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M.Sc. in Civil Engineering

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**UNIVERSITY OF GAZİANTEP**

**GRADUATE SCHOOL OF**

**NATURAL & APPLIED SCIENCES**

# FRICTION CHARACTERISTICS OF ORGANIC SOIL WITH CONSTRUCTION MATERIALS

**M.Sc. THESIS**

**IN**

**CIVIL ENGINEERING**

**BY**

**FEVZİ EVİZ**

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# Friction Characteristics of Organic Soil with Construction Materials

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**in**

**Civil Engineering**

**University of Gaziantep**

**Supervisor**

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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**Fevzi EVİZ**

## ABSTRACT

### FRICTION CHARACTERISTICS OF ORGANIC SOIL WITH CONSTRUCTION MATERIALS

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**January 2016**
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The understanding of the basic phenomena controlling the mobilization of friction at soil-solid surface contact is an important task for traditional foundation structures such as piles, micropiles, anchors, etc. In this study, interface frictional characteristics of organic soil and some of solid construction materials such as concrete, steel, and wood were investigated. Interface friction angles of organic soil-solid surfaces were determined for different water content and granular soil content. In addition, the relationship between surface roughnesses and interface friction was investigated. All tests in this study were performed using a direct shear test device under different normal stresses. The test results showed that water and granular soil content of the organic soil, material type, and surface roughness has an effect on frictional resistance between construction material and organic soil.



**Keywords**: Organic soil, Construction materials, Interface friction angle, Surface roughness.

## ÖZET

## ORGANİK ZEMİNLE YAPI MALZEMELERİ ARASINDAKİ SÜRTÜNME ÖZELLİKLERİ

**EVİZ, Fevzi**
**Yüksek Lisans Tezi, İnşaat Mühendisliği Bölümü**
**Tez Yöneticisi: Doç. Dr. Hanifi ÇANAKÇI**
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**Sayfa 69**

Zemin-yapı elemanları arasında oluşan sürtünmenin değerlendirilmesi yaygın olarak yapılmakta olan kazıklı temeller, ankraj uygulamaları gibi temel mühendisliği alanları için önemi aşikardır. Bu çalışmada, farklı iki kum türü (kırma ve dere kumu) içeren ve farklı su muhtevalarında bulunan organic zeminin bazı yapı malzemeleriyle (beton, pürüzlü-pürüzsüz çelik ve ahşap) arasında ki sürütnme parametreleri incelenmiştir. Bunlara ek olarak, bu malzemelerle organic zemin arasında ki sürtünme parametreleriyle yüzey pürüzlülüğü arasında ilişki değerlendirilmiştir. Bütün deneyler klasik direk kesme test cihazı kullanılarak farklı yüklemeler altında yapılmıştır. Deney sonuçları, organik zemin içersinde ki kum ve su içeriği, malzeme türü ve malzemelerin yüzey pürüzlülük katsayıları organik zemin-yapı malzemesi arasında oluşan sürtünme değerleri üzerinde önemli etkiye sahip olduklarını göstermiştir.



**Anahtar Kelimeler:** Organik zemin, Yapı malzemeleri, Yüzey sürtünme açısı, Yüzey pürüzlülüğü.

**Dedication**

**To**

**My parents**

**Who supported & encouraged me from the beginning of my life up to now**

**All my teacher**

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First, praise be to "ALLAH" who gave me the strength and health to work and think to finish this work.

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# LIST OF SYMBOLS/ABBREVIATIONS

A Cross sectional area of specimen in shear box test

CD Consolidated drained test

$c_u$ Undrained shear strength

$c'$ Cohesion intercept in terms of effective stresses

c Cohesion intercept in terms of total stresses

$D_r$ Relative density

d Diameter

e Overall void ratio of soil

$e_0$ Initial void ratio

$e_{cv}$ Critical void ratio

$e_{max}$ Maximum void ratio

$e_{sk}$ Skeleton void ratio

h Height

$I_p$ Plasticity index

LL Liquid limit

N Normal load

$P_h$ Horizontal load

PI Plasticity index

$P_v$ Vertical load

UU Unconsolidated undrained

u Pore water pressure

$\psi$ Angle of dilation

$\varepsilon_v$ Vertical strain

$\phi$ Friction angle in terms of total stresses

$\phi'$ Friction angle in terms of effective stresses

$\phi'_{max}$ Maximum angle of shearing resistance

$\phi'_{cv}$ Critical angle of shearing resistance

$\phi'_u$ True angle of friction

$\lambda$ Unit weight

$\sigma_f$ Normal stress on failure plane

$\sigma'$ Effective normal stress

$\tau$ Shear stress in shear box test and drained shear strength

$\tau_f$ Shear stress on the failure plane

# CHAPTER 1

# INTRODUCTION

## 1.1General Overview

Organic soil is a mixture of fragmented organic material formed in wetlands under appropriate climatic and topographic conditions, and it is derived from vegetation that has been chemically changed and fossilized (Dhowian and Edil, 1980). This type of soil has low shear strength and high compressive deformation (Anggraini, 2006). Problems with bearing capacity and settlement problems are generally solved by using pile foundations or various improvement methods.

In civil engineering, there are many problems associated with constructionnon soft soil especially peat. Engineers consider peat as an extreme form of soft soil and very problematic. These results in the tendency to either avoid construction and buildings on the soils, to simply remove, replace or displace them. In some instances, the replacement method may lead to uneconomical design and construction.

Engineers defined peat as a very problematic soil that should be avoided where it is possible. Majör construction problems related to structures on soft soils such as peat is due to the low shear strenght and large compressibility with high ground water level. Certain characteristics of peat have set it apart from most mineral soils and require special consideration for construction on the soil. These characteristics include high natural moisture content (up to 1500%) high compressibilty including significant secondary and tertiary compression and also high degree of spatial variability.

The method used to assess the shear strenght of peat is not well defined yet. For a fibrous peat, the shear strength can be determined in laboratory by the direct shear test which is a drained test. Most peat is considered frictional or non-cohesive material due to the fiber content, thus the shear strength of peat is determined based on drained condition.

Organic soil at a construction site is not always completely useful for constructing structures for instance buildings, bridges, highways and dams. In organic soil, there is usually large consolidation settlement depending on depth of layer and structural load. Under these problems, soils needs ground modification such as reducing consolidation and elastic settlement and increasing shear strength of organic soils. If it is possible, the problematic organic soils must be removed and replace with better soil at site. If not possible different modification techniques need to be used such as hydraulic modification, inclusion, chemical modification, compaction, mixing pile foundation. Also, knowledge of the interface friction angle in the determination of the magnitude and line of action of the wall reaction is significant.

Interfaces between soils and structure are commonly seen in civil engineering. Soils are assemblies of small mineral particles with different radius and properties. Many kinds of structural components, such as raft, piles and retaining walls, are made from concrete or steel, which can be treated as solid continuum materials compared with soils. The interfaces between these two types of materials are of unique properties. The organic soils contain generaly lots of voids, which make them easy to undergo large deformation when being loaded (both compression and shear). As a result, the widely accepted and commonly used Coulomb's Friction Model should be checked before applied to problems involving such interfaces. Interfaces between soils and solid structural components exist everywhere. For instance, interfaces between piles and surrounding soil, between raft and ground soil, between retaining wall and soil behind it, and those between dams and neighboring rocks. The mechanical properties of such interfaces mainly include: bonding and slipping behaviors, strength and stiffness properties, the thickness of interfacial shearing layer, the main influential factors such as normal pressure, particle size, shearing velocity, materials types and their effects on the interface behavior. For the many unsolved problems, this paper summarizes and discusses researches on this subject all around the world, including the experiments and numerical simulation efforts, to present some conclusions and references for both researchers and engineers.

Pile foundation used in this type of soil is generally friction piles, where loads are transferred to soil through interface friction between soil and pile material. One of the important parameters for frictional resistance is the friction coefficient between pile material and soil. The majority of the design interface friction values are based on empirical correlation. They are generally related to soil shear strength parameters. In current geotechnical engineering practices, the soil–structure friction values recommended by the Naval Facilities Engineering Command (NAVFAC) Design Manual (DM) 7.02 (US Department of Navy, 1986) has been widely used. NAVFAC DM 7.02 gives interface friction angles between and adhesion values of construction materials and soils such as sand, gravel silt and clay. However, interface friction angle between construction materials and organic soil is not included in the manual.

An extensive series of researches on this topic has already been performed by several authors both in laboratory and in situ (Potyondy, 1961; Coyle and Sulaiman, 1967; Kulhaway and Peterson, 1979; Evgin and Fakharian, 1996; Hryciw and Irsyam, 1993; Uesigi et al., 1988; Hu and Pu, 2004; Canakci et al., 2011; Celik and Canakci, 2014; Nasir and Fall, 2008). Potyondy, (1961) measured the ratio of skin friction and adhesion with soil friction and cohesion, respectively. He performed direct shear tests on the interface of concrete, steel, and wood with sand, sandy silt, cohesive soil, rock flour, and clay. The tests were conducted for certain pre-set moisture contents as well as for dry specimens. The results showed that frictional resistance of a soil depends on the amount of mixed sand it possesses. Coyle and Sulaiman (1967) investigated the frictional resistance between sand and steel pile, whereas Kulhaway and Peterson (1979) measured the frictional resistance between sand and concrete. Several other researchers such as Evgin and Fakharian (1996), Hryciw and Irsyam (1993), Uesigi et al. (1988) and Hu and Pu (2004) conducted direct shear tests on the interface between steel or concrete and sand to measure the interface frictional resistance. As an alternative to the direct shear device, Paikowsky et al. (1995) developed a dual interface apparatus. In addition, Yoshimi and Kishida (1981) developed a ring shear device to measure interface frictional resistance for large deformations.

At early times, the researches on the interface behaviors were focused on the friction resistance between dry sand and mild steel by experiments. Uesugi and Kishida (1986)

did the laboratory experiments on such friction properties and examined the significance of possible influential factors including surface roughness of the steel, 50 percent diameter of sand (mean diameter *D*50), sand types, test type (simple shear and shear box) and uniformity coefficient of sand. It showed that steel roughness, *D*50 of sand and sand type are the most significant factors to influence the interface friction resistance properties. Furthermore, the coefficient of friction can be correlated with the modified roundness of sand particles and the normalized roughness of sand-steel interfaces. Such conclusions were very helpful for us to evaluate the shaft friction and relative displacement between steel piles and surrounding sand soil. And the given curves between friction and shear displacement verified the correctness of the mechanical models presented by dozens of scholars, for instance the "perfectly plastic model".

In order to investigate the failure behavior of granular-continuum interfaces, Frost (2002) focused on two influential factors: roughness and hardness of continuum materials. A series of surface roughness and hardness measurements were conducted ahead of interface shear tests. The continuum materials were geomembranes, hardened steel, fibre-reinforced polymer, woods and rough finished concrete. Quantitative roughness and hardness index were presented for each of the selected material. On the basis of that, a series of interface shear tests were performed with all the continuum materials and two types of sands with different particles shapes: the Ottawa 20-30 sand with sub-rounded particles and the Valdosta blasting sand with angular particles. The tests were done with a direct shear apparatus. Frost pointed out that the friction angle of sand were the upper bound of the interface friction angle, for the shearing failure occurred in the shear zone near the interface even if the continuum material still stick with the granular materials. The test results showed that the peak and residual friction angle increase with the increase of surface roughness and decrease of surface hardness. And the two factors have a significant coupling effect, which means that the friction angle reaches a largest value with a largest surface roughness and a smallest surface hardness.

Hu and Pu (2001) did a series of direct shear tests on soil-structure interface using an improved apparatus with the digital camera to record particle movement at the interface. The sample was medium sand with a *D*50 of 1mm. Two sand samples with different relative density and five steel plates with different roughness were included. A critical

relative roughness $R_{cr}$ (the ratio of surface roughness to the mean diameter of sand particles) was found to be a critical factor for the shear behavior of the interface. When $R_{cr}$ is greater than 0.01, the strain localization occurs at the interface and a shear band in which large relative motions of particles happen forms. The thickness of the shear band was demonstrated to be $5D_{50}$. The shear failure is accompanied by strain softening and strong normal dilatancy. The changing laws of peak and residual friction ratios of rough interfaces were also characterized.

Peng et al. (2010) reported simple shear test on the interface between coarse-grained soil and concrete. Zhu et al. (2011) continued the study by focusing on the comparison of simple shear test and torsional shear test. A series of simple shear tests with different vertical pressure were done. Two different interfaces were considered, one without mud layer between concrete and soil (SC interface), the other with a 1 mm thick mud layer (SMC interface) to simulate some of the real interfaces, such as interfaces between soil and concrete piles. A conclusion was drawn that the simple shear test is more suitable for studying the shear displacement and deformation properties of interface in low stress state, while the torsional shear is suitable for testing the strength of the interface.

The previous studies showed that several factors affect the value of the interface friction angle. These factors are mineralogical composition, density, grain shape, grain size and gradation, as well as the properties of the material surface roughness (Uesugi et al, 1986; Lambe and Whitman, 1979; Yoshimi and Kishida, 1981).

### 1.2 Objectives of the study

A survey of existing literature showed that limited information is available for practicing engineers about interfacial friction between organic soil and some construction materials. In this study, an intensive investigation was carried out to determine interface friction values. For this purpose, concrete, smooth and rough steel, and wood were selected as structural materials. Tests were done at different water contents and different granular soil content in the organic soil. All tests were performed using the direct shear test device.

## 1.3 Organization

In this study focuses on the intensive investigation of determination for interface friction values. For this purpose, concrete, smooth and rough steel, and wood were selected as structural materials:

**Chapter One:** gives a general overview of the study area, the aim of the work and a brief introduction about previous work and the thesis skeleton

**Chapter Two:** presents a literature review that was performed to summarize the previous study about interface friction values between soils and construction materials.

**Chapter Three:** gives detailed information about materials and methods used in this study.

**Chapter Four**: Test results and discussion are given in this chapter.

**Chapter Five**: summary of the conclusions of this study are given.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Previous studies on interface friction between soils and materials

This chapter covers reviewing literature that studied interfacial friction between organic-inorganic soil and some construction materials.

