RUNNING HEAD: GEOTECHNICAL ENGINEERING

Literature Review

Parth Patel

Institution

Literature Review

# Introduction

Unconfined compressive strength is a term that appears to cause many people a little confusion. In soils and rock testing, there is a well-known test called a triaxial test. In the case of confining stress, the application of stress on the soil specimen reduces its tendency to fail at lower axial loads. The tendency of the soil specimen is reduced by bursting at axial loads. There is also an uniaxial compressive test (UCS) performed on a rock, in the absence of confining stress. However, specimen friction at the edges of soil specimen leads to confinement in such regions, owing to specimen friction the specimen fails to bear axial loading. They cannot so easily burst as the analyst move from mid-height to the ends. Even though the specimens are relatively long and thin. Their aspect ratio is ideally 3:1 according to some methods.

Maximum dry density and optimum moisture content of soil are of great importance in geotechnical engineering because without these two parameters compaction degree of a particular soil cannot be measured. Maximum dry density test is important in order to have a larger bearing capacity of the soil. If compaction analysis is not carried out in a correct manner, and optimum moisture content and maximum dry density of soil are not calculated then there is a chance of settlements in the soil that impact the structure’s stability.

# Research problem

The compaction of soil is one of the most significant facets of earthwork construction. The improvement in the engineering properties of soil owes soil stabilization and soil compaction. Dry unit weight of the soil plays a vital role in compaction because compaction specifications of soil hinge upon a dry unit weight. As far as the stabilization of soil is concerned, it consists of shear strength of the soil, the permeability of the soil, and bearing capacity of a particular soil. Prior to start any construction project, it is imperative to calculate the compressive strength of the soil. Earth materials are inevitably required by all the infrastructure projects in a very large quantity. More often than not, some of the soils are plastic and expansive in nature and do not support such infrastructure projects. So, the accurate calculations of precise compressive strengths of the soils are required by means of the maximum dry density/dry unit weight and optimum moisture content of the soil.

# Unconfined Compressive Strength

Shakoor and Barefield (2009) suggested the relationship between unconfined compressive strength and curing time of soil in the following way:

QD = QD0 +K log (D/D0)

D0 represents the unconfined compressive strength at D days in Kilopascals; QD0 represents the unconfined compressive strength at D0 days in kilopascals. The value of K for granular soils is taken as 480Aw, and for fine-grained soils, the value of K was taken as 70 Aw. However, Aw was the content of cement that was taken in percentage by mass.

Unconfined compressive tests on four different soil samples were conducted by Naeini et al. (2012). They conduct unconfined compressive tests on soils that contained distinct liquid limits and following the tests the relationship was generalized as:

QD / Q14= a + b ln(D)

In the above relationship, QD represents the unconfined compressive strength at D days, whereas Q14 represents the unconfined compressive strength at 14 days. Unconfined compressive strength – at D days and 14 days – were calculated with water content in soil being equal to the liquid limit of soil. As far as the values of ‘a’ and ‘b’ are concerned, these were -0.20 and 0.458 respectively for inland soils. A technique called a computational intelligence technique was also used for the development of a mathematical model to predict the unconfined compressive strength of soil-cement mixture (Narendra et al., 2006). Unconfined compressive strength in cemented-clays was predicted by conducting a series of laboratory tests on cement stabilized clay. These laboratory tests introduced a total ratio of water to cement. The water to cement proportion represents the ratio of water weight in cemented clays – that includes the water content in original clays and slurry cement – to cement weight in dry form.

The purpose of the unconfined compression test is to determine inexpensively the UU (unconsolidated, undrained) strength of cohesive soil. The bearing capacity test in the field is not always feasible. Taking the undisturbed soil sample and testing its power in the laboratory are sometimes cheaper. In addition, one must carry out resistance tests on the chosen specimens in order to select the finest material for the embankment. Under such circumstances, the unconfined compression test is easy to perform on uninterrupted and re-formed samples of soil.  Cohesive soils are used for the unconfined compression, and this will give an indication of the soils ability to withstand load on its own, however, the test is often done on clayey soils. Cohesion is the attraction between soil particles of the identical nature, origin, or type as the term itself indicates. Cohesive soil is, therefore, a form of soil where inter-particular attractive forces exist, and cohesion enhances the soil's shear. Surface forces control such kinds of the soils; besides, another primary characteristic of these soils is that their particles are very fine. Clay is one of the best representations of cohesive soils. As far as pure cohesive soils are concerned, inter-particular friction does not exist, and therefore, internal friction does not play any role to complement the shear strength of soils (Harichane et al., 2011). This is because the angles of the internal friction do not have any role to play in increasing the shear strength of the soil.

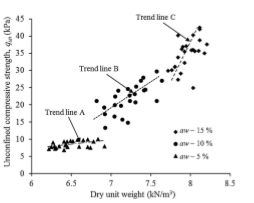
Mostafa et al. (2008) discussed that there are no cohesive forces present in non-cohesive soil, as it is obvious from the term; non-cohesive. Non-cohesive soils relatively consist of particles that are coarse, besides, the self-weight of non-cohesive soils govern their behaviour. Angles of internal friction in non-cohesive soils are pivotal for shear strength of these soils. Besides, Sabat (2012) delineated that internal friction also exists between the coarse particles of non-cohesive soils. Sand is one the best illustrations of non-cohesive soils, and there is a zero cohesion in non-cohesive soils. Majority of the naturally occurring soil deposits do not fall under the categories mentioned above. Mostly, these soils are C-φ soils, which means these soils possess both forces; frictional forces and cohesive forces.

