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THE EFFECT OF SOIL TYPE ON DRY UNIT VOLUME WEIGHT INTERNAL FRICTION ANGLE

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The Effect of Soil Type on Dry Unit Volume Weight Internal Friction Angle

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İMZA SAYFASI BURAYA GELECEK

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

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ABSTRACT

THE EFFECT OF SOIL TYPE ON DRY UNIT VOLUME WEIGHT INTERNAL FRICTION ANGLE

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Soils can be found not only in saturated form but also partially saturated or dry in nature. The basic engineering property of the soil that controls the stability of the soil mass under structural loads is defined as shear strength. The internal friction angle and cohesion of the soil can be determined by both laboratory and field tests. One of the most common tests to determine internal friction angle and cohesion values in the laboratory is direct shear tests. In the experimental study, the change of strength parameters of completely dry soils were investigated for different relative densities and normal stresses. Direct shear test, which is one of the most used in the literature, was used.

For this study, the changes of strength parameters of completely dry soils for different relative densities and normal stresses were investigated. The comparison with the assumption that the cohesion of the sand is zero was made only based on the internal friction angle. The obtained internal friction angle, the relative density and normal stress relationship were examined by considering the grain size distribution of soils. Four different type of sands were used in this study. The essential properties of the sands, such as the median particle diameter (D_{50}), coefficient of uniformity (C_u), and coefficient of curvature (C_c), were used to analyze the effects.

Conclusions from the direct shear tests represent that the extent of the angle of shearing resistance of the well graded sand is higher than the poor graded sand.

The internal friction angle is usually increasing with increasing the median particle diameter (D_{50}) and the relative density (D_r). It was achieved that the friction angle varies depending on the grain size, type of sand, relative density and five normal stress applied. It was obtained that maximum and ultimate shear stress increases with increasing internal friction angle for the same relative density.

Key words: Shear strength, direct shear test, internal friction angle, relative density, normal stress

ÖZET

ZEMİN TÜRÜNÜN KURU BİRİM HACİM AĞIRLIK İÇSEL SÜRTÜNME AÇISI İLİŞKİSİNE ETKİSİ

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Zeminler doğada sadece doygun halde değil, aynı zamanda kısmen doygun veya kuru halde bulunabilir. Kayma dayanımı, zemin kütlesinin yapısal yükler altında stabilitesini kontrol eden, zeminin göçme gerçekleşmeden karşı koyabileceği en büyük dayanım kayma gerilmesi olarak tanımlanmaktadır. İçsel sürtünme açısı ve kohezyon gibi zeminin kayma parametreleri hem arazi hem de laboratuvar deneyleri ile elde edilebilmektedir. Laboratuvarda, zeminlerin içsel sürtünme açısını ve kohezyon değerlerini belirlemek için yapılan en yaygın deneylerden biri direk kesme deneyidir.

Bu çalışma kapsamında, tamamen kuru zeminlerin dayanım parametrelerinin, farklı relatif sıkılıklar ve normal gerilmelerdeki değişimleri incelenmiştir. Kumun kohezyonunun sıfır olduğu varsayımı ile karşılaştırma yalnızca içsel sürtünme açısına bağlı olarak yapılmıştır. Elde edilen kayma mukavemeti açısı değerleri ile rölatif sıkılık ve normal gerilme ilişkisi, zemin tane çapı değişimi parametresi de göz önünde bulundurularak incelenmiştir. Bu çalışmada dört farklı kum türü kullanılmıştır. Etkileri analiz etmek için, ortalama dane çapı (D_{50}), üniformluk katsayısı (C_u) ve eğrilik katsayısı (C_c) gibi kumların temel özellikleri kullanılmıştır.

Doğrudan kesme testlerinden elde edilen sonuçlar, iyi derecelendirilmiş kumun içsel sürtünme açısının, kötü derecelendirilmiş kumdan daha yüksek olduğunu göstermektedir. İçsel sürtünme açısı genellikle ortalama dane çapı ve rölatif sıkılık (Dr) arttıkça artmıştır. İçsel sürtünme açısının tane büyüklüğü, kum tipi, rölatif sıkılık ve uygulanan normal gerilmeye bağlı olarak değiştiği görülmüştür. Numunelerin test edildiği rölatif sıkılıklarda, içsel sürtünme açısı gibi fiziksel özelliklerin artışını içeren normal gerilmedeki artışla birlikte maksimum ve artık kayma gerilmesinde de bir artış olduğu görülmüştür.

Anahtar kelime: Kayma dayanımı, kesme kutusu deneyi, içsel sürtünme açısı, rölatif sıkılık, normal gerilme

__To My Dear Parents__

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LIST OF SYMBOLS AND ABBREVIATIONS

SW	Well graded sand
SP	Poorly graded sand
FS	Fine Sand
SM	Sity Sand
ND	Not Determined
Gs	Specific gravity
ASTM	American society for testing and materials
C_u	Coefficient of uniformity
C_c	Coefficient of curvature
D_{50}	Median grain size
D_{10}	Effective size
D_{30}	Effective size
D_{60}	Effective size
e_{min}	Minimum void ratio
e_{max}	Maximum void ratio
e	Void ratio
W_P	Plastic Limit (%)
W_L	Liquid Limit (%)
USCS	Unified Soil Classification System
SEM	Scanning Electron Microscope

CHAPTER 1

INTRODUCTION

In geotechnical engineering, the direct shear test is one of the oldest methods used to find the shear strength parameters due to its ease of performing. The test is generally used to obtain drained shear strength parameters of soils which contain a certain amount of fine grains (clay-silt) in both undisturbed and disturbed condition. Although the triaxial compression test seems to be the most appropriate, the direct shear test is more preferred because it is much more practical than the triaxial compression test.

The shear strength of soils can be determined by conventional laboratory methods. It is clear that the test results will be affected by the test conditions (sample size, sample preparation method, grain size, adversity from the test system, etc.). While the direct shear device is generally performed manually, in this study, an all-automatic automatic direct shear device in Kilis 7 Aralık University Civil Engineering laboratories is used and thus the error margin in the experiments is minimized.

In all aspects of geotechnical engineering, design values (the permissible load that a foundation can bear or the geometry of a slope) are determined taking into account the final values that will cause collapse. This is also referred to as failure, since the occurrence of settlements above the expected level without collapse may damage a superstructure or a surrounding structure. Theoretically, however, failure is related to the concept of shear strength. Therefore, it can be said that the concept of shear strength is one of the most important subjects of geotechnical engineering.

1.1. Purpose of the Thesis

Assignment of shear strength of dry soils is usually more complex and time consuming than determination of shear strength of saturated soils. Much investigate has been done on the shear strength parameters of saturated soils compared to the strength of dry soils. However, there is still a strong need to transform the strength of dry soils into application. Therefore, further studies are needed to improve the visibility of the results of the shear strength parameters of dry soils. The laboratory tests were performed using direct shear test apparatus for dry sand soils with direct shear test.

In this study, the effect of different relative densities and normal stresses on the shear strength parameters (internal friction angle, peak and ultimate shear strength) of the different soil types were investigated by using the direct shear test. The purpose of this study is summarized below.

1. For completely dry cohesive soils, observe the change in shear strength.
2. Of dry soils definition of shear strength by direct shear test.
3. Examine the change in internal friction angle of the cohesive soils for six different relative densities from very loose to very dense (Dr=30% to 80%).
4. To research the impact of shear strength of soils on grain size distribution for four different soil types, six different relative densities and six different normal stresses.

1.2. Profile of the Thesis

This thesis consists of five chapters. In Chapter 1, gives information about the aims and the problem statement of the thesis. Chapter 2 gives detailed information on the research areas in the literature on shear stress shear displacement relationship between full dry sands. In Chapter 3, the materials used in the experimental study and the methods used are introduced. The test results in Chapter 4 are given together with the interpretation of these test results. The detailed comparison was made with the test results obtained for four different soil types. Chapter 5 outline the conclusions of the thesis study.

CHAPTER 2

LITERATURE STUDY

2.1 Literature

One of the most important problems of geotechnical engineering is the determination of the shear strength parameters of soils in accordance with the loading conditions of soils.

When the tight soil is tested in the direct shear test, the resistance quickly reaches its maximum value in small movements, but after a while the resistance is suspended in the sliding plane, the measured stresses reach the ultimate value. If the same observation is made in the loose sample, it will be seen that the resistance increases gradually and the maximum value of ‘ϕ’ appears at permanent resistance (Önalp, 2007).

Shear strength parameter is the most important soil parameter that affects the stability of deep and shallow foundations such as bearing capacity, slope stability, retaining wall design and road pavement design. Structures and slopes should be stable against collapse under maximum loading conditions (Holtz et al., 2015) . Failuring, collapsing or breaking of soils is defined as the loss of the ability of the environment to withstand the stresses applied. In other words, it is necessary to exceed the shear strength along a possible shear plane for collapse to occur in the soils. The specified shear plane may not always be the largest shear stress plane. Shear strength can be defined as the greatest shear stress that the soil can resist without collapse (Özaydın, 2016).

Shear resistance (τ) of soils can be expressed simply by parameters such as internal friction angle (shear resistance angle) ϕ and cohesion c. One of the most important shear strength parameter of the soil is internal friction angle ‘ϕ’. The first investigation of shear resistance was made by Coulomb. Shear resistance of soils simply depends on the void ratio (e) or porosity (n), the type of soil, total or effective stresses (σ, σ`) and the soil fabric (Önalp, 2007). In fact, cohesion is a mechanical / physical property of materials containing molecular bonds. Geological materials "real cohesion", as in rock minerals of igneous rocks can be determined by a thermal weld attachment or a cementing of entering into the matrix material. The only exception is the cohesion value, which has a limited value in overconsolidated clays. This can be said to be due to negative pore water pressures (capillarity) that may occur on soils on the water table, negative excessive pore water pressures due to the volumetric expansion that may occur during shearing, or particle coupling (Coduto, 1998).

In order to determine the stress-strain behavior and shear strength of the soil layers, many laboratory test methods have been developed on the samples taken from the layers. These include the more commonly used; uniaxial compression test, direct shear test and triaxial compression test. One of the oldest and most widely used laboratory tests to determine the shear strength is the direct shear test. In the direct shear test, the soil sample is placed in a rigid box consisting of two parts with square or circular cross-section. Under an applied shear force, the upper part of the box is held stationary while the lower part is moved horizontally and thus the soil is forced to slide along the horizontal plane passing through the middle of the sample. The shearing process should be continued until the failure strain (%15-20) values are reached. A number of specimens of the soils are tested, each under a different vertical force and the value of shear stress at failure is plotted against the normal stress for each test. The shear strength parameters are then obtained from the best line fitting the plotted points. The peak shear stress and ultimate shear stress values in the stress-strain curves should be taken into consideration when forming the failure envelope. When the stress-strain relations are examined, two kinds of behavior are observed. In the first type, with the increasing deformation value, the shear strength of the soil first makes a peak and then decreases to a constant value. This behavior is observed in dense sand and over consolidated clays. In other behavior, no specific peak is observed, the shear stress increases with increasing deformation and does not change with increasing deformation value after a certain value. This type of behavior is seen in loose sand and normal consolidated clays. This constant value of the shear strength, which does not change with increasing deformation value seen in both behavior types, is called ultimate shear strength of soils (Yılmaz, 2006).

Sand is generally quartz based granular material which is formed by crushing of siliceous masses, rocks, crushing by natural factors or breaking of rocks. The diameter is between 0.075-4.76 mm. Quartz is the most common crystalline form of silica and consists of chains formed by aligning the four-sided (SiO_4) units clockwise or counterclockwise. Quartz has trigonal symmetry. At high temperatures and pressures, quartz is the stable state of silicon dioxide.

Quartz maintains its stability up to 573°C at a pressure of 1 kilobar. The chemical structure of the mineral SiO_2, white, red, pink, blue, purple can be found in various colors. It is resistant to temperature, radiation collecting property, abundant abundance in the earth has increased its use as dosimetric material (Akkaya, 2011).

When the cohesion parameter of the sands is zero, the shear strength relation is shown in equation 2.1.

$$\tau_f = \sigma * tan\emptyset \qquad (2.1)$$

In this study, (60*60*20) mm standard direct shear test device was used to investigate the effect of relative density and normal stress, which is the shear strength parameter of soils, on the internal friction angle. The main publications and studies related to these experiments were searched and examined and summarized below.

Wasti and Alyanak (1968), in their work on clayey sands, in the case of clay content decreases only the cavities will fill and reach maximum porosity. They also determined that due to the changes in the structure, the plastic and liquid limit of the clay was not taken into consideration and the compressibility and behavior of the clay material would change from clay to sand.

Ahmed (1993), used Ottowa sand and hard Crosby clay and in a mixture with waste tires. In addition to purely sand and clay soils, they carried out direct shear test and triaxial compression tests on these mixtures containing certain percentages of waste tires and commented on the effects of waste tires on the shear strength parameters of soils. The results obtained showed excellent engineering properties of the material at 33% and less rubber content and showed low dry density, low compressibility and high drainage properties. Although it is not known what the environmental impact of rubber-soil mixtures will be on the soil water in the long term, it is indicated that it may be suitable to be used as filling material in road works and in structures above soil water level.

Bayoğlu (1995), performed by the sand and clay mixtures on the shear strength and compressibility properties of their work, no silt and clay-free sand, silt-clay mixtures with zero sand percentage is discussed in the wide grain distribution. In the mixtures, the ratio of fine material was taken as the basis and the effect of the changes in the ratios on the shear strength and compression and settling properties were investigated. According to the results of the drainage direct shear tests performed on 6 different mixtures with thin material ratio of 5%, 15%, 35%, 50%, 75% and 100%, shear strength angles up to 50% generally vary between 30-38 degrees and with the increase in the percentage rate, a small decrease in value is observed. After 50%, the decrease in angular values becomes very significant and can go down to 10 degrees. According to the results of undrained triaxial compression tests performed on soils containing 35%, 50%, 75%, 100% fine materials, the shear strength angles give close values and behave independently of the fine material ratio.

Foose et al. (1996), investigated the effect of rubber content on shear strength by mixing 10% and 20% of waste tires with sandy soils. The shear test under the constant normal stress of 25.5 kPa, holding two different tire lengths of 5 and 15 cm with vertical and random orientations, keeping the unit weight of the mixtures obtained in the study constant at two different values as 14.7 and 16.8 kN/m^3 have applied. As a result of the tests, it was found that the unit volume weight, tire orientation and tire length variables did not have a regular effect on the shear stress values. In this study, it was found that the only parameter which had a regular effect on increasing the shear strength was the increase in the tire content.

Tatlısöz et al. (1998), in his study, by carrying out large-scale direct shear test investigated the effect of waste tires on the shear strength of sand and sandy-silty soils. For this purpose, the mixture prepared in the granular size of 10%, 20% and 30% by mixing with sand and sandy silt ratios according to the condition of the use of fully soil sample (non-reinforced soil) has looked at the effect of sliding parameters and the highest cohesion value of 39 kN/m^2 In the set with 30 tires, the highest internal friction angle was 54° with 20% tire content. They stated that the internal friction angle and cohesion values in the 20% and 30% rubber content were very close to each other and that the mixture range giving the highest strength values was the 20-30% range.

Vallejo and Mawby (2000), measured the shear strength and the porosity of the kaolinite clay–sand mixtures with various clay content. The shear strength of the mixtures was governed by sand at clay content lower than 25%, while governed by clay at clay content higher than 60%.

Vallejo and Mawby (2000), sand-clay mixtures, depending on the large grain rates observed in the shear resistance changes, sand and/or clay is examined by adding the results of the previous study. He reported that the shear strength of the mixture was provided by coarse grains if the coarse grain content was greater than 75%, by fine grains if less than 40%, and by both sand and clay if the ratio was between 40-75%. It emphasizes that the porosity of the mixture is effective in forming these limits.

In this study, tests were carried out at 4 different speeds consisting of 8 steps of 0.01 mm/min, 0.1 mm/min, 1 mm/min and 10 mm/min. In the results of the study, the ultimate friction angles were calculated with directly measurable parameters; total normal stress, shear resistance and pore water pressure. As a result, the effective ultimate friction angle depends on the shearing speed. While the effective ultimate friction angle of silica sand is independent of the shearing speed, it is demonstrated that the illite and bentonite mixture depend on the shearing speed of the samples. Depending on the effective ultimate friction angle depend on the shearing speed, it was observed that the shearing mode changes with the shearing speed (Lemos, 2003).

Kokusho et al. (2004), were performed on granular soils consisting of sand and gravel with different particle gradations and different relative densities reconstituted in laboratory. They found that only a small difference was observed in undrained cyclic shear strength or liquefaction strength defined as the cyclic stress causing 5% double amplitude axial strain for specimens having the same relative density.

Edinçliler et al. (2004), in the study of the effect of rubber dust on the shear strength of sandy soils in mixtures with the use of completely sand and rubber in addition to the use of 5%, 10%, 20% and 30% by weight of rubber dust mixtures were obtained by performing large-scale direct shear test. As a result of the experiments conducted during the study, it was observed that the use of rubber dust did not have a regular effect on the internal friction angle and cohesion values. The highest cohesion value was 15.5 kPa in the set containing 20% rubber and the highest internal friction angle value was in the sand set 33º.

Zornberg et al. (2004), investigated the effect of rubber slices on shear strength by applying large-scale direct shear tests by mixing sliced tires with sandy soils. Experiments were also carried out using completely sand and completely rubber and the highest cohesion value was obtained with 41.2 kPa in the set containing 38.3% rubber. It was found that the internal friction values generally decreased with the use of tires and the highest value was realized with 41° completely sand. Based on the cohesion values, the optimum value was obtained in the set containing 38.3% tires.

Kokusho et al. (2004), tested the soil and concluded that although the soils had almost the same relative density, their behavior against shear stresses was very different.

In the study performed by Ghazavi and Sakhi (2005), direct shear tests were applied to the rubber-sand mixtures consisting of sand and waste tires of different shapes and sizes, and the effect of waste tire content and forms on the shear strength of the soil was investigated. According to the findings; it was determined that the dimensions of the tires used as additive and additive were the parameters affecting the shear strength, and the internal friction angle could reach 67º in the sample containing 50% rubber.

Gotteland et al. (2005), in their studies of waste rubber particles in the horizontal and vertical orientations by mixing 14% and 22% by weight of sandy soil content by applying a large-scale direct shear test, investigated the effect of rubber particles on sandy soils. In addition, they carried out experiments using entirely sand and completely rubber. As a result of the experiments, they obtained the highest cohesion value at 22% tire content with 50 kPa and the highest internal friction angle at 42.6º and 14% tire content. When the obtained data is examined, it is seen that the optimum strength is 14-22% tire content.

Trauner et al. (2005), stated that the relationship between shear strength and water content of fine-grained soils is determined by two parameters of soil type and one of these parameters depends on the soil mineral composition. It is known that these parameters are mainly dependent on mineral composition of soils; however, these relationships in the literature are said to have not been investigated yet. For (Trauner et al., 2005), a soil type with a literature type of 0.08–0.40 mm. made a comparison of different soil contents of a soil type in the grain diameter range. The findings described in this paper describe the mineralogical properties of soils that determine the values of both parameters. As a result of the scientific study, the parameters are mainly dependent on the size of clay minerals, the amount of soil composition and the amount of interlayer water in the expanding clay minerals. Since this dependency is well defined, the parameters and therefore the unlimited shear strength at different water content can be defined from this mineralogical soil properties knowledge.

Cerato and Lutenegger (2006), observed the change in shear strength angle due to box size and relative density. In this study, direct shear tests were performed on the soil with three different relative density (loose, medium dense and dense). Although ASTM D 3080-90 does not meet the requirement that the specified box width should be 10 times larger than the largest grain diameter, experiments have been carried out on small scale shearing boxes with Winter sand and crushed stone. In some of the experiments, the sand continued to expand and did not reach a fixed volume. In these experiments, the friction angle of the sand was determined by using the shear stresses at the moment when the horizontal unit deformation reached 10%. According to the experiments, it was seen that the effect of the box size was more pronounced on the samples in the loose state and the highest values were obtained in the 60x60 mm box. As a result, it was found that the friction angle varies depending on grain size, sand type, relative density and shear box size. It was observed that the shear strength angle (ϕ) decreased as the box size increased.

Al-Mhaidib (2005), using a traditional direct shear test performed a total of 45 shearing tests. Tests were performed on smooth and rough steel surfaces under 3 different normal forces. Samples were cut at 5 different speeds. Experimental results showed that as the shearing speed increases, the internal friction angle θ and the interface friction angle increase. The correlation between the angles and the shearing speed is represented by a straight line on a semi-logarithmic graph. In addition to this study, while significant studies have been conducted on the behavior of non-cohesive soils under different shear rates, there are relatively few studies in the literature regarding the effect of shear rate on the internal friction angle between sand and steel. In general, when the results of previous studies are examined, it is observed that the effect of shear rate on cohesive soil on final shear strength is not very significant in drainage tests but this effect is important in tests under undrained conditions.

Attom (2006), three different grain size sand with 10% by weight, 20%, 30% and 40% by mixing rubber particles obtained by mixing direct shear test on the mixture and investigated the effect of the shear strength. As a result of the study, as the tire content increased, shear strength values and internal friction angle values increased. The highest shear strength was found in the set with 40% rubber content. The highest increase in internal friction values was observed in the fine grained sand. As a result of the study, it was found that the shear strength generally changed directly in relation to the waste rubber content, regardless of the type of sand.

The waste rubber particles are divided into two grain size as coarse and fine, and these rubber particles by mixing cohesion soil samples. They obtained the direct shear test and standard compaction tests were applied to the mixture. With these experiments, they examined the change of shear strength depending on different tire content and forms and tried to determine the mixture set which gives the highest shear strength. As a result of the shear test and compaction tests, they obtained high shear strength values in the mixtures prepared with thin-sized rubber particles containing 20% and 30% (Çetin et al., 2006).

Yılmaz (2006), study of the relationship between the ultimate shear strength parameters of clay soils and index properties of clay soils were investigated. Ultimate shear strength parameters are generally determined by triaxial compression test and direct shear tests. In his study, ring shear experiments are more useful in determining the strength of soils after major deformations. Ring shear and repetitive direct shear tests were performed on 15 samples with different index characteristics selected among the many samples whose index properties were determined within the scope of the study. Repetitive direct shear tests were performed at 0.035 mm/min and ring shear tests were performed at 25 mm/min. Within the scope of the experimental studies, 15 sets of experiments including repeated ring shear and repeated direct shear tests were performed under normal stresses of 200 kPa, 300 kPa and 400 kPa. Decreasing the angle of ultimate strength with increasing liquid limit, plastic limit, percentage of clay and plasticity index. The ring shear test data were examined using regression analysis and the relationship between index properties and ultimate shear strength angle was determined. The analysis of the singular and binary relationships for the ring shear test data was repeated for the repeated direct shear test data and appropriate correlations were obtained. Repetitive direct shear tests give higher strength parameters than ring shear tests. Regression analyzes were performed on the experimental data and when the binary relations were examined, it was determined which index properties were more effective on the ultimate shear strength mechanism. The relationship between peak and ultimate shear strength values obtained from both repeated direct shear test and ring shear experiments was examined and practical correlations were obtained showing the relationship between peak and ultimate values. In addition, Yılmaz stated that the relations he obtained within the scope of his study could be used for practical purposes and that experimental results could never be substituted.