Potyondy (1961) used strain controlled shear box and stress controlled shear box to determine the strength of soil, and the interface friction between construction materials and soils. The strain controlled shear box had an area of shearing of 5.59 sq. inches and the stress controlled shear box had a shearing area of 12.4 sq. inches. The former was used to determine the frictional resistance of saturated soils. Direct shear test machine was used in this test, as illustrated in figure 2.1. The construction materials he used for his tests were steel, wood, and concrete. The steel used was commercial steel; it is commonly used for piles, especially sheet piles so it would be more practical. For wood, pine was the most common type of wood to use and it did not have any unnatural surface. The wood was used in two directions in reference to its grain, at right angle and parallel. For concrete, there were two concrete surfaces used for the tests. The difference between them is the grain size of aggregate. For rough surface, the maximum grain size was 7.5 mm and the maximum grain size was 2.5 mm for fine surface. Soils used were sand, clay, and mix of both to get silty soils. The data published by Potyondy (1961) show the internal friction angle between 39° and 44° for saturated and dry sand, respectively. Dry sand-steel interface friction angle was ranging from 24° to 34° for smooth and rough surfaces and 24° for saturated sand with smooth steel. The interface friction angle between wood and sand is different for wood parallel to grain and wood at right angle to grain. The value of interface friction angle for dry sand under dry conditions were 35° and 39° for wood parallel and right angle to the grain, respectively and 33° and 34° for parallel and right angle under submerged conditions. For dry sand with concrete, the interface friction angles were 39° for smooth surface and 44° for rough surface. For saturated sand, the interface friction angle for smooth surface was 39°. The above data are for normal

stress of 1000 psf. Table 2.1 summarizes the data for the normal stresses of lOOO psf and 3000 psf.

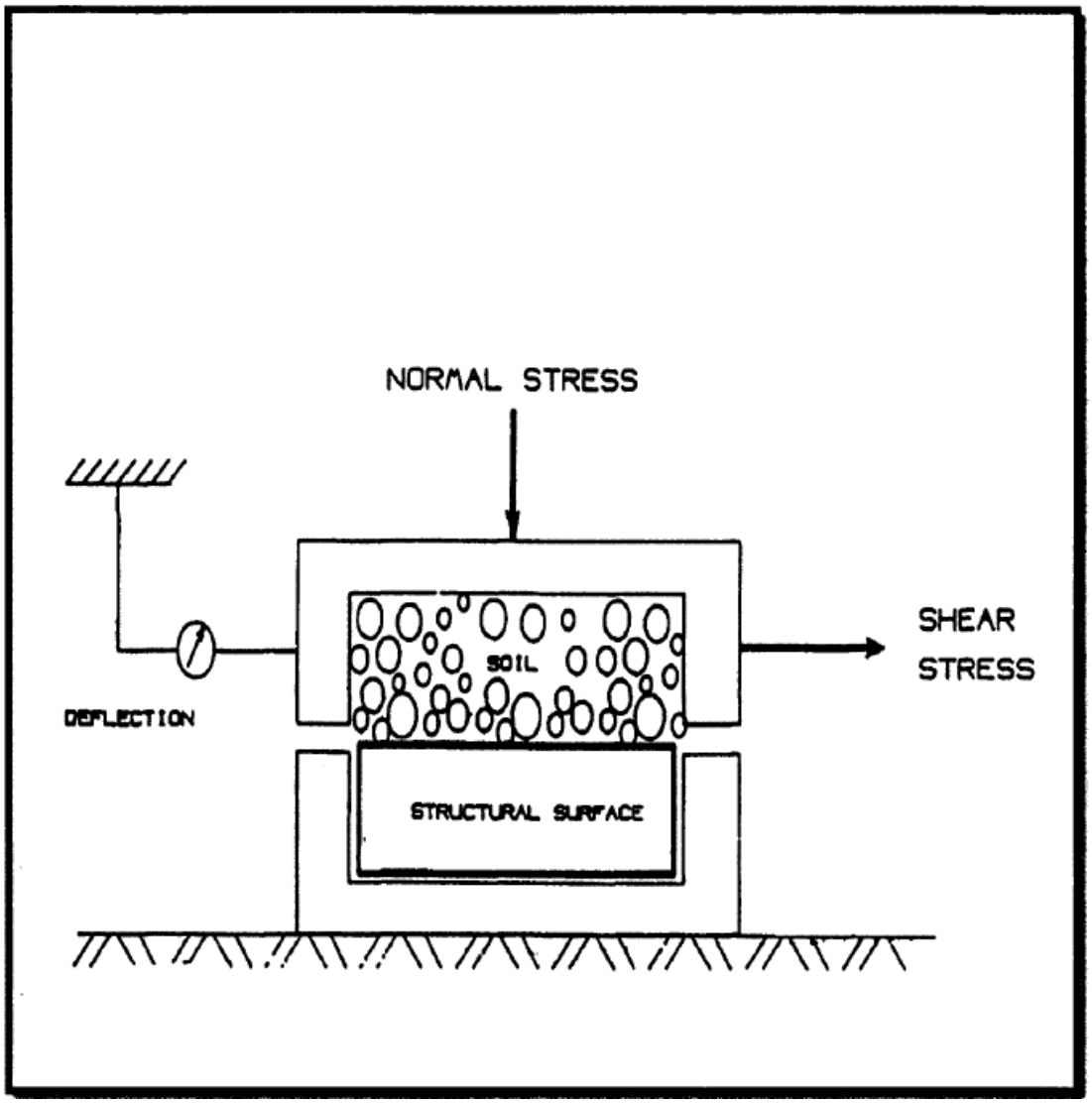


Figure 2.1: Modified direct shear test machine for interface testing (Rinne, 1989)

It can be seen from table 2.1 that the internal friction angle for dry sand increasedfrom 43° to 44° and 37° to 39° for saturated sand respectively when the normal stress decreased from 3000 psf to 1000 psf. The sand used for these tests was dense with void ratio of 0 .66, and moisture content of 0.8%.

Table 2.1: Interface friction angle for sand with different construction materials (Potyondy, 1961)

| Normal stress | 3000 psf | | | | 1000 psf | | | |
|---|---|---|---|---|---|---|---|---|
| Soil | Dry Sand | | Saturated Sand | | Dry Sand | | Saturated Sand | |
| Material | φ | δ | φ | δ | φ | δ | φ | δ |
| Smooth steel | 43 | 24 | 37 | 23 | 44 | 24 | 39 | 24 |
| Rough steel | 43 | 33 | - | - | 44 | 34 | - | - |
| Wood parallel to grain | 43 | 33 | 37 | 33 | 44 | 35 | 39 | 33 |
| Wood at right angle to grain | 43 | 38 | 37 | 34 | 44 | 39 | 39 | 34 |
| Smooth concrete | 43 | 38 | 37 | 33 | 44 | 39 | 39 | 34 |
| Rough concrete | 43 | 42 | - | - | 44 | 44 | - | - |

Gireesha and Muthukkumaran (2011) highlighted the importance of frictional resistance between soil and foundation. The results that they obtained showed that the interface friction angle (**δ**) and internal friction angle (φ) for both well graded sand and poorly graded sand increase with increasing value of relative density. They calculated the ratio of **δ**/φ for all the three materials (wood, steel and concrete) and found that the concrete gives higher value for the interface friction angle among the three materials. The friction angles of all three materials change with different gradation significantly. The study showed that the friction angle can be affected by the roughness of the material, type of sand and relative density. The maximum and minimum relative densities of the soil and a 50% relative density of soil were prepared for comparison. The study was conducted by using Direct Shear Machine. The bottom part of the shear box was filled with different construction materials (wood, steel and concrete) and the top part of the box was filled with soil. The soils used were well graded and poorly graded sand with different relative densities. Table 2.2 shows the variation of **δ** for well graded and poorly graded sand with wood, steel and concrete respectively and also different relative densities.

$$Dr\% = \frac{e_{max} - e}{e_{max} - e_{min}} \quad (2.1)$$

Where: $e_{max}$= maximum void ratio

$e_{min}$= minimum void ratio

e = minimum void ratio

Table 2.2: Internal and Interface Friction Angles for SW and SP with the material Wood, Steel, and Concrete (Gireesh and Muthukkumaran, 2011)

| Material | Dr | Well graded sand | | | Poorly graded sand | | |
|---|---|---|---|---|---|---|---|
| | | φ | δ | φ/ δ | φ | δ | φ/ δ |
| Wood | Min | 36,6 | 26,7 | 0,72 | 33 | 25,4 | 0,76 |
| | 50% | 38,2 | 29 | 0,75 | 34,8 | 27 | 0,77 |
| | Max | 40,1 | 30,7 | 0,76 | 36,1 | 28,4 | 0,78 |
| Steel | Min | 36,6 | 27,5 | 0,75 | 33 | 25,6 | 0,77 |
| | 50% | 38,2 | 29,6 | 0,77 | 34,8 | 27,2 | 0,78 |
| | Max | 40,1 | 31,5 | 0,78 | 36,1 | 28,7 | 0,79 |
| Concrete | Min | 36,6 | 28,1 | 0,76 | 33 | 25,9 | 0,78 |
| | 50% | 38,2 | 30 | 0,78 | 34,8 | 27,5 | 0,79 |
| | Max | 40,1 | 32,1 | 0,8 | 36,1 | 28,8 | 0,79 |

Ampera and Aydogmus (2005) said that there is no possibility to have skin resistance higher than the shearing strength of soil and they showed the importance of finding ratio between soil strength and skin resistance. The stress-strain curves could be predicted just from the experimental results because the development of skin friction depends on displacement. The experimental stress-strain relation for granular soil was expressed in a mathematical formula by Kezdi (1959) and it is used to calculate the vertical and lateral earth pressure and resistance of piles. The exponential function of displacement of stress-strain curve, in the case of skin friction, was shown as below:

$$\frac{\tau}{\sigma} = tan\delta[1 - \exp\left[-\mathrm{k}\frac{S}{S_o - S}\right]] \qquad (2.2)$$

Where:

$\tau$=shearing stress which produces a displacement of "s"

$\sigma$=normal stress

δ=angle of skin friction

S=displacement

$S_o$=maximum displacement at failure
k=constant for the soil.

To determine the strength of soil and interface friction between soil and construction material, Ampera and Aydogmus (2005) used strain controlled shear box (40 $cm^2$) for their investigation. For measuring the horizontal displacement, a dial gauge was fixed on the base plate. The soil was placed on the top part of the box and the lower portion was filled with a construction material. It is found, during the investigations, that different construction materials have different moisture contents of the contact surface. Wood and concrete specimens were saturated for two days in water to avoid moisture absorption by construction materials and the surfaces were dried just before testing. The average moisture content of construction materials were ranging between 41% for wood and 3% for concrete. The moisture content between steel and soil was higher than the moisture of the soil itself. The increment was 2-3% in case of rough steel and 4.5- 5.5% in case of smooth steel. For wood, the increment of moisture was 0-1.5% if the wood is parallel to the grain and there was no increment for wood at right angle to the grain. The moisture content reduced for the contact surface between concrete and soil by 5-8% for rough surface and 7-10% for smooth surface. A 2 mm thick slice was taken from the soil to determine the moisture content between soil and construction material. The saturated silt was used in this investigation. The rate of shearing using strain controlled box was 0.3 mm/min. The ratio of interface friction angle to the internal friction angle was 0.876 for right angle to wood grain and 0.785 when shearing parallel to the wood grain. The values of $\delta$ and $\varphi$ increase slightly as the normal stress increases; normal stresses used for this investigation were 12.5, 25, and 50 $kN/m^2$. The interface friction angle of steel-soil was increased from 29° to 30° when the normal stress increased from 12.5 kPa to 50 kPa with the same ratio of interface friction angle to internal friction angle for different normal stresses. A shearing rate of 0.3 mm/min was used for this test. The interface/internal friction angle ratio was 0.977 for rough steel and 0.746 for smooth steel. For concrete, skin resistance for rough surface was higher than that with smooth surface. The values of interface/internal friction angle were 0.994 for rough concrete and 0.849 for smooth concrete. Table 2.3 shows the detailed values of internal and interface friction angle for silt and the three construction materials.

Table 2.3: Values of internal and interface friction angle for silt material (Ampera and Aydogmus 2005)

| Material | σ (kPa) | c (kPa) | δ or φ (degree) | tanδ/ tanφ |
|---|---|---|---|---|
| Silt-Silt | 12,5 | 214 | 23 | 0.742 |
| | 25 | 208 | 23 | 0.729 |
| | 50 | 158 | 24 | 0.827 |
| Smooth Steel | 12,5 | 152 | 22 | 0.714 |
| | 25 | 154 | 21 | 0.677 |
| | 50 | 161 | 22 | 0.749 |
| Rough Steel | 12,5 | 173 | 30 | 0.98 |
| | 25 | 158 | 28 | 0.93 |
| | 50 | 149 | 29 | 1.008 |
| Wood parallel to grain | 12,5 | 204 | 22 | 0.689 |
| | 25 | 212 | 23 | 0.715 |
| | 50 | 186 | 25 | 0.861 |
| Wood at right angle to grain | 12,5 | 173 | 26 | 0.828 |
| | 25 | 212 | 28 | 0.896 |
| | 50 | 186 | 25 | 0.842 |
| Smooth Concrete | 12,5 | 224 | 22 | 0.707 |
| | 25 | 230 | 27 | 0.884 |
| | 50 | 199 | 26 | 0.888 |
| Rough Concrete | 12,5 | 200 | 29 | 0.976 |
| | 25 | 221 | 30 | 0.972 |
| | 50 | 205 | 30 | 1.029 |

Laskar and Dey (2011) have done a study to evaluate the deformation of the interface between steel and sand under shearing stress. A large direct shear test was performed. A CBR apparatus was used as a direct shear machine. Perspex glass was used to make the shear box of dimensions 20 cm X 20 cm and 10 cm high. The bottom portion of the box was filled with standard Ennore sand with relative density of 85% using sand Rainer. Over the sand, a steel plate was placed and a normal stress was applied on the steel plate. For this study, a maximum displacement of 5mm was obtained with constant shearing rate. This study was done to predict the stress-strain properties and the movement of soil particles in contact with construction material. The physical

properties of the sand used for this study are presented in table 2.4. The sand was placed in thin strips at L/4, L/2, and 3L/4 of the box; L is the length of the shear box in the shearing direction. As presented in figure 2.3, the movement of grain particles is not uniform throughout the steel plate. They highlighted that the ordinate is not the absolute particles before and after shearing at the interface and it is just a reference scale. It is also not the level of the soil surface. It could be clearly seen that the grain particle displacement is too small and it lies between (0 to 0.5 mm) at the edges of the shear box where (b/B=0) and (b/B=l). In contrast, the maximum grain displacement was observed at the center of the shear box at (b/B=0.4) to (b/B=0.6). A test performed to evaluate the stress-strain relationship by using (60mm X 60mm and 30mm high) direct shear box. Different surface roughnesses were used for a constant normal stress. The roughness was expresses as a roughness factor which is defined as the ratio of the steel surface roughness to the mean diameter of grain size $D_{50}$. Figure 2.2 shows the details relationship of stress-strain for a constant normal load with different roughness factors.