Ayeldeen et al. (2016), with the help of a plot, discussed the dry unit weight of soil in contrast to the compaction energies for diverse ratios of cement, where the compaction process intends to increase the unit weight of soil. The compaction process will not help in decreasing the settlement of ground but also the rising bearing capacity and shear strength of the soil. It can be analyzed from the figure that dry unit weight is positively impacted by increasing the compaction energy, and the average value dry unit weight, also increased from 7.0 to 7.3 kN/m3. The positive impact on dry unit weight of soil was due to the growing energy of compacting force that increased from the values 0 kN m/m3 to the value of 460 kN m/ m3. Besides, the energy of compaction i.e. 920 kN m/m3 stretched the dry unit weight of soil to the value of 7.5 kN/m3. It was expected that increasing the compaction energy will result in boosting the dry unit weight of soil that owes the positive impact of compaction energy on lessening inter-particular spaces of soil sample. Nevertheless, some other factors can also have an impact on the compaction efﬁciency, for instance, water content and soil permeability as indicated by the low level of compaction energy. Albeit, no noticeable difference was observed on the energy of compaction that increased from 0 kN m/ m3 to 230 kN m/ m3 on the dry unit weight, however, this impact was noticeable when the energy of compaction was at 460 kN m/ m3. The interface between the content of water that was present between the void of soil and masses of clay-cement can be well described by this aforementioned factor.

When cement and soft clay gets mixed together, both combine together to create big clay-cement clusters eventually decreasing the soil penetrability (Ayeldeen et al., 2016). Where the values of the energy of compaction, when hit the lowest limit i.e. 230 kN m/m3 or less, are insufficient to remove the water inside a mixture of soil. ultimately increasing the unit weight and shrinking the pore holes’ size. On the other hand, speaking of the values of compaction energy that are greater than the lowest limit i.e. 230 kN m/ m 3 and giving a boost to the compaction energies will also increase the soil unit weight as a result from an increase in water extraction from the soil pore holes. Dry unit weight is also affected by the cement content, where increasing the content of cement yields upsurge in the dry unit weight of soil. For instance, by increasing aw from 5 to 10 %, the value of dry unit weight increased from 6.7 kN/ m3 to 7.5 kN/m3, and to 8.1 kN/m3 as a result of increasing aw to 15 %. This can be clarified because of growing cemented pozzolanic creations of voids in soil that rose by increasing ratio of cement.

The shear strength developed in cohesive soils depends upon the value of cohesion. The shear strength of soil under zero vertical is called cohesion. Cohesive property can be explained as cohesive forces acting between particle to particle bonding in clays. These soils are mostly having high clay content and it is difficult to pulverize these kinds of soils as they get very rigid after being dried. On the other hand, there is no cohesion value in cohesionless soils, and cohesionless soils have either 0 or very less value of cohesion. Barreto and O’Sullivan (2012) studied that the strength of these soils mainly depends on inter-particular friction. Sand illustrates the cohesionless soils in the best possible manner. The angle of internal friction contributes to the shear strength of cohesionless soils, however, the angle of internal friction either hinges upon density or slackness of soils. Cohesionless soils are of great use to the construction owing to their excellent drainage properties.

The association between disturbed unconﬁned compressive strength and dry unit weight for various cement ratios can be understood from another graph plotted in the research results (Ayeldeen et al., 2016). It can be observed that this associated is impacted by altering the content of cement and can be understood beforehand as of the slope of the line of a graph that is as follows:



The slope of the first line i.e. line A, demonstrates that qun for aw = 5 % are not influenced by the variations in the dry unit weight does, while the trivial behaviour of line A is because of the dry unit weight that increased from the value of 6.3 kN/m3 to 6.9 kN/m3. Besides, the trivial behaviour of line A is also because of the normal variation in qun that was estimated from 6.5 kPa to 8.5 kPa. On the other hand, another line that is termed as line B clearly shows the connection vis-à-vis the dry unit weight of the mixture and qun\_D for aw = 10 %. It can be viewed following the variation in the value of dry unit weight that increased from 6.9 kN/m3 to 7.7 kN/m3 alongside altering qun\_D from 15 to 27 kPa. Speaking of the trend line C, this relationship becomes clearer wherein by slight changes in the value of the dry unit weight of mixture resulted in a high variation qun\_D—from 26 to higher than 40 kPa. The calculation of the pore/void ratio that hinges upon the content of water in the soil and the energy of compaction is carried out by the relation that follows:

*e = [(1 +wc) X GS x γW / γT ] – 1*

*wc=* water content

*γT*= unit weight following the cure of cement

*γW* = unit weight of water content

Gs = Specific gravity of mixture.

The deposits of soft soil can be discovered from several parts of the world and they are geologically fresh accumulated. These deposits can be found specifically in the swamp areas and in the tidal plane (K and V, 2016). For instance, these can be found in the areas of Tamilnadu and Kovalam. Some inferences can be drawn from the detailed experimental investigation and data analysis that are as follows:

* The curing period of soil plays a significant role because soil shows a relatively low strength when mixed with stabilizers such as ash, cement, and lime and glass powder and tested instantaneously.
* Increase in the curing period and enhancing the percentage of stabilizers results in increased strength of soil, when unconfined compressive strength of soil was examined after treating with different percentages of stabilizers such as cement, ash, lime, and glass powder, etc.
* The whole increase in strength was observed to be 6 times on the 14th day of lime in comparison with the strength on the 0th day of lime.
* Speaking of cement, the strength observed at the day 14th was 2.4 times to that of strength at 0th day of cement.
* In case of fly ash, the strength observed as 3.7 times more at the day 14th
* The strength observed in case of glass powder was 3.6 times more at the day 14th
* I case of glass powder combined with cement; the strength observed was 10 times higher at the 14th day
* In addition, the mixture of soil + cement results in a significant value of strength as compared to the other stabilizers

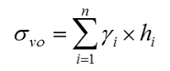
Chen et al. (2012), discusses that the application of pressure from all sides of soils, or trapping water in the soil represents the phenomenon of confinement in soils. In shear strength tests for soil that is triaxial and unconfined tests soil is confined and unconfined respectively. In confinement of soil, there exists an additional confinement pressure from all sides (sigma 3 as commonly known). Confinement pressure is as if the soil is entrapped or enclosed in a rubber sheath, and the rubber sheath blocks the lateral movement of the soils and exerts confining pressure on the soil. There is no such membrane in the unconfined compression test, therefore, no confined stress. It can be seen below where the soil is confined with white rubber membrane and in another test soil is open.