Ünverdi (2006), conducted experimental studies on clay soils containing gravel in his study. High plasticity clay and fine round gravel and crushed gravel were used in the mixtures used in the experiment. Some geotechnical properties of clays and gravels were determined and subjected to standard and modified proctor tests. In this way, unconsolidated undrained triaxial compression tests on samples prepared with optimum water content and maximum dry density were carried out. With these values, samples were prepared for shear strength tests. The prepared samples were subjected to undrained shear test at ambient pressures of 0.5 kgf/cm^2, 1.0 kgf/cm^2, 2.0 kgf/cm^2 and loading speed of 0.5 mm/min in the triaxial compression test and the related parameters were determined. At the end of this experimental study, it was observed that the cohesion decreases and the internal friction angle increases as the gravel content increases. The increase in the internal friction angle is directly proportional to the increase in gravel content. Although this increase decreases the cohesion value, it generally increases the shear strength of the mixture. Shear strength of crushed gravel-clay mixture was higher than gravel-clay mixture. It was concluded that the main reason for this could be explained by the fact that the river pebbles are round and semi-round.

Yu et al. (2006), the shear strength of sand depends on the relative density, the presence of water, grading, particle strength, particle size and shape and the degree of saturation of the sample. The effects of particle size distribution on the shear strength of accumulated soil (Wang et al., 2013)showed that the shear strength angle generally increased with increasing median particle diameter and gravel content.

Ryuta et al. (2006), show the relationship between shear strength and shear rate on cohesive soils. Experiments were carried out with an undrained ring shearing device on silica sand, silica sand-illite mixture sample and silica sand-bentonite mixture sample. In this study, the dependence of effective ultimate friction angle on shear rate is defined in the sample of illite or bentonite mixture. According to the measured effective ultimate friction angle values, it is seen that shearing mode changes with shearing speed. This change in shear mode is considered as the effect of the speed mechanism on the shear strength of cohesive soil. Furthermore, Skempton (1985), presented that shear velocity had an important effect on the ultimate strength of cohesive soils in this study.

Ayhan (2007), in the study of sand, completely rubber particles and rubber and sand mixtures at specified rates of normal and large-scale direct shear tests were applied. By doing these experiments, he investigated the effect of waste tires on the shear strength of sandy soils and tried to determine the mixture giving optimum shear strength. In this study, three different rubber sets, which are larger than 40 mm, between 20-40 mm and smaller than 20 mm, were used and the effect of these differences in tire forms on shear strength was investigated. As a result of direct shear tests; cohesion and internal friction angle values varied. Shear strength values generally increased between 15-40% tire contents and then decreased. According to the results of the large-scale shear test, the highest shear strength was obtained in the mixture containing 20% rubber with rubber particles larger than 40 mm. Experiments have shown that the shear strength generally increases between 15-30% of the tire content, and as the tire content continues to increase, the strength decreases. It was found that rubber-sand mixtures had higher shear strength values than 100% sand in all experiments. In the set where 100% rubber was used, the lowest shear strength and internal friction angle values were obtained. Shear strength values; normal amount of stress, tire content and tire shape significantly affected.

Çanakçı and Güllü (2007), low-plasticity clay 5, 15, 30, 50, 70% by weight, mixed with poorly graded sand, examined the change of the internal friction angle in constant water content experimentally. It is observed that the internal friction angle of pure clay at the plastic limit level is 30°, the internal friction angle of the mixture containing 15% sand decreases up to 8° and if the sand ratio is 70% it increases to 40°.

In both small and medium sized shear boxes, they calculated the stresses transmitted to the shear region and formed an apparatus for this. After their studies in small scale and medium scale system, they observed that 92% of the load applied to the shearing surface was transferred to the shearing surface and 99.7% average in the small scale system (Edil et al., 2007).

Güven (2007), geotechnical properties were examined and slip parameters were observed by adding fine sand, medium sand and coarse sand in high plasticity clay. As the amount of sands of certain size in the clay increased, the cohesion value increased until the rate of 25% sand was applied, and as the amount of sand continued to drop, the cohesion value decreased. In addition, it has been found that in high plasticity clay, optimum water content decreases with increasing amount of sand and dry unit volume weight increases.

Durmuş (2007), by low-plasticity clay samples of fine and medium grain size sand as a result of examining the shearing parameters by adding certain proportions. The shear resistance angle of the medium size sand added samples decreased with respect to the fine size sand added sample. The cohesion of 25% sand + 75% clay mixture (c) in both sizes of sand decreased, increased slightly in 50% sand + 50% clay mixture and was found to be 24. In 75% sand + 25% clay mixtures, cohesion had the lowest values. These values are 15 for fine sand and 5 for medium sand. Therefore, increasing the amount of sand in the sample means that after some point the properties of the ultimate sand in the mixture are dominant.

Dağdeviren et al., (2008), conducted direct shear test on mixtures with high plasticity clay (CH) by adding 10, 25, 50, 75% by weight of fine, medium and coarse sand. According to the results of the experiment, the change of porosity and shear resistance parameters according to sand percentage were investigated. Shear resistance decreases when the amount of sand added to the mixture is between 25% and 50%. In mixtures contain up to 25% sand, the cohesion value increases and the internal friction angle decreases with increasing sand content. The smallest porosity value is observed in coarse sand mixtures with 75% sand + 25% clay ratios. The results show the importance of choosing appropriate mixing ratios, especially if uniform sands are required as building material.

Ölmez et al. (2008), investigated the effects of the amount of fine material on the shear strength on the soils. A clean sand sample with a fine material content of about 5% was mixed with kaolin clay with a content ranging from 5% to 40% in order to form different amounts of sand-clay mixtures. Three series of experiments were conducted during the study. In the first series of experiments, undrained triaxial compression tests were performed. The mixtures in this series were formed by homogeneous mixing of the pre-determined kaolin and sand. The samples used in the experiments were obtained by consolidating the previously prepared homogeneous soil mixture in a box and without leaving the box under water. In the second series of tests, undrained triaxial compression tests were performed. Test samples in this series were obtained by consolidating the previously prepared homogeneous soil mixture in a box and submerging the box under water. In the third series of experiments, drainage pole shear tests were performed. The test specimens were prepared directly in the shear box without being initially consolidated. Samples placed in the shear box were consolidated before starting the shear test. It has been found that the mixture containing 20% kaolin and 80% sand is a threshold point because as the amount of fine material is increased to exceed this threshold point, there are changes in the drainage and non-drainage shear stress-shear strain behaviors.

Nakao and Fityus (2008), conducted a direct shear test to estimate the effective internal friction angle of the granular (non-cohesive) material in constant volume situations. Tests were carried out in 300 mm and 60 mm cut-out boxes, test samples were prepared under 19 mm and 4.75 mm dimensions and different shearing speeds were used. Different shearing speeds were used to determine the effect of the shearing speed on the effective internal friction angle. These speeds are handled at about 10-fold ratios (eg 5, 0.5 and 0.05 mm/min). In fact, tests for the large-scale direct shear tests were carried out at speeds of 7.06 to 0.63 and 0.05 mm/min, and for the small direct shear tests at speeds of 6.03 and 0.42 mm/min. The effect of velocity was evaluated by comparing different velocities in the same sizes of shearing tests. In almost all cases, for equivalent speeds, the shear strength values in the large-scale direct shear test are greater than those in the small direct shear test, even with normal stress differences.

Ürkmez (2009), in order to determine the parameters of ultimate shear strength in the scope of their work, samples with different consistency limits and percentages of clay were repeated under different stresses with direct shear test device. In the repeated direct shear test, undisturbed soil samples from various regions were used. Ultimate shear strength parameters obtained as a result of the experiments were investigated in relation to the Atterberg limit properties of soils. For practical purposes, it has developed correlations to easily estimate the angle of ultimate shear strength based on the Atterberg limit properties of soils. Experimental results were compared with previous studies. As a result of repeated direct shear tests, the ultimate shear strength parameters decreases with increasing liquid limit, plastic limit and plasticity index.

Asadzadeh and Soroush (2009), in their study under different normal stresses dry, saturated and semi-saturated samples prepared on the medium-sized shear box with rock fill material have made experiments. The size of the medium-sized shear box used in the experiments was stated to be 300 * 300 * 150 mm. The rock fill material used. The shearing speed used in the experiments was selected according to the speed range of 0.0025 - 1.0 mm/min specified in ASTM D3080. In order to carry out the saturation direct shear test experiments, the material was placed in the direct shear test dry and then kept in water for 48 hours. For dry - saturated direct shear test experiments, the test was carried out with the sample placed in the dry state, after the test in the dry state, it was stopped after reaching 90% of the shear strength determined under the same normal stresses and kept in water for three hours. The migration envelope is not linear. This is more pronounced at low stresses. It was observed that the friction angle in dry samples ranged from 57^o to 48^o and in the water saturated state from 56^o to 46^o. In dry-saturated experiments, the friction angle was found to be less than the saturated experiments. The same tendency has been observed between normal shear strength and normal stresses and peak shear strength and normal stresses.

Ataç (2009), used ring shear and repeated direct shear test methods which are commonly used to determine the ultimate shear strength parameters in laboratory conditions. In the direct shear test, the sample is shear back and forth until it reaches ultimate strength. Therefore, the sample is not subjected to continuous sliding in the same direction. The ring shear test has been developed to allow unlimited deformation of the sample and gives reliable results from repeated direct shear testing due to the modeling of the rolling slip seen in cohesive soils. Ataç (2009), conducted ring shear and repeated shear tests on clay samples with different properties. The effect of plasticity on ultimate shear strength and the change of ultimate shear strength parameters with liquid limit and plasticity index were investigated. Experimental results were compared with previous studies and developed various correlations for practical purposes.

İkiz (2010), conducted direct shear tests without drainage by placing sand columns of different diameters and numbers in low plasticity clay. In the sand-clay mixture, sand which is below the No. 5 sieve and above the No. 40 sieve was used. In this experiment, the effect of the diameter and number of sand columns placed vertically in clay soil on the internal friction angle and cohesion which are the shear strength parameters of sand-clay mixture was investigated. According to the results of the test, it was observed that the sand columns placed in the clay affected the shear strength parameters of the mixture and that the internal friction angle increased by increasing the number of sand columns placed in the clay without changing the diameters. The amount of sand placed in the same amount of clay is increased by increasing the column diameter of the internal friction angle and increased cohesion observed decreased in this study. In addition, the volume changes of sand and clay mixture during shear are influenced by the number and diameter of sand columns.

Yan and Dong (2011), were studied through a series of numerical triaxial tests using the three-dimensional (3D) discrete-element method. They found that an assemblage with a wider particle grading gives more contractive response and behaves toward strain hardening upon shearing.

Muawia (2013), investigated the reliability of using the direct shear test for different clay contents and different moisture contents using an adequate shearing strain. His result shows that the cohesion of the mixture was found to increase consistently with the increase of clay content.

Dafalla (2013), investigated the effects of clay content and moisture content on shear strength of clay–sand mixtures. As the water content increased, the cohesion and internal friction angle of clay–sand mixtures decreased.

Çabalar and Akbulut (2013), using clay-crushed stone mixes and crushed stone mixed with waste tires; permeability, direct shear, odometer, compaction and CBR transport rate tests in their studies, depending on the changes in the amount of clay, rubber and crushed cohesion, internal friction angle and unit volume weight values were examined. In their odometer tests, they found that the amount of clay and waste tires increased and compressibility increased. In direct shear tests, they observed an increase in cohesion values and a decrease in internal friction angle as clay and waste tires increased. As a result of the compaction experiments applied to crushed stone and clay mixtures, the maximum dry unit volume weight decreased as the sand increased, the optimum water content was increased.

Marto et al. (2013), in order to analyze the effects of normal stress, to determine tire content and unit volume weight of sand, direct shear change by adding a certain amount of waste rubber to the shear resistance of sand was investigated; For this purpose, direct shear tests were performed on the samples. The sand and rubber particles were mixed in different proportions by weight and three different normal stresses were designed for the experiments. The internal friction angle and the effect of different parameters were analyzed and discussed. The results of the experiment showed that the increase in the waste tire content decreased the internal friction angle. It has shown that the soil increases the shearing resistance.

Pourfarid (2013), prepared waste tire-sand mixtures containing 100% sand and 10%, 20% and 30% tires in their study, which used two different types of waste tires, polishing tires and tire dust. He applied direct shear tests to investigate the shear strength of rubber particles on the sand. As a result of the tests, the load carrying capacity values of the mixture containing 30% polishing rubber were decreased. It was concluded that the rubber dust did not show a positive effect on the carrying capacity. It was found that the shear resistance parameters increased by a certain amount if the tire powder was added up to 10%, and the values decreased when more tires were added. It was observed that both rubber types used in the study increased cohesion in their mixtures with sands. It is thought that it is possible to apply it to retaining structures by reducing the lateral pressure due to the fact that the sands are light weighted materials in the mixtures formed with tires.

Türer (2014), conducted standard direct shear tests on poorly graded sand (SP) and poorly graded crushed-stone (GP) soils. He compared the results of the experiments using a medium-sized direct shear test device (30x30x15) mm manufactured within the scope of his studies. Prepared the test specimens as loose (Dr = 30%), medium dense (Dr = 50%) and dense (Dr = 70%) and performed shear tests at 1 mm /min under normal stresses of 20 kPa, 40 kPa and 60 kPa.

The relationship between the internal friction angle and the test specimen size was obtained. The shear strength parameters obtained from the direct shear tests were evaluated. As a result of the experiments, it was found that the shear strength parameters decreased as the specimen size increased. In addition, as the soil density and applied normal stress increased, the internal friction angle of the soil increased.

In the study conducted by Uysal (2013), the internal friction angle of sand mixtures with polymers such as network copolymer and virgin homo-polymer was tried to be increased. Direct shear test to calculate the internal friction angles by forming networked copolymer-sand and virgin homo-polymer-sand mixtures in 0.5%, 1.0% and 1.5% by weight with additive soil samples having relative density values of 20%, 30% and 40% it is made. As a result of direct shear tests consisting of 21 different test sets, relative density and shear strength angle increased with increasing additive material. In the experiments, the lowest shear strength was obtained as 21º in the set having the lowest relative density with 100% sand without additives. The highest shear strength angle was obtained in the set having 40% relative density with 1.5% virgin homo-polymer added by mass.

Pellumbi (2014), conducted direct shear tests under normal stresses of 50, 100 and 200 kPa according to ASTM D 3080M-11 standard on Koper port sludge prepared in different water contents. The results of the experiment are evaluated as follows. As the water content decreases from 27% to 21%, the cohesion resistance increases approximately 3 times. On the other hand, there is no significant change in the internal friction angle. The internal friction angles of the mixtures range from 27° to 33°. The cohesion strength of the mixture containing 2/3 base sludge was obtained as approximately 100 kPa. The cohesion strength of the mixtures containing 1/3 base sludge was obtained around 30 kPa. It is seen that the strength of the mixture increases with decreasing water content. According to the direct shear tests carried out on the dredging sludge of Koper port, the cohesion strength increased approximately 3-fold with the decrease of water content from 27% to 21%, but no significant change was observed in the internal friction angle.

Khayat (2014), states that it is aimed to evaluate the shear strength of compacted sand - clay mixtures at optimum water content. In the scope of his research, he prepared a mixture of 10, 30, 50 and 70% by weight of dry clay and sand to prepare the required samples and then compacted these samples with the optimum water content according to the standard proctor test. Finally, the compacted samples were subjected to direct shear testing. Stress-strain relationships were found to exhibit ductile behavior and an increase in the percentage of sand, a decrease in cohesion parameter in the mixtures and an increase in the internal friction angle.

Şekercioğlu (2015), determine the mechanical and potential benefits of geosynthetic use on sandy soils, performed 78 direct shear tests with 6 different types of geosynthetics that can be easily found on two types of soils. Various parameters that may have an impact on interface behavior have been examined. According to the results obtained from the experiments, it was found that the shear strength of the reinforced soils were generally higher than that of the non-reinforced soils.

In their experimental studies, Shi and Herley (2015) proposed a simple model for predicting undissolved shear strength and water content distribution of non-fluffy clay minerals and refolded clay mixtures. They suggest that this model stems from the simplification of the structure of a clay mixture in which the elements of the components are distributed in a random representative base volume. By defining a water content ratio (water content ratio between components), the shear strength of each ingredient is estimated separately and then combined with the corresponding volume fractions. Comparisons between experimental data and predictions indicate that the proposed model represents a good representation of shear force of clay mixtures.

Dey et al. (2015), shows the effect on stress rate based on direct shear tests performed on dry incompatible soils prepared at four different relative densities. The test results showed that peaks and ultimate internal friction angle were significantly affected by changes in stress rate and that there were more pronounced effects on loose sands.

Batman (2015), within the scope of the study, 1 meter sampled from normally consolidated red and green clay layers at depth. The clay samples were soil, dried and sieved through sieve 40. milled quartz sand was added to both clay samples at 10%, 20%, 30% and 50% by weight and experiments were conducted to investigate the geotechnical properties of the mixtures prepared according to optimum water content values. In general, the results showed that as the amount of grinded sand increased, optimum water content, consistency limits and swelling pressures decreased. There was an increase in maximum dry unit volume weight and internal friction angle. It is stated that sand additive samples generally increase their shear strength. With the effect of soil sand additive, the class of clay soil has changed from high plasticity to low plasticity. Finally, it has been found that the soil quartz sand additive generally improves some geotechnical properties of clay soils.

İspiroğlu (2016), aimed to measure the drainage and non-drainage shear resistance parameters of silty samples by direct shear test. While the shear speed is high due to the high permeability of the coarse soils, the shear speed is very slow due to the low permeability of fine grained soils, and in the literature, there are some empirical formulations depending on the consolidation speed developed for the estimation of the shear speed in experiments with the direct shear test. It was found that it was necessary to carry out preliminary operations to determine the consolidation rate of the sample before starting the direct shear test, leading to loss of time and labor. A comparison of shear speed approaches accepted in the literature has been made. In his study, he performed direct shear tests under pressure stresses of 100 kPa, 200 kPa and 300 kPa on 5 different geotechnical samples consisting of 14 pieces consisting of 4 sets of 3 pieces and 1 set of 2 pieces. He explained the results of the experiments by comparing them with the shear speed approaches accepted in the literature. As a result of direct shear test for silty clay, 26° drainage internal friction angle and 13 kPa cohesion value were obtained for silty clay sample. Furthermore, drainage internal friction angle obtained from the direct shear test results performed on the samples were indicated to be between 12°-31°. The cohesion obtained from the drainage experiment was between 0-33 kPa.

Alak (2016), was used to replace EPS sand as a light material for recycling EPS waste. Heat treated EPS waste was used in this thesis. EPS waste was left in the oven for 15 minutes at 130 15C and EPS was converted to another form to obtain modified EPS (MEPS). These MEPS particles were mixed with good grade (SW) sand at 5, 10, 15 and 20% by weight. Direct shear tests were performed on the mixtures. The effect of modified EPS content on shear strength properties such as internal friction angle and adhesion was investigated. The MEPS and sand were adjusted to the same gradation and mixed loosely and tightly with 2, 4, 6, 8 and 10% by weight. Experimental results showed that the shear resistance values of MEPS samples prepared with similar grading with sand were similar to the shear resistance values of sand. Therefore, it has been demonstrated that MEPS waste can be used as light filling material in geotechnical applications.

Beren (2016), examined the effect of shear rate on shear strength parameters of 4 different samples with different content of clay and sand taken from Neogene deposits of Denizli region. In this context, the test samples were prepared in dimensions of 6*6*2 cm and 207 direct shear tests at 9 different shear speeds ranging from 0.05 mm/min to 5 mm/min under normal stress values of 54.5 kPa, 109 kPa and 218 kPa under both drainage and non-drainage conditions made the experiment and evaluated all the results statistically. In general, the results show that the internal friction angle (ϕ) and peak shear strength values increase with a certain amount as the shearing speed increases. In this study, the change in the internal friction angle is 1-1.5 degrees for a few samples, whereas it increases 2-3 degrees in other samples. He stated that cohesion (c) values decreased slightly in general, or was not affected much by the shearing speed, but stated that cohesion was reduced to a certain extent, especially in clay soils under undrained conditions.

Islam et al. (2017), investigated the effect of fine content on the shear strength and internal friction angle of sand. He performed several experimental tests and indicated the variability of the internal friction angle with fine content and relative density of the soil. The test used sand samples from different parts of Bangladesh, Gabtoli (Gojaria sand), Sylhet (Sylhet sand) and Turag (Turag sand). He changed the percentage of sieving in soil samples prepared and tested. As a result of the experiments, he says that the internal friction angle generally decreases with increasing fine content. In the study, it is said that the relative density changes significantly as the fine content changes. It is stated that fine content and relative density significantly affect the shear strength parameters of the sand, but are uncertain to draw a specific result from the test result. Accordingly, an attempt was made to characterize a correlation between friction angle, relative density, and percentage fine content. As a result of the experiments, it was found that the internal friction angle decreases with a percentage increase up to 5% fine content under loose and very dense conditions for Gojaria sand and loose and medium dense conditions for Turag and Sylhet sand.

Badhon and Islam (2017), study is to evaluate the effect of grading on the shear strength of sand with various water contents. A number of direct shear tests were performed on the reconstituted sand samples with different grain size distribution (good grade, intermittent and uniform grade) with variable water content of 15% and 25%. Test results show that higher shear strength is obtained for gap grade (GG) soil compared to good grade (WG) and smooth grade (UG).

Benessalah et al. (2017), aimed to determine the relationship between water content and shear strength in order to evaluate the effects of water content on the mechanical properties of Chlef sandy soil. Several series of direct shear tests were performed on samples with various water content. They report that there is a significant decrease in shear strength when the soil is examined tightly and loosely. It is said that the water content added to the soils adversely affects the cohesion and internal friction angle that make up the shear parameters of the soil and therefore the shear strength decreases as the water content increases due to these parameters.

Kim et al. (2018), investigate the effect of clay content on the shear strength of clay-sand mixtures. Test samples of clay-sand mixtures were prepared from commercially available Bentonite and Jumunjin sand, clay-sand mixtures having a clay content of 5, 10, 15, 20, 25 and 30%. The shear strength of the clay-sand mixture was measured using direct shear tests and repeat angle tests in dry conditions. Samples were prepared in a loose manner such that the dry unit weight was minimum for each mixture. In order to investigate the effect of clay content on the mechanical behavior of the mixtures, the measured internal friction angle, ultimate friction angle and dry unit weight were compared and analyzed. It was stated that the internal friction angle (ϕ) of the clay-sand mixture was higher than that of pure sand and the maximum internal friction angle was reached at a clay content of 10%. The internal friction angle of the clay-sand mixture was ϕ=35.7° for pure sand; this increased to a peak value (ϕ_{peak}=38.7°) up to a clay content of 10%; the clay content of 30% gradually decreased to ϕ=34°. However, it was found that the angle of repetition increased up to a higher clay content (25%) with dispersion of significant test results that could result from the predominance of clay content in the mixtures. Loosely recalculated voids are between 20% and 25% clay contents, and this finding assumes good dry unit weight variation. According to the photomicrographs, the sand grains were surrounded by clay particles at high clay contents and the cavity was filled with clay particles at lower clay contents.

Aktürk (2018), investigated the effect of waste tire additive on the shear strength of sands, by taking 10%, 20%, 25%, 30%, 40% and 50% of the waste tires of granular size and mixed them with poorly graded (SP) sand. The generated rubber-sand mixtures were subjected to a series of laboratory tests to determine mechanical properties such as cohesion, internal friction angle, shear strength. In addition, it has obtained physical parameters such as specific gravity of the soil, water content, unit volume weight. As a result of the studies, it was observed that waste tires had a positive contribution to shear strength when compared with 100% sand. According to the data obtained from the tests, the highest shear strength was found on the soil with 20% tire content, while the higher rate of rubber additive caused a decrease in shear strength and when 50% tire content was used, it showed lower results than 100% sand.