Table 2.4: Physical properties of sand (Laskar and Dey, 2011)

| Sand properties | Value |
|---|---|
| Particle diameter, $D_{50}$ (mm) | 0.5 |
| Maximum void ratio, $e_{max}$ | 0.88 |
| Minimum void ratio, $e_{min}$ | 0.62 |
| Relative density, Dr | 0.85 |
| Specific gravity,Gs | 2.65 |

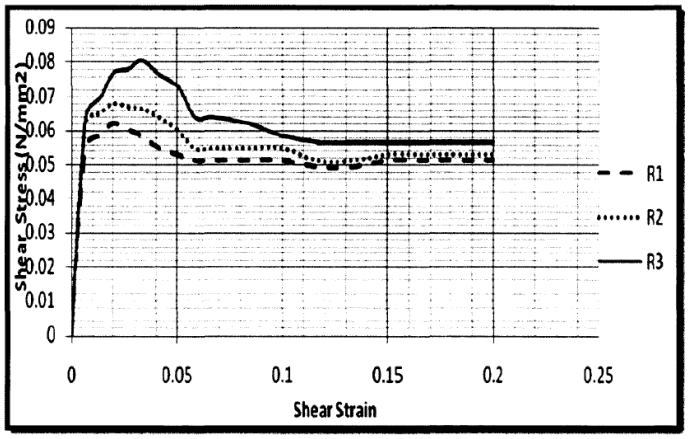


Figure 2.2: Stress-strain relationship at the interface for different surface roughness (Laskar and Dey 2011)

Where R1, R2, and R3 are the roughness factors for the material and they have values of 0.1, 0.2, and 0.3, respectively.

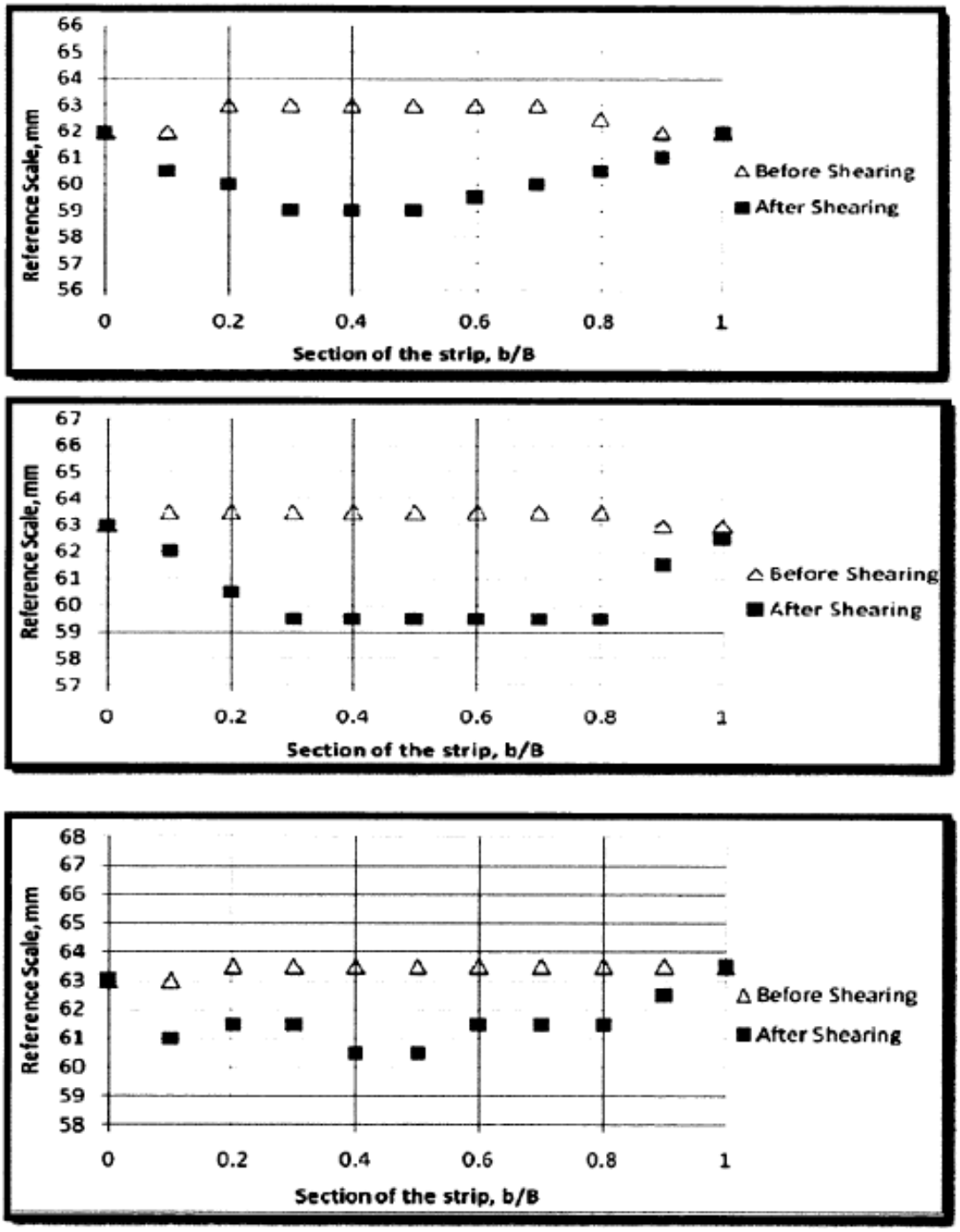


Figure 2.3: Grain movement at the interface after shearing at L/4, L/2 and 3L/4 of the shear box (Laskar and Dey 2011)

Al-Mhaidib (2006) conducted a direct shear test to evaluate the effect of shearing rate on the skin friction between steel and cohesionless soil. The box dimensions used for this study were 100mm x 100mm. The unit weight of the sand was 16.5 kN/m$^3$ and the

relative density was 64%. The shearing rates used to shear the specimens were 0.9 mm/min, 0.4 mm/min, 0.08 mm/min, 0.048 mm/min, and 0.0048 mm/min and the normal stresses were 50 kPa, 100 kPa, and 150 kPa for all tests. When the shearing rate increases, the maximum shear stress increases both for smooth and rough steel. Figure 2.4 shows the relationship between shear stress and normal stress for different shearing rate.

Al-Mhaidib (2006) estimated an approximate equation between the interface friction angle and the shearing rate, assuming that the relationship between them is straight line as below:

$$\delta_S = 1.34\ \mathrm{Ln}(SR) + 23.0 \quad (2.3)$$

$$\delta_T = 1.44\ \mathrm{Ln}(SR) + 43.80 \quad (2.4)$$

Where

$\delta_S$ = interface friction angle between sand and smooth steel in degrees

$\delta_T$ = interface friction angle between sand and rough steel in degrees

SR = shearing rate in mm/min.

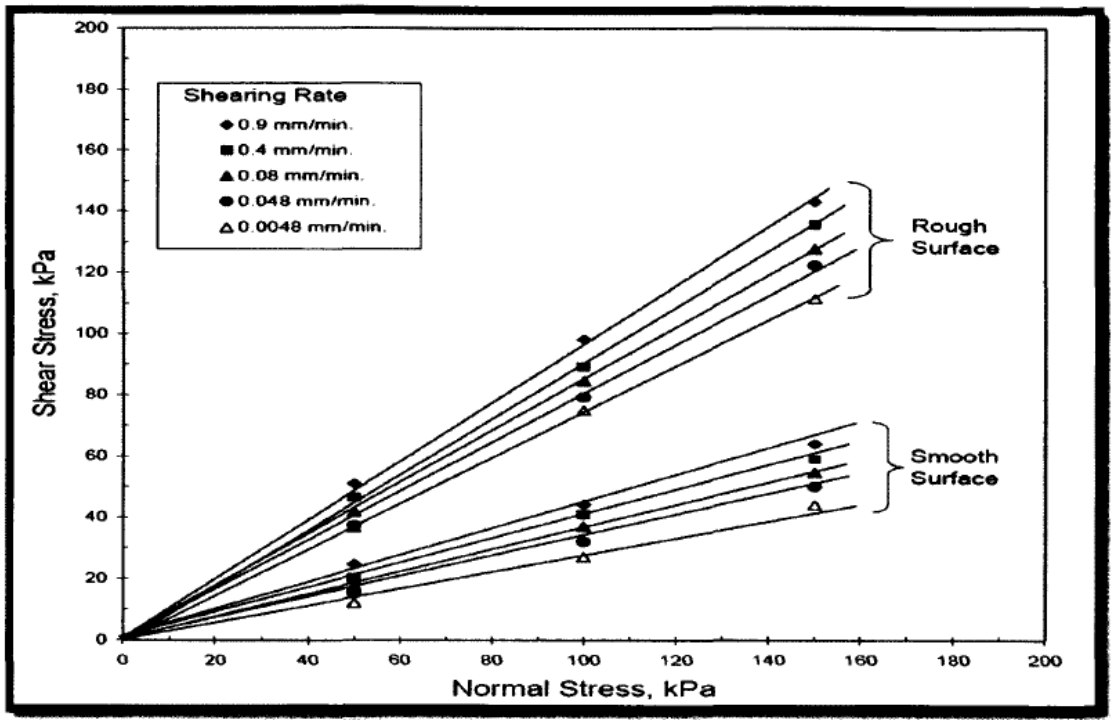


Figure 2.4: Failure Envelopes for Sand and Smooth and Rough Steel Surfaces (Al-Mhaidib 2006)

It is found that the smooth and rough steel surfaces were affected equally by the shearing rate and have same slope for the straight line which is equal to around 1.4 as shown in figure 2.5.

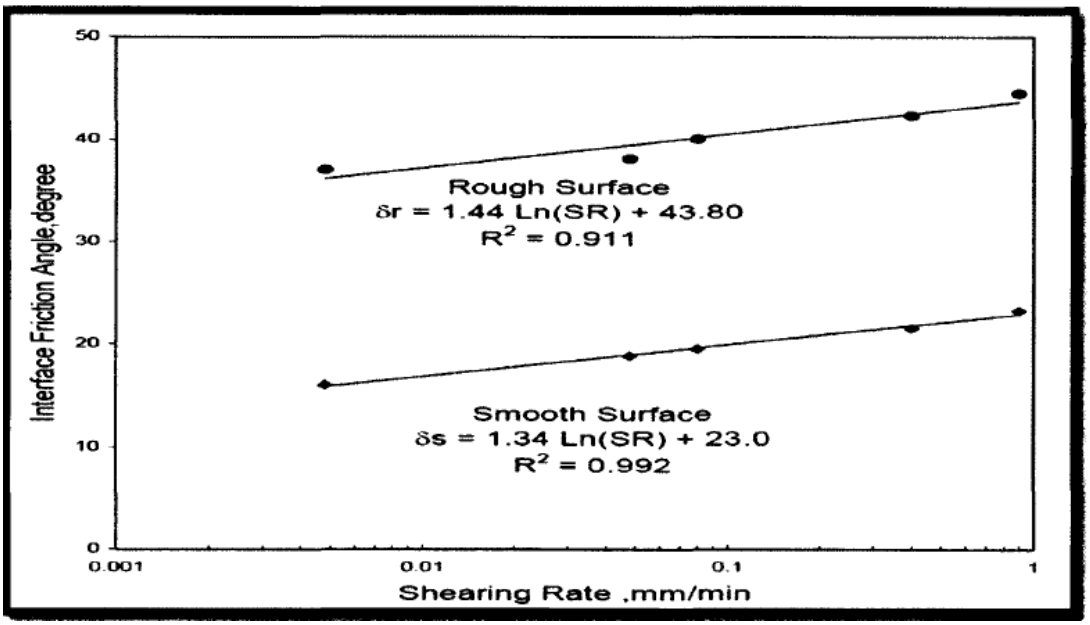


Figure 2.5: Effect of Shearing Rate on Interface Friction Angles between Sand and Steel (Al-Mhaidib 2006)

Tiwari et. al (2010) have done a more systematic study to evaluate the interface friction angle between different construction materials and different type of soils classified with USCS system with constant void ratio (e=0.7) for all soils to compare the results among them. The construction materials used for this study were wood, steel, and concrete plates with the dimensions of 100 mm length, 100 mm width, and 6.25 mm in thickness. The soils used for this study were 1-well graded sand (SW), 2-poorly graded sand (SP), 3-silty sand (SM), 3- poorly graded sand with silt (SP-SM), 5- elastic silt (MH), 6- silt (ML), and 7-lean clay (CL). Four different normal stresses were used for each test 50 kPa, lOO kPa, 150 kPa, and 200 kPa. All tests showed that the interface friction angle for soil-concrete is always higher than those for soil-steel and soil-wood. That can be as a result of rough surface for concrete compared to wood and steel. Figure 2.6 shows the shear envelope for the interface between poorly graded sand (SP) and different construction materials; all other tests had the same trend.

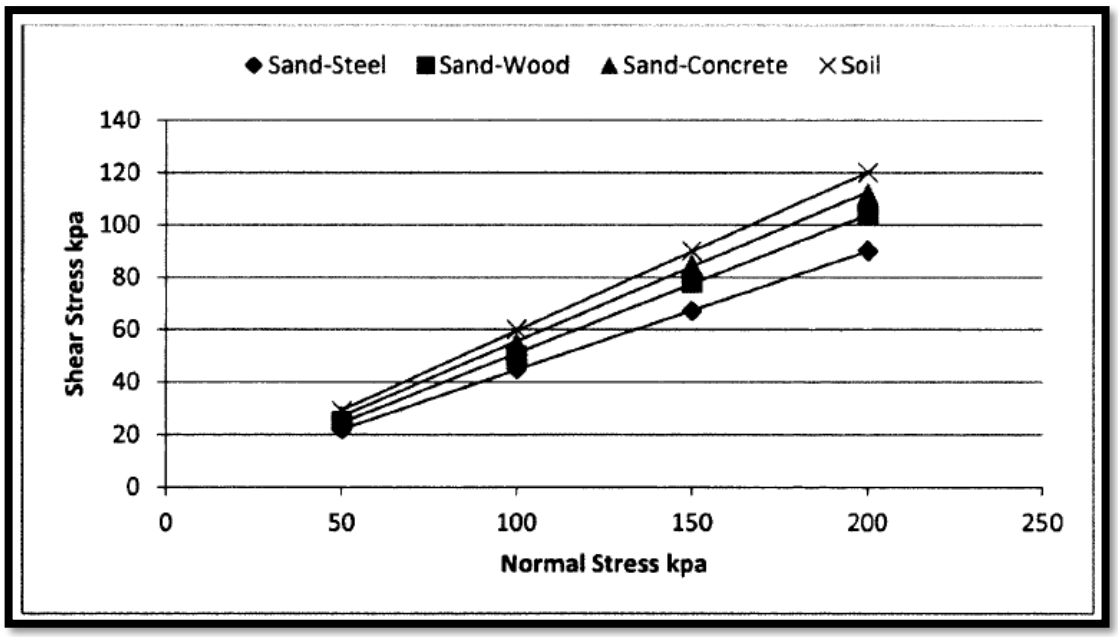


Figure 2.6: Shear envelope obtained for the interface between SP material and different blocks of construction materials (Tiwari et. al 2010)

## 2.2 Organic soils (Peats)

### 2.2.1 Definition

Peat soil is defined as a mixture of fragmented organic material formed in wetlands under appropriate topographic and climatic conditions and it is come from vegetation that was chemically decomposed and fossilized (Edil and Dhowian, 1980). Peat is totally or partially changed remains of dead plants which were accumulated under water for houndred to thousands of year. Peat can be generally seen in thick layers in limited areas, has high compressive deformation and low shear strength which often cause some difficulties when construction work is doing on the deposit (Anggraini,2006).