Fattet et al. (2011) stated that engineers and scientists put more focus on the shear force in the analysis of the strength of soil, but the compression and tension are also important? First, what engineers usually understand about compression strength is indeed shear strength, which means, as the soil is under confining stress and it is free to deform to the sides the failure will occur because of shear. Although, there is a consideration for engineers’ request and it's related with the settlement, when evaluating a soil, they need to check either the bearing capacity (shear) or total settlement (punching, compression). On the other hand, the tension is considered to be too low that engineers do not take it into account, but it's important to consider this effect for the hydraulic fracturing of soil also an excavation in overconsolidated soils. Besides, owing to the meshing of the grains in consolidated soils the structural resistance of the movement of the soil is pivotal. Besides, Horváth et al. (2000) delineated that the frictional resistance, that establishes when individual grains of the soils slide past each other, in another important component of consolidated soils. These are the factors that influence the strength properties which are related to the shear force, hence in the analysis of soil strength, we give much importance to shear strength along with comp n tension. In the design of embankment and soil structure shear strength plays an important role. T=c + sigma tan(pi) where c and pi are shear parameters. Foundation design should be checked for bearing capacity of soil based on at least the following two parameters:

1. Bearing Capacity based on shear strength of soil
2. Bearing Capacity based on Settlement of foundation (elastic + consolidation)

The bearing capacity of soil will be lesser of the above two figures. engineers will find that the second term will usually govern.

The importance of confining pressure in unconfined compressive strength UCS cannot be downplayed. Vertical stress, overburden stress also referred to as overburden pressure is the burden exerted on a soil layer by the upper deposits on the top of it. This vertical stress can result in errors or miscalculation in the CPT measurements, resulting in the need for improvement factors in deeper tests depths and pulverized or soft soils. Nevertheless, overburden pressure is also valuable in evaluating the mechanical properties of soil (Sridharan and Sivapullaiah, 2005). The impact of overburden pressure CPT testing can be examined from the discussion below. The formula for overburden stress is given by:



Where;

σvo = overburden stress

ɤi = in situ density of soil layer

hi = height of soil layer

This means that for every layer of soil, the density of the layer is multiplied by its height and the weights obtained as a result are added together till the burden at the preferred depth is recognized. In reality, it is generally not possible to know the precise density and height of soil layers at the test site, therefore, a regular density depending on the known geology of the area has to be determined.

With the increase in depth and rising overburden pressure, CPT measurements of pore pressure, tip resistance, and sleeve friction also have a tendency to rise. This impact can be clearly perceived at right in the graph. Owing to this fact, overburden stress is rectified in determining the standardized tip resistance and standardized friction ratio to make sure the consistency in data, and it is imperative to use these parameters in pulverized or soft soils and deep tests.

Moreover, to standardized CPT parameters, overburden stress enables one to compute the following engineering parameters:

* Effective overburden stress: This is also referred to as effective stress on soil skeleton and this stress can be computed by deducting the pore pressure from the overburden pressure.
* Over consolidation ratio: This is the ratio of previous maximum effective overburden stress to the current effective overburden stress. (Consolidation speaks of the process that reduces the soil in its volume.) Normally consolidated soil is presently below its extreme effective overburden stress and has an OCR of 1. Over consolidated soil is the one that has practised a greater pressure at least once (for instance, if it was one time below a glacier) and it also has a higher OCR. This previous maximum pressure is denoted as reconsolidation pressure. It is also worth mentioning that OCR is defined in a different way for aged or cemented soils.

The OCR is normally computed in a CPT test, depending on the ratio of the excess additional pore pressure (∆u) and the overburden stress:

σ’vo = effective overburden stress

∆u = excess pore pressure

(This pressure can be defined as the temporary increase in pore pressure when the CPT cone is moved forward). Overburden pressure or Vertical stress is also imperative in defining the liquefaction potential of soil and its shear strength as well (Sridharan and Sivapullaiah, 2005). Hence, these subjects are worthy of thorough treatment.

# Optimum Moisture Content of Soil and Dry Unit Weight

The optimum moisture content of the soil is the amount of water present in the soil for attaining maximum dry unit weight following the compaction of the soil. There will not be any void in the soil after attaining maximum dry unit weight. The test called as Proctor compaction test (PCT)determines the optimum moisture content, besides, any given type of soil will achieve maximum dry density when the moisture content in the soil is in an optimal range. Maximum dry density and optimum moisture content of the soil are of great importance in terms of usage of the soil. Optimum moisture content and maximum dry density; both are pivotal in case of compaction test on the construction site. Compaction on site is to determine how many rollers should be used (3Layers 25blow) and much water to be sprinkled (OMC) to attain maximum denseness of soil (MDD) while in actual compaction practice. Besides, they are part of the techniques used to reach maximum grade and subgrade compaction in highways. The maximum dry of soil is required to have larger bearing capacity After reaching maximum density with the optimum moisture content, and there exists a test to find if the percentage of the maximum dry density has been reached.

Hossein Alavi et al. (2010) predicted an optimum amount of moisture and maximum dry density in the soil- stabilizer mix of soil by using artificial neural networks (ANNs). They used a multilayer perception that is considered one of the most commonly used ANN architecture. ANN builds the most precise and all-inclusive models concerning maximum dry density and optimum moisture content of the soil. The models that ANN constructs are related to the properties of natural soil such as linear shrinkage, plasticity, the quantity and type of additives used for stabilization, and particle-size distribution. Hossein Alavi et al. (2010) built five models of ANN architecture by taking combining and taking input from different parameters. Two of the five models projected maximum dry density and optimum moisture content separately, however, the remaining three used input parameters that were potentially influential and yielded multiple outputs.

The calculation of various models of relative-importance values of several inputs determined the importance of each variable related to optimum moisture content and maximum dry density. Garson’s algorithm inferred the most relevant input parameters and carried out modifications in ANN models separately that were developed for optimum moisture content and maximum dry density. The modifications in ANN models introduced an explicit formulation of optimum moisture content and maximum dry density. Hossein Alavi et al. (2010) also conducted a parametric study for the evaluation of the sensitivity of optimum moisture content and maximum dry density. The parametric study owed changes in the input parameters that were most influential. As far training and testing of the prediction models are concerned, Hossein Alavi et al. (2010) used a comprehensive set of information that included many soil types. The comprehensive information was found from the formerly available test results of soil stabilization. Hossein Alavi et al. (2010) carried out Detailed and in-depth analysis and comparison of the performance of the models based on ANN architecture subsequently. The result yielded from the in-depth analysis concluded that the accuracy of the proposed ANN models was satisfactory compared to the results yielded from experiments.