Çalışkan (2018), in his experimental work of plastic with a wide range of kneaded soils with direct shear test obtained from the total tensile strength parameters and the same soil poultry shear test obtained by applying the undrained shear strength on a model slope and model basis of the results obtained from the first experiment It is aimed to make an assessment that it is substantially consistent. In this study, 24 kinds of kneaded samples with liquid limit between 30 and 150 were used. These samples were soaked in plastic limit water content, consolidated under 50 kPa load for 1 day and subjected to direct shear test under 4 different normal loads to obtain defeat envelopes. The samples which were mixed by wetting at plastic limit were subjected to poultry shear test and uniaxial pressure test and undrained shear strengths were obtained. The same methods were applied at higher water contents than the plastic limit and also on 4 natural soils. The hypothesis in the study is that high undrained shear strength and low friction angles will be obtained directly from the shear test; it has been suggested that undrained shear strength will decrease with increasing water content and increase with increasing plasticity, but results supporting this hypothesis could not be obtained. The results obtained from the poultry shear test were found to be consistent with soil plasticity and changing water content. The results of the uniaxial compressive strength test were not as good as the poultry shear test.

Bouria et al. (2018), conducted a series of laboratory experiments directly on the sand-silt mixture in the shear test to examine the effect of water content and fine sand on the mechanical behavior of Chlef sand. Samples were diluted in the laboratory (Dr=80%) for relative density and made by applying three normal stresses of 100, 200 and 400 kPa. The data obtained as a result of the experiments interpreted that shear strength increased as normal stress increased. In addition, the results show that increasing the fine sand content reduces shear strength. In addition, it is stated that the water content has a significant effect on the mechanical properties of sand-silt mixtures in terms of cohesion and internal friction angle.

Su et al. (2018), states that the characterization of shear strength should be done carefully, as it is susceptible to large soil water content, considering that engineering constructions are rapidly increasing in the western and central regions of China, where large soils are widely distributed. For ease of use in the experimental study, the Mohr-Coulomb criterion is generally adopted to define the shear strength of large soils. In this study, the physical meaning of adaptation and frictional strength of expanded soil is explained and the variation of strength parameters with water content is examined.

HouZhen et al. (2018), conducted a series of large-scale direct shear experiments with different water contents and different grain distributions to investigate the mechanical properties of so-called soil-rock mixtures in their research. The macro-mechanical behavior of S-RMs is highly dependent on deformation rate, water content and particle sizes. As a result, experiments have shown that the lower the shear speed, the higher the macroscopic strength. As the water content increases, the soil strength gradually decreases, and when the water content reaches 8% it is observed that it receives a moderate value. They stated that clogging, fracture and rearrangement of large-sized rock blocks in the structures S-RM have a great effect on the mechanical properties of the samples.

Altun and Erdoğan (2018), examined the effect of the use of sandy geotextile on the increase in soil stability under static loading conditions. This investigation was performed by performing a series of direct shear tests. In the experimental studies, the shear resistance properties of sands have been investigated by using different types and properties of geotextiles. In all of the experiments, quite high peak interface friction angles were obtained, especially at low normal stresses. The experiments were carried out at 300 mmx300 mm instead of 100 mm x 100 mm small direct shear tests. In the case of the direct shear test, it may be expected that the friction angles of the interface will decrease slightly, since the stress distributions at the interface will be more uniform. Regardless of the grain size diameter distribution and relative density of the sand, the internal friction angles obtained at the low normal stress range at the sand/geotextile interfaces were higher than the internal friction angles obtained at the high normal stress range.

Adamska (2019), aimed to determine the interfacial shear strength between fly ash and HDPE geo-membranes as a material underlying the artificial sealing layer of storage areas. In engineering applications, it is said that the sample must be compacted at a specified humidity range to achieve 90% to 95% of the maximum compression, depending on the method. Furthermore, it is stated in the scientific paper that the degree of compression (% of maximum compression) should not be used as the only parameter that evaluates the compression of the material in the sealing layer. This information applies to both cohesive soils and fly ash. By using the standard Proctor test, the fly ash was compressed at a moisture content of ± 5% optimum water content. Shear strength is made with cylindrical shear in direct shear test. Shear resistance for fly ash, textured and smooth HDPE geo-membranes determined shear strength under 5 different normal tensile strengths of 50, 100, 150, 200 and 300 kPa for moisture content in ± 5% compaction, depending on sample displacement. The bottom box frame for interface strength testing is equipped with a poly-carbonate plate that ensures geo-membrane fixation. It is stated that the shear strength formed at the interface of fly ash and smooth HDPE geo-membrane is not dependent on the water ratio in the compression, but the water ratio for the textured geo-membrane is of great importance for shear strength. Lowest interface force for both geomembranes $w=w_t+5\%$. The minimum values of shear strength of the interface were obtained at the highest saturation degree ($w = w_{opt} + 5\%$) since the fly ash grains were softer and slippery. At greater saturation, pore water caused a shift between the fly ash particles and the geo-membrane. The interface shear strength did not always decrease with increasing water during compaction, as for clay-smooth geo-membranes, but it was noted that the fly ash w_{opt} could reach the maximum level and the difference increased with increasing normal stress.

Aday and Hamid (2019), investigated the effect of moisture content on shear strength on 4 types of soil types collected from different places in the south of Iraq classified as productive sand, sand-silt, sand-clay and productive silt. As a result of the experimental study, it is stated that the shear strength decreases as the moisture content of the soil types increases. Soil shear strength is made of coils and bulk shear strength. Clay shear strength decreased as soil moisture content increased. The highest drop was in the hard state of the soil compared to brittle and plastic conditions. The mass shear strength was low in the hard state and then increased with the soil moisture content to approach the maximum value after the lower plastic limit, and then significantly reduced so that the upper plastic limit decreased. Application procedures should generally be carried out in a friable state, as the soil shear strength is minimum. However, the best friable area is where the soil is weak and therefore the lowest shear strength. The lowest soil shear strength, which can be done in the field of agriculture that is the lowest soil resistance moisture content up to 14-20% for high clay (heavy soils) is obtained 14-18%.

2.2. Mohr–Coulomb Failure Criterion

The mathematical representation of the shear resistance of soils began with Coulomb (1776) and Tresca (1869). The first valid failure hypothesis for soils was first developed by Mohr in 1911. Over the years, other theories have followed the Mohr hypothesis, which is applicable to soils in every case. The simplest and most widely used in practice is the Mohr-Coulomb failure hypothesis. According to this hypothesis, the shear strength of soils is based on the Coulomb friction law (Bardet, 1997).

The Mohr hypothesis is combined with the horizontal relation of Coulomb over time to form the Mohr-Coulomb collapse hypothesis. Accordingly, the shear strength of the soil is represented by the break envelope shown in Figure 2.1 In this way, normal stresses are shown on the horizontal axis and shear stresses are shown on the vertical axis. For stress conditions below the failure envelope, failure does not occur, but as soon as this envelope is reached, collapse occurs on the soil. Although it is known that the failure envelope of the soil is not linear, in practice this curve is considered a line.

When the vertical axis of this line intersects and the horizontal angle of the line shows the intersection, the shear strength giving relationship

$$\tau = c + \sigma \times \tan \emptyset \qquad (2.4)$$

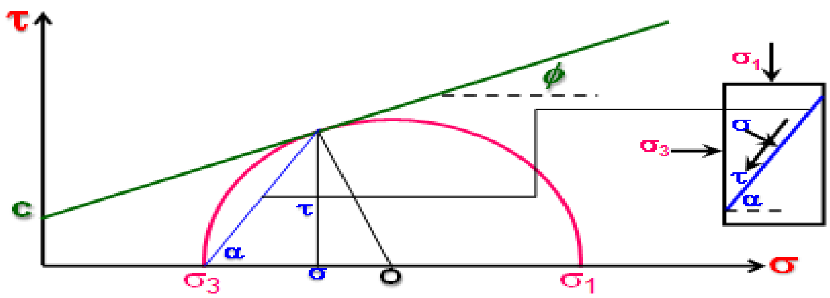


Figure 2.1 Refraction according to Mohr-Coulomb hypothesis (İspiroğlu, 2016)

In this equation, c and ϕ show the shear strength parameters. The angle ϕ is known as the shear strength angle of the soil. The shear strength angle represents the total resistance, including the frictional resistance between the grain surfaces and the locking effect, which prevents the movement of the grains relative to each other. The other shear strength parameter c in the Mohr - Coulomb failure hypothesis is cohesion. The commonly known explanation of this coefficient is that the grains are due to their ability to retain one another. Shear strength parameters are not constant for a particular soil and vary according to the loading and drainage conditions prevailing during the experiment (Özaydın, 2016).

Shear strength equation is obtained with the help of tangent drawn according to Mohr circles in the graph seen in Figure 2.2.

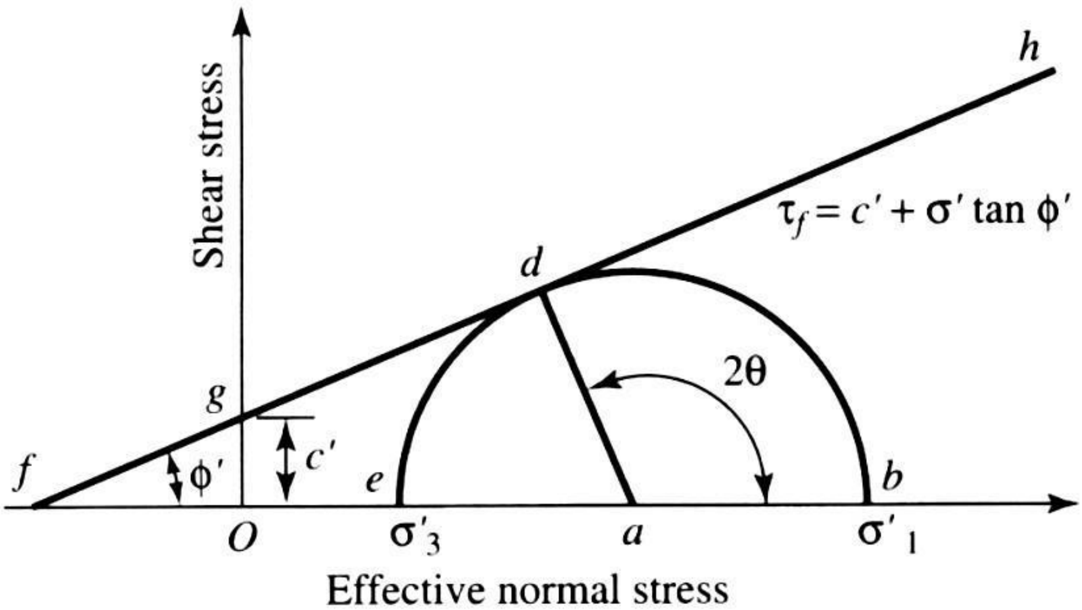


Figure 2.2 Mohr’s circle and failure envelope (Das, 2008)

2.3. Shear Strength of Soils

Coarse or described as cohesionless sand, gravel, one of the most prominent features in the soil, and mixtures thereof with silt in the system is dominated by the force of gravity that mass. However, the fact that the grains are microscopic in the clays, the dominant force is due to the grain surfaces and the presence of water, and the mass forces are secondary effective. Because of these differences, friction is particularly effective on granular soils.

It is a realistic approach to accept that drainage conditions apply to sands under static loads in the field. In this case, the pore water can easily come out of the soil during loading, and no change in the pore water pressures occurs. Therefore, when investigating the behavior of non-cohesive soils under field loading, it is sufficient to find the drainage (or effective) shear resistance angle.

Coulomb relation on cohesionless soils;

$$\tau = \sigma \times \tan \emptyset \tag{2.5}$$

The term "τ" slip-plane shear stress effect immediate failure during "σ" is the normal stress. The "ϕ" value, which is accepted as the shear strength angle of cohesion-free soils, is obtained by correlation from field penetration tests or laboratory tests on specimens prepared in field conditions. For this purpose, direct shear test, triaxial compression test and simple shear tests are performed in the laboratory. It was observed that the shear strength angle values determined by simple shear tests were in agreement with the values found by direct shear test and triaxial compression test (Dinçer, 1994).

Granular materials "friction" "internal friction angle of the material that the factor increasing the frictional resistance is expected to result in an increase (Holtz et al., 2015). First, the factors affecting internal friction angle are void ratio or relative density, grain shape, grain size distribution, grain surface roughness, water content, normal stress and consolidation ratio (Özaydın, 2016).

CHAPTER 3

EXPERIMENTAL STUDY

In this study, sieve analysis was used to determine the grain size distributions of the soil samples obtained from the Çaparoğlu manufacuter, pycnometer test for grain unit volume weight specific gravity determination of the soil and maximum and minimum void ratio tests (e_{min}-e_{max}) were used to determine the void ratio of the sample. Finally, the samples were prepared with a (60*60) mm soil direct shear box device connected to the automatic data acquisition unit available at Kilis 7 Aralık University Laboratory for direct shear strength determination.

3.1 Automatic Direct Shear Test Device

This device, which is located in Kilis 7 Aralık University Laboratory, is a fully automatic device (Figure 3.1). For the direct shear test, the inner size of the rectangular direct shear box is 60×60 mm in plan, and 20 mm in height (Figure 3.2). The specimen, which water content is zero, was poured by using dry deposition method.

Figure 3.1 Schematic of the direct shear box

Thirty direct shear tests for four soils curves were carried out. After applying vertical pressure equal to 50 kPa, 75 kPa, 100 kPa, 125 kPa, and 150 kPa on the specimen in the direct shear box, horizontal thrust was acted on the upper box until the soil failure. The testing table for direct shear test which was made in this study as shown in figure 3.1. In the tests, the rate of horizontal loading is controlled at 1 mm/min. The rate of displacement was selected with reference to ASTM D3080-90 (ASTM, 1990). Figure 3.3 shows the direct shear test apparatus.

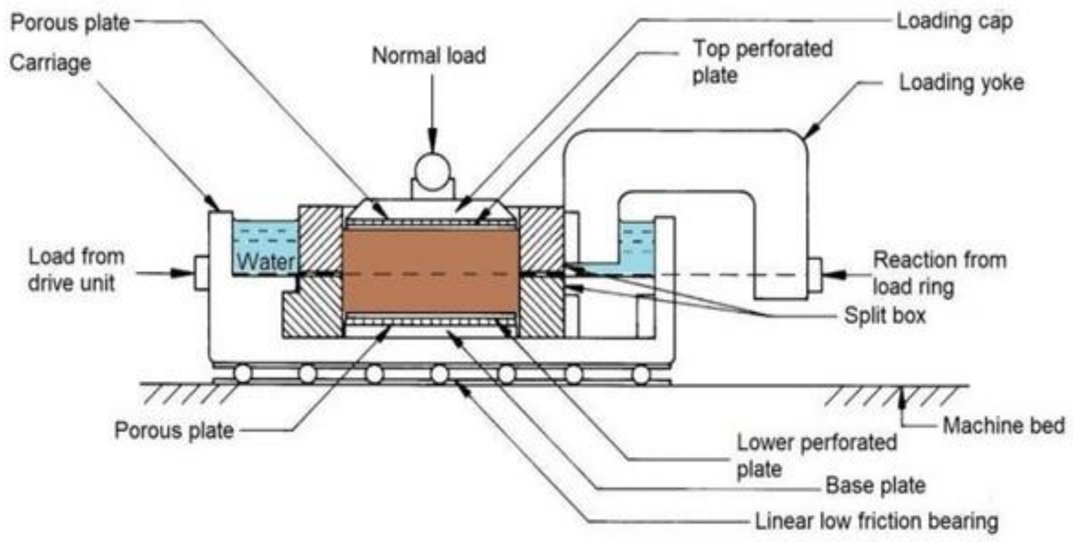


Figure 3.2 Typical setup for a direct shear test

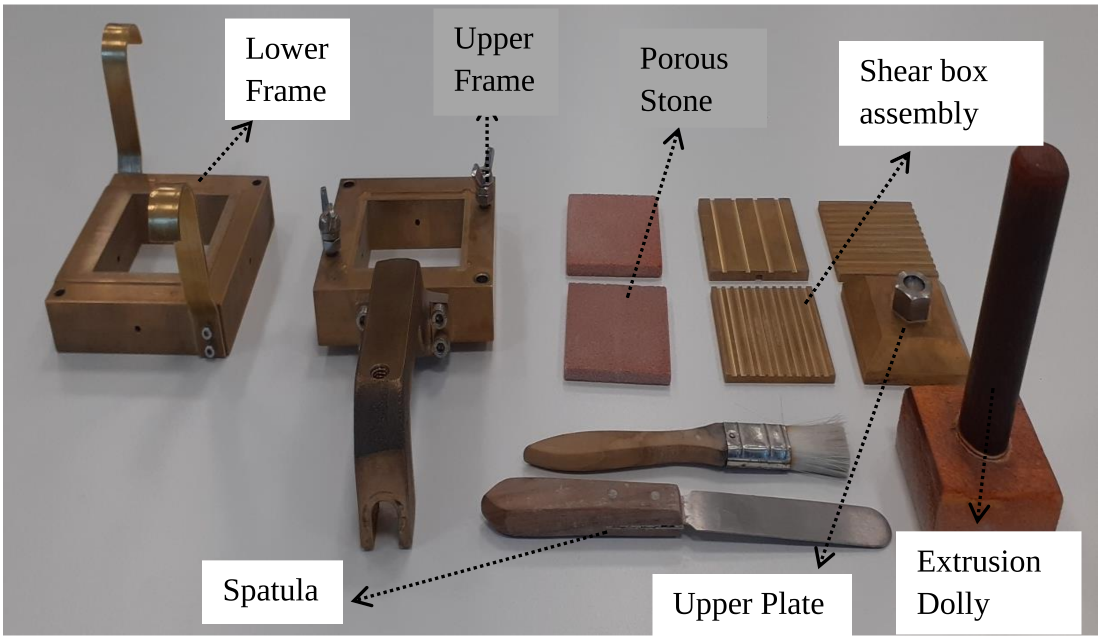


Figure 3.3 Direct Shear test apparatus.

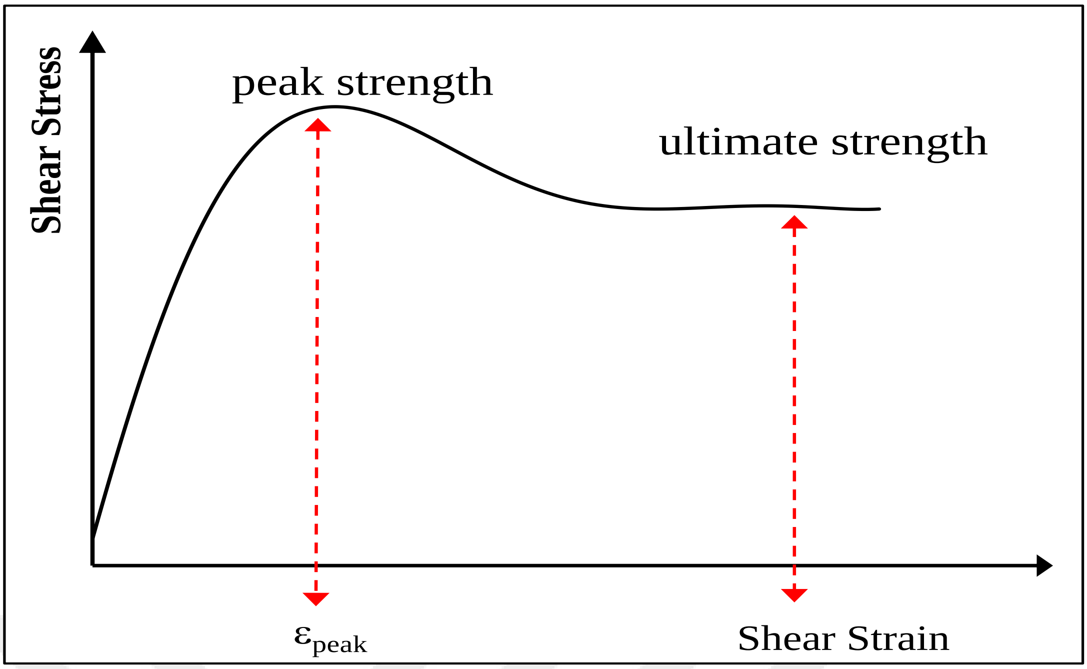


Figure 3.4 Stress – strain curve representing peak angle-ultimate state friction angle

The other friction angle is the so called ultimate state friction angle. Ultimate state is applied to the state during which the soil is sheared at constant volume and constant rate (Figure 3.4). Ultimate state friction angle is the friction angle that sand hill the frictional attribute of the soil at the critical state.

3.2 Testing Material

In this study, dry sand having four different particle size distribution is used. The soils were sieved and particle size distributions are shown in Figure 3.8. The detailed results of all basic properties are tabulated in Table 3.1. All the experiments carried out within the scope of the thesis were made for the dry state of the soil. The soil type of the samples was determined according to the Unified Soil Classification (USCS) (Figure 3.9). The scanning electron microscope (SEM) pictures are shown in figure 3.5 and 3.6.

