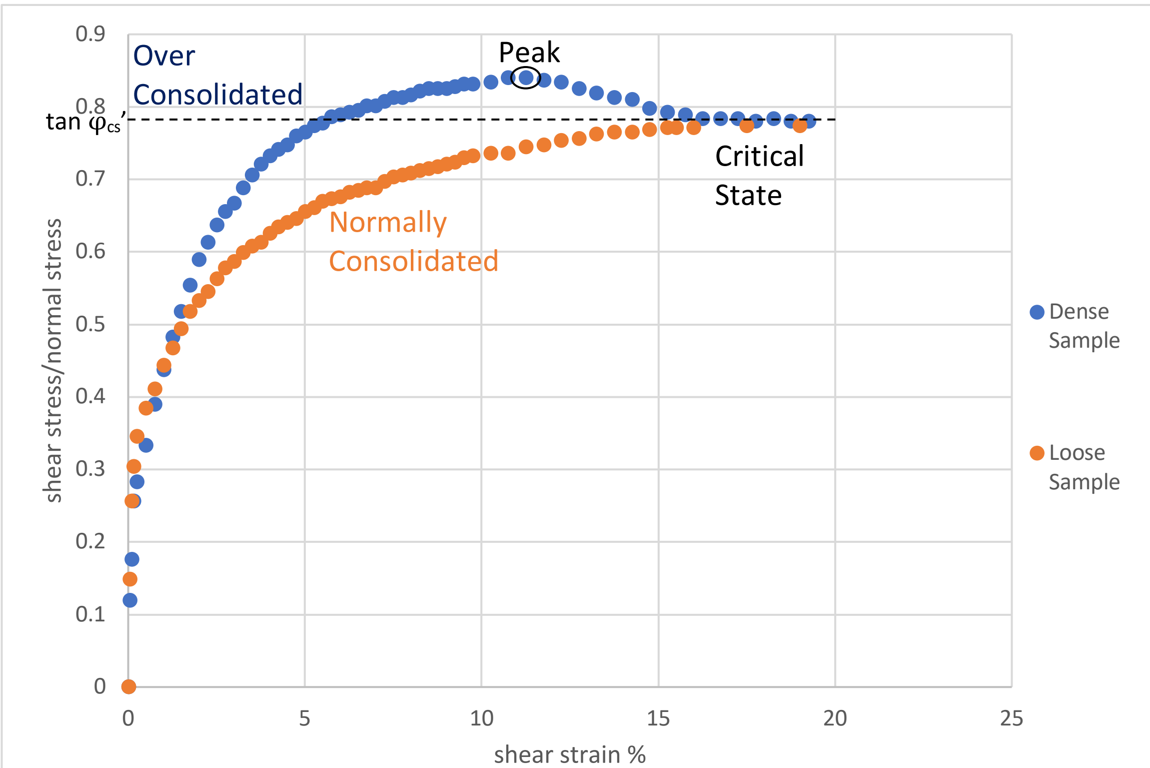
5.2 Graph 2 - Void ratio against Vertical Effective Stress for Natural and Reconstituted samples