Measuring the optimum amount of moisture in the soil is a difficult task, especially in spatially comprehensive and consistent basis (Bindlish et al., 2006). However, in order to determine the amount of water in the soil, non-destructive methods are more suitable. Non-destructive methods not only compute the movement of water in soil but also give precise results of moisture content in the soil by using direct estimation. The methods that are available for computing the content of moisture in soil are categorized as indirect methods and direct methods. Indirect methods compute the moisture content through calibrations against other measuring variables that vary with the amount of moisture in the soil. Direct methods calculate the amount of moisture in the soil by computing the variance in the weights of the soil before and after it is dehydrated (Muñoz-Carpena et al., 2004). The direct method is; thermostat-weight technique or gravimetric method, however, all other methods save these two are indirect methods. Besides, all the methods used for calculating the amount of moisture in the soil are ground-based except for remote sensing.

The calculation of moisture content in the soil using instruments that comes in direct contact with the particles of soil is called a ground-based technique. Spatial interpretation is difficult in ground-based technique because the instruments only give the point measurements. However, the instruments in ground-based techniques not only give depth-wise measurement regarding the content of moisture in the soil but the logging of the instruments is also possible at any time scale.

One of the most widely used methods for calculating the amount of moisture in the soil is a thermostat-weight technique or gravimetric method. This is the direct method that is based on the oven drying of the soil sample whose volume is known, at the temperature of 150 degree Celsius for 24 hours. Following the oven drying of the soil sample difference between the weights of soil sample before and after drying is calculated, and the difference between the weights computes the water content in the soil (Lunt et al., 2005). The unit of moisture content in the soil could be inches of water per foot or per cent water by volume of the soil. The gravimetric technique is not cheap but also accurate and easy to carry out, however, the technique is not suitable for rocky soils and also time and labour-intensive. Besides, the usage of the oven drying technique is complicated with the soils with heterogeneous profiles.

Neutron probe technology is another technique used for obtaining the optimum content of moisture in the soil. This technology consists of an electron counting scaler and a probe. Radioactive source bombards the soil with fast-moving and high energy neutrons. The nuclei of hydrogen atoms, present in the water molecules present in the soil, slow down the neutrons upon collusion. Neutron Probe technology is further categorized into two types: Surface Probe that measures the content of water in the soil at the uppermost layer of the soil, and depth probe that measure the content of water in the soil at particular depth (Lunt et al., 2005). The results of neutron probe technology are non-destructive and accurate (Muñoz-Carpena et al., 2004). The results that neutron probe technology yield are directly proportional to the amount of moisture content in the soil. The measurements of moisture content in the soil obtained from neutron probe technology are related to the physic-chemical properties of the soil. Neutron probe technology is expansive and limited in use owing to the extensive soil specific calibrations.

Time-domain reflectometry calculates the propagative velocity of an electromagnetic pulse in the soil. 2-3 rods metallic probe calculates the velocity after receiving an electric pulse. The simple formula for calculating the propagation velocity is v= 2l/t where; “t” is a travel time, and “2l” is the length that electric pulse travels along twice (Dobriyal et al., 2012) The variations in the amount of moisture in the soils alters the velocity of the electric pulse owing to the electric value of water that is relatively larger than that of soil (Muñoz-Carpena et al., 2004). In time-domain reflectometry, neither soil specific calibrations are required nor it is destructive and time and labour-intensive. However, the equipment used in this technique is not only portable but also easy to erect and safe to operate. The measurements taken by time-domain reflectometry are reliable and accurate with an error limit of plus, minus one per cent (Ferrara and Flore, 2003).

Another method that is similar to time domain reflectometry is known as frequency domain reflectometry, however, it provides the estimation about optimum content of moisture on the basis of frequency variation in electric pulse through the soil (Dobriyal et al., 2012). Soil functions as a dielectric for the capacitor and the capacitance of the capacitor hinges upon the amount of moisture in the soil. The coupling of oscillator and capacitor that makes an electrical circuit reads the variations in the frequency. Such variations in the frequency are indications about the changes in the amount of moisture content in the soil. The amount of water content is calculated by restricting the frequency of the oscillator and determining the frequency at resonance (Muñoz-Carpena et al., 2004).

The suction forces exerted on water also measure the optimum content of moisture in the soil by using tensiometers. An airtight hollow tube coupled with a permeable ceramic cup makes the tensiometer. Tensiometers measures the moisture content after being inserted into the soil with a vacuum gauge connected to the upper end. A manometer is attached with the permeable ceramic cup and inserted at the soil depth to measure the optimum content of moisture. Following the insertion of the instrument in the soil, it is filled with water and sealed. Capillary tensions are measured by manometer and the water flow rate is calculated by variations in the volume of the water required to yield new reading in the manometer (Dobriyal et al., 2012). Tensiometers give continuous measurements of moisture content in the soil sans instigating any sort of disruption in the soil. Moreover, there is not any kind of complicated electronics involved in this instrument which makes it use cost-effective and easy.

A radioactive method that measures the optimum content of moisture in the uppermost layer of the soil (up to 1-2 cm) is called gamma-ray attenuation. An assumption delineates the correlation between absorption of gamma rays, diffusion and density of the moisture in the soil. Gamma-ray attenuation estimates the optimum content of moisture in the soil by calculating the changes in the wet density of the soil (Dobriyal et al., 2012). This technique not only gives depth-wise measurements of soil content but is also non-destructive and un-affected by the moisture state. Moreover, if the soil is frozen state, even then gamma-ray attenuation can measure the content of moisture in the soil, and if there are temporal variations in the soil gamma-ray attenuation will measure those changes as well. However, gamma-ray attenuation is not a cost-effective technique and require high skills, and these two limitations restrict the applicability of gamma-ray attenuation (Pires et al., 2005).