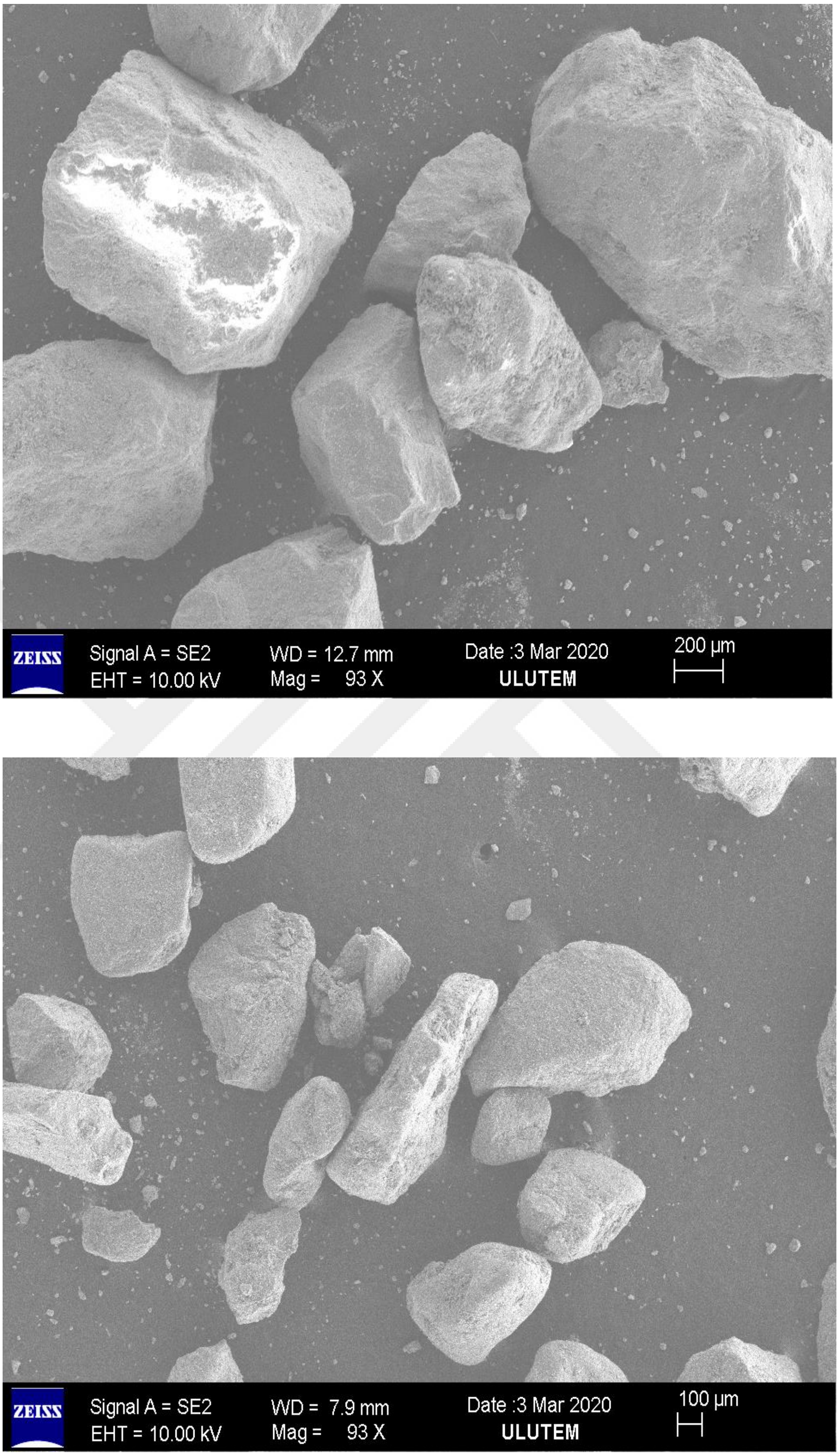
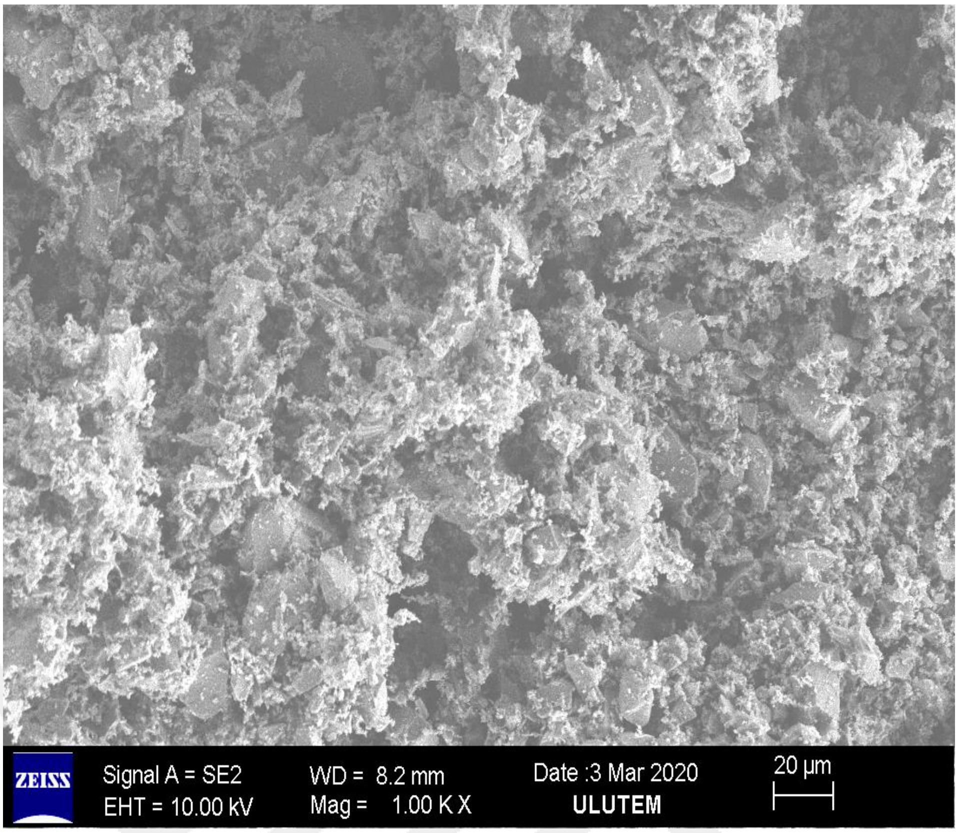


Figure 3.5 SEM pictures of the (top) SW and (bottom) SP used during the experimental study



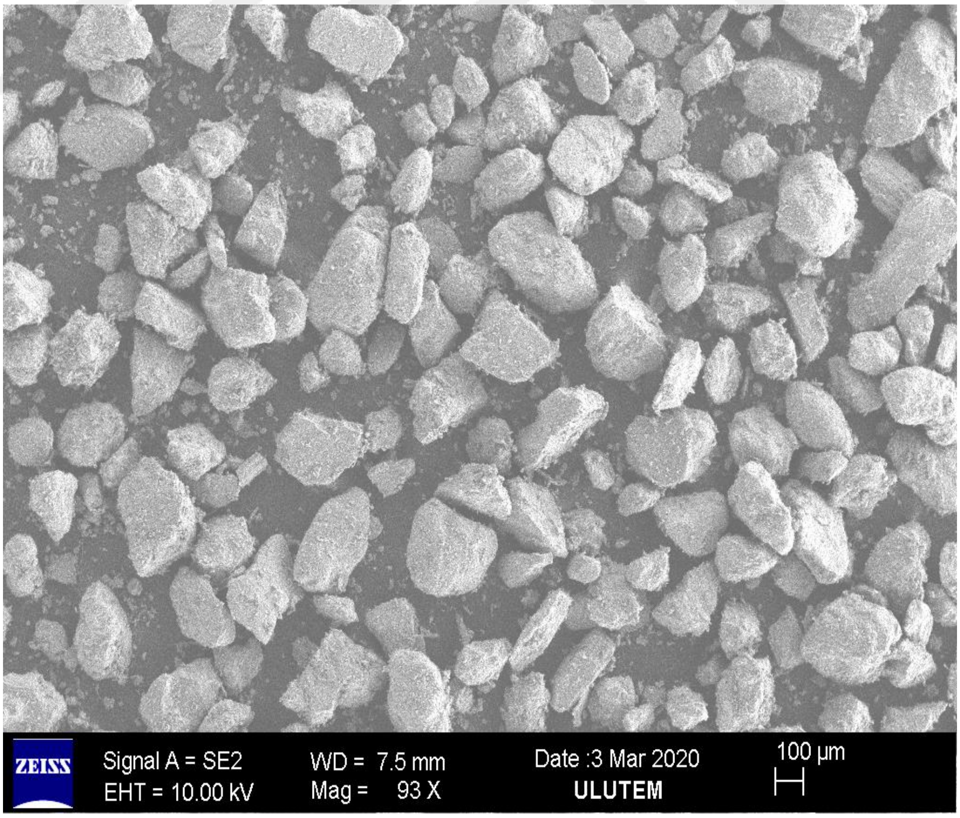


Figure 3.6 SEM pictures of the SM (top) and FS (bottom) used during the experimental study

Table 3.1 Index properties of soils used in experiments

Soil Type	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_c	C_u	e_{min}	e_{max}	G_s
SW	0.26	0.647	1.396	1.869	0.861	7.19	0.3	0.6	2.63
SP	0.14	0.245	0.34	0.41	1.05	2.93	0.485	0.787	2.69
SM	0.022	0.383	1	1.535	-	-	0.281	0.763	2.69
Fine sand	0.088	0.152	0.187	0.205	1.281	2.84	0.668	0.986	2.72

*SOIL TYPE ACCORDING TO USCS: SW- SP – SM – Fine SAND. *Gs : Specific gravity, *D_{10} – D_{30} –D_{60} : Effective size, (mm), *D_{50} : Median diameter, (mm) *C_u : Uniformity coefficient, *C_c : Coefficient of gradation. *e_{min} : Minimum void ratio,*e_{max} : Maximum void ratio

In order to obtain SM soil type according to Unified Soil Classification (USCS) an artificial mixture of well graded soil 80% and quartz silt 20% was obtained. Liquid limit and plastic limit tests were conducted for this mixture. The results of tests on mixture are shown in Table 3.2. Liquid limit was obtanied 15.96% and plastic limit not determination.

Table 3.2 Index properties of sand – quartz mixture tested

Property	Value
W_L (%)	15.96
W_P (%)	N.D
USCS	SM

*ND= Not Determined, *W_L= Liquid Limit, *W_P= Plastic Limit, *SM= Silty sand.

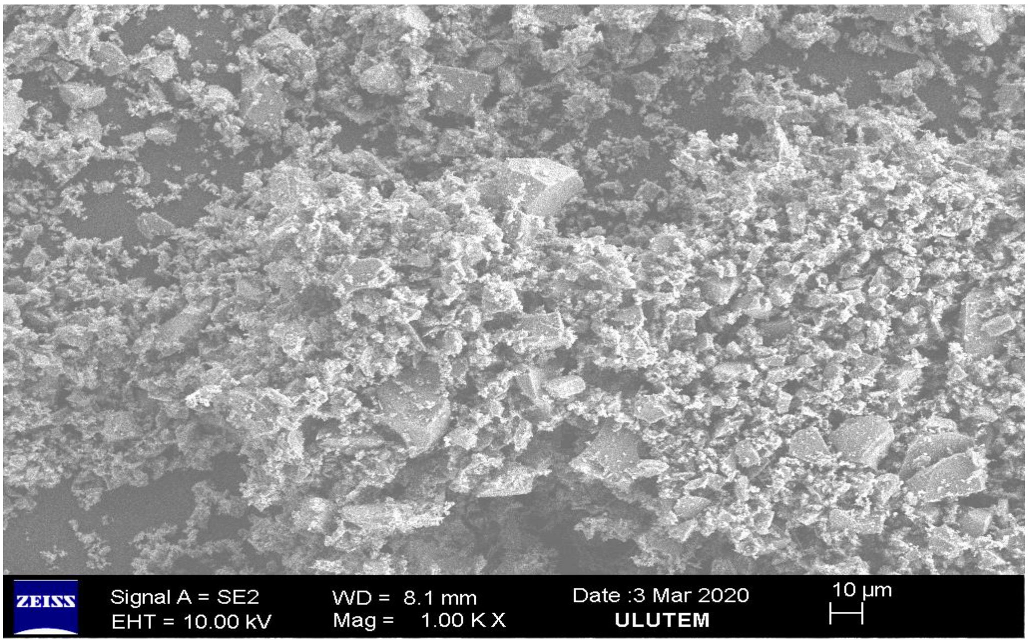


Figure 3.7 SEM picture of quartz used during experimental study

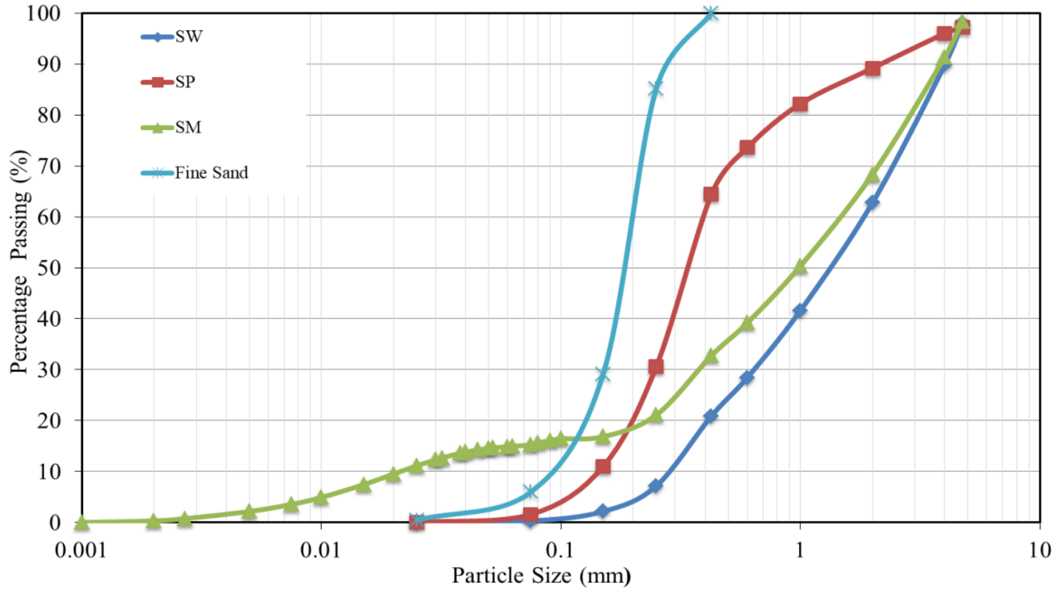


Figure 3.8 Grain size distribution of soils contains 100 g soil of mass.

3.3 Sample Preparation

Air pluviation method chosen for preparation of sand samples in this study is a convenient way to reach target void ratios in such a way that dry sand is poured within a funnel to a mold from a predetermined height. Funnel is gradually moved upwards as the sand is poured in order to keep the raining height constant. By this means uniformity in sample is preserved as well. According to literature, the relative displacement of 10 mm was verified to be sufficient for the soil to enter the ultimate state. Thus, the constant shear velocity of 1 mm/min was selected for the present test. Finally, experiments were finished when the shear displacement reached 12 mm. These values were accepted as the ultimate displacement values of the soil samples. During the experiments, respectively, the shear force, shear displacement and vertical displacement, were recorded continuously data with a force sensor, horizontal and vertical linear variable displacement (LVDTs) as shown in figure 3.1.

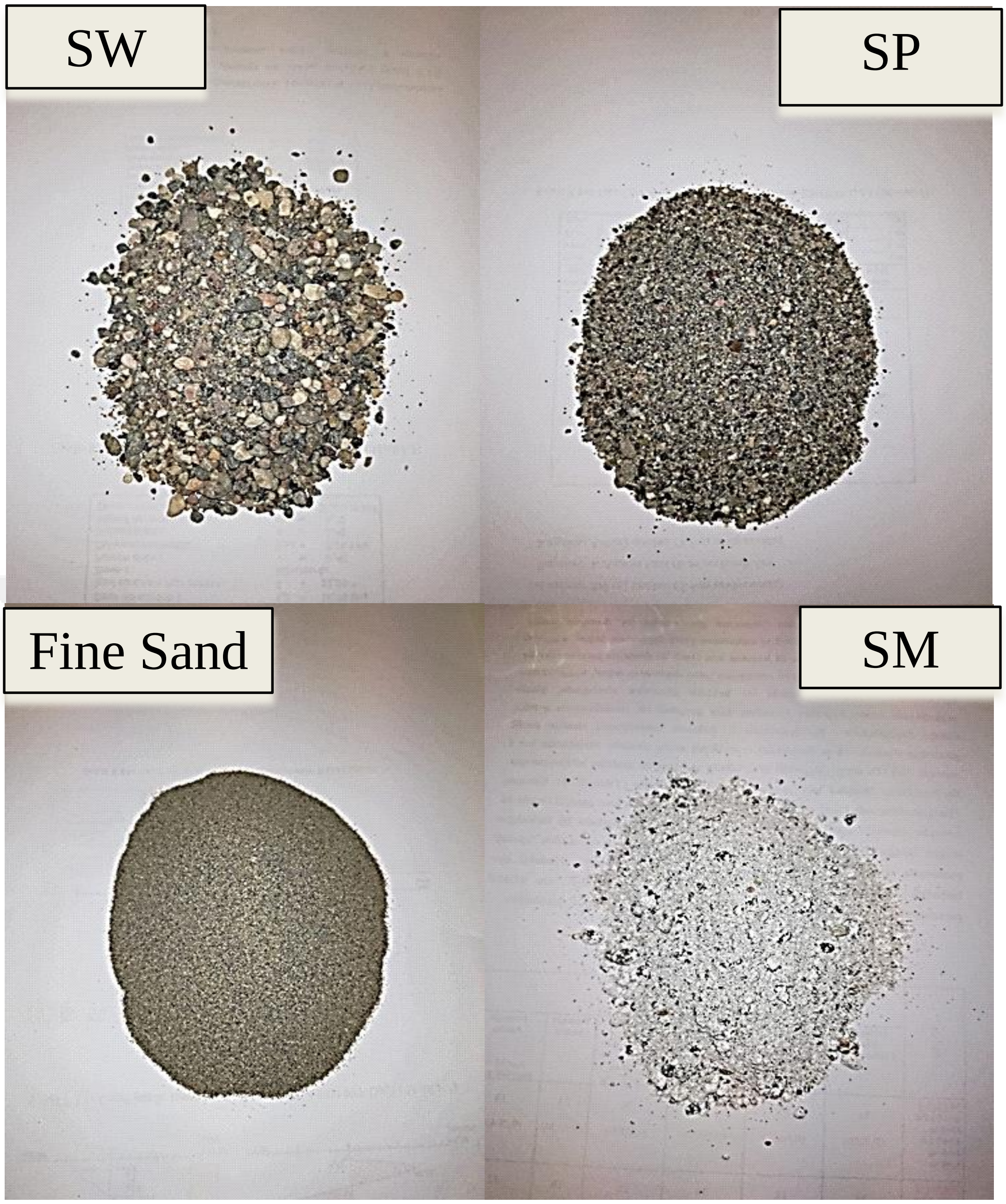


Figure 3.9 Sand particles at different ranges of grain sizes. Every photograph

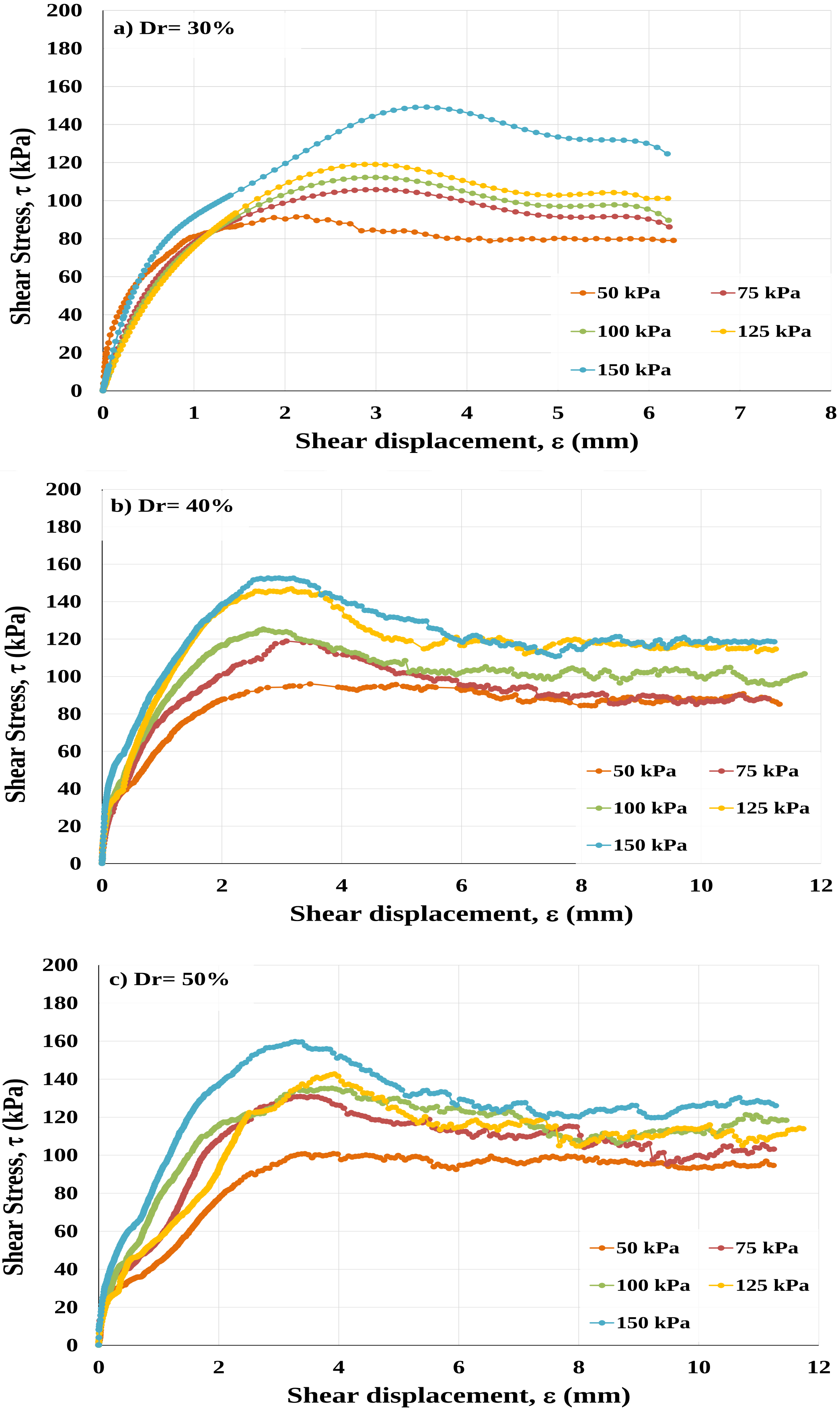
CHAPTER 4

RESULTS AND DISCUSSION

In this study, the shear strength parameters of dry sand were obtained using a direct shear test device. Shear strength parameters were calculated at different relative densities, normal stresses and the results obtained from the tests were compared according to shear stress. In addition, the effect of normal stress on shear strength is discussed on the basis of theoretically obtained graphical and graphical comparisons.

4.1 Results of Direct Shear Test with Well Graded Sand (SW)

Firstly, the influence of the relative densities on the mechanical behaviour of the dry sand is studied. To study this effect, dry sand with six relative densities were taken. For the constant relative densities, shear stress increased as normal stress increased. For this series of tests, the relative density was increased from 30% to 80% and the normal stress for each test was varied from 50 kPa to 150 kPa. Using the test results, the shear stress - shear displacement of dry sand was created for different relative densities as shown in Figure 4.1. A series of simple shear tests were conducted to investigate the stress-strain relationship and dilation behavior of the dry sand with different relative densities. As seen clearly in Figure 4.1-a, the lowest shear stress is obtained 91.5 kPa for the loosest (Dr= 30%) relative density under 50 kPa normal stress. From Figures 4.1-f, it can be seen that the shear strength of the dry sand, increases significantly with the progress of horizontal displacement, due to the good adhesion between the grains of dry sand. For denser samples (Dr=80%), Figure 4.1-f shows that the shear stress increases continuously with the progress of the test up to peak stress after that there is a decrease of shear stress until a residual value. The peak value obtained in the test is 187.61 kPa for a normal stress of 150 kPa.



a) Dr= 30%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
50 kPa
75 kPa
100 kPa
125 kPa
150 kPa
b) Dr= 40%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
50 kPa
75 kPa
100 kPa
125 kPa
150 kPa
c) Dr= 50%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
50 kPa
75 kPa
100 kPa
125 kPa
150 kPa