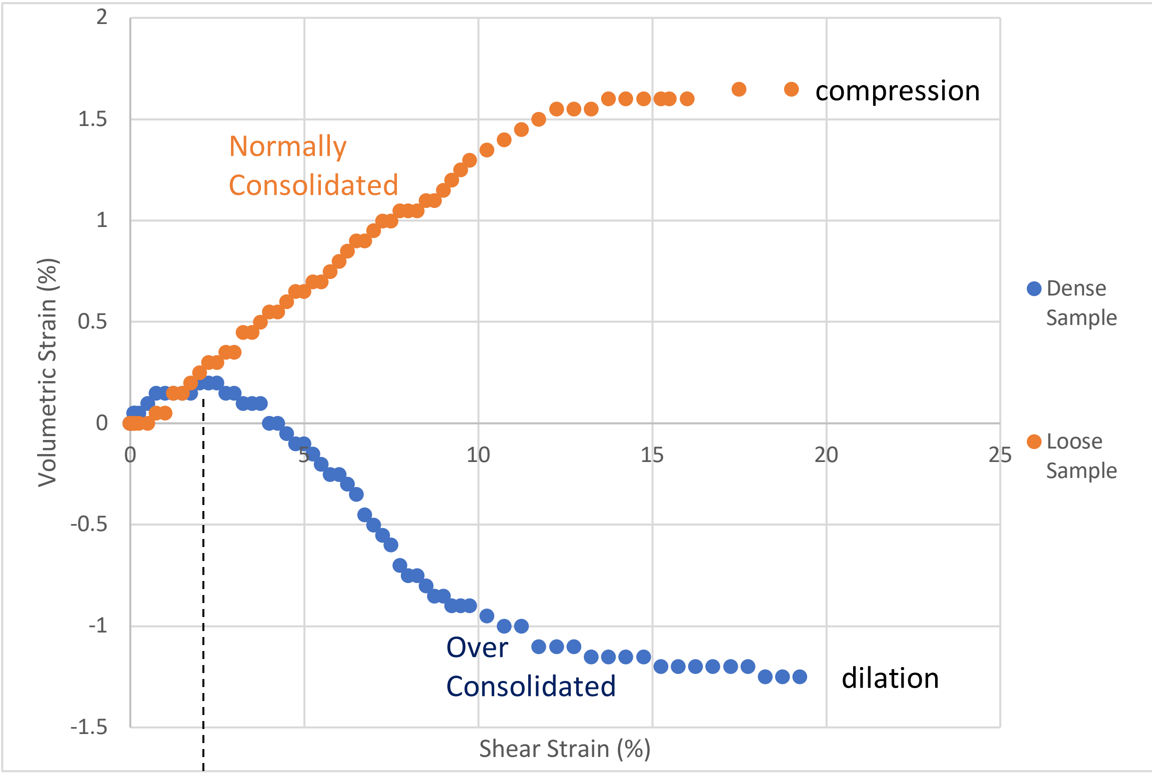
5.3 Graph 3 – Settlement against Square Root of Time



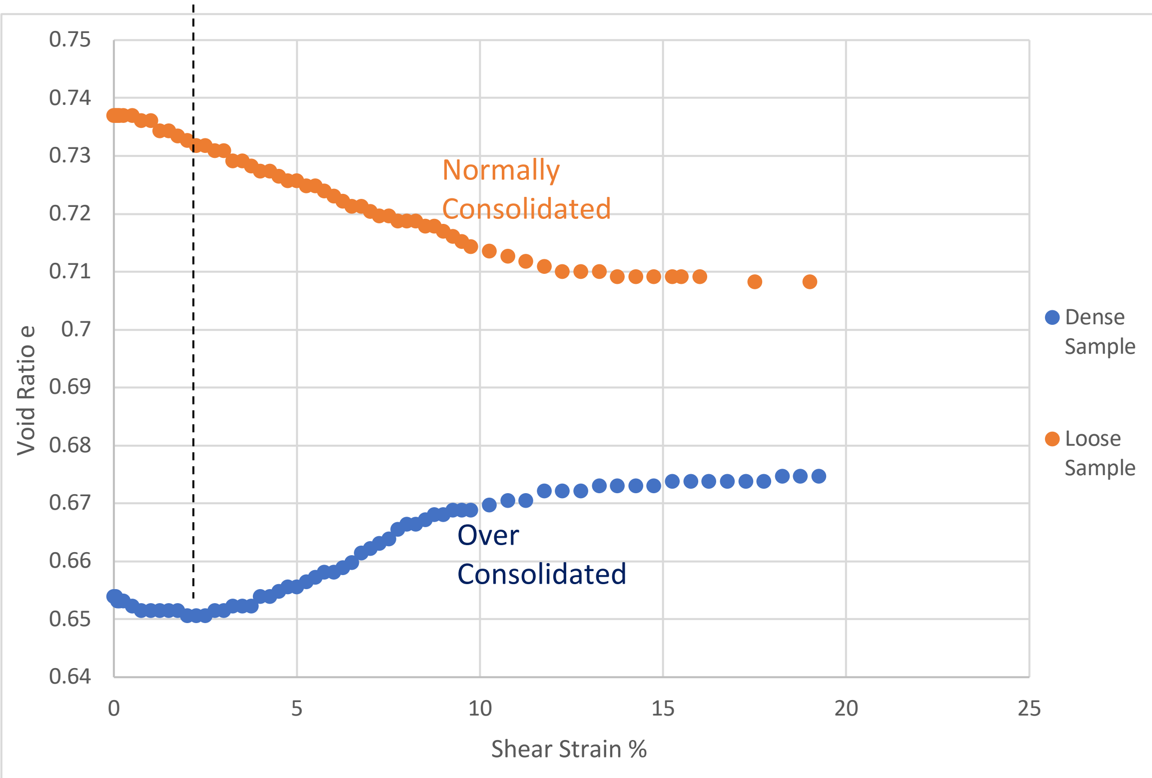
5.4 Graph 4 – Shear Stress/Vertical Stress against Shear Strain for Dense and Loose Sand