The amount of moisture in the soil is of great importance in civil engineering. The first job on-site being a civil engineer is the identification and classification of the soil using a soil classification system. There is a need to determine the Atterberg limits of the soil sample for the classification of the soil with fine grains. In order to determine the Atterberg limits of the soil sample, it is imperative to find the amount of moisture present in the soil (Smith et al., 1985). The parameters such as; liquid limit, shrinkage limit, and plastic limit of the soil determine the liquid index and plastic index, and activity - clay content - of the soil. Atterberg Limits are defined for clay because of its ability to accommodate added water as part of its particle to particle bond (on mineral levels-Vander Vaal forces) and increase its bond length without destruction of the bond. Hence on the addition of water, the clays record an increase in volume (Smith et al., 1985). In the case of sand, the same cannot be said because particles are neutral without any force of attraction. Water added beyond saturation would appear as free water. Particles do not stick together and this can also be seen as wet clay and can be drawn into threads while sand cannot.

Nature of the construction project governs which other properties of the soil are to be determined inevitably. As far as the application of the soil is concerned then one can witness that the construction of earthen dams, sub-grades, and embankments use soil as a foundation and construction material. Some of the engineering properties of the soil such as settlement, degree of expansion, bearing capacity, etc. depends on the amount of moisture in the soil (Jafer et al., 2016). The engineering properties of the soil assist engineers and researcher in understanding the soil behaviour in different situations. The understanding of soil behaviour in different scenarios helps to evaluate; whether the soil is suitable for the required application, or the soil requires any engineering to make it suitable (Jafer et al., 2016).

The role of optimum moisture content is important in designing construction projects. It is for slope stability (and yes landslide or mudflow). It is for the validation of the Atterberg data output from the lab. It comes to challenge to bring the whole involved office staff and lab technician into the field just to see the condition of the slope. Hence, that is why only the drilling team and 1–2 engineers are involved to take photograph and demonstrate the conditions to engineers at the office (Roy and Bhalla, 2017). After the lab comes up with the output, there will be a requirement to validate the in-situ condition with the soil sample. if the field engineer said the topmost soil is fairly wet, there is a pool of water and left a footprint when stepped upon but the moisture content turns out it’s far below the Liquid limit (or even sometimes below plastic limit) (Roy and Bhalla, 2017). In such a case, there must be a breach in the sample tube and probably the sample data is invalid. hence re-sampling is probably required (or sometimes if it’s impossible, and the only reliable sources are the values of CPT and SPT).

The parameter required for the analysis of soil liquefaction potential is moisture content and the Atterberg limits. Plotting these into Bray and Sancio chart or other methods, liquefaction potential will be calculated. these are very important when designing the foundation of the high-rise building. The amount of moisture in the soil has a great significance in civil engineering; one of its most important uses is in the construction of an embankment, where the density of the compacted embankment is dependent upon the moisture content. A structure is only as strong as its foundation, however, most of the places require stabilization, drying out or compaction of the soil inevitably to prevent a crack in the foundation or minimising the foundation movement (Roy and Bhalla, 2017). Moisture is considered as an enemy to any modern structure, so, while testing for the amount of water in the soil, one can compute the necessary quantity soil amendments for stabilization (Roy and Bhalla, 2017). Moreover, water holding capacity is another parameter that can be computed during the test. During the formulation of the drainage plan, there is a need to consider run-off water to avert the flooding risks, because structures do not absorb rainfall or precipitation.

It is imperative to find out the optimum amount of moisture in the soil for achieving maximum density compaction and therefore, maximum bearing capacity. Moisture content specifications typically necessitate that the soil is compressed or compacted within -2 points to +4 points of optimum and achieve 95% or higher density (Roy and Bhalla, 2017). Moisture content is incredibly important. Rather than explain some or attempt to explain all the ways it is important. (Roy and Bhalla (2017) recommend taking an introductory course on geotechnical engineering as a start. Here, moisture content (MC) in the soil would be introduced in a very short time. The case could be made that the appearance of disturbed and undisturbed soils would change with MC, depending on the context of observation and appearance (Roy and Bhalla, 2017). Such as an excavator just scooped a bucket full of previously undisturbed in situ soil.

How the moisture content is favourable for construction is also an important thing that should be discussed in the literature review. There are basically two limits of soil i.e. elastic and plastic limits. Both; elastic and plastic limits of the soil are vital while finding a suitable foundation. So, there is a need to compute the optimum amount of moisture in the soil to know where it achieves maximum strength. So, the moisture content is required to keep in pack solid (Compacted). The Compaction of soil increases while the content of moisture in the soil increases up to the optimum level of moisture, and following optimum moisture content it starts decreasing (Hossein Alavi et al., 2010). The amount of moisture in the soil also depends upon the type of construction, if it’s a highway project the moisture content is necessary for soil to receive compaction, the quantity of moisture present should be equal to OMC of the particular soil which is about 8–10 % by weight. When it comes to structural work, again soil in moisture plays an important role since there is a requirement to compact the soil before going for substructure, and for compacting moisture (OMC) is must , simply rolling the dry soil is useless, as it never achieve the density, and is susceptible to shrinkage after load is applied (Roy and Bhalla, 2017).

Soil should be compacted at or near optimum moisture. However, engineers may check the compaction sometime later when moisture conditions have changed. As long as the unit weight percentage standard is met it may be assumed that the soil was compacted at or near optimum. Soil density meters measure dry density. Besides, it also depends on whether the soil is clayey or sandy. For sands, it would not make much of a difference whether the soil compacted is slightly ‘wet’ or ‘dry’ of the optimum moisture content. However, if it is clay, then compacting it ‘wet’ or ‘dry’ of optimum will have a significant effect on the way it is likely to behave (Roy and Bhalla, 2017). Naturally, a clay compacted ‘wet’ of optimum will be relatively soft, while the one compacted ‘dry’ of optimum will be stiff - and hence, they will exhibit different settlement behaviour. It also depends on whether the clay is expansive or not. Hence, there is no single answer to the question; soil should be compacted at or near optimum moisture.