Peat has high organic content that would exceed 75 %. The organic contents of peat are basically the plant remains for which rate of decay is slower than the rate of accumulation. The content of peat soil differs from location to location due to the factor such as humidity, temperature and the origin of fiber. Decomposition involves

the loss of organic matter either in solution or in gas, the vanishing of physical structure and the change in chemical state (Huat, 2004).

Peat is usually found as an extremely loose, wet, unconsolidated surface deposit which forms as an integral part of a wetland system, therefore access to the peat deposit is usually very difficult as the water table exists at, near, or above the ground surface. The peat deposit is generally found in thick layers on limited areas.

Edil and Dhowian, 1979; Edil and Dhowian, 1981) have found that the behavior of amorphous peat is similar to clay soil, thus evaluation of its compressibility characteristics can be made based on Terzaghi one-dimensional theory of consolidation. Fibrous peat is the one that consists of fiber content more than 20 % (ASTM D4427). The behavior of fibrous peat is very different from clay due to the existence of the fiber in the soil. The fibrous peat has many void spaces existing between the solid grains. Due to the irregular shape of individual particles, fibrous peat deposits are porous and the soil is considered as a permeable material. Therefore the rate of consolidation of fibrous peat is high but the rate decreases significantly due to consolidation.

### 2.2.2 Physical and Chemical Characteristic

Variability of peat is extreme both horizontally and vertically. The variability results in a wide range of physical properties such as texture, color, water content, density, and specific gravity. The results of previous researches on the physical properties of peat around the world are presented in table 2.5.

Fibrous peat generally has very high natural moisture content to absorbe more water keeping capacity. Soil content, defined by organic coarse particles, holds a very huge amount amount of water because the coarse particles are generally very loose, and the organic particle includes largely full of water and hollow. Unit weight of peat is lower than inorganic soils. The unit weight of water is about equal to or slightly lower to compared to the average unit weight of fibrous peat. Sharp reduction of unit weigh was defined with respect to increasing of water content.

Table 2.5: Physical properties of peat based on location (Huat, 2004)

| Soil deposits | Natural water content ($\omega_o$, %) | Unit weight $\gamma$ (kN/m$^3$) | Specific gravity ($G_s$) | Organic content (%) |
|---|---|---|---|---|
| Fibrous peat Quebec | 370-450 | 8.7-10.4 | - | - |
| Fibrous peat, Antoniny Poland | 310-450 | 10.5-11.1 | - | 65-85 |
| Fibrous peat, Co. Offaly Ireland | 865-1400 | 10.2-11.3 | - | 98-99 |
| Amorphous peat, Cork, Ireland | 450 | 10.2 | - | 80 |
| Cranberry bog peat, Massachusetts | 759-946 | 10.1-10.4 | - | 60-77 |
| Peat Austria | 200-800 | 9.8-13.0 | - | - |
| Peat Japan | 334-1320 | - | - | 20-98 |
| Peat Italy | 200-300 | 10.2-14.3 | - | 70-80 |
| Peat America | 178-600 | - | - | - |
| Peat Canada | 223-1040 | - | - | 17-80 |
| Peat Hokkaido | 115-1150 | 9.5-11.2 | - | 20-98 |
| Peat West Malaysia | 200-700 | 8.3-11.5 | 1.38-1.70 | 65-97 |
| Peat East Malaysia | 200-2207 | 8.0-12.0 | - | 76-98 |
| Peat Central Kalimantan | 467-1224 | 8.0-14.0 | 1.50-1.77 | 41-99 |

The percentage and composition of the organic content is an important parameter for specific gravity of peat .When an organic content is greater than 75 %, the specific gravity of peat ranges between 1.3 and 1.8 with an average of 1.5 (Davis, 1997). Because of the lower specific gravity low mineral content and low degree of

decomposition occurs. The inorganic soils is generally lower than that of natural void ratio of peat because of their higher capacity for compression. The range of natural void ratio is changing as 5 – 15 respectively and a value as high as 25 was reported for fibrous peat (Hanrahan, 1954).

In general, peat soils are so acidic with low pH values, often ranges between 4 and 7 (Lea, 1956). Chemically, peat contains small amount of nitrogen, oxygen, hydrogen and carbon. Previous researches (Soper and Obson, 1922; Chynoweth, 1983; Schelkoph et al., 1983; Cameron et al., 1989) showed that the percentage of small amount of nitrogen, hydrogen, and oxygen are in the ranges of 40-60 %, 20-40 %, 4-6 %, and 0-5 % respectively.

### 2.2.3 Classification of peats

The geotechnical characteristic, physical, and chemical used for classification of inorganic soil may not be suitable to the defining of peat. On the other side, properties which are not relevant to inorganic soil may be important for classification of peat. Moreover, the ranges of values applied for some properties of inorganic soil may not be relevant for peat soil. Generally, the classification of peat soil is developed based on the decomposition of fiber, the vegetation forming the fiber content, and organic content.

Von Post (1922) proposed the classification of peat based on the degree of decomposition in which the degree of decomposition is ranged into $H_1$ to $H_{10}$ : when the number increase, the degree of decomposition increae also (Table 2.6).

Organic content is the most common used classification system in geotechnics (Table 2.7). Ash content is defined as the percentage of ash to the weight of dried peat. In addition, the peat is classified according to fiber content because the consolidation process of fibrous peat from that of organic soil or amorphous peat can be changed by presence of fiber. If fiber content is less than % 20 in any organic soil, this soil is called as amorphous peat (ASTM D4427). It includes mostly particles of colloidal size (less than 2 microns), and it absorbe the pore water around the particle surface. There are some similarities between the behavior of amorphous granular peat and clay

soil. If fiber content is more than % 20 this soil is called as fibrous peat (ASTM D4427).

Table 2.6: Classification peat soil from von Post (Huat, 2004)

| Condition of peat before squeezing | | | | Condition of peat on sequeezing | | |
|---|---|---|---|---|---|---|
| **Degree of Humification** | **Soil color** | **Degree of decomposition** | **Plant structure** | **Squeezed solution** | **Material extruded (passing between fingers)** | **Nature of Residue** |
| $H_1$ | White or yellow | None | Easily identified | Clear, colorless water | Nothing | Not pasty |
| $H_2$ | Very pale brown | Insignificant | Easily identified | Yellowish water/pale brown-yellow | Nothing | Not pasty |
| $H_3$ | Pale brown | Very slight | Still identified | Dark brown, muddy water not peat | Nothing | Not pasty |
| $H_4$ | Pale brown | Slight | Not easily identified | Very dark brown muddy water | Some peat | Some what pasty |
| $H_5$ | Brown | Moderate | Recognizable but vague | Very dark brown muddy water | Some peat | Strongly pasty |
| $H_6$ | Brown | Moderately strong | Indistinct (more distinct after squeezing) | Very dark brown muddy water | About one-third of peat squeezed out | Very strongly pasty |
| $H_7$ | Dark brown | Strong | Faintly recognizable | Very dark brown muddy water | About one-half of peat squeezed out | Very strongly pasty |
| $H_8$ | Dark brown | Very strong | Very indistinct | Very dark brown pasty water | About two-third squeezed out | Very strongly pasty |
| $H_9$ | Very dark brown | Nearly complete | Almost recognizable | Very dark brown muddy water | Nearly all the peat squeezed out as fairly uniform paste | Very strongly pasty |
| $H_{10}$ | Black | Complete | Not discernible | Very dark brown muddy paste | All the peat passes between the fingers; no free water visible | N/A |

Table 2.7: Classification of peat based on organic and fiber content

| Classification peat soil based on ASTM standards | |
|---|---|
| Fiber Content (ASTM D1997) | Fibric : Peat with greater than 67 % fibers |
| | Hemic : Peat with between 33 % and 67 % fibers |
| | Sapric : Peat with less than 33 % fibers |
| Ash Content (ASTM D2974) | Low Ash : Peat with less than 5 % ash |
| | Medium Ash : Peat with between 5% and 15 % ash |
| | High Ash : Peat with more than 15 % ash |
| Acidity (ASTM D2976) | Highly Acidic : Peat with a pH less than 4.5 |
| | Moderately Acidic : Peat with a pH between 4.5 and 5.5 |
| | Moderately Acidic : Peat with a pH between 4.5 and 5.5 |
| | Slighly Acidic : Peat with a pH greater than 5.5 and less than 7 |
| | Basic : Peat with a pH equal or greater than 7 |

### 2.2.4 Shear Strength Properties of Peats

Direct shear test is directed in according to ASTM D3080. Direct shear test is common for estimating the shear strength of soil with respect to friction. In a direct shear test, the prepared soil is put in a divided shear box and subjected to failure by making motion upper part of the container relative to lower. Schematic diagram of direct shear test is shown in figure. 2.7.

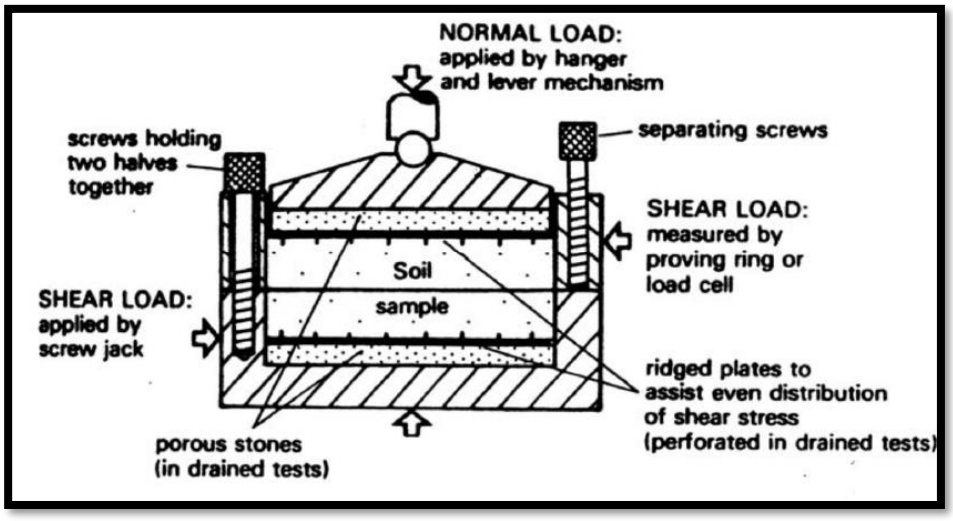


Figure 2.7: Direct shear apparatus (Whitlow, 2001)

A vertical normal force (N) is enforce to prepared specimen through a loading plate and shear stress is gradually occured on horizontal friction plane by causing the two divided shear box to move relative to each other. The shear displacement (Δl) being measured together with respect to shear force (T). Additionally the change in thickness (Δh) of the specimen could be measured. Minimum 3 number of specimens of the soil are tested under different normal forces, and the value of shear stress at failure is plotted against the normal stress for each test. Therefore it is easy to obtain the shear strength parameters from the best line fitting the plotted points.

The shear strength of peat is generally so low and the estimation of shear strength is always connected to the problems because of several variables such as degree of humification ,the origin of soil, organic content and water content. In addition, sample disturbance has an important great effect on the evaluation of shear strength of peat.

Some researches showed that shear strength properties of several types of peat with respect to laboratory applications and it was clearly seen that the behavior of the shear strength properties of peats is basically frictional, with high internal friction angles and usually low cohesion intercepts (Adam, 1965; Edil and Dhowian, 1981).

Edil and Dhowian (1981) also discussed that the friction of peat soil mostly depends on the fiber and the fiber is not always solid because it usually contains water and gas. Therefore , the high friction angle does not actually show the high shear strength of the soil. The higher angle of friction is generally seen in the more fibrous peat. According to Edil (2003), the existence of fiber always has an effect on the shear strength behavior of peat. The fiber cause to the shear strength since it is seen as reinforcement. The effect of reinforcement depends on the loading direction in relation to main fiber direction. In this condition where peat is loaded by the shear force, friction can develop among adjacent fibers and between the fill material and the fibers. When the load direction is placed on the same direction as the fibers, there is an effect of reinforcement on shear strength of peat. Water content that is parameter has an inportant effect on shear strength of organic soils. As it is seen in figure 2.8 cohesion of the organic soil has the highest value in dry condition. Then, while water content is increasing gradually chesion decreases. According to the figure 2.8 water content changing decrease the cohesion of the peat soils.