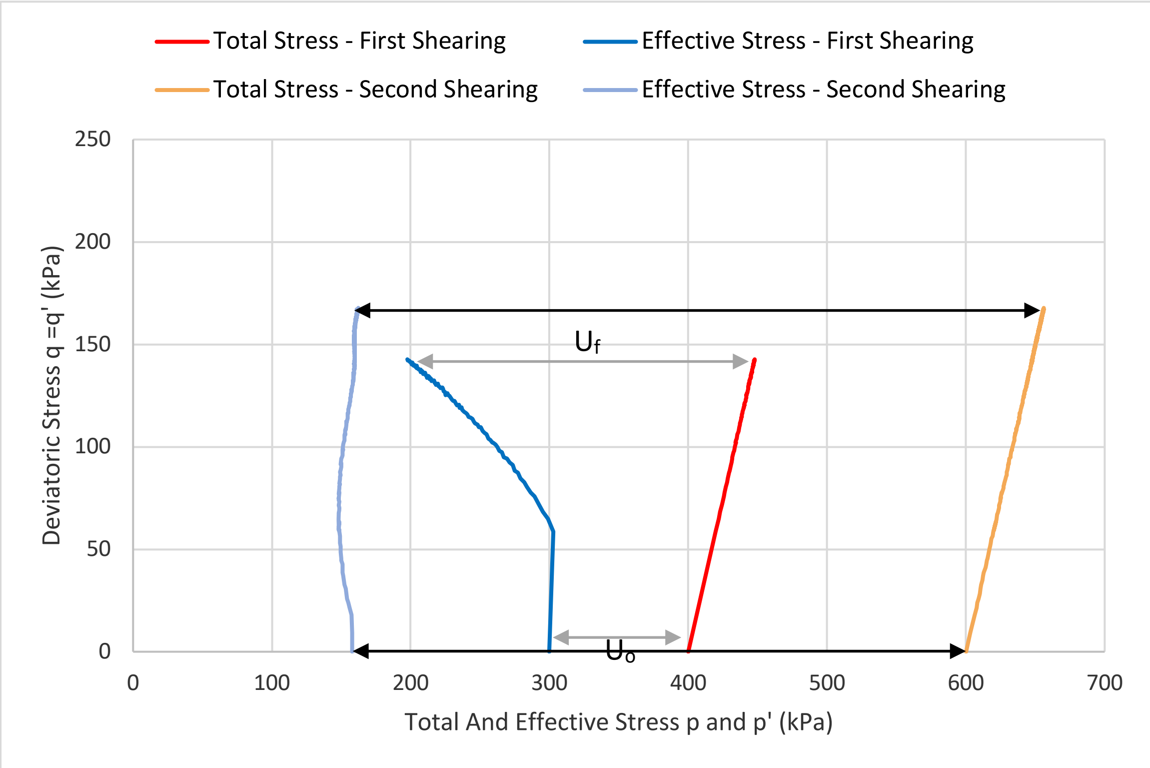
5.5 Graph 5 – Volumetric Strain against Shear Strain for Dense and Loose Sand