The liquid limit of soil has a major role in the moisture content of the soil. If the liquid limit is the sufficient amount water to change the property of soil to become flowable, and optimum amount of moisture in the soil is the quantity of water required to compact the soil under pressure, so there are no voids in the soil (Roy and Bhalla, 2017). Probably determining the optimum moisture content is more utilized in farming, because tillage carried out on fields, which are drier or wetter than the soil with the optimum amount of water, can cause damage in the structure of the soil through the creation of huge lumps. The liquid limit would be a useful thing to know during construction because engineers would not want to build on a surface that can move too much due to its being an expansive soil (Dobriyal et al., 2012). Of course, I may be wrong because our house was built on top of a granite outcropping and it moved up and down an inch every year due to wet and dry seasons. It will be interesting to see the answers from scientists or engineers.

There is also a relationship between moisture content and bearing capacity of the soil. Moisture content affects almost every other property of soil. If engineers are familiar with optimum moisture content in soil compaction, they will find out that water increases its density until it begins to reduce it at some point when the water in the soil is beginning to replace the particle of soil (KS et al., 2015). In the formula of ultimate bearing capacity of the soil, there is a property cohesion which is affected as there is an increase in the water content such that the ultimate bearing capacity is reduced (KS et al., 2015). Take slopes for example as the water level rises the slope becomes unstable and fails under smaller loads. There is a level at which the water content in the soil makes the soil to flow like water this is the liquid limit. Hence at any point in time whether in foundations or soils the moisture content is always controlled by drains.

Generally, when the bearing capacity of the soil decreases as the moisture increases. This happens because water fills the pores between the grains of the soil, and water being an incompressible fluid does not allow the grain of soil to carry more weight. Besides, the effective stress between the grains also affects the shear strength of soil that depends upon it. And, when the amount of moisture in the soil increases, effectively stress between the pores decrease that consequently lessen the shear strength of the soil. Nevertheless, this is only the general behaviour, there are exceptions (KS et al., 2015). While testing the compaction of compacted soil in a field, the soil should be compacted at or near optimum moisture. However, engineers maybe checking the compaction sometime later when moisture conditions have changed. As long as the unit weight percentage standard is met engineers may assume that the soil was compacted at or near optimum. Soil density meters measure dry density. The indication about the compactness of soil comes from its dry unit weight, hence, to find out the degree of compaction it is imperative to calculate a dry unit weight (Roy and Bhalla, 2017). So, the aforementioned argument concludes that if there is higher dry density in the soil, lesser will be the pore ratio, higher will be the compactness of the soil.

Since ultimate bearing capacity depends upon the physical state of the soil as is quite evident from the Terzaghis Bearing capacity equation (Lee and Salgado, 2005).Now during monsoon seasons instead of unit weight of soil we will have to take into account buoyant unit weight in the Terzaghis equation which can almost halve the value of ultimate bearing capacity and that is why some structures do fail by not designing our structures for reduced bearing capacity during monsoons (Cerato and Lutenegger, 2007). In building structures, engineers do not use moisture content as a parameter unless they are building on reclaimed land or an embankment. If they do, then optimal moisture content along with maximum dry density is what ultimate bearing capacity depends upon, however, that is just for quality control. There is still a need to conduct an SPT testing on the compacted reclaimed land to give parameters for bearing capacity analysis.

There is a decisive role played by the optimum moisture content in the processes concerning ecosystem levels (Rhymer et al., 2010). There is a need to maintain the moisture content in the soil, and for that reason, geotechnical engineers and scientist are under immense pressure for devising such mechanisms. The geotechnical scientist has the responsibility to maintain the moisture of the soil and maximize its productivity for agrarian and natural ecosystems. There is a requirement of evidence-based data by hydrological research and soil moisture measurement concerning Spatio-temporal distribution of the moisture content in the soil in distinct land cover types/land use (Sommer et al., 2011). Agricultural planning, afforestation, land-unit mapping, and regional management planning are expected to improve by optimum content of soil moisture in distinct land-use classes (Dobriyal et al., 2012; Merry, 2009). Besides, it will also contribute to comprehending the reciprocal impact of land surface progressions on climate and weather change. The methods that are discussed in the literature review concerning the calculations of optimum moisture content of soil are applicable on the basis of availability of resources and landscape types. Hence, the literature concerning the moisture content in the soil concludes that different situations will require different methods for moisture measurement. However, the contemporary review is useful at the regional and global level for estimating optimum moisture content for validation and simulation studies. The literature on the optimum moisture content of the soil will provide information for the distribution of soil moisture in distinct land types and decision making.

The soil with greater maximum dry density will have higher unconfined compressive strength than soil with lesser maximum dry density. This happens in general as Greater maximum dry density will lead to the more dense arrangement of the particles which will add to the interlocking of the particles and thereby increasing the shear strength (Hossein Alavi et al., 2010). The unconfined compressive strength (popularly known as UCS) is a measure of the strength of the material. However, there is no relevance of such tests as compacted materials are generally tested for MDD as well as for CBR. The UCS test is not carried out on compacted material but on natural materials. Similarly, the UCS test is, in general, carried out for cohesive materials while the materials used for compaction in roads and building embankment are generally of sandy nature (Dobriyal et al., 2012).

Fine-grained soil has more voids than coarse-grained because fine soil particles are so fine and are packed closely, so they should have less void ratio, but in actual things are not always the same, the way we look at it. In actual fine-grained soil have more void ratio as compared to the coarse-grained soil. For instance, two blocks having straight cut edges, when put together, it look like they are one piece of block, but when one looks at microlevel, then one gets to know that the surfaces are not smooth enough to act like one, instead for each surface point contact they are leaving a space in between them. Similarly, in soil particles also, the concept of Surface area prevails.For the same volume of soil, coarse-grained soil has less surface area when compared to that of fine soil. Hence the voids created between the fine particles are more as compared to coarse-grained. The particles of fine-grained soil not only divided in a fine manner but also possess chemical repulsion. Owing to such chemical repulsion between the finely divided particles the void ratio increases in fine-grained particles of soil. This void ration is greater than that of the present in coarse-grained soil.