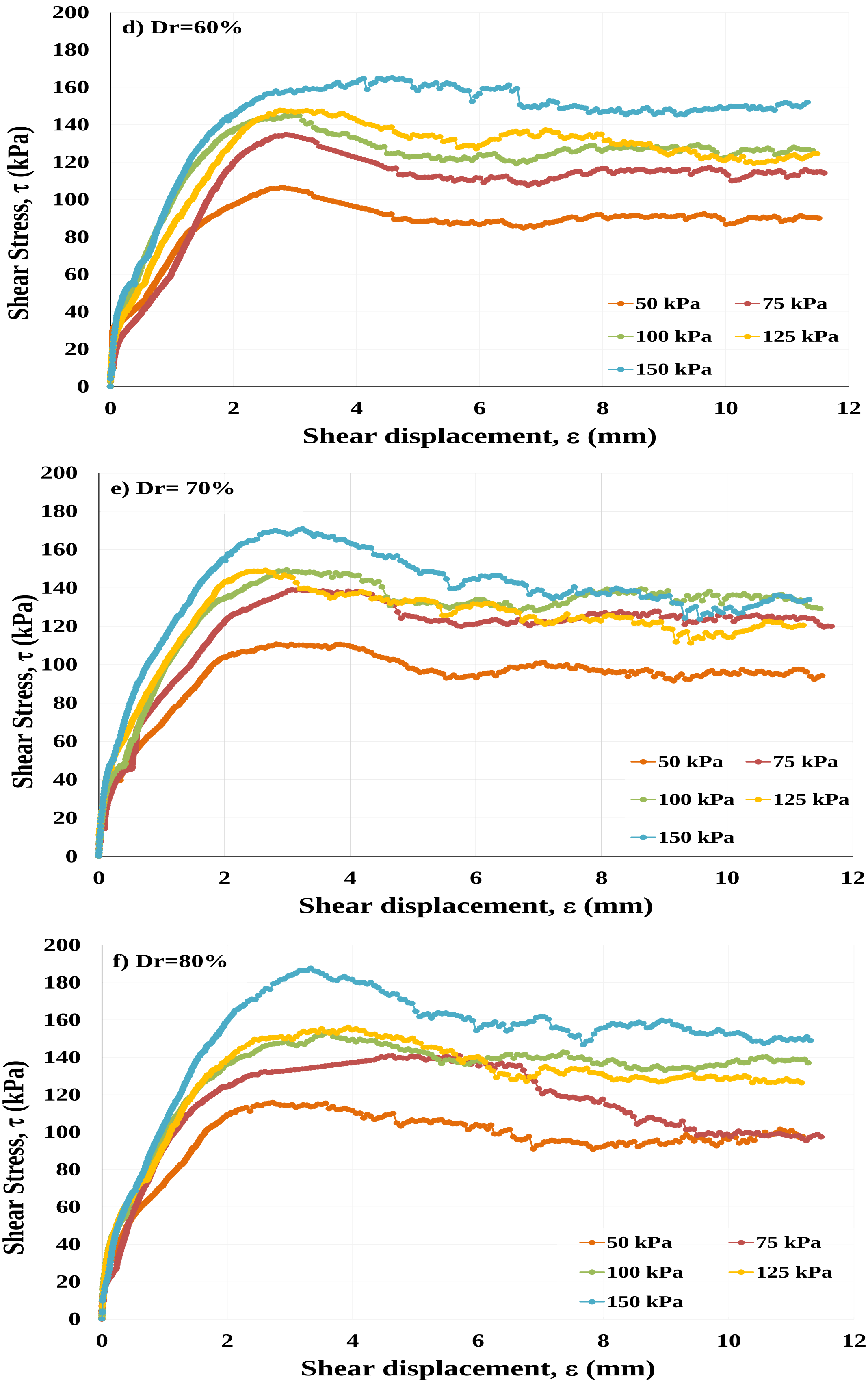


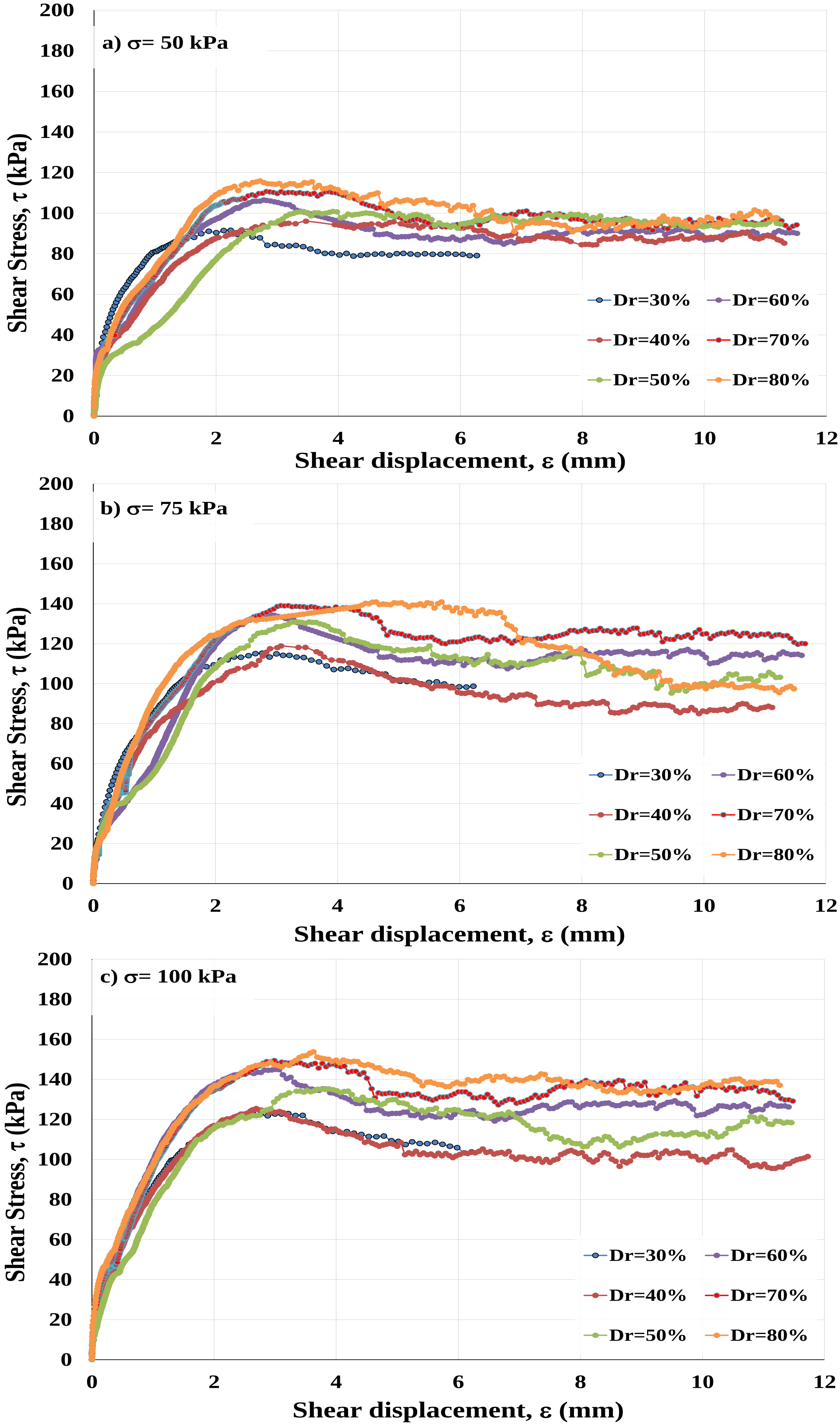
Figure 4.1 Varitions of shear stress with different normal stress for sample under the constant relative densities. (Dr=30%-80%).

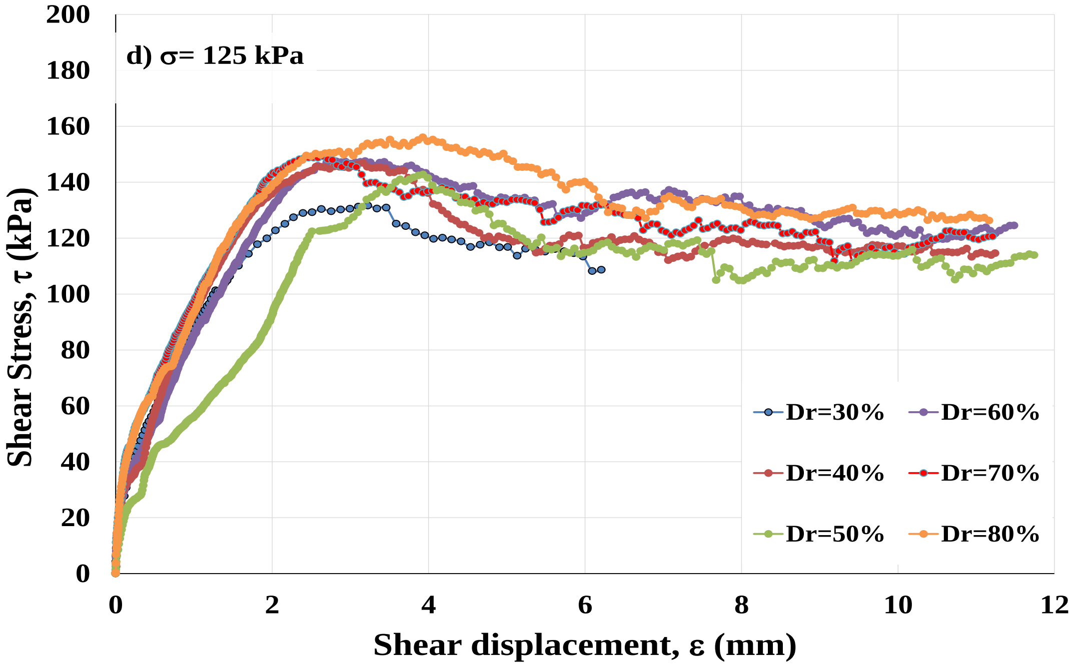
Figure 4.2-a to 4.2-e shows the test results obtained from direct shear tests with the applied under constant normal stresses for different relative densities. The experiments shown in Figure 4.2 were performed under 50, 75, 100, 125 and 150 kPa. As was expected, the shear strength of the dry sand increased with normal stress, while it increases with relative densities.

The results of the experiments carried out under 50 kPa normal stress and 6 different relative densities are shown in Figure 4.2-a. As shown in Figure 4.2-a, the minimum shear stress value was obtained for Dr= 30%, while the highest shear stress value under the same stress was obtained for Dr= 80%. The minimum shear stress value shown in Figure 4.2-a is 91.5 kPa for Dr= 30%, and the maximum shear stress is 115.8 kPa for Dr= 80%. As expected from the experimental results, the maximum shear stresses increased as the relative densities increased. However, when the test results obtained under normal stress of 50 kPa were examined, it was observed that as the relative density increase from loose (Dr= 30%) to dense (Dr= 80%), the maximum shear stress increased in a very narrow band.

In addition, it has been found that as the normal stress increases from 50 to 150 kPa, the resulting maximum shear stress relatively increases (Figure 4.2b-2e). Similar results were obtained in experiments under normal stress of 75, 100 and 125 kPa.

The tests were performed at a maximum normal stress of 150 kPa (Figure 4.2-e). Figure 4.2-e shows the results of the experiments performed under 6 different relative densities under normal stress of 150 kPa. The highest shear stress in the experiments was obtained for a relative stress of Dr= 80% and a normal stress of 150 kPa. The lowest shear stress was 115.8 kPa and the highest shear stress was 187.6 kPa for 150 kPa normal stress.


a) σ= 50 kPa
b) σ= 75 kPa
c) σ= 100 kPa
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
Dr=30%
Dr=40%
Dr=50%
Dr=60%
Dr=70%
Dr=80%



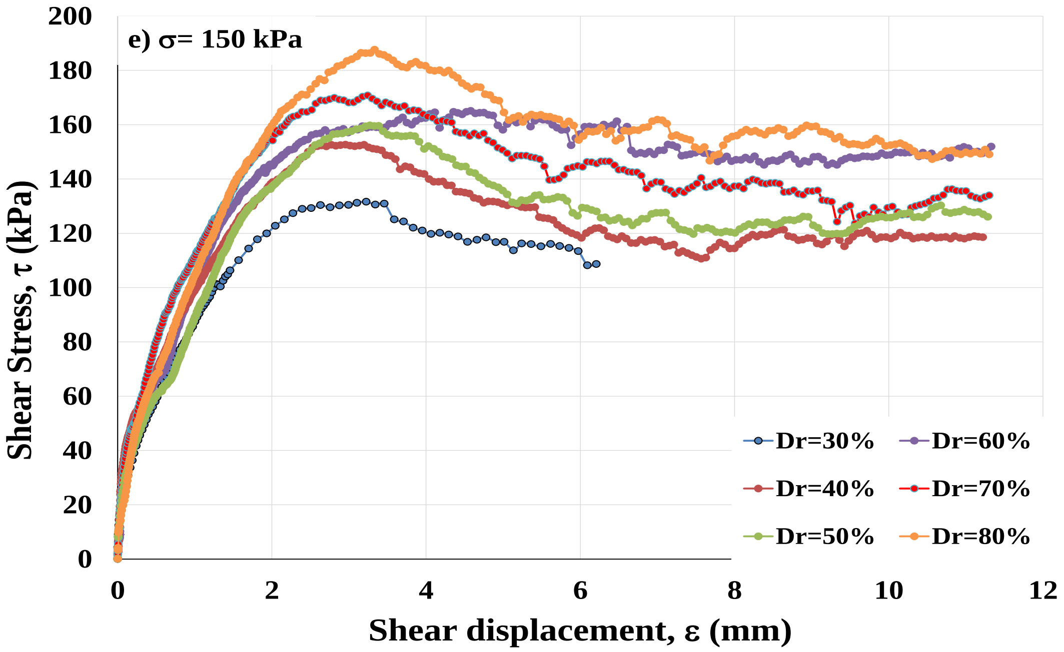
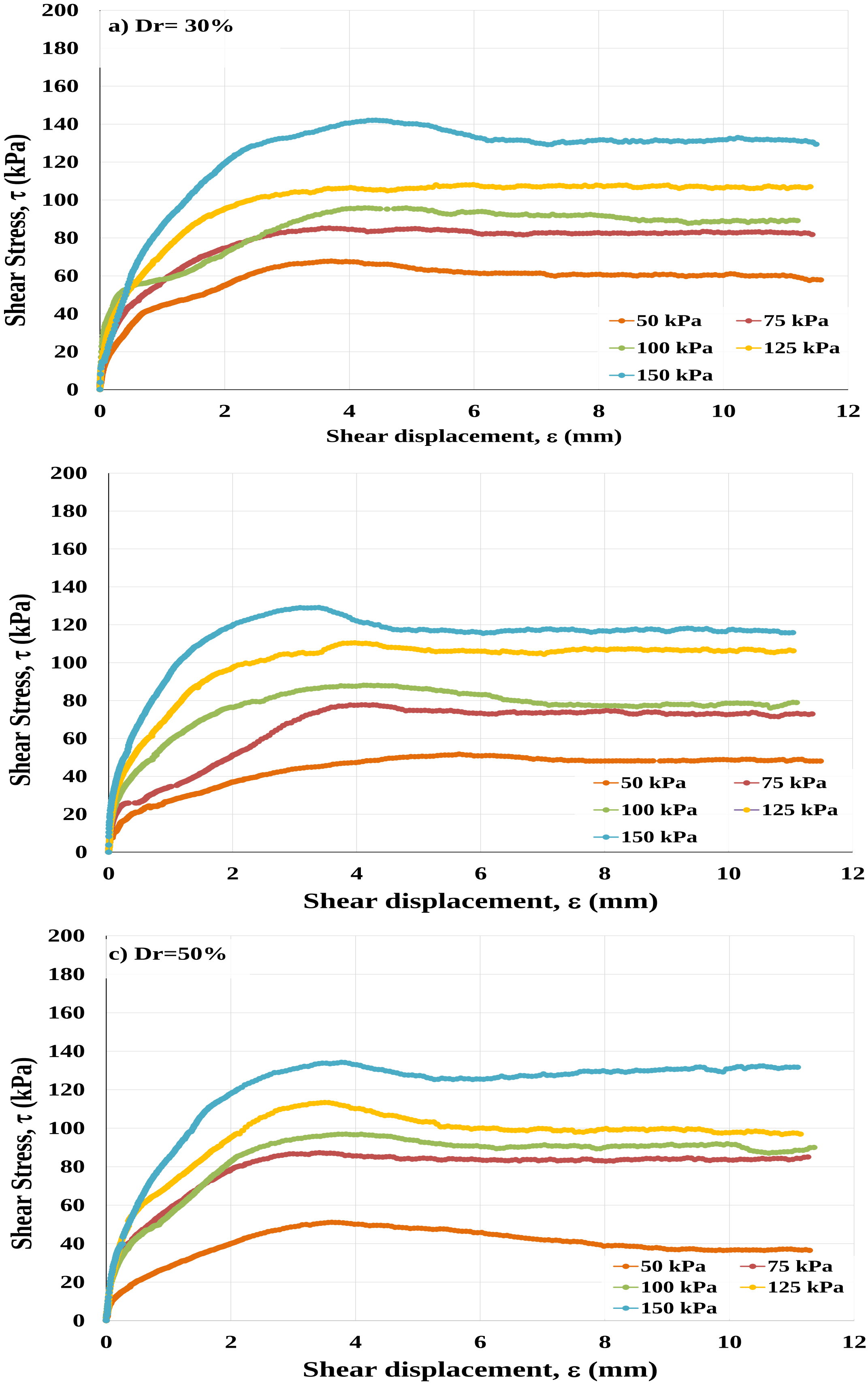


Figure 4.2 Shear stress - displacement relationship for different normal stresses (σ= 50- 150 kPa)

4.2 Results of Direct Shear Test with Poorly Graded Sand (SP)

In the tests, the rate of horizontal loading is controlled at 1 mm/min. The rate of displacement was selected with reference to ASTM D3080-90 (ASTM, 1990). The experiments shown in Figure 4.3 were performed under 50, 75, 100, 125 and 150 kPa. The minimum shear stress value represents in Figure 4.3– a is 67.77 kPa and maximum shear stress is 142.04 kPa for Dr= 30%.


a) Dr= 30%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
50 kPa
75 kPa
100 kPa
125 kPa
150 kPa
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
50 kPa
75 kPa
100 kPa
125 kPa
150 kPa
c) Dr=50%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
50 kPa
75 kPa
100 kPa
125 kPa
150 kPa

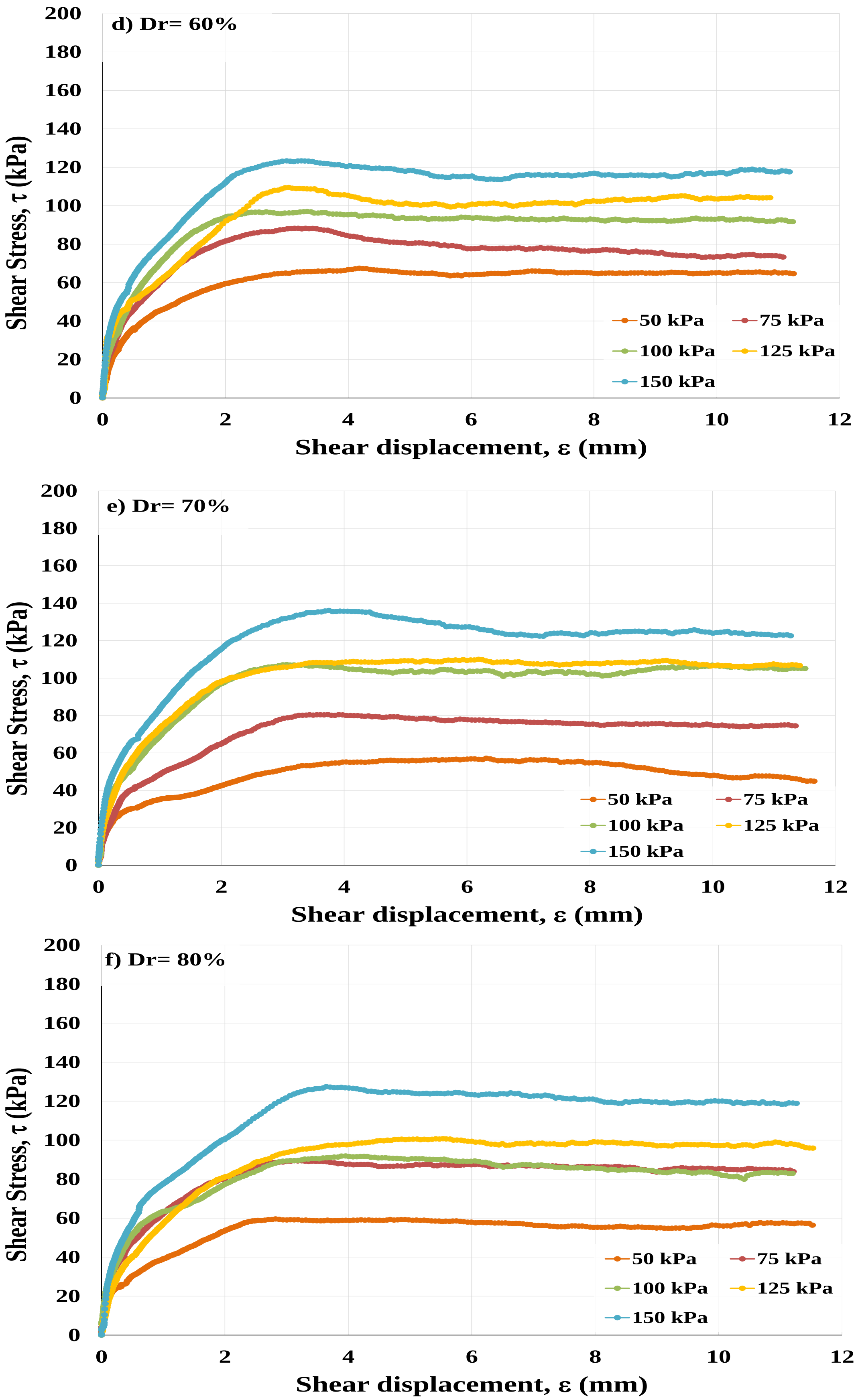
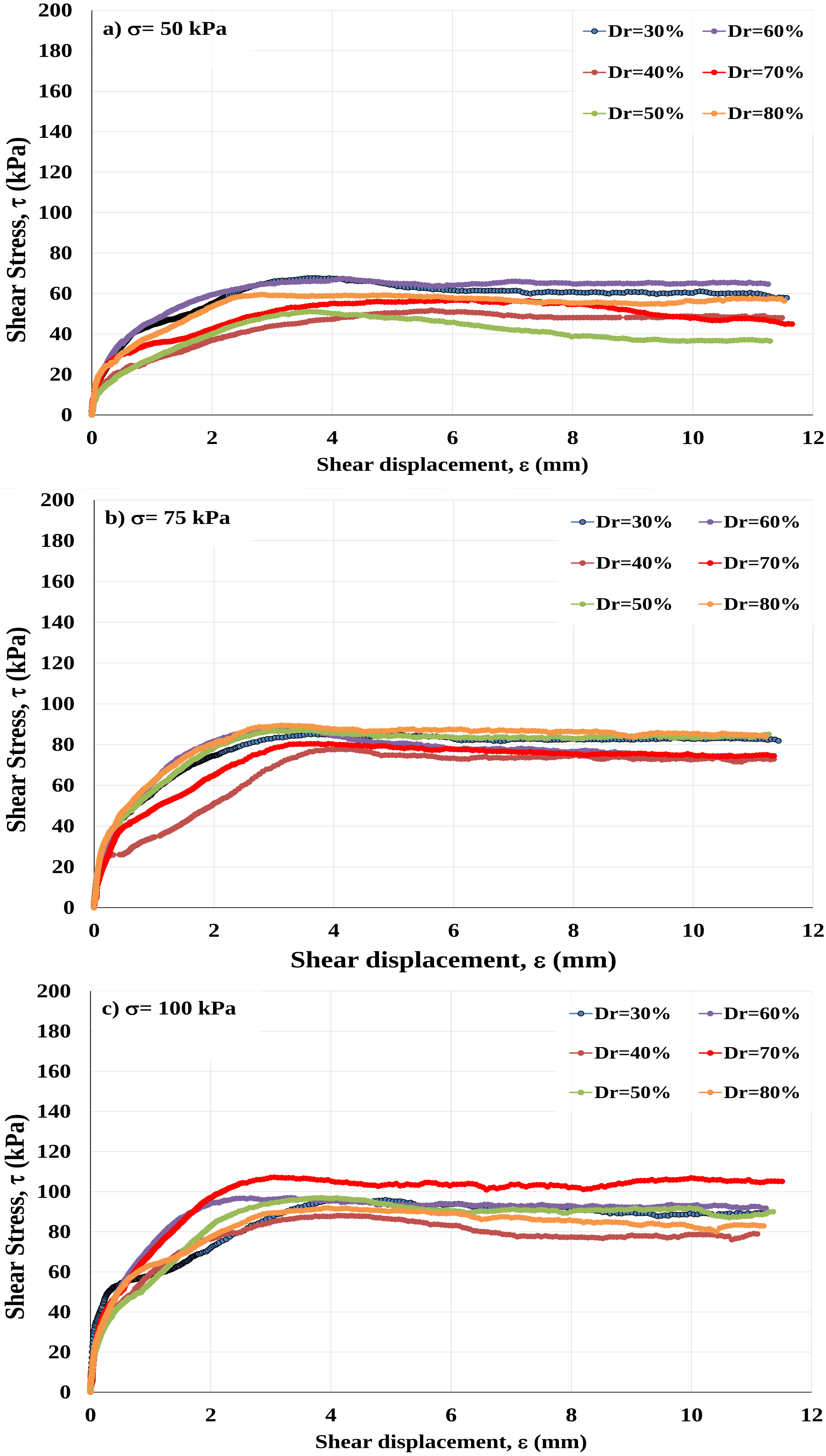
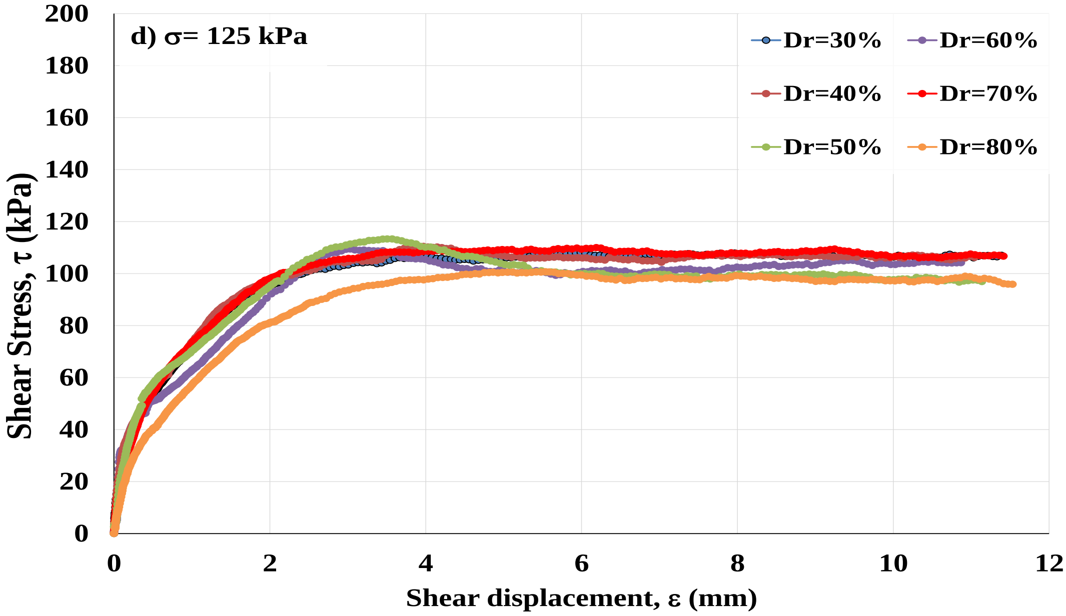


Figure 4.3 Varitions of shear stress with different normal stress for sample under the constant relative densities (Dr=30% – 80%).