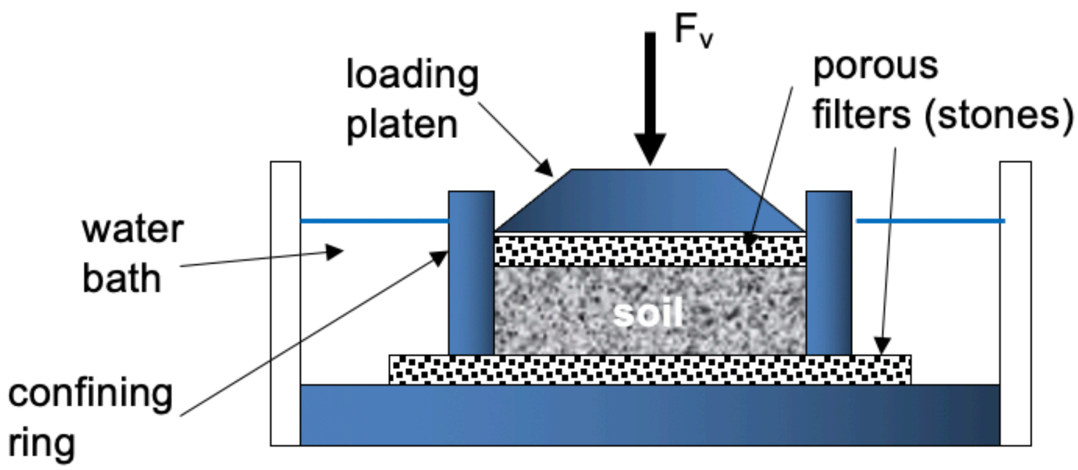
5.6 Graph 6 – Void Ratio against Shear Strain for Dense and Loose Sand



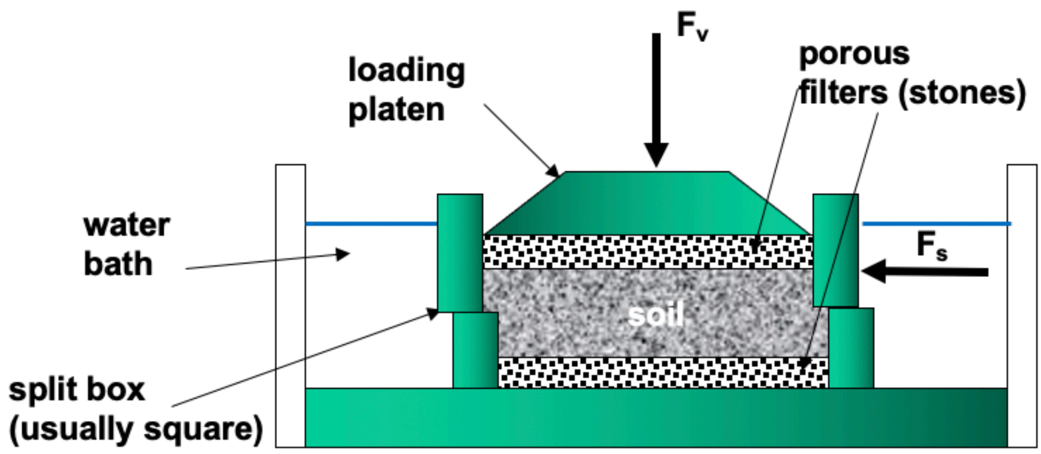
5.7 Graph 7 – Deviatoric Stress against Total and Effective Stress for First and Second Shearing