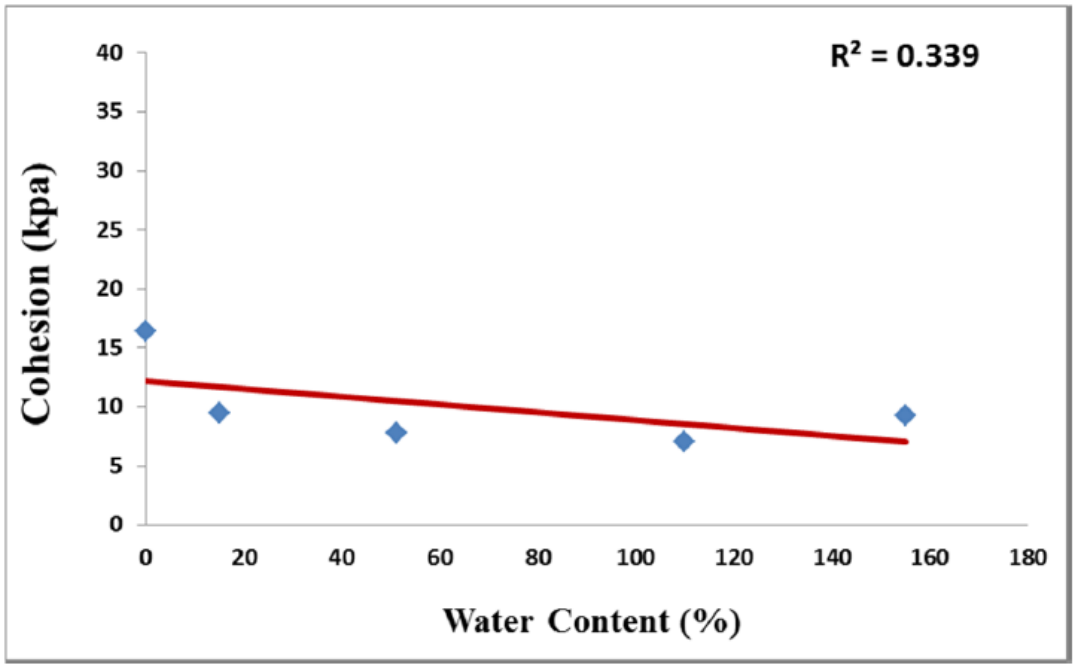


Figure 2.8: Water content – Cohesion Relation in Constant Density (Çelik and Çanakçı, 2010)

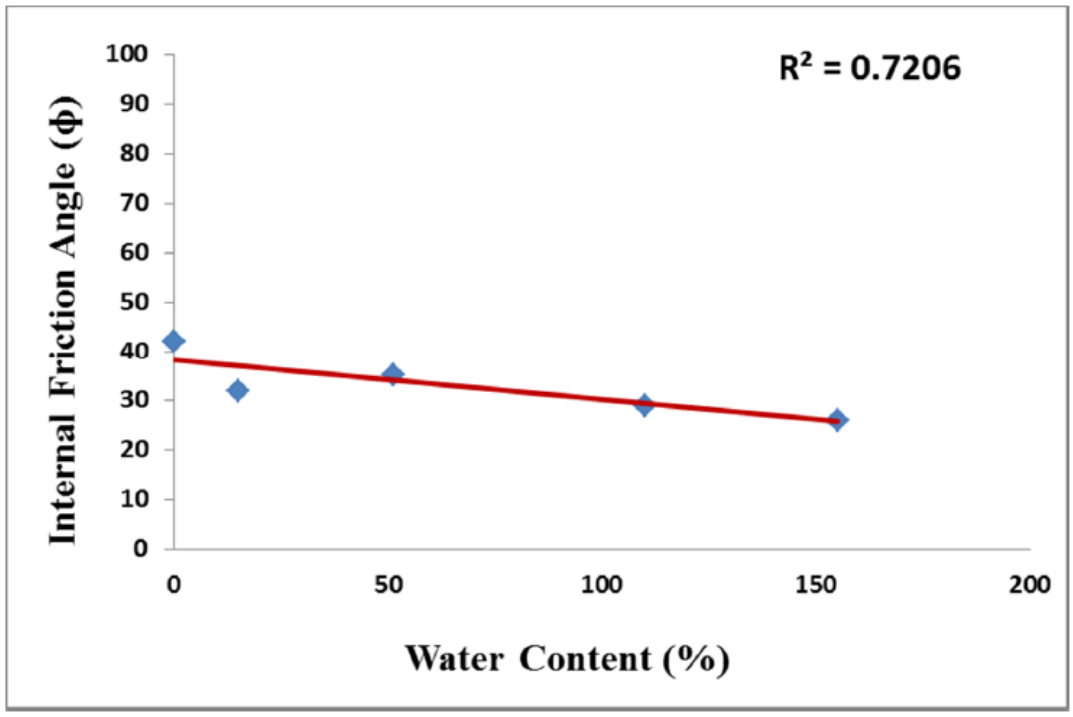


Figure 2.9: Water content – Internal Friction Angle Relation in Constant Density (Çelik and Çanakçı, 2010)

Also water content has an important effect on internal friction angle of organic soils. As it is seen in figure 2.9 increasing of water content decreases the internal friction angle of the organic soil gradually. Therefore, it can be said that water content increasing will decrease the shear strength of the organic soil.

Sand content that is an important parameter has an important effect on the cohesion of the organic soils. As it is seen in figüre 2.10 sand content increasing of the organic soil decrease the cohesion of the soil regularly. In addition, sand content also affect the internal friction angle of the organic soils.As it is shown in figüre 2.11 when sand content of the organic soil increase internal friction angle of the organic soil increase also. According to these results it can be said that sand content increasing has an important effect on the shear strength of the organic soils.

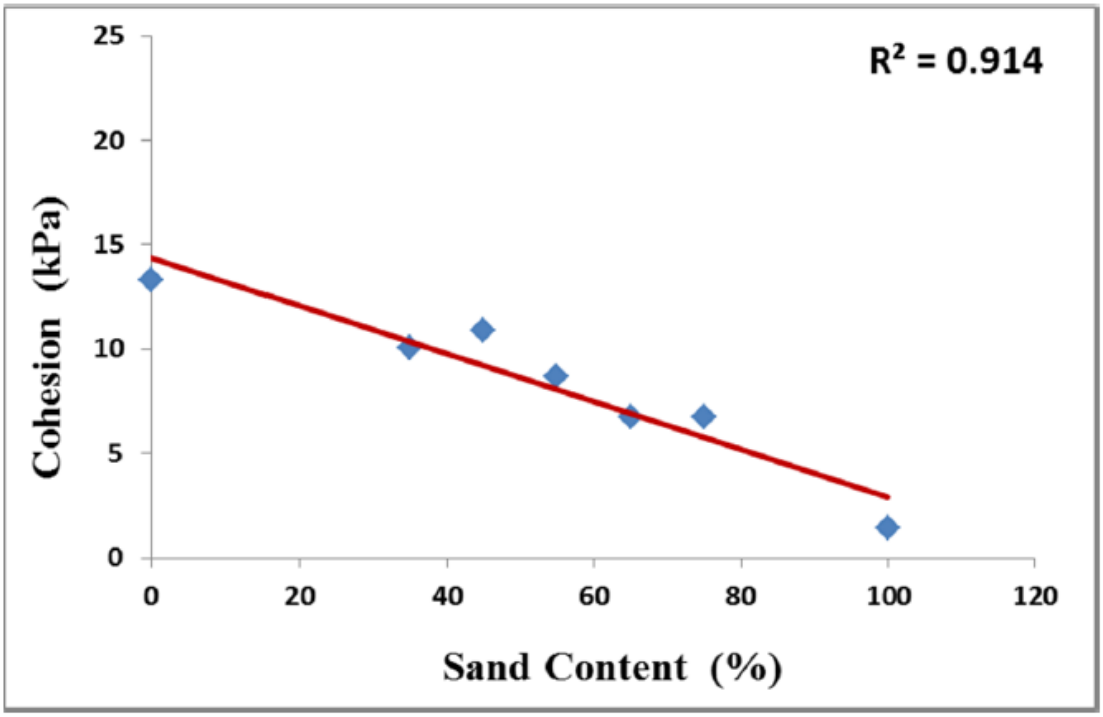


Figure 2.10: Sand Content – Internal Friction Angle Relation in Constant Density (Çelik and Çanakçı, 2010)

Density that is an important parameter for the organic soils has an important effect on the cohesion. As it is seen in figüre 2.12 density of the organic soil increasing rise up to cohesion of the organic soil regularly. There is a strong positive linear correlation

between these parameters. Also increasing of the density of the organic soil increase the internal friction angle of the organic soil as it is shown in figüre 2.13. There is a strong positive linear correlation between these parameters also. According to these results it can be said that increasing of the density of the organic soil will increase the shear strength of the organic soil.

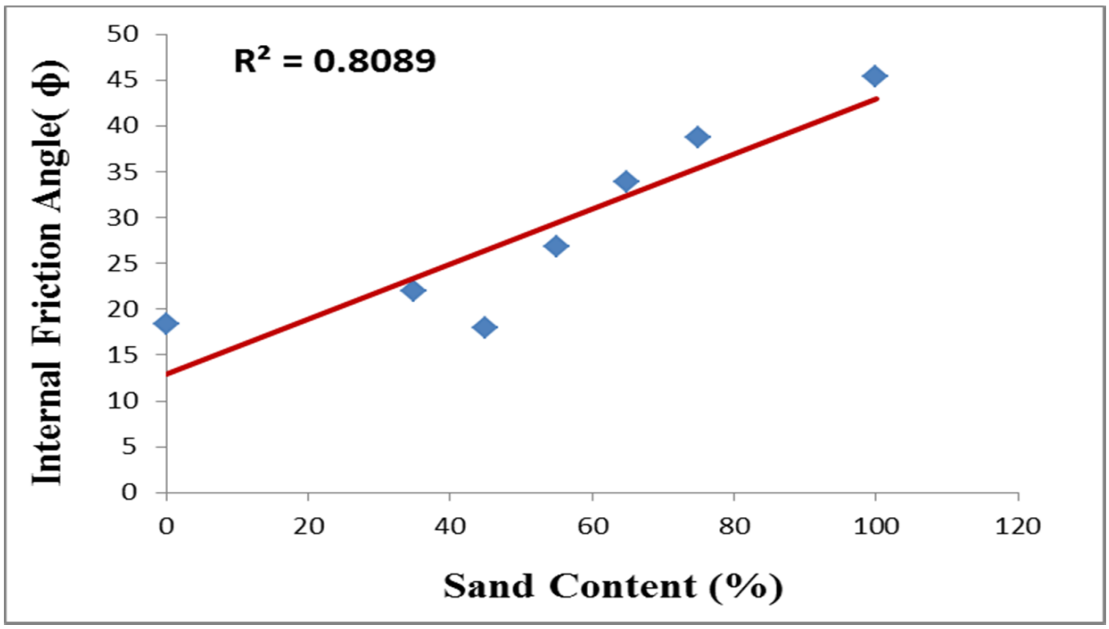


Figure 2.11: Sand Content – Internal Friction Angle Relation in Constant Density (Çelik and Çanakçı, 2010)

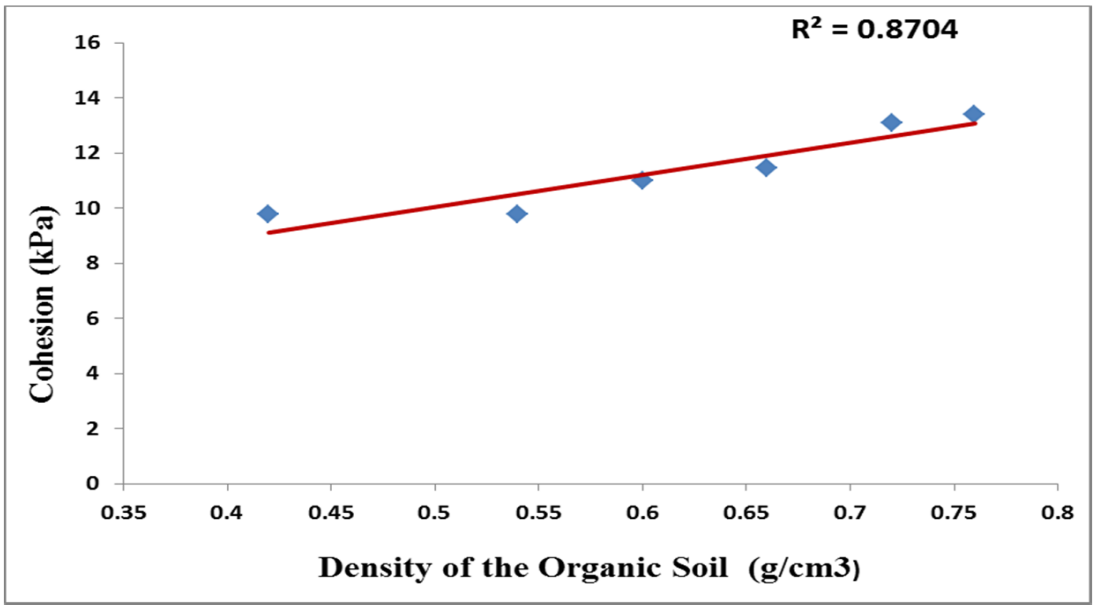


Figure 2.12: Sand Content – Internal Friction Angle Relation in Constant Density (Çelik and Çanakçı, 2010)

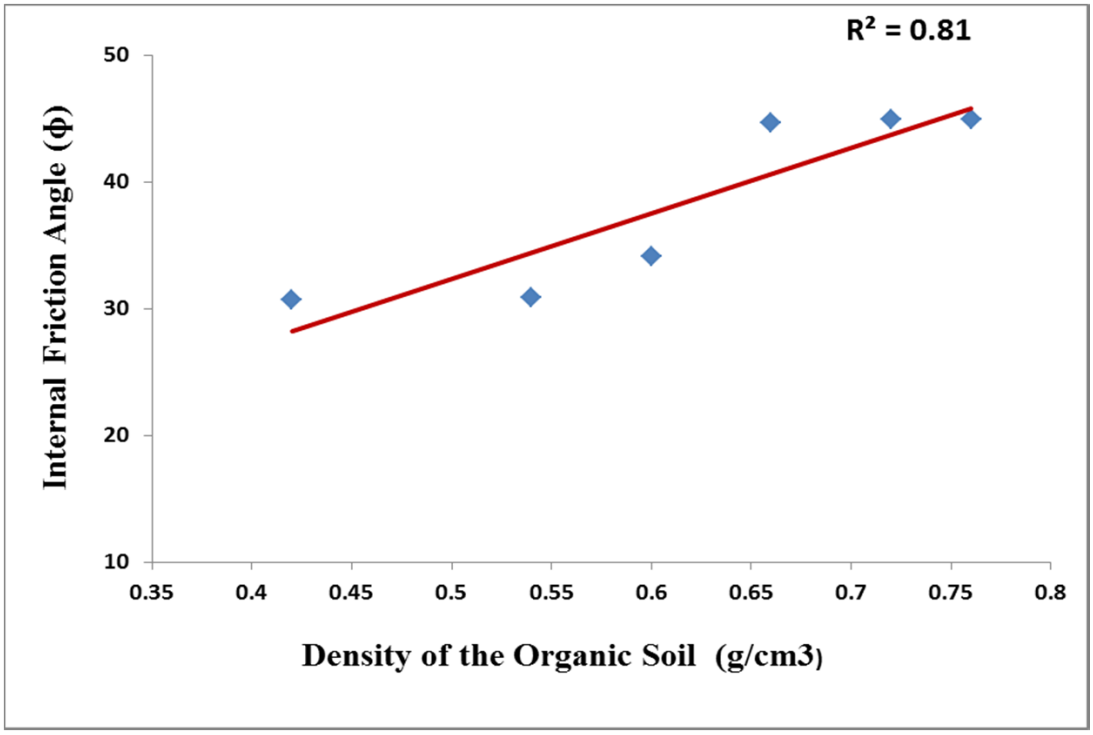


Figure 2.13 Sand Content – Internal Friction Angle Relation in Constant Density (Çelik and Çanakçı, 2010)

# CHAPTER 3

# MATERIALS AND METHODS

This chapter presents the materials and methods used in this study and gives detailed information about the materials and preparing methods of soil samples and construction materials.