Figure 4.4-a, the minimum shear stress value was obtained for Dr= 30%, while the highest shear stress value under the same stress was obtained for Dr= 80%. The minimum shear stress value shown in Figure 4.4-a is 67.77 kPa for Dr= 30%. As anticipated from the experimental results, the maximum shear stresses increased as the relative densities increased. However, when the test results obtained under normal stress of 50 kPa were analyses, it was observed that as the relative density increase from loose (Dr= 30%) to dense (Dr= 80%), the maximum shear stress increased in a very narrow band. The tests were performed at a maximum normal stress of 150 kPa (Figure 4.4-e). Figure 4.4-e shows the results of the experiments performed under 6 different relative densities under normal stress of 150 kPa. The highest shear stress in the experiments was obtained for a relative stress of Dr= 80% and a normal stress of 150 kPa. The lowest shear stress was 142.04 kPa and the highest shear stress was 127.37 kPa for 150 kPa normal stress.


a) σ= 50 kPa
Dr=30%
Dr=60%
Dr=40%
Dr=70%
Dr=50%
Dr=80%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
b) σ= 75 kPa
Dr=30%
Dr=60%
Dr=40%
Dr=70%
Dr=50%
Dr=80%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
c) σ= 100 kPa
Dr=30%
Dr=60%
Dr=40%
Dr=70%
Dr=50%
Dr=80%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)



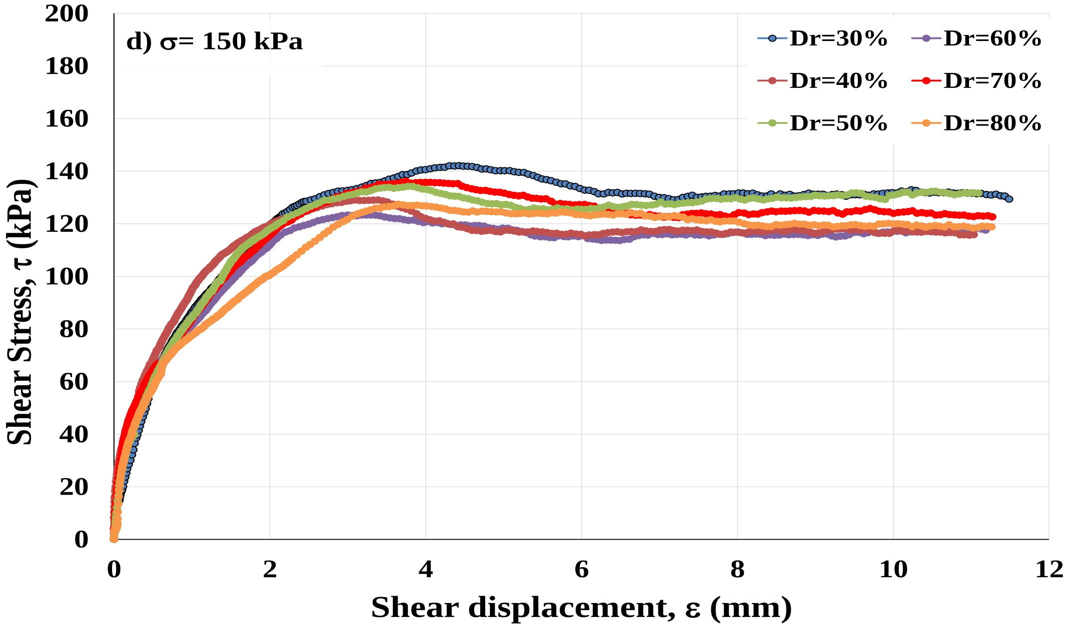
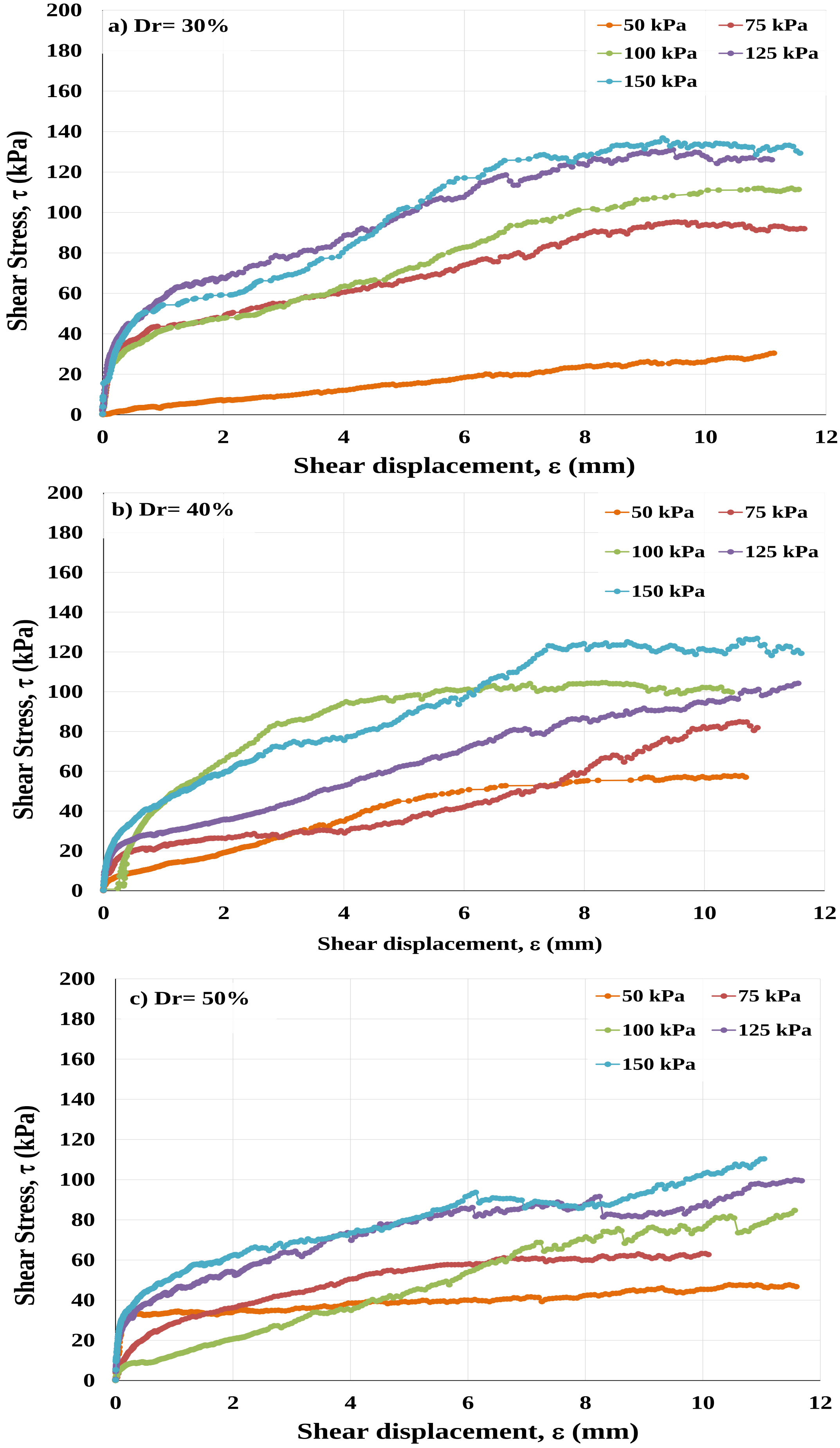


Figure 4.4 Shear stress – Sear displacement relationship for different normal stresses (50, 75, 100, 125, 150 kPa)

4.3 Results of Direct Shear Test with Silty Sand (SM)

The experiments shown in figure 4.5 were performed under 6 relative densities. The minimum shear stress value represents in figure 4.5– a is 30.42 kPa and maximum shear stress is 136.815 kPa for Dr= 30%.


a) Dr= 30%
b) Dr= 40%
c) Dr= 50%
50 kPa
75 kPa
100 kPa
125 kPa
150 kPa
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12

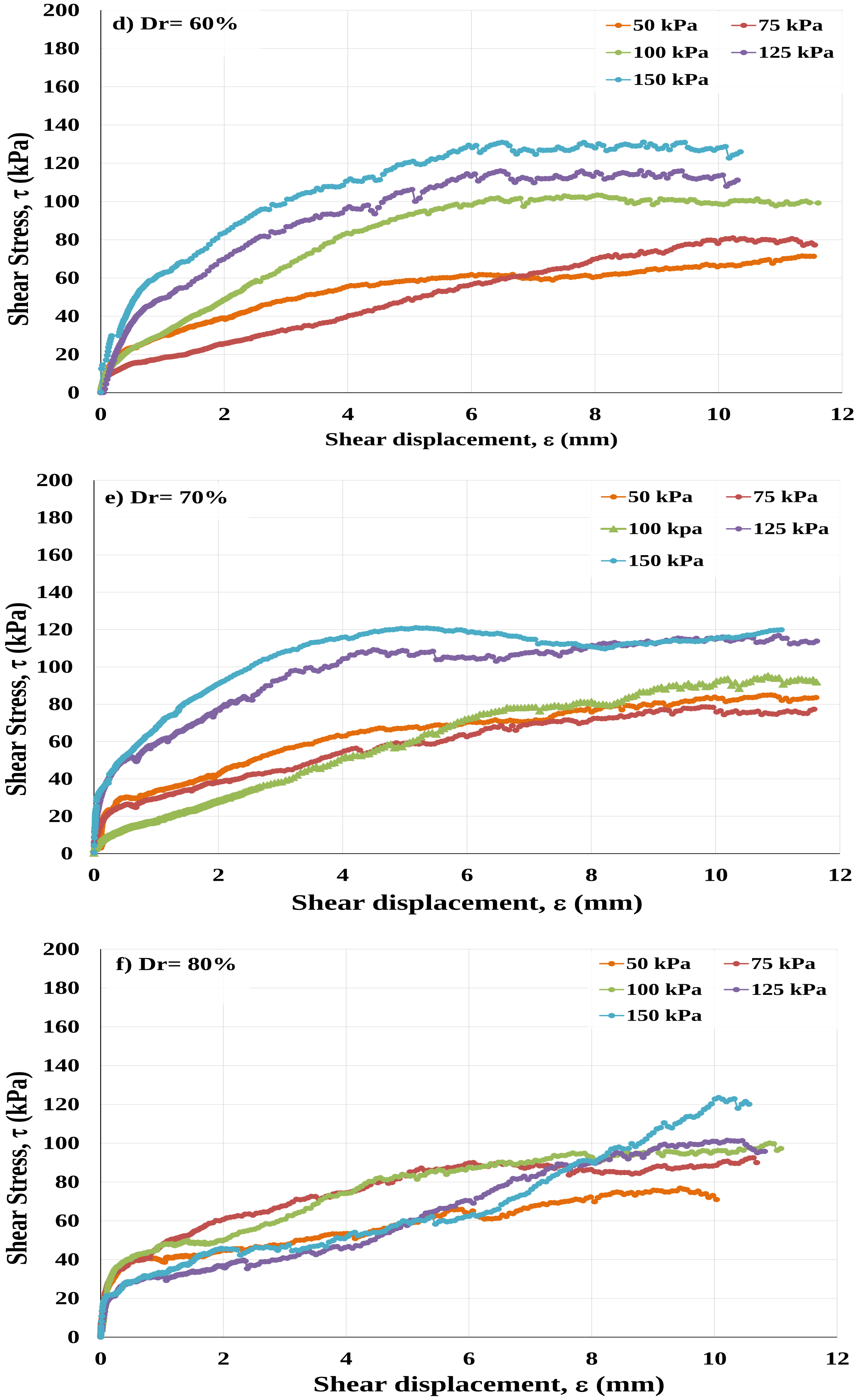
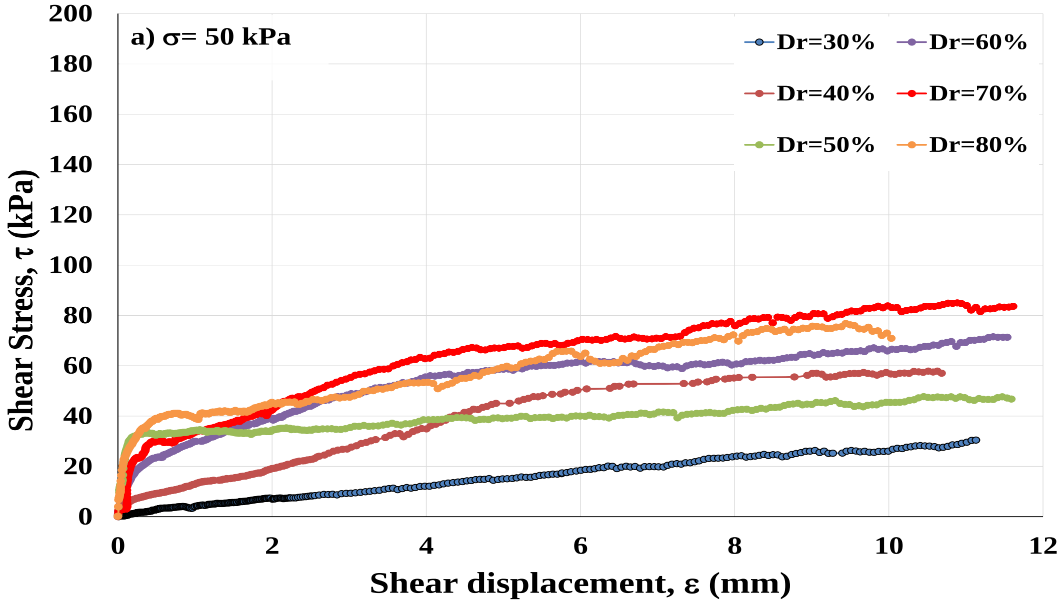
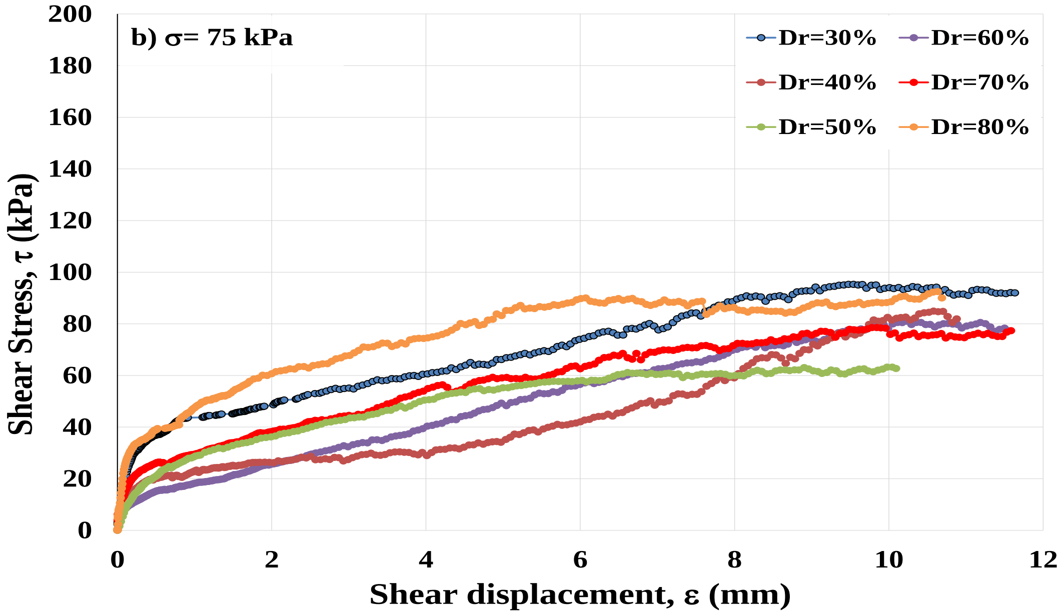
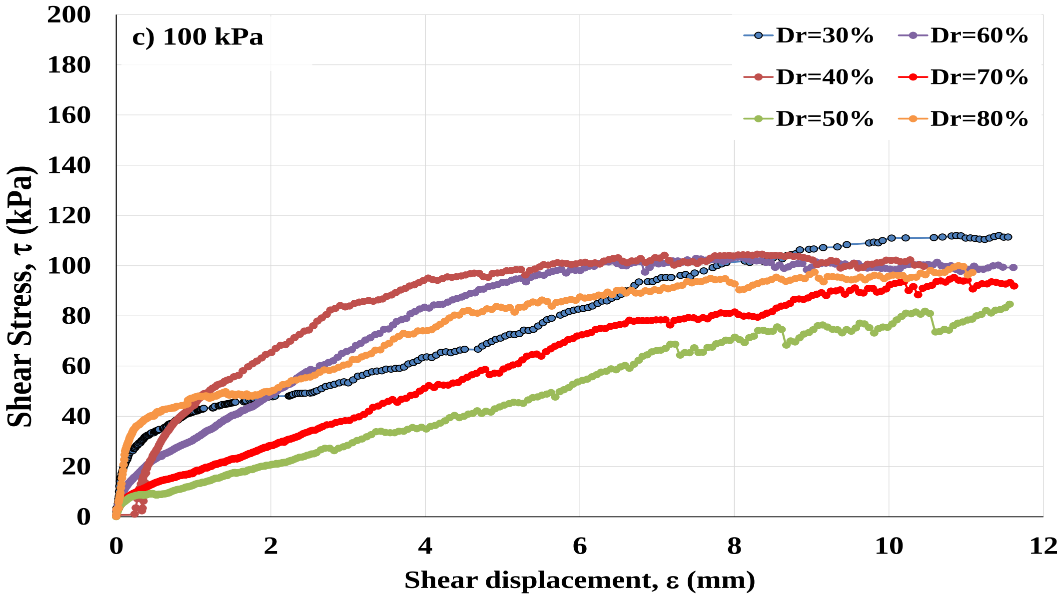


Figure 4.5 Varitions of shear stress with different normal stress for sample under the constant relative densities. (Dr=30%-80%).


a) σ= 50 kPa
Dr=30%
Dr=60%
Dr=40%
Dr=70%
Dr=50%
Dr=80%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12


b) σ= 75 kPa
Dr=30%
Dr=60%
Dr=40%
Dr=70%
Dr=50%
Dr=80%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12


c) 100 kPa
Dr=30%
Dr=60%
Dr=40%
Dr=70%
Dr=50%
Dr=80%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12

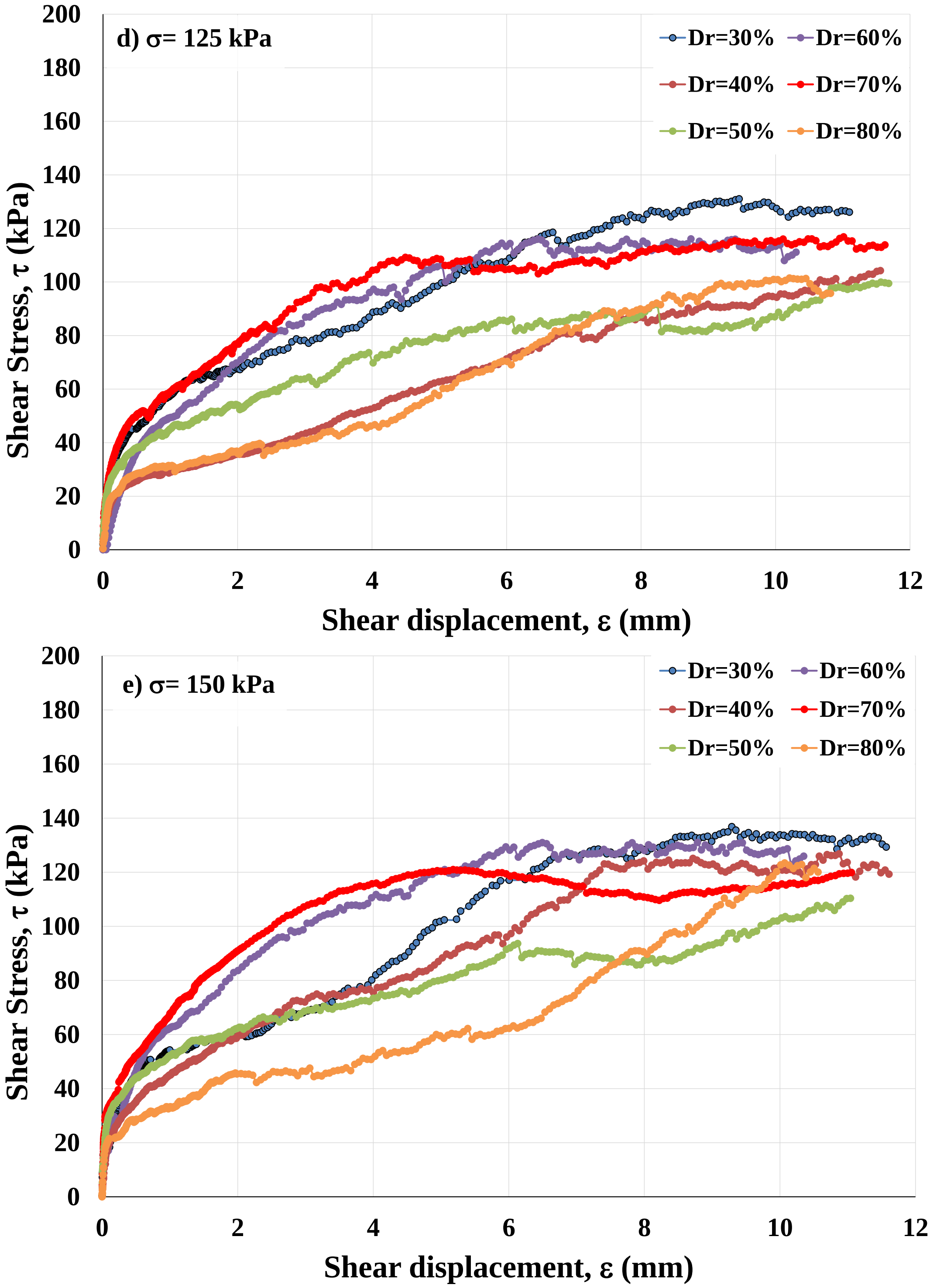
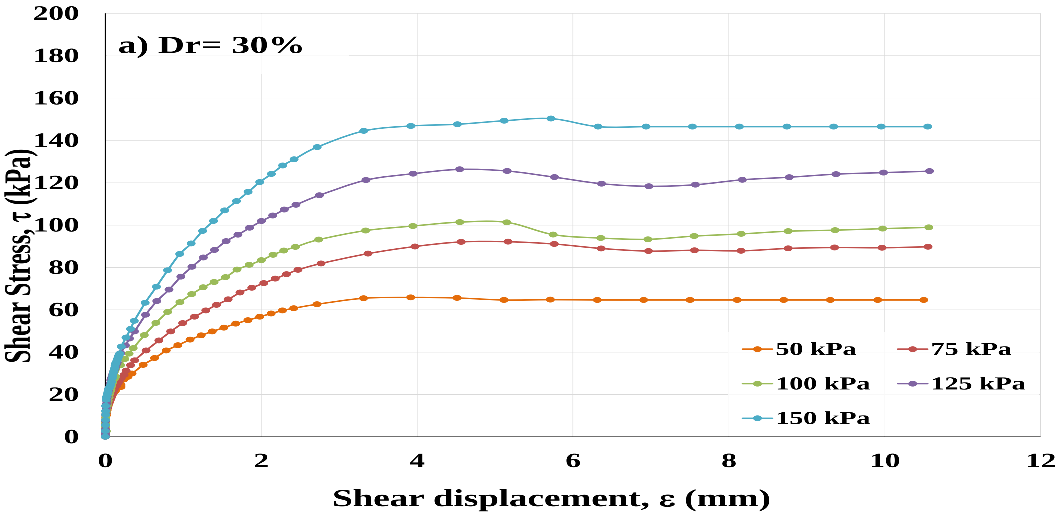