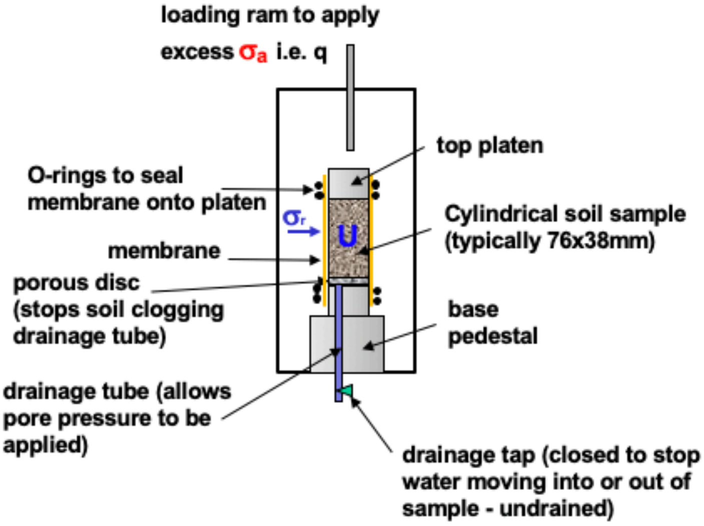
5.8 Diagram 1 – Oedometer

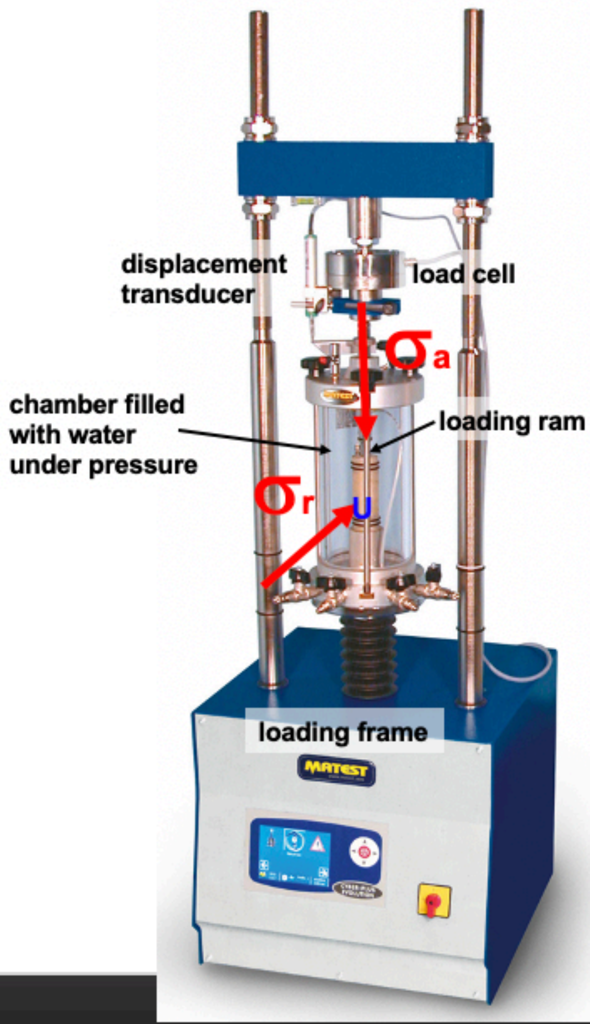


5.9 Diagram 2 – Shear Box