## 3.1 The organic soil used in this study

The organic soil used in this study was obtained from the Sakarya region of Turkey. This peat was bought from a commertial firm as being packed. After the peat came to laboratory all of it was dried in an oven. Then, its moisture contents were aranged. Sakarya peat (natural soil) has herbaceous characteristics, and it can absorb water 3 to 4 times its weight with respect to its decomposition rate. Its initial density is ranged from 0,121 to 0,217 g/ $cm^3$. Remoulded soil also has 6,44 $kN/m^3$ maximum dry density and 58% optimum moisture content.The fibrous peat used for all tests is passing from 2 mm sieve size and retaining on #100 (0.15 mm) sieve size. This organic soil is classified as peat by Unified Soil Classification System (USCS) and Wüst et al. (2003) as shown in figure 3.1. It is also classified as fibric according ASTM D 1997, high ash according to ASTM D 2974, moderately acidic according to ASTM D 2976, and is $H_1$ to $H_4$ on degree of decomposition (Von Post, 1922). Engineering properties of the organic soil is listed in table 3.1. Organic content was estimated by firing process at 440 °C in an oven for 4 hours according to ASTM D 2974. According to this process, ash content of the soil was 30%. Liquid limit of the organic soil was estimated by the fall cone test according to ASTM D 4318 and found to be 119%.

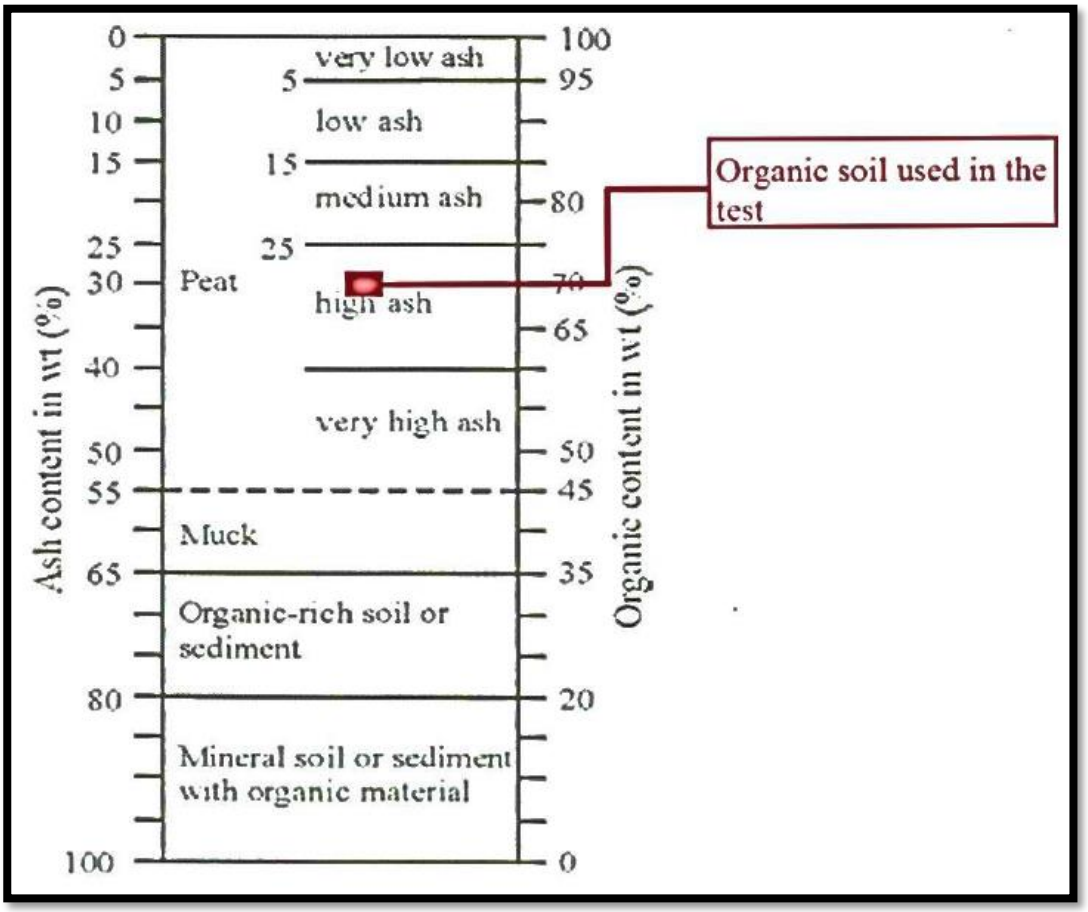


Figure 3.1: Classification system for peat deposits (Wüst et al., 2003)

Table 3.1: Engineering properties of the organic soil

| Properties of organic soil | |
|---|---|
| Organic content (%) | 70 |
| pH | 5.0 |
| Natural water content (%) | 256 |
| Liquid limit (%) | 125 |
| Plasticity index (%) | None plastic |
| Specific gravity | 1.97 |

### 3.2 The sand used in this study

Two types of sand, rounded and angular, were used in this study. Both of them were poorly graded passing from 2 mm sieve size and retaining on 0.425 mm sieve size. These types of sandy soil were used to test the effect of particle shape on interface friction.

### 3.3 The structural materials used in this study

To evaluate the interface frictional resistance between organic soil and solid structural materials, four plates of commonly used construction materials were prepared; concrete, rough and smooth steel, and wood. Steels plates used in this study were prepared in the laboratory from metal sheets. The concrete plate was prepared in the laboratory using aggregates and cements, and cast in food frame, while the wood plate used in this study was cut from a pine tree. The construction materials used in the study are shown in figure 3.2. The size of all types of structural materials was 60 x 60 x 10 mm the exact same size of the lower box of the direct shear device.

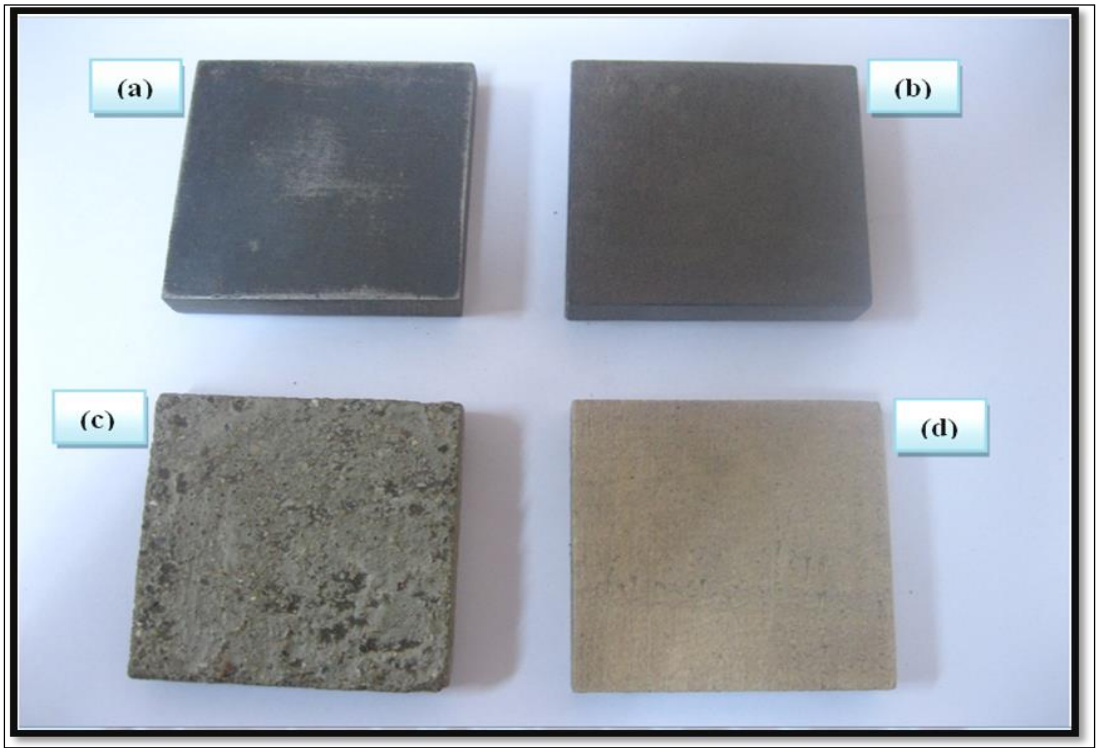


Figure 3.2: Construction materials used in the test; a) smooth steel b) rough steel c) concrete d) wood

### 3.4 Testing method

A fully automated direct shear device was used in this study. The total dimensions of the upper and lower shear boxes were 60 x 60 x 25 mm (Figure 3.3a). To perform the interface tests between organic soil and solid materials, the lower box of the direct shear device was completely blocked with the solid plates (Figure 3.3b). Internal friction angle of the original soil is 43° and the cohesion is 5.8 kPa. Organic soil samples were prepared in different water content and sand-organic content. The temperature during the test was at room temperature (24 $^{0}$C) and all of the tests were consolidated and drained (CD). To investigate the effect of sand content in organic soil on interface friction angle, 10, 20, 30, and 40% sand by weight were mixed with the organic soil. For this series of tests, water content was kept constant (w=0.75). In the second series of tests, the effect of water content on interface friction angle was investigated. Various water contents were used 8%, 17%, 28%, and 4,5%, respectively, and granular soil content was taken at 40%. The density of the soil was kept constant as 1.39 g/cm$^3$ for all mixtures. The testing program and mix proportions are presented in table 3.2.

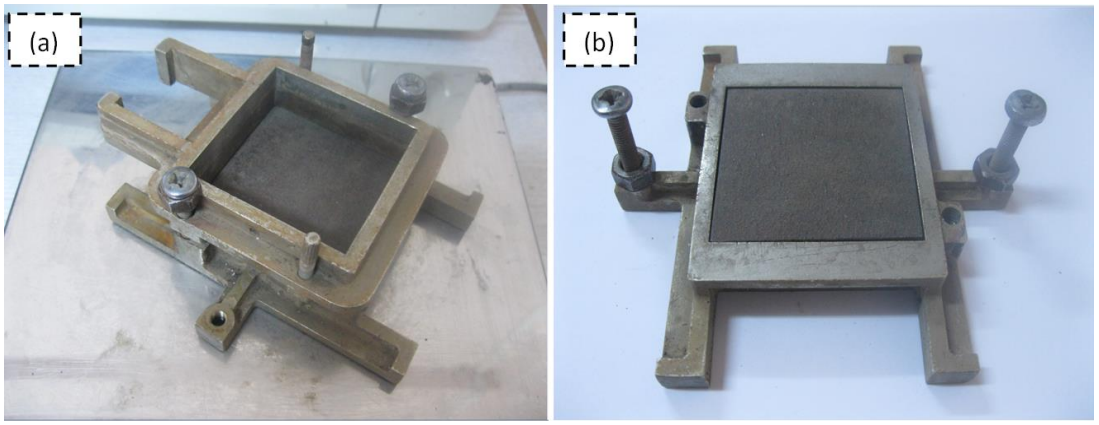


Figure 3.3: Soil testing method used in this study; a) Lower and upper box of the direct shear device used for this study; b) Lower shear box, filled with the structural material.

During the shearing test, the rate of shearing displacement was kept equal to 1 mm/min for all tests. Three different normal stresses (30, 60, and 120 kPa, respectively) were used and shear stress at 10% horizontal displacement of box was

taken as maximum shear stress.

Table 3.2: Mix proportions of the soils used in the tests.

| Materyal Type | Sand content (%) (CS-RS)* | W/O (%) | Sand (g) | Organic Soil (g) | Water (g) |
|---|---|---|---|---|---|
| Wood<br>Concrete<br>Smooth steel<br>Rough steel | 0 | 0,75 | 0 | 42,86 | 32,14 |
| | 10 | | 4,29 | 38,57 | |
| | 20 | | 8,57 | 34,28 | |
| | 30 | | 30 | 12,85 | |
| | 40 | | 25,71 | 17,14 | |
| | Water content (%) (CS-RS)* | S/O (%) | Water (g) | Organic Soil (g) | Sand (g) |
| | 0 | 40 | 0 | 55 | 20 |
| | 10 | | 5,5 | 49,5 | |
| | 20 | | 11 | 44 | |
| | 30 | | 16,5 | 38,5 | |
| | 40 | | 22 | 33 | |

Roughness index is also one of the important parameters of material surface that influences interface friction angle. The roughness index is a function of the smoothness of the structural materials (Sayers, 1995). Rough surfaces usually have higher friction coefficients than smooth surfaces. The surface roughness is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is considered to be rough; if they are small the surface is smooth (Kwang et al., 1992). The roughness coefficients of the structural materials were estimated by using an electronic dial gage. This dial gage was moved on the structural materials and then the readings were taken by a data logger and recorded. For each plates the measurement were taken at different points along the centerline from the edges of the plates. Figure 3.4 shows measured surface wave for different construction material. By using these figures the Roughness index were calculated as described by Kwang et al. (1992).

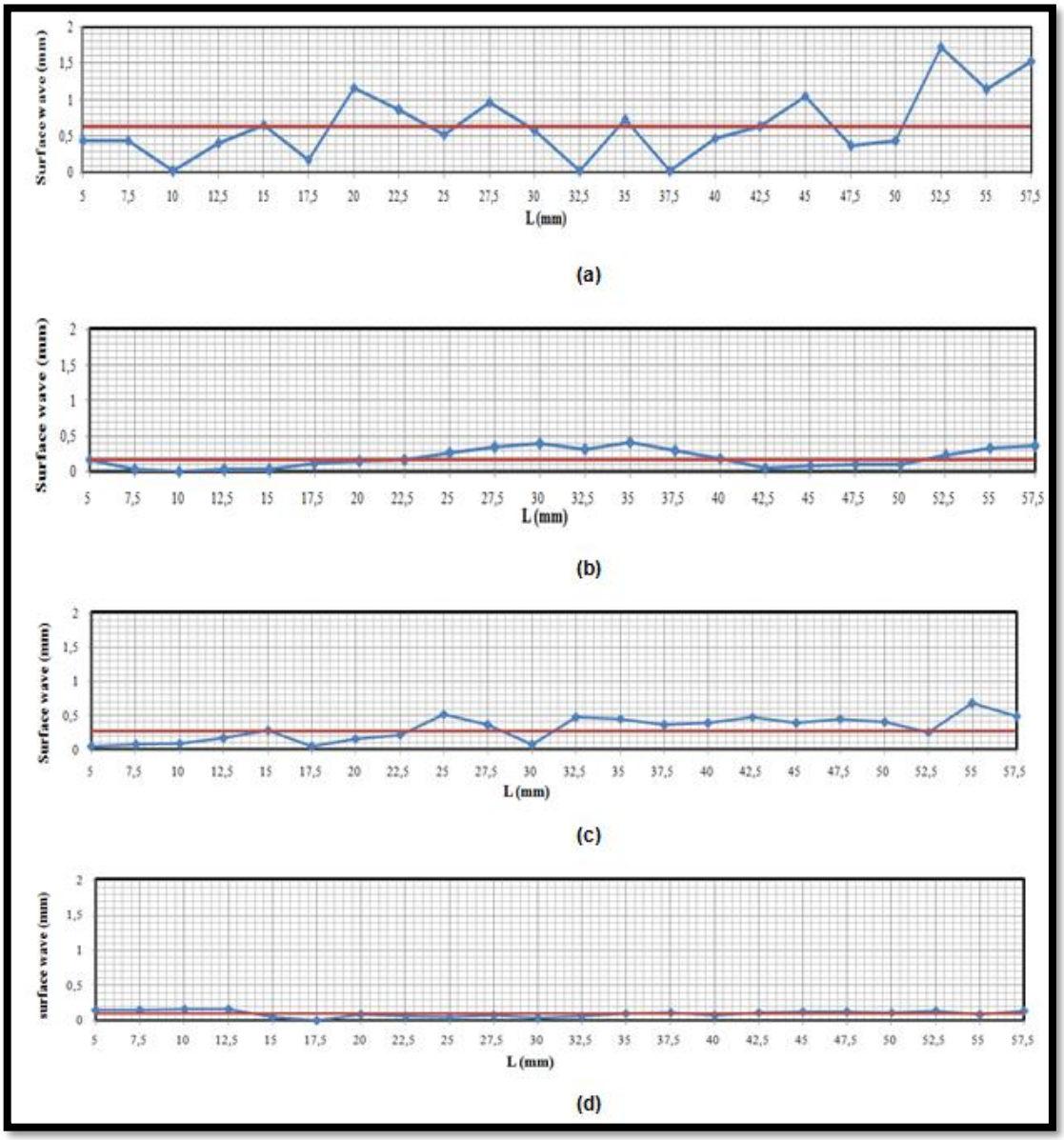


Figure 3.4: Surface waves with respect to surface length ; a) concrete, b) wood, c) rough steel, d) smooth steel.