As far as specific gravity is concerned, fine-grained soil has more specific gravity than coarse-grained soil. The difference in the specific gravities of fine-grained and coarse-grained soil owe the difference between the void-space of fine-grained and coarse-grained soil – fine-grained soil has less void space than coarse-grained soil. Due to the more void space in coarse-grained soil, it occupies more by unit weight which decreases its density, as we know that density is the weight per unit volume (Basha et al., 2005). Owing to such an inverse relationship between density and volume, fine-grained soil has more density because it occupies less volume per unit weight. Since specific gravity = density of particle/density of the reference liquid or water. Specific gravity is directly proportional to the density of the particle. So, specific gravity is more in case of fine-grain particle. Besides, coarse particle size is more thus chance of occurrence void (empty space) is also more and density contented in a given volume is low (Basha et al., 2005). Similarly, for the fine particle (size<75 microns). The volume void is less and mass content in a given volume is more, therefore, the density of the particle is high So, the fine particle has more specific gravity.

 Void ratio is the volume of air and water compared to the volume of solid particles in a soil mass. When all the voids in a soil mass are filled with water, the soil is said to be 100% saturated. For example, if 40% of a soil’s volume is water and/or air, the soil is said to have a void ratio of 0.4. The solid soil particles give the soil its strength and its ability to support loads imposed upon it from a combination of particle friction and particle adhesion. Void ratio is a predictor of how much solid particle contact is present and the amount of potential settlement that can occur with additional imposed loads. If soil is subjected to additional pressure from a footing, slab or fills placement, the void ratio will decrease as solid particles realign to carry the additional load and force air and water out of its mass, thus reducing the void ratio. At first, the water may occupy the space being taken by air, but any additional consolidation will result in the water being pushed out of the soil mass as well (KS et al., 2015). At the end of the soil consolidation process, the dry unit weight of the soil will be higher and the moisture content may be lower.

Each soil has a pressure-consolidation curve and time-consolidation curves. In the laboratory, tests are performed by adding pressure increments and measuring the settlement or consolidation that occurs with time (Hossein Alavi et al., 2010). The first step is to confine and saturate the soil sample so that there are no air voids before starting the test. The pressure increments are doubled for each addition and held for at least 24 hours. Based on the measured settlement of the sample being tested and knowing the specific gravity of the soil, it is easy to calculate the void ratio changes in the sample (Roy and Bhalla, 2017).

The saturated soil would be heavier since water would fill whatever voids existed in the soil while dry. Some expansive soil might actually absorb water and expand in volume enough that the actual unit sample would contain less soil (the heavier material), and the saturated soil would be lighter than the dry material, but that would be material like bentonite clay that swells considerably when wetted, most soils do not expand that much. However, the moisture content is also reported - so one can determine the “wet” and “saturated” total unit weights for stress calculations (Roy and Bhalla, 2017). With that information, the total stress can then be calculated at some point Z by summing the product of Z\*UW and the effective stress by Z\*UW-(Z-Zw) \*UW. This may require multiple steps, depending on if there are soil changes in the logs and how sensitive the analysis is.

For computational convenience, engineers calculate the moisture percentage of soil from dry unit weight instead of wet weight. This is because there is any variation in the moisture content of soil for compaction control or other purposes, using the dry weight of the soil provides a constant for use as a comparison. It does not change when moisture is added or removed. If wet unit weights had been used, it would have to continually adjust for both the dry unit weight, plus the starting moisture content when the effect of changes are taken into account (Roy and Bhalla, 2017). It also makes more sense in the presence of partially saturated soil, as is normally the case in fill control. One can only compact the air spaces of clayey soil, and cannot drain out the moisture content on the time scale of a compaction effort. Using dry unit weight and soil specific gravity, zero voids line for given dry unit weight and sample volume can be calculated. This allows one to have a sense of how much available voids have been closed when drawing Proctor compaction curves.

Compaction test in the laboratory on a soil sample will yield maximum dry unit weight at a certain amount of moisture in the soil sample. On the construction site engineer will have to get the value of the maximum dry unit weight of the soil at the site while testing on the site, not less than 90–95% of the maximum dry unit weight of the soil sample as computed in the laboratory which is what calculated in the laboratory. Therefore, 95% compaction means that the soil at the site it compacted up to 95% of the maximum dry unit weight possible of the soil (which is computed in the laboratory).

Compaction properties such as optimum moisture content and maximum dry density, when examined in the laboratory is very costly and time taking. This factor highlights the significance of creating the simple correlation equations in order to evaluate the compaction properties exploiting a restively simpler index properties test (KS et al., 2015). Hence, this study aims to explore the association between optimum moisture content and maximum dry density and their correspondence function with index properties. Established on the results obtained from nine soil samples utilizing the standard proctor compaction test, a significant correlation was found between both the optimum moisture content and maximum dry density. Besides, it is worth mentioning that these two compaction properties revel higher correlation with plasticity index as compared to any other index properties. Established in the multilinear regression (MLR) analyses, three finest predictive models were projected to evaluate the compaction properties. More variables such as specific gravity and grain size distribution were added in the MLR analyses rather than the other index properties. Only specific gravity and plasticity index was needed in the recommended model.

The two most important compaction properties of soil are optimum content of moisture and maximum dry density of the soil. Both of these compaction properties play a pivotal role in field compaction control. KS et al. (2015) drew the relationship between two types of the properties of the soil i.e. index properties and compaction properties. The relation presented in the study is for fine-grained soil and standard proctor test was used drawing the relationship between index and compaction properties of the soil. Another important thing presented in the research is multilinear regression analysis that developed a statistical model for the estimation of moisture content in the soil and maximum dry density of the soil. The study concluded the correlation between maximum dry density and optimum moisture content of the soil. Besides, the model developed by multilinear regression analysis is restricted only to the soils with similar features (KS et al., 2015).

# Research Gap

All the literature discussed in this chapter spin around the calculation of maximum dry density and optimum content of moisture in the soil and finding the unconfined compressive strengths of soils. The literature has presented data regarding the calculation of soil moisture by using different techniques, calculating the UCS of soil with the amalgamation of different other materials such as cement, fly-ash etc. However, the main gap in the data is; no research found the compressive strength of different soil samples by using maximum dry density and optimum moisture content. There are more than twenty-five articles included in this literature review that focused on the maximum dry density, optimum moisture content, and UCS of soil. However, the calculating compressive strength by means of optimum moisture content and maximum dry density is missing in the literature searched. And, this constitutes the research gap and urges the researcher to calculate UCS by using optimum moisture content and maximum dry density.