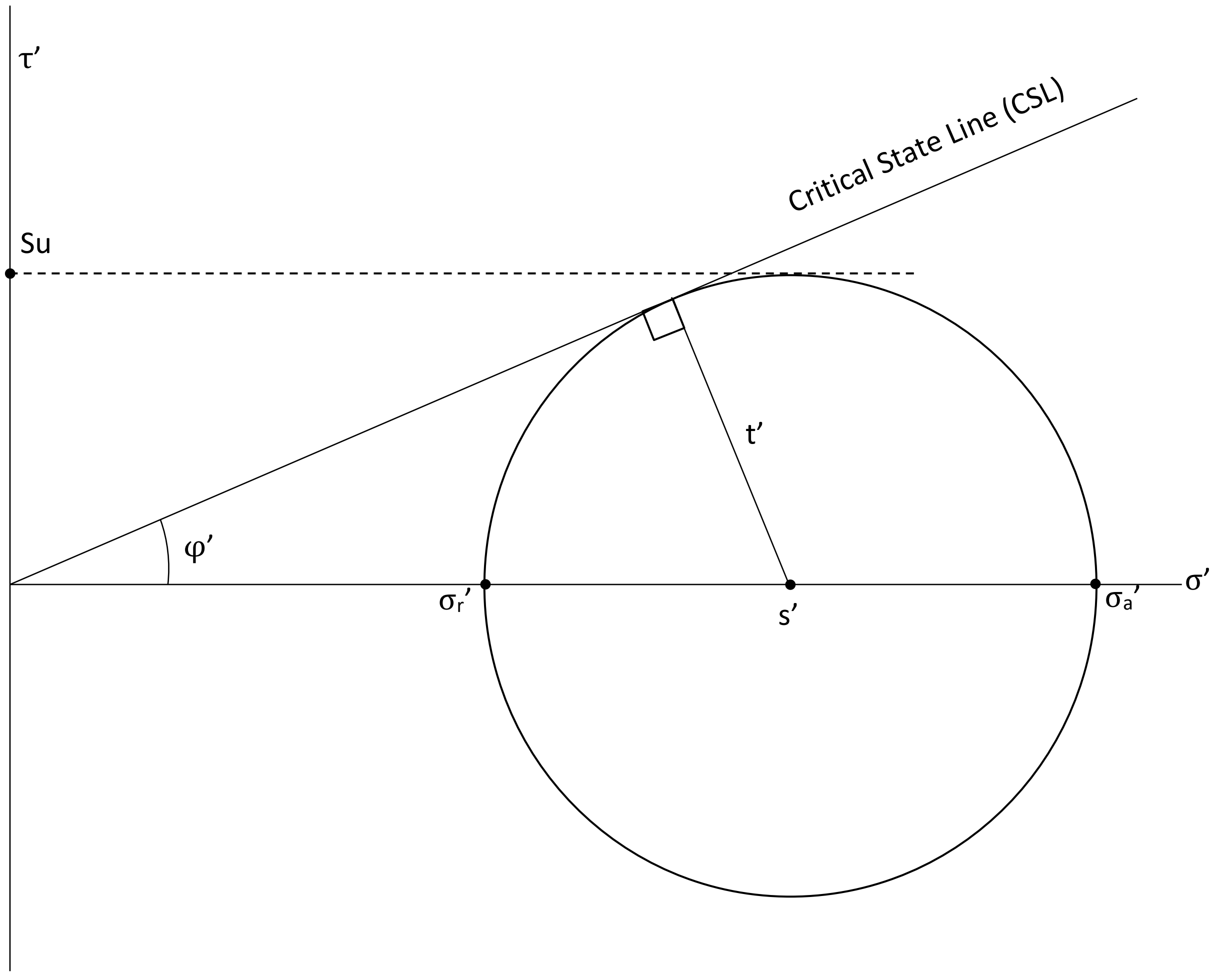


5.10 Diagram 3 – Triaxial Test





5.11 Diagram 4 - Mohr Circle for First Shearing



5.12 Diagram 5 – Mohr Circle for Second Shearing