# CHAPTER 4

# TEST RESULTS AND DISCUSSION

## 4.1 General

Typical direct shear test results for different organic soil-construction material interfaces were presented and discussed in this section. Generally, shear test results are presented by using three types of graphs: (1) the shear stress–horizontal displacement curves, (2) the horizontal shear displacement –vertical deformation curves, and (3) the shear strength envelopes, which give the interface shear strength parameters (cohesion or adhesion, c; friction angle, φ).

## 4.2 The shear stress–horizontal displacement

Typical shear stress versus horizontal displacement performed on the organic soil containing 40% angular and rounded sand under 120 kPa normal stress is shown in figure 4.1 a–b. These figures show a relatively similar trend and shape. In addition, it can be seen from the figures that interface shear stress increases gradually with horizontal displacement until certain deformation, beyond which it becomes relatively constant. The curves showed slight strain softening behavior. Since maximum horizontal deformation reached for all the tests was 10% shear deformation, residual shear condition could not be achieved in the tests. Similar behavior was observed for the same soils under different normal stresses for all tested construction materials. In all tests, the maximum shear stress values were obtained in the interface between the organic soil and concrete, while the minimum values were observed in the interface between the organic soil and smooth steel.

### 4.2.1 Shear stress–shear strain for crushed sand

Typical shear stress versus shear strain performed on the organic soil containing 0%-40% angular sand with construction materials (concrete, rough steel, smooth steel and wood) under 30 kPa, 60 kPa and 120 kPa normal stresses are shown in figures 4.2–

4.21. These figures show a relatively similar trend and shape. In addition, it can be seen from the figures that interface shear stress increases gradually with horizontal displacement until certain deformation, beyond which it becomes relatively constant. The curves showed slight strain softening behavior. Since maximum horizontal deformation reached for all the tests was 10% shear deformation, residual shear condition could not be achieved in the tests.

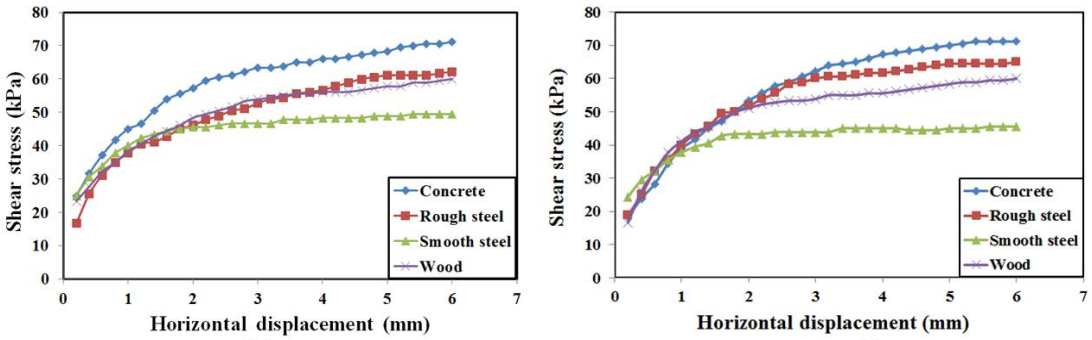


Figure 4.1: Shear stress-horizontal displacement curves for 120 kPa normal load; a) 40% crushed sand content, b) 40% rounded sand content.

#### 4.2.1.1 Concrete-Organic soil with respect to crushed sand

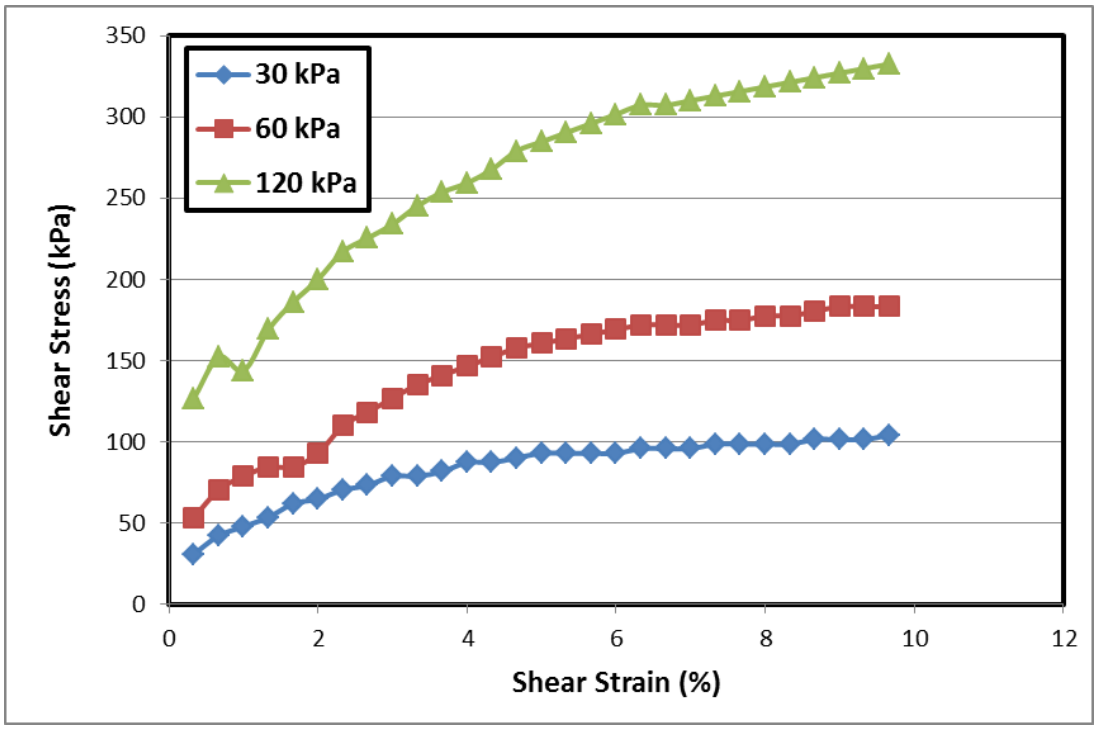


Figure 4.2: Shear stress-shear strain curves at 0% sand content for concrete-organic soil with respect to crushed sand

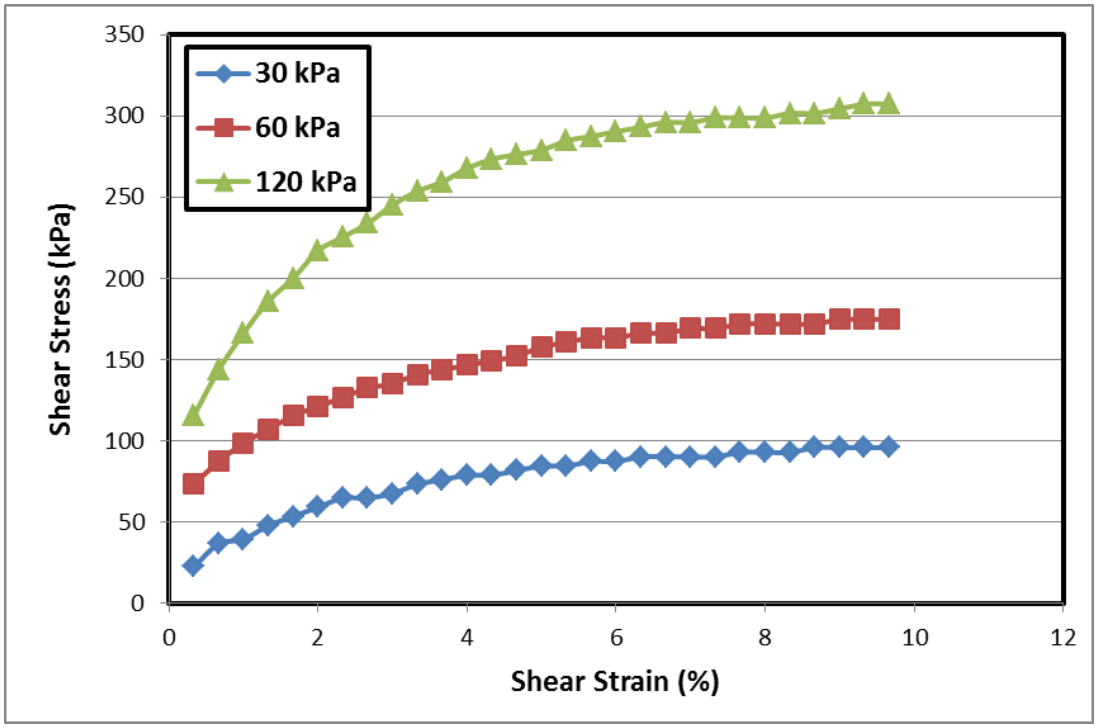


Figure 4.3: Shear stress-shear strain curves at 10% sand content for concrete-organic soil with respect to crushed sand

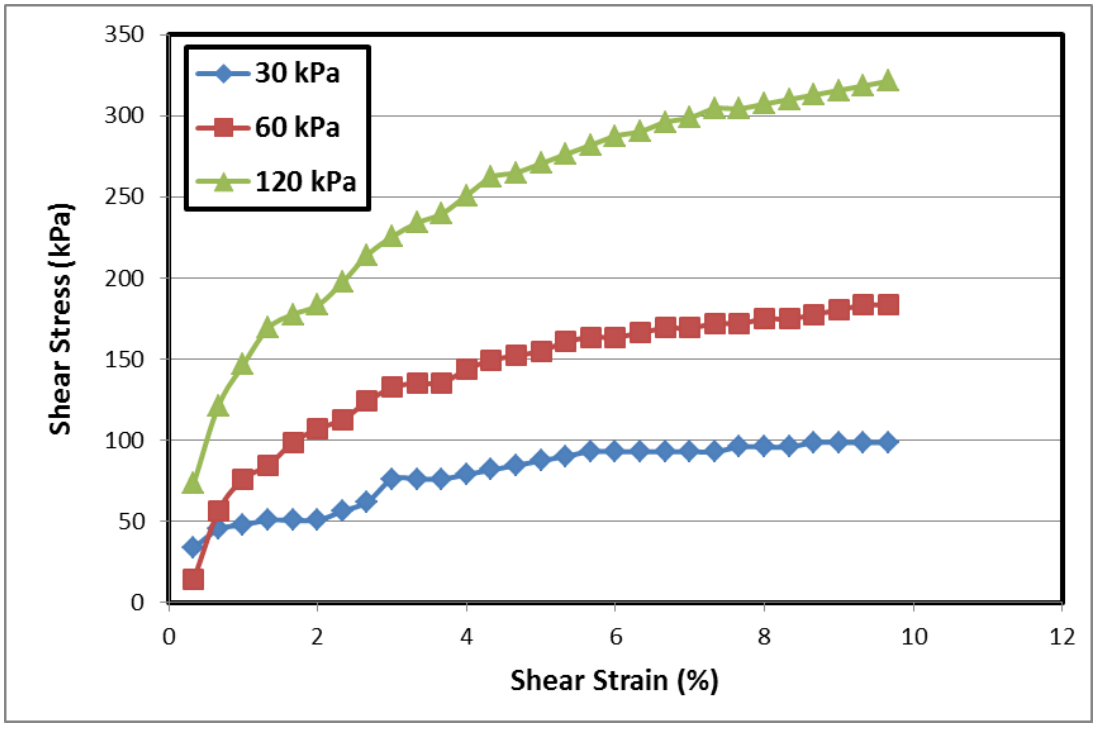


Figure 4.4: Shear stress-shear strain curves at 20% sand content for concrete-organic soil with respect to crushed sand