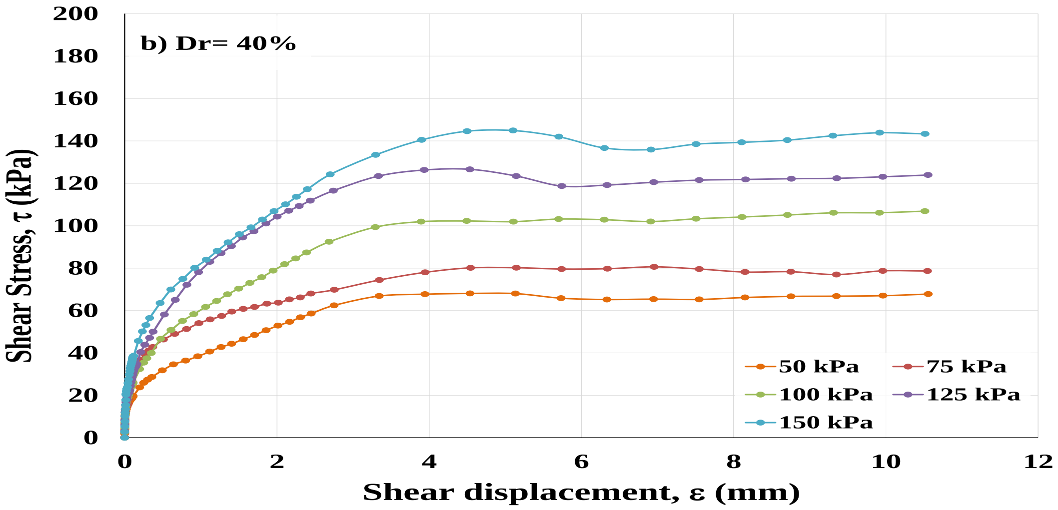
Figure 4.6 Shear stress – Sear displacement relationship for different normal stresses (50, 75, 100, 125, 150 kPa)

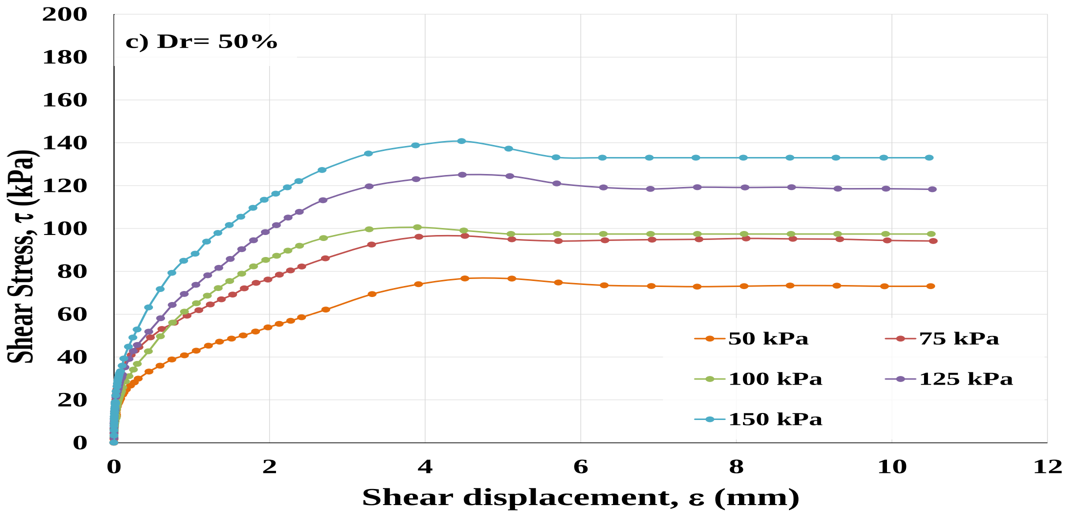
The experiments shown in figure 4.6 were performed under 50, 75, 100, 125 and 150 kPa. The minimum shear stress is obtained under 50 kPa and for %30 relative density (Figure 4.6- a). The maximum shear stress is obtained under 150 kPa for %80 relative density (Figure 4.6- e).

4.4 Results of Direct Shear Test with Fine Sand

The experiments shown in figure 4.7 were performed under 6 relative densities. Looking at Figure 4.7-f, it is observed that typical tight soil behavior is observed.







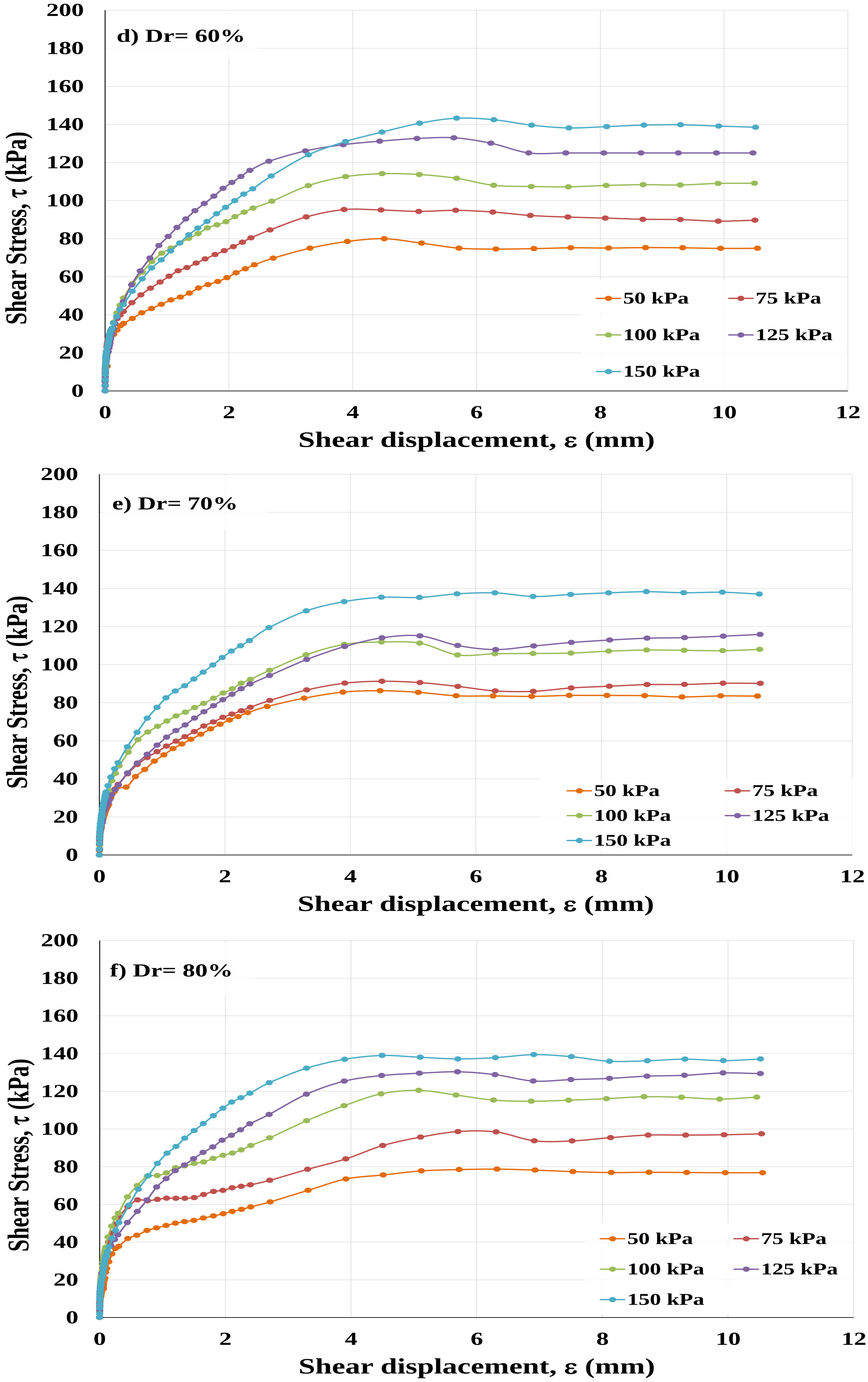
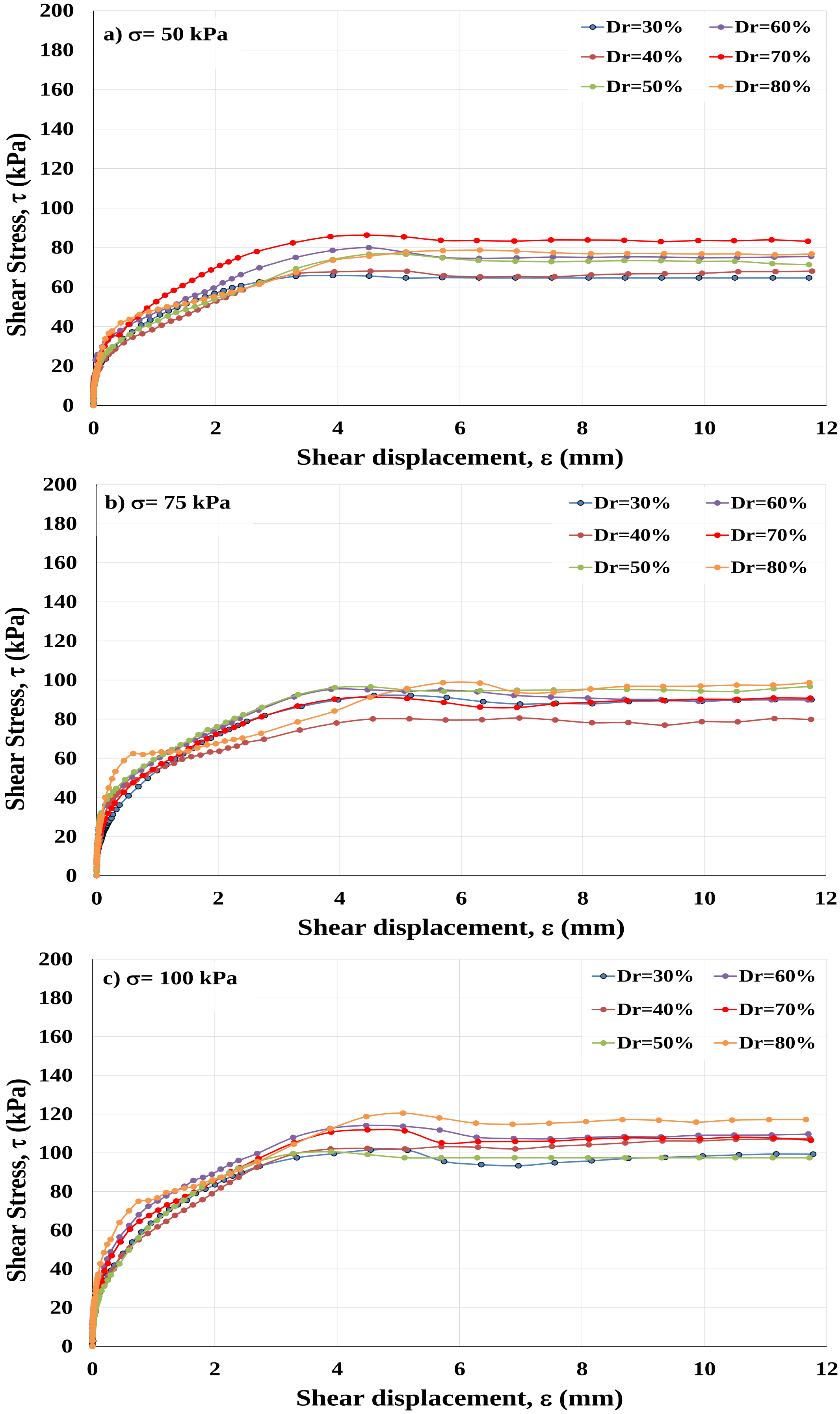


Figure 4.7 Variation of shear stress with different normal stress for sample under the constant relative densities (Dr=30%-80%).

Using the test results, the internal friction angles of dry sand was obtained for different relative densities as shown in Figure 4.8. When the result of the experiments is examined, it is seen that the strength of the dry sand until it reaches horizontal deformation is increased. It is observed that the shear stress decreases after peaking. Later the soil past in ultimate state. It is seen that the shear strength of the soil increases with the increase of normal stress. It was observed that higher stresses were required for the soil to failure. This is because the stresses on the grains complicate the movement of the grains on each other and cause them to be tightened together. In this case, it causes the soil to show more strength at high stresses.


a) σ= 50 kPa
b) σ= 75 kPa
c) σ= 100 kPa
Dr=30%
Dr=40%
Dr=50%
Dr=60%
Dr=70%
Dr=80%
Shear Stress, τ (kPa)
Shear displacement, ε (mm)
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12

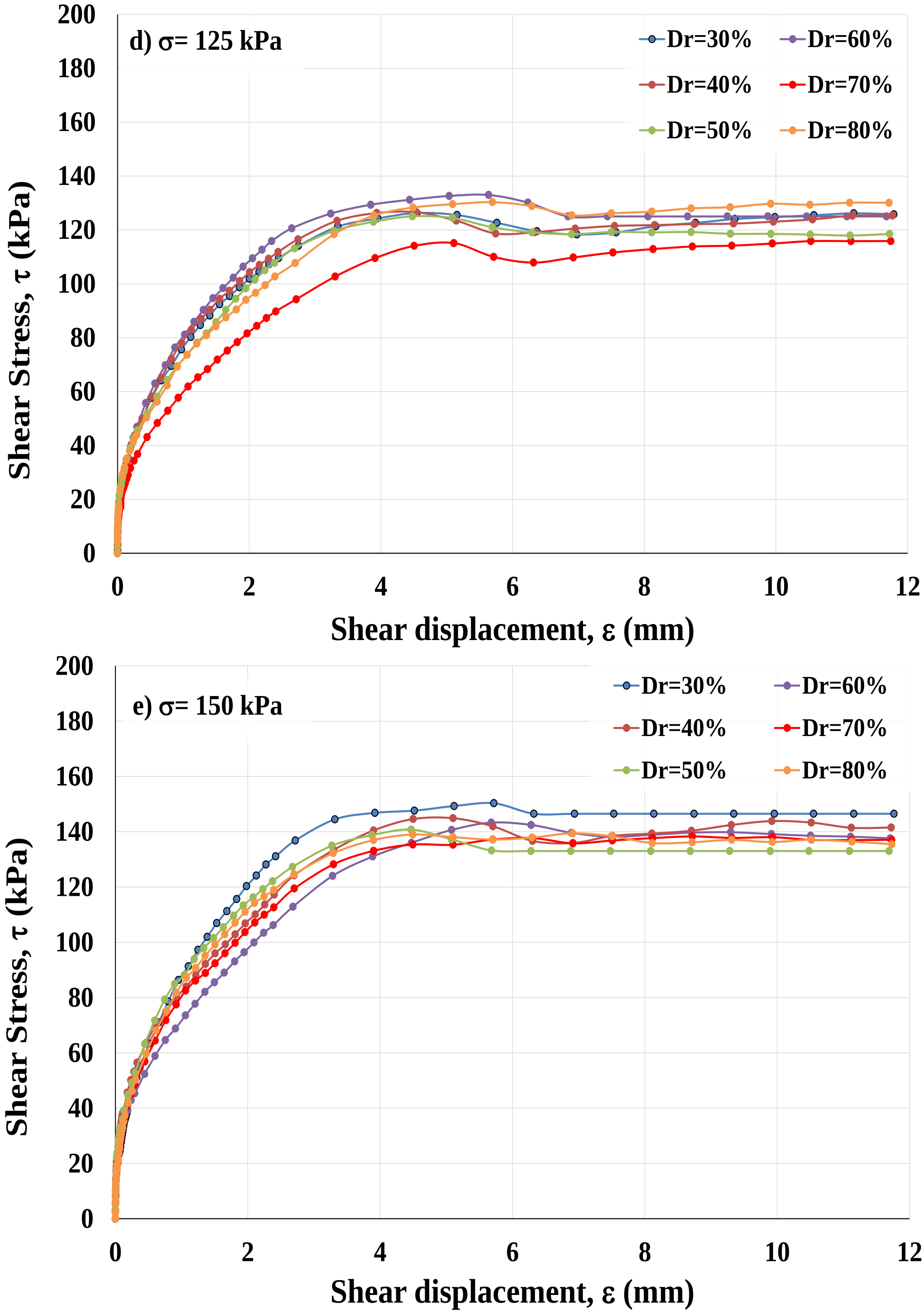


Figure 4.8 Shear stress – Sear displacement relationship for different normal stresses (50, 75, 100, 125, 150 kPa)

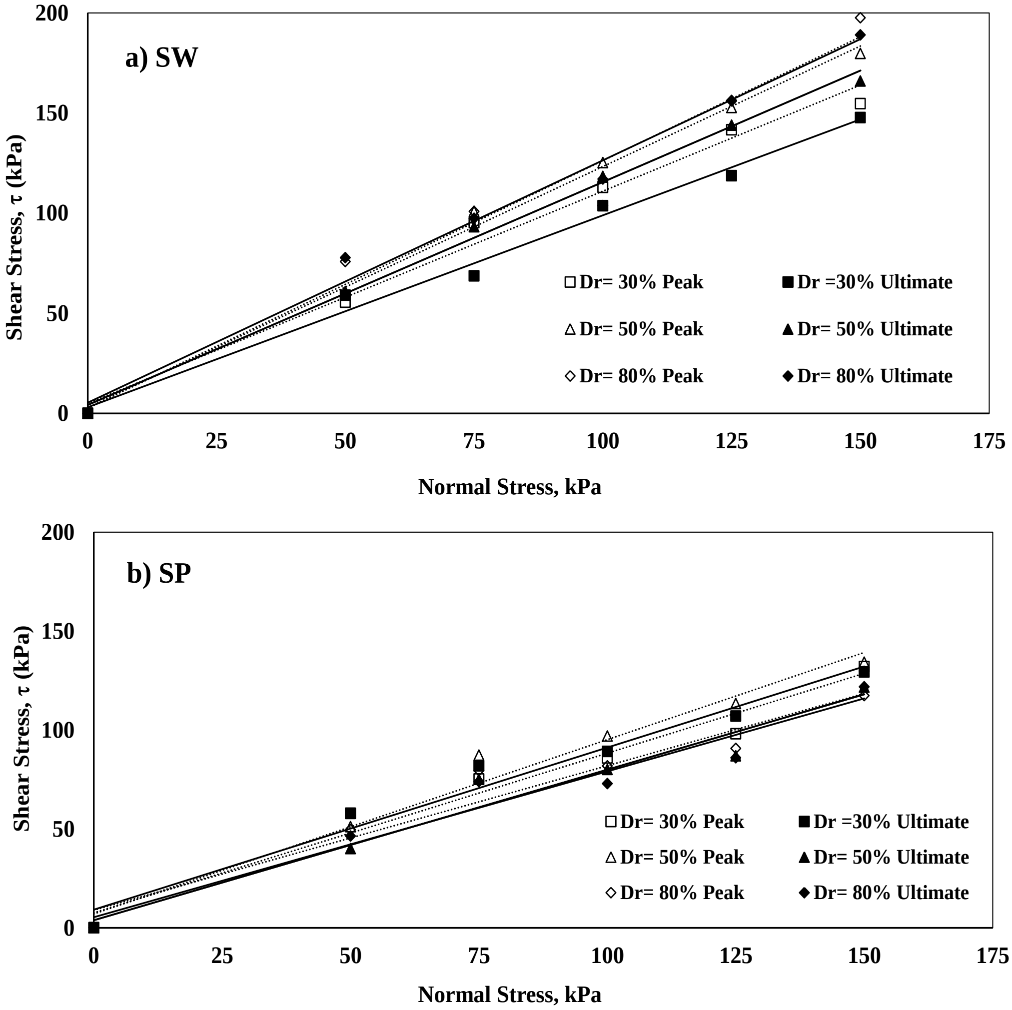
Table 4.1 The minimum shear strength - the maximum shear strength

Dr, (%) / σ, (kPa)	30	80
50	65.83	78.72
150	139.43	150.29

The minimum shear stress was obtained 65 kPa under a normal stress of 50 kPa with a relative density of 30%. The maximum shear stress was obtained 150 kPa under a normal stress of 150 kPa with a relative density of 80%.

4.5 The Effect of Relative Density

Figure 4. 9 shows peak and ultimate shear stress for different relative densities of the soil for loose (Dr= 30%), medium dense (Dr= 50%), and dense (Dr= 80%). As shown in the figure, normal stress increases the shear stress for the ultimate and peak value.