# Bibliography

Ayeldeen, M., Hara, Y., Kitazume, M., Negm, A., 2016. Unconfined compressive strength of compacted disturbed cement-stabilized soft clay. International Journal of Geosynthetics and Ground Engineering 2, 28.

Barreto, D., O’Sullivan, C., 2012. The influence of inter-particle friction and the intermediate stress ratio on soil response under generalised stress conditions. Granular Matter 14, 505–521.

Basha, E.A., Hashim, R., Mahmud, H.B., Muntohar, A.S., 2005. Stabilization of residual soil with rice husk ash and cement. Construction and building materials 19, 448–453.

Bindlish, R., Jackson, T.J., Gasiewski, A.J., Klein, M., Njoku, E.G., 2006. Soil moisture mapping and AMSR-E validation using the PSR in SMEX02. Remote Sensing of Environment 103, 127–139.

Cerato, A.B., Lutenegger, A.J., 2007. Scale effects of shallow foundation bearing capacity on granular material. Journal of Geotechnical and Geoenvironmental Engineering 133, 1192–1202.

Chen, J.-J., Zhang, L., Zhang, J.-F., Zhu, Y.-F., Wang, J.-H., 2012. Field tests, modification, and application of deep soil mixing method in soft clay. Journal of Geotechnical and Geoenvironmental Engineering 139, 24–34.

Dobriyal, P., Qureshi, A., Badola, R., Hussain, S.A., 2012. A review of the methods available for estimating soil moisture and its implications for water resource management. Journal of Hydrology 458, 110–117.

Fattet, M., Fu, Y., Ghestem, M., Ma, W., Foulonneau, M., Nespoulous, J., Le Bissonnais, Y., Stokes, A., 2011. Effects of vegetation type on soil resistance to erosion: Relationship between aggregate stability and shear strength. Catena 87, 60–69.

Ferrara, G., Flore, J.A., 2003. Comparison between different methods for measuring transpiration in potted apple trees. Biologia Plantarum 46, 41–47.

Harichane, K., Ghrici, M., Kenai, S., Grine, K., 2011. Use of natural pozzolana and lime for stabilization of cohesive soils. Geotechnical and geological engineering 29, 759–769.

Horváth, T., Szilágyi, V., Hartyáni, Z., 2000. Characterization of trace element distributions in soils. Microchemical journal 67, 53–56.

Hossein Alavi, A., Hossein Gandomi, A., Mollahassani, A., Akbar Heshmati, A., Rashed, A., 2010. Modeling of maximum dry density and optimum moisture content of stabilized soil using artificial neural networks. Journal of Plant Nutrition and Soil Science 173, 368–379.

Jafer, H.M., Hashim, K.S., Atherton, W., Al-attabi, A., 2016. A statistical model for the geotechnical parameters of cement-stabilised hightown’s soft soil: a case study of liverpool, UK. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering 10, 885–890.

K, S., V, D., 2016. Unconfined compressiv strength of stabilized soil. (IJETCSE 12.

KS, N., Chew, Y.M., Osman, M.H., SK, M.G., 2015. Estimating maximum dry density and optimum moisture content of compacted soils.

Lee, J., Salgado, R., 2005. Estimation of bearing capacity of circular footings on sands based on cone penetration test. Journal of Geotechnical and Geoenvironmental Engineering 131, 442–452.

Lunt, I.A., Hubbard, S.S., Rubin, Y., 2005. Soil moisture content estimation using ground-penetrating radar reflection data. Journal of hydrology 307, 254–269.

Merry, R.H., 2009. Acidity and alkalinity of soils. Environmental and ecological chemistry 2, 115–131.

Mostafa, T.S., Imran, J., Chaudhry, M.H., Kahn, I.B., 2008. Erosion resistance of cohesive soils. Journal of hydraulic research 46, 777–787.

Muñoz-Carpena, R., Shukla, S., Morgan, K., 2004. Field devices for monitoring soil water content. University of Florida Cooperative Extension Service, Institute of Food and ….

Naeini, S.A., Naderinia, B., Izadi, E., 2012. Unconfined compressive strength of clayey soils stabilized with waterborne polymer. KSCE Journal of Civil Engineering 16, 943–949.

Narendra, B.S., Sivapullaiah, P.V., Suresh, S., Omkar, S.N., 2006. Prediction of unconfined compressive strength of soft grounds using computational intelligence techniques: a comparative study. Computers and Geotechnics 33, 196–208.

Pires, L.F., Bacchi, O.O., Reichardt, K., 2005. Soil water retention curve determined by gamma-ray beam attenuation. Soil and Tillage Research 82, 89–97.

Rhymer, C.M., Robinson, R.A., Smart, J., Whittingham, M.J., 2010. Can ecosystem services be integrated with conservation? A case study of breeding waders on grassland. Ibis 152, 698–712.

Roy, S., Bhalla, S.K., 2017. Role of geotechnical properties of soil on civil engineering structures. Resources and Environment 7, 103–109.

Sabat, A.K., 2012. Stabilization of expansive soil using waste ceramic dust. Electronic Journal of Geotechnical Engineering 17.

Shakoor, A., Barefield, E.H., 2009. Relationship between unconfined compressive strength and degree of saturation for selected sandstones. Environmental & Engineering Geoscience 15, 29–40.

Smith, C.W., Hadas, A., Dan, J., Koyumdjisky, H., 1985. Shrinkage and Atterberg limits in relation to other properties of principal soil types in Israel. Geoderma 35, 47–65.

Sommer, S., Zucca, C., Grainger, A., Cherlet, M., Zougmore, R., Sokona, Y., Hill, J., Della Peruta, R., Roehrig, J., Wang, G., 2011. Application of indicator systems for monitoring and assessment of desertification from national to global scales. Land Degradation & Development 22, 184–197.

Sridharan, A., Sivapullaiah, P.V., 2005. Mini compaction test apparatus for fine grained soils. Geotechnical Testing Journal 28, 240–246.