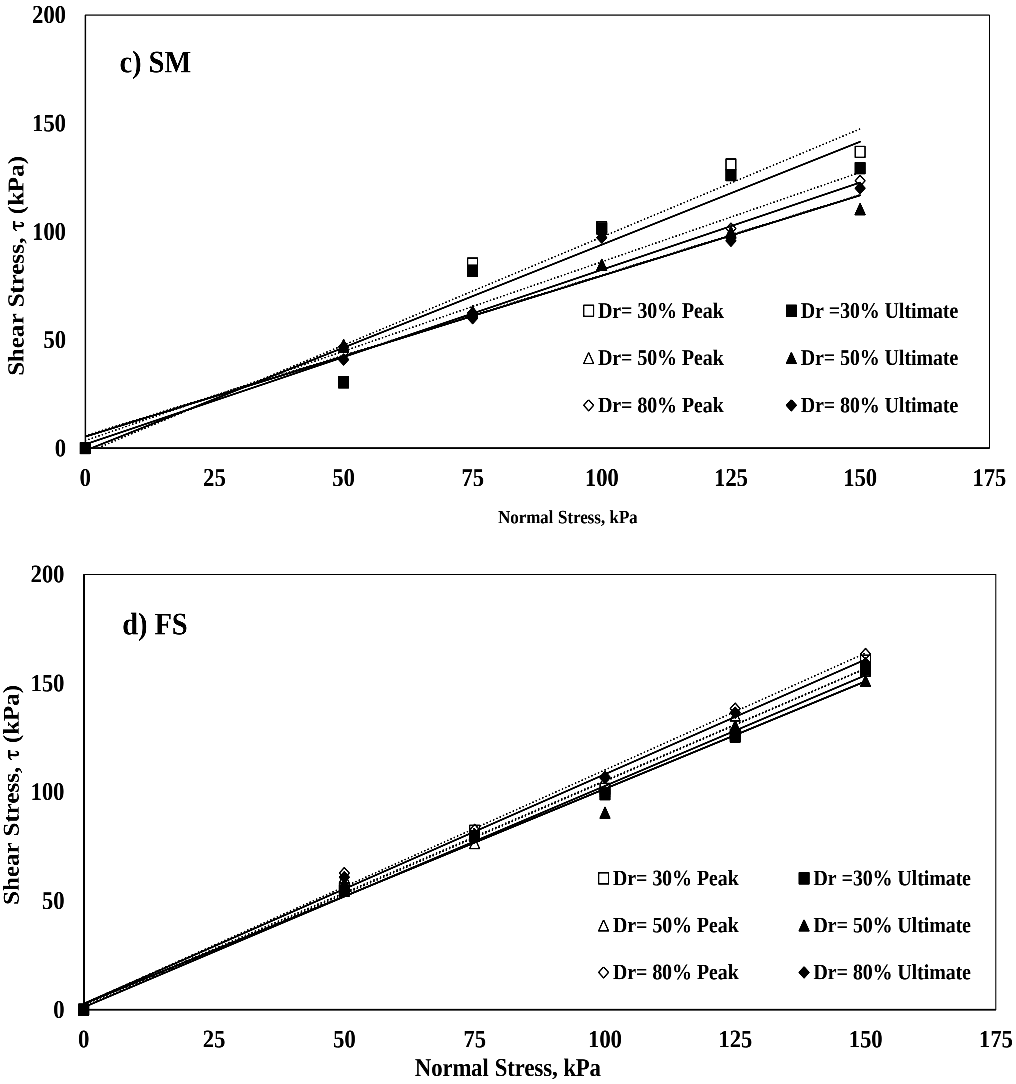


Figure 4.9 Peak shear strength - change of permanent shear strength due to normal stress .

4.6 The Internal Friction Angle

4.6.1 The Void Ratio Effective

As shown in figure 4.10;

1. As the intergranular void ratio increases, the internal friction angle increases for the same relative densities.
2. Intergranular void ratio decreased with increasing relative density at different relative densities. Accordingly, the internal friction angle is increased.

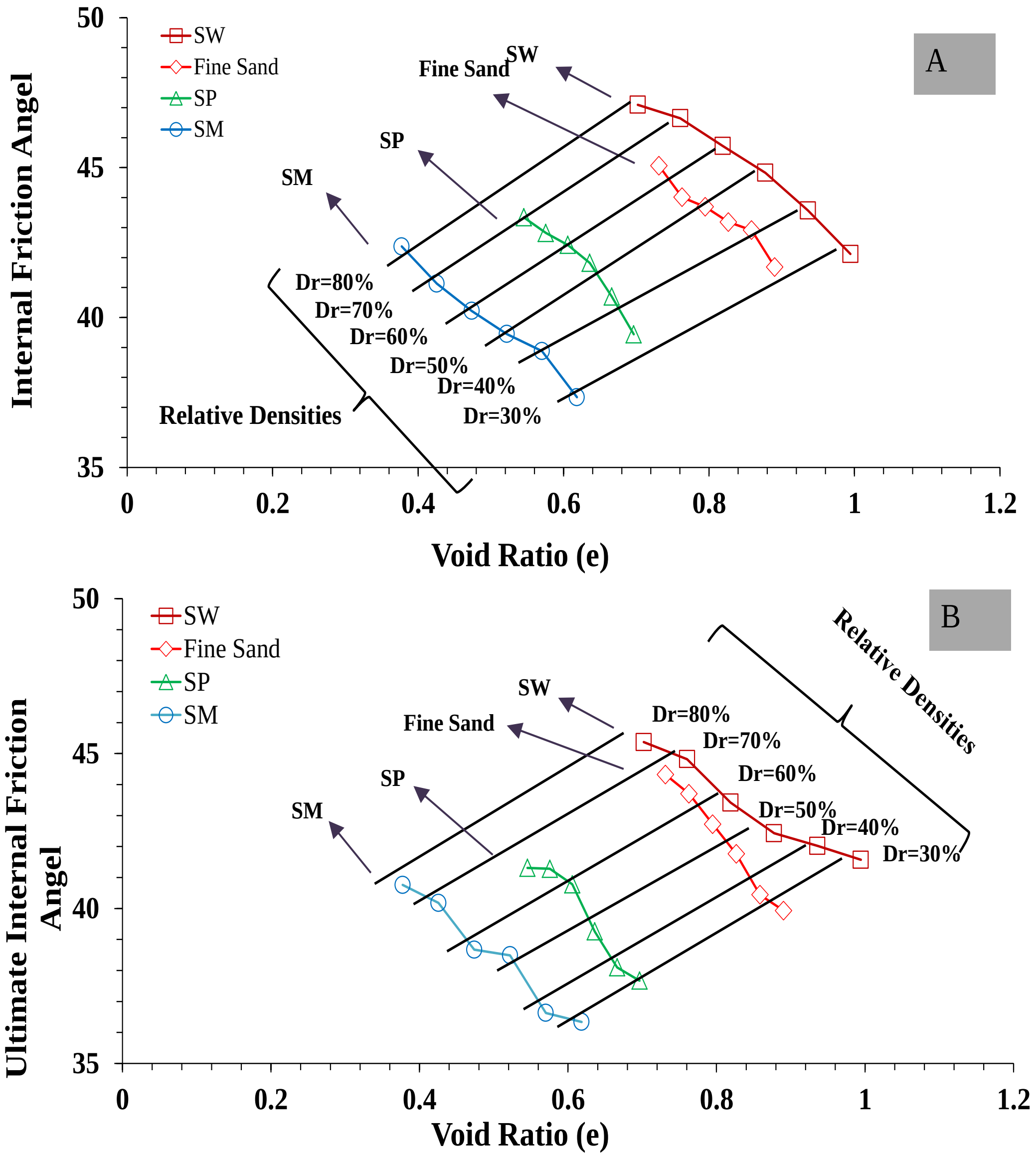


Figure 4.10 Peak (A), ultimate (B) internal friction angle – void ratio relationship.

4.6.2 The Porosity Effective

As shown in figure 4.11;

1. When in the same relative density porosity increases internal friction angle increases.
2. Porosity decreased as relative density increased.
3. The internal friction angle decreased as the relative density increased.
4. Porosity and internal friction angle increased as intergranular void ratio increased.

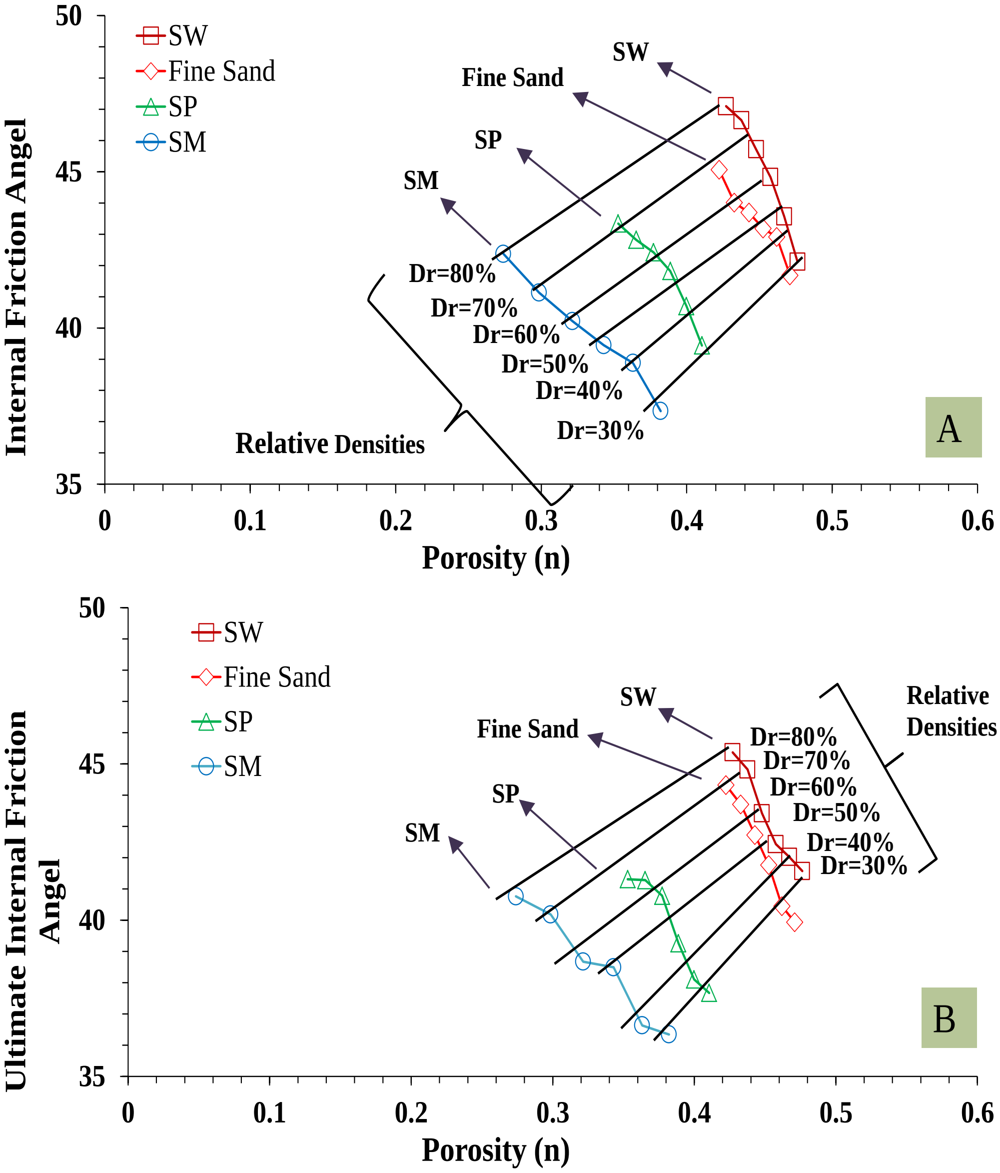
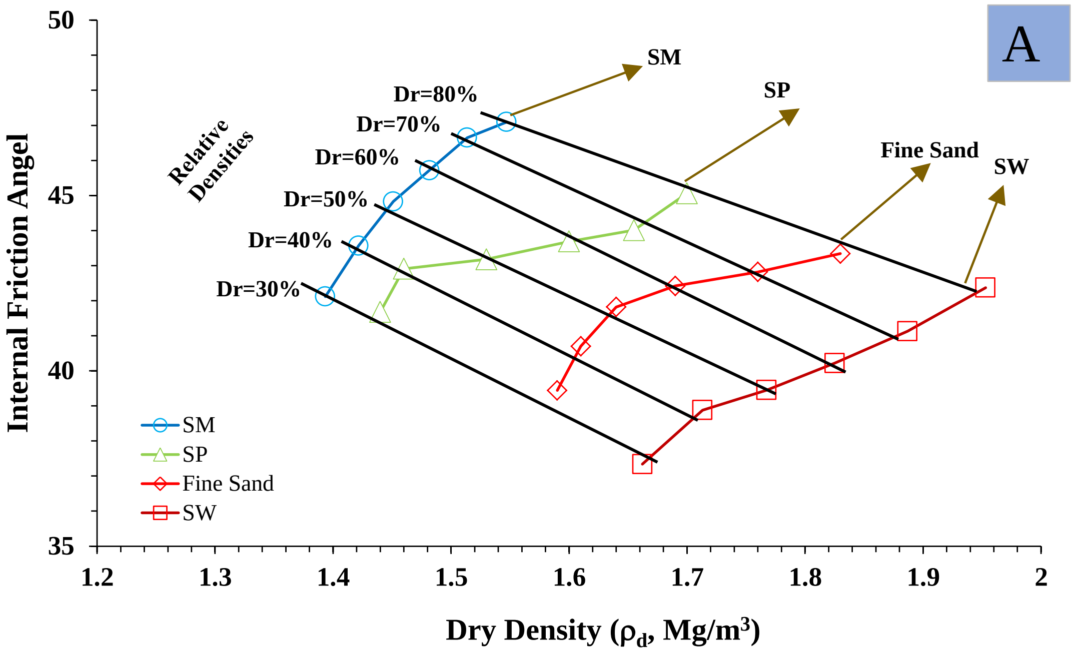


Figure 4.11 Peak (A), ultimate (B) internal friction angle – porosity relationship.

4.6.3 The Dry Density Effective

As shown in figure 4.12;

1. As the relative density increased, the internal friction angle and dry density increased.
2. When in the same relative density dry density increases internal friction angle is decreases.
3. As the intergranular gap ratio increases, the internal friction angle increases.
4. Dry density decreased as the intergranular void ratio increased.



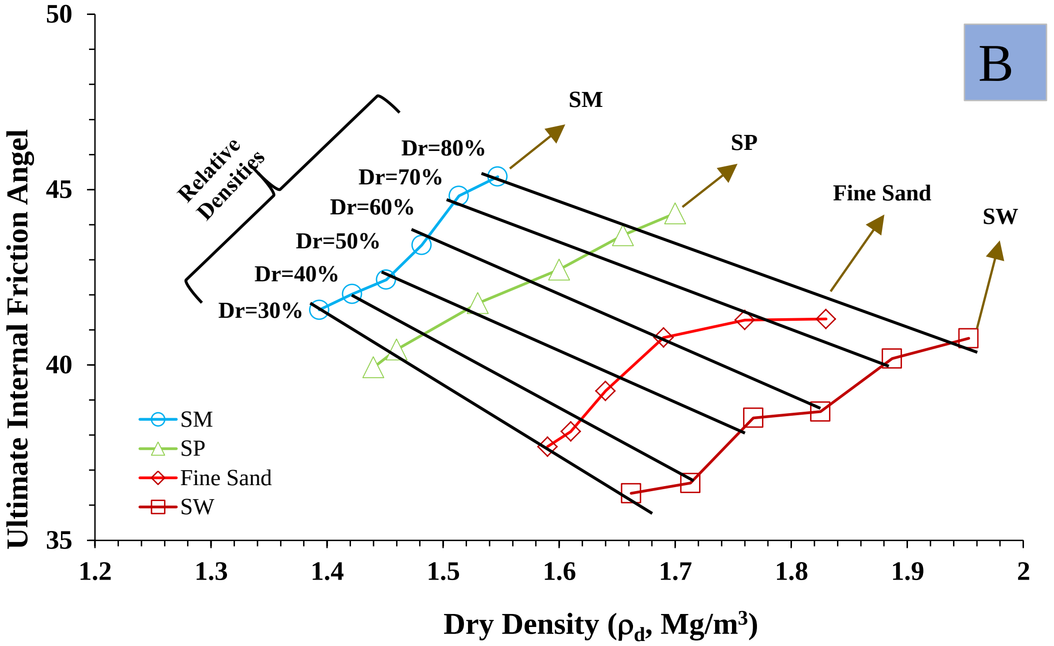
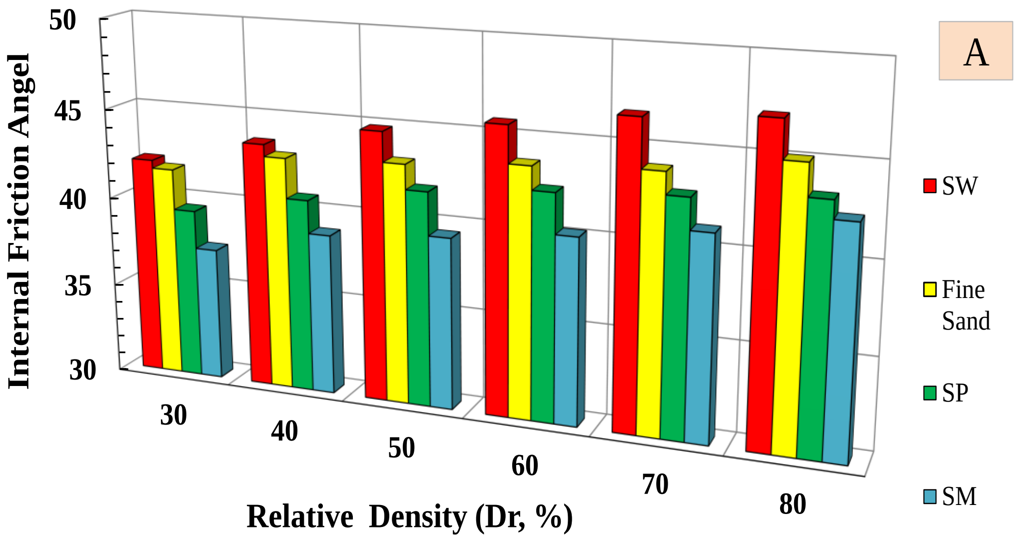


Figure 4.12 Peak (A), ultimate (B) internal friction angle – dry density relationship

4.6.4 The Relative Density Effective

As shown in Figure 4.13, the relative densities for all types of soils increases, the internal friction angle increases.



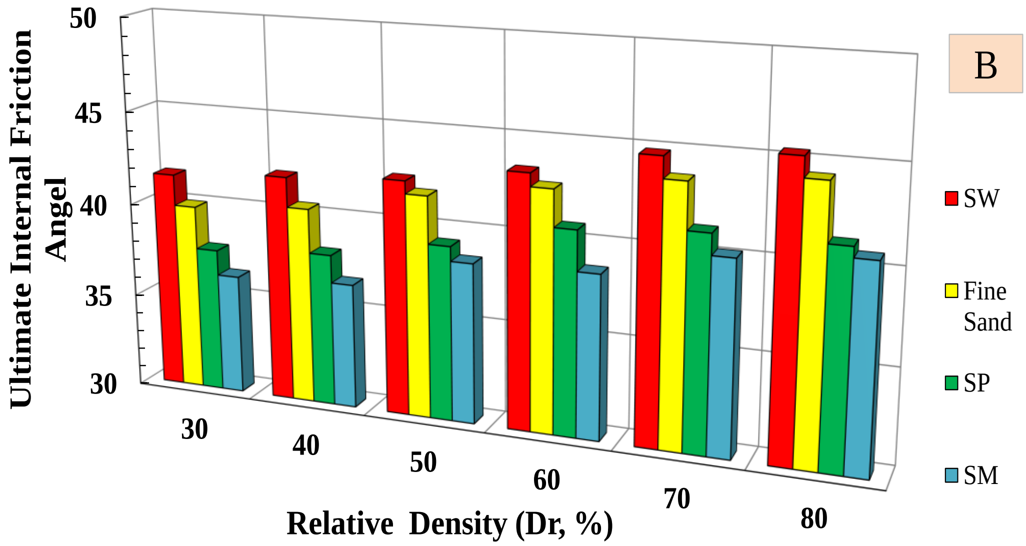


Figure 4.13 Peak (A), ultimate (B) internal friction angle – relative density relationship

The highest internal friction angle was obtained for well graded sand. The lowest internal friction angle was obtained for silty sand. The same results were obtained for both ultimate angle and peak angles for all type of soils. The results show that soil classification is the most important parameter to obtain the internal friction angle. In addition, one of the parameters that determine the internal friction angle of soils is grain size distribution. Well graded sands have a higher internal friction angle than poorly graded or incompletely graded sands.

Table 4.2 Comparison of literature and experiments

REFERENCE	SOIL TYPES	e_{max}	e_{min}	BOX SIZE (mm)	ϕ (°)
Cerato (2006)	Brown mortar- SW	0.91	0.58	59.9×59.9	37.3
Cerato (2006)	winter sand- SW	0.67	0.37	59.9×59.9	49.7
Cerato (2006)	Ottowa- SP	0.69	0.46	59.9×59.9	35
Cerato (2006)	Morie Sand- SP	0.78	0.59	59.9×59.9	38.5
Cerato (2006)	Crushed Stone	0.83	0.67	59.9×59.9	44.5
Nakao (2008)	Silty sandy gravel	-	-	60×60	31.6
Türer (2004)	Trakya Sand	0.81	0.5	60×60	46.2
This study (2019)	SW	0.6	0.3	60×60	46.81
This study (2019)	SP	0.787	0.485	60×60	41.82
This study (2019)	SM	0.763	0.281	60×60	36.34
This study (2019)	Fine Sand	0.986	0.668	60×60	43.18

When the experiments on SW sand are examined according to the results of the thesis, it is seen that similar results are obtained in the literature. According to the literature, the highest internal friction angle was obtained for SW sand. The reason for this is that SW sand has a coarse and angular structure when compared to the other types of soils, and therefore the movement of the soil on each other is more difficult. This strength keeping increases due to density and the increase of the applied stresses. And it is seen that higher values are obtained for the internal friction angle.

CHAPTER 5

CONCLUSIONS

In this study, the effect of different relative densities and normal stresses on the shear strength parameters (peak and ultimate internal friction angle) of the different soil types were investigated by using the direct shear test. A set of experimental tests were conducted on well graded sand, poorly graded sand, silty sand and fine sand samples to understand the effect of relative density on the physical and mechanical properties of the samples. Moreover, this study investigated the effect of the relative density of a dry sand on the shearing behaviors using a direct shear test device. The variations of the friction angle for the soil and the maximum vertical displacement with the relative density were analyzed.

The following conclusions can be drawn in this study.

1. It was achieved that the internal friction angle varies depending on the grain size distribution, sand type, relative density and normal stress applied.

2. The result of the direct shear test indicated that, when the normal stress increased, also the internal friction angle increased.

3. At the densities which the samples were tested, it is noted an increment in the maximum and residual shear stress with the increment in normal stress, which involves increment of the physical characteristics such as the internal friction angle.

4. The basic properties of soil affect the mechanical behavior of soil. The gradation of the soils affects the packing of the soils, causing them to exhibit different strengths. The morphological and mineralogical properties of soil particles affect the mechanical behavior of soil. Shape of the soil particle can influence the packing of the soil, hence altering the mechanical behavior of the soil. The particle size gradation in the soil may also contribute to the strength of the soil. Direct shear test results show that the internal friction angle of soil increases then decreases as the relative density.

5. Results from the direct shear tests indicate that the range of the angle of shearing resistance of the well graded sand is higher than the poor graded sand. The internal friction angle is generally increasing with increasing the median particle diameter and the relative density (Dr), and decreasing with increasing the coefficient of uniformity.

6. When the results of the experiments are examined, it is seen that the strength of the dry sand until it reaches horizontal deformation is increased. It is observed that the shear stress decreases after peaking. Later the soil past in ultimate state. It is seen that the shear strength of the soil increases with the increase of normal stress.

7. As the intergranular void ratio increases, the internal friction angle increases for the same relative densities. Intergranular void ratio decreased with increasing relative density at different relative densities. Accordingly, the internal friction angle is increased.

8. When in the same relative density, porosity increases internal friction angle increases. Porosity decreased as relative density increased. The internal friction angle decreased as the relative density increased. Porosity and internal friction angle increased as intergranular void ratio increased.

9. The relative densities for all types of soils increases, the internal friction angle increases. The highest internal friction angle was obtained for well graded sand. The lowest internal friction angle was obtained for silty sand. The same results were obtained for both ultimate angle and peak angles for all type of soils. The results show that soil classification is the most important parameter to obtain the internal friction angle. In addition, one of the parameters that determine the internal friction angle of soils is grain size distribution. Well graded sands have a higher internal friction angle than poorly graded or incompletely graded sands.

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