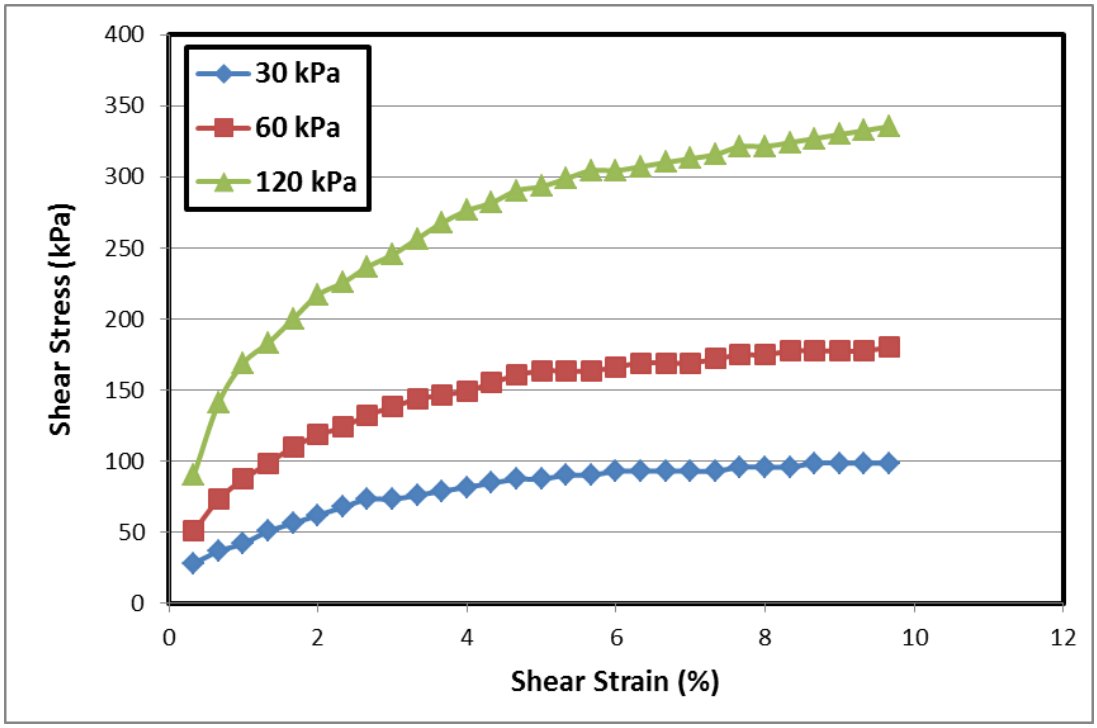


Figure 4.5: Shear stress-shear strain curves at 30% sand content for concrete-organic soil with respect to crushed sand

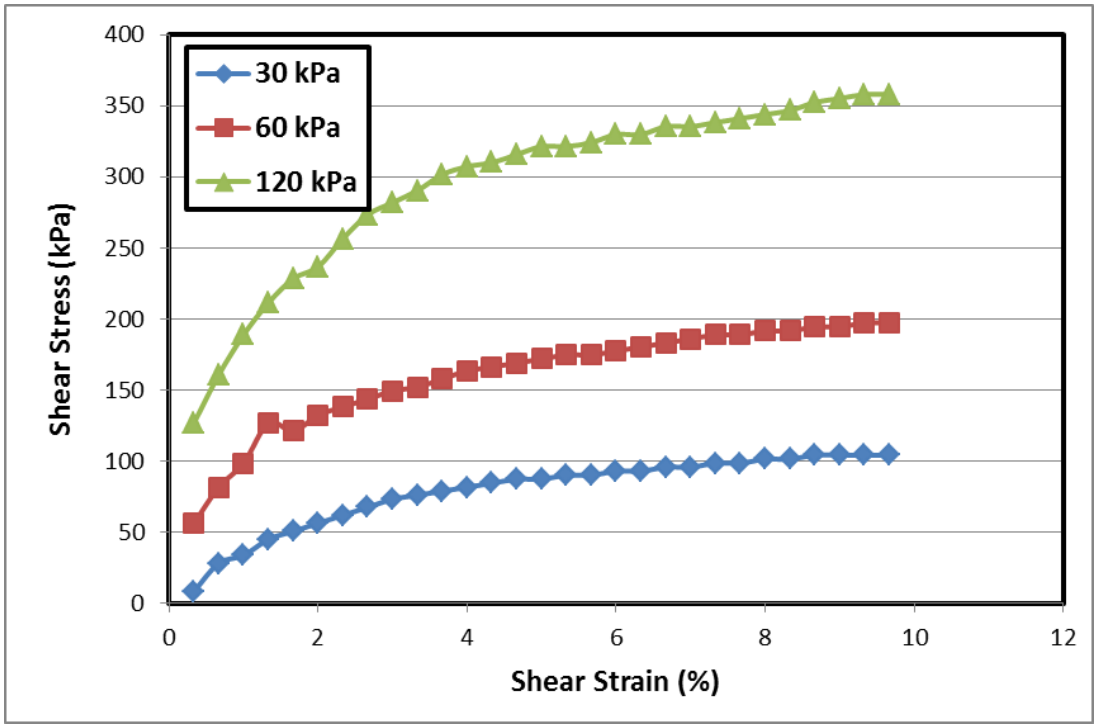


Figure 4.6: Shear stress-shear strain curves at 40% sand content for concrete-organic soil with respect to crushed sand

#### 4.2.1.2 Rough steel-Organic soil with respect to crushed sand

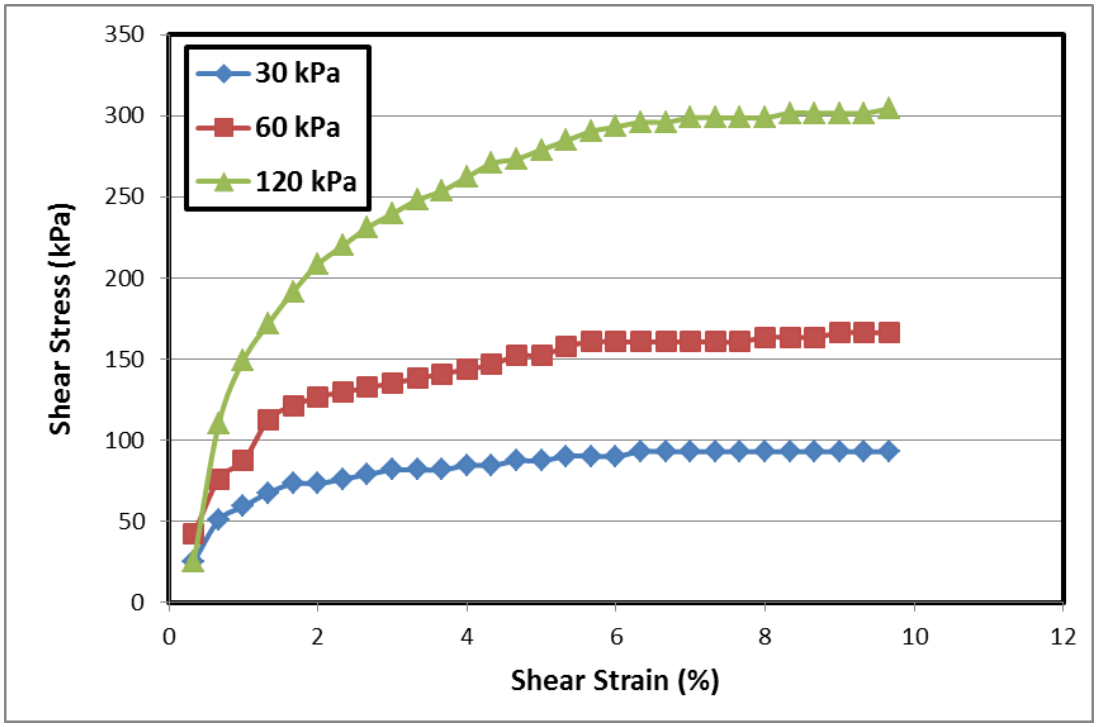


Figure 4.7: Shear stress-shear strain curves at 0% sand content for rough steel-organic soil with respect to crushed sand

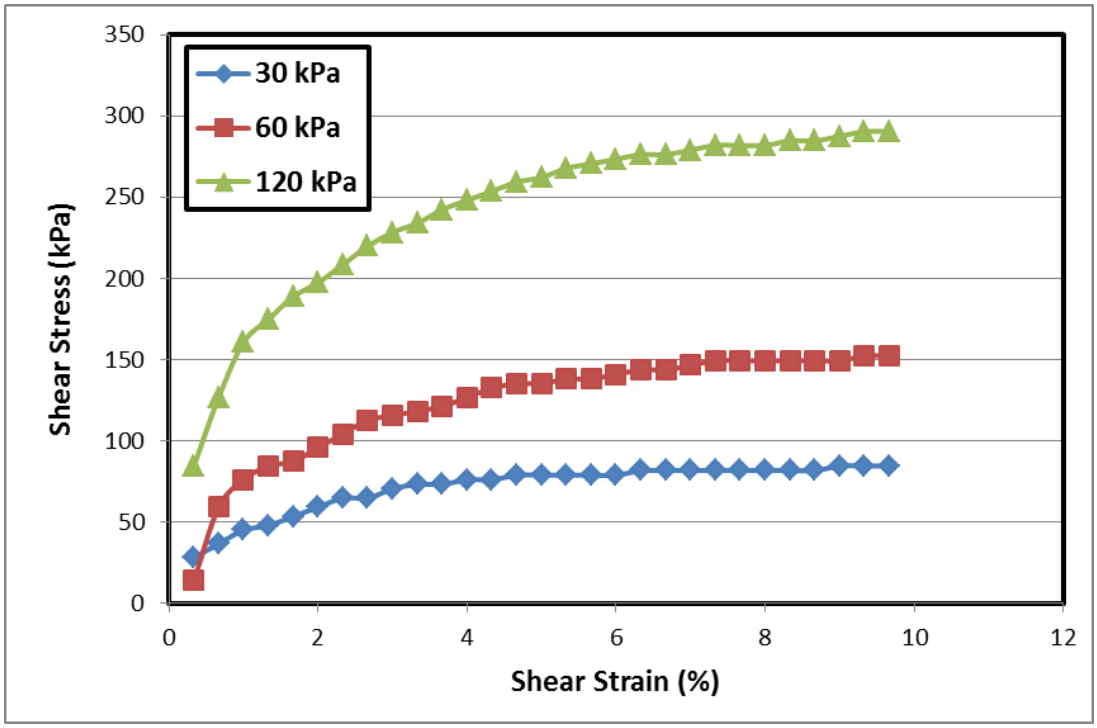


Figure 4.8: Shear stress-shear strain curves at 10% sand content for rough steel-organic soil with respect to crushed sand

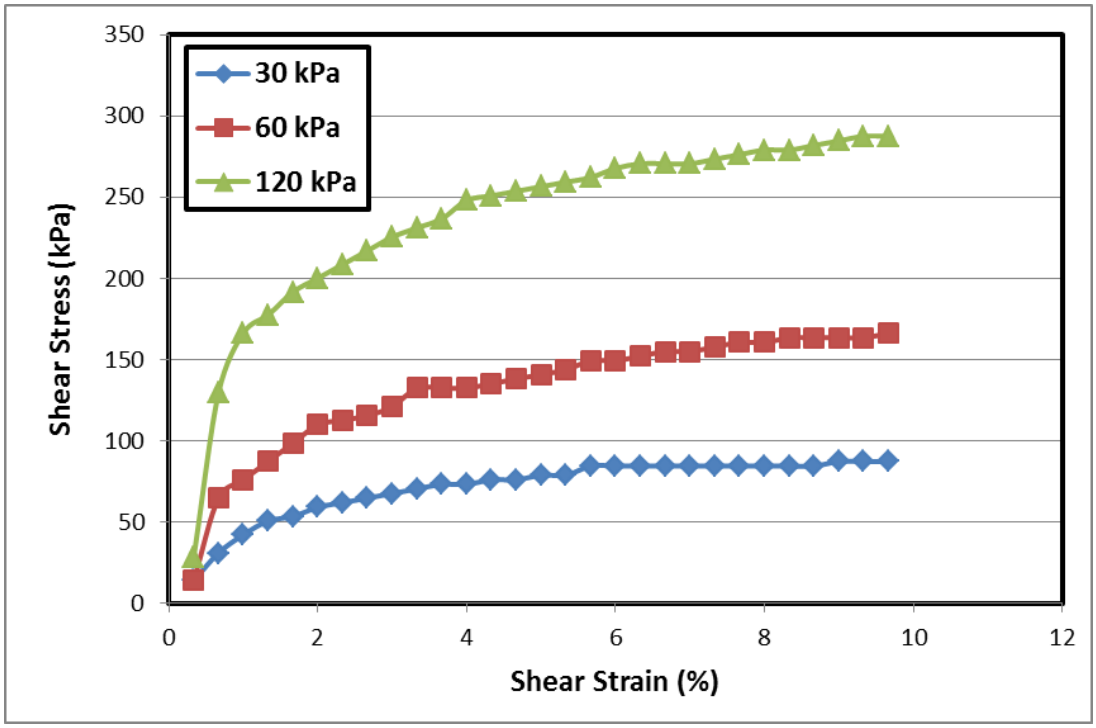


Figure 4.9: Shear stress-shear strain curves at 20% sand content for rough steel-organic soil with respect to crushed sand

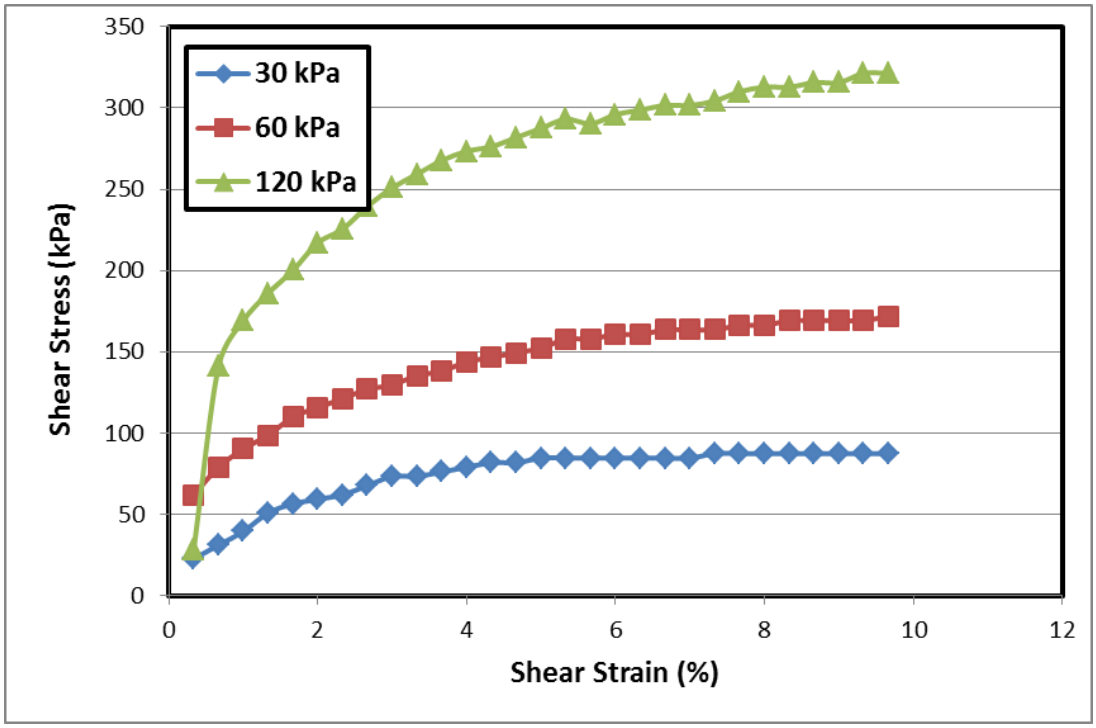


Figure 4.10: Shear stress-shear strain curves at 30% sand content for rough steel-organic soil with respect to crushed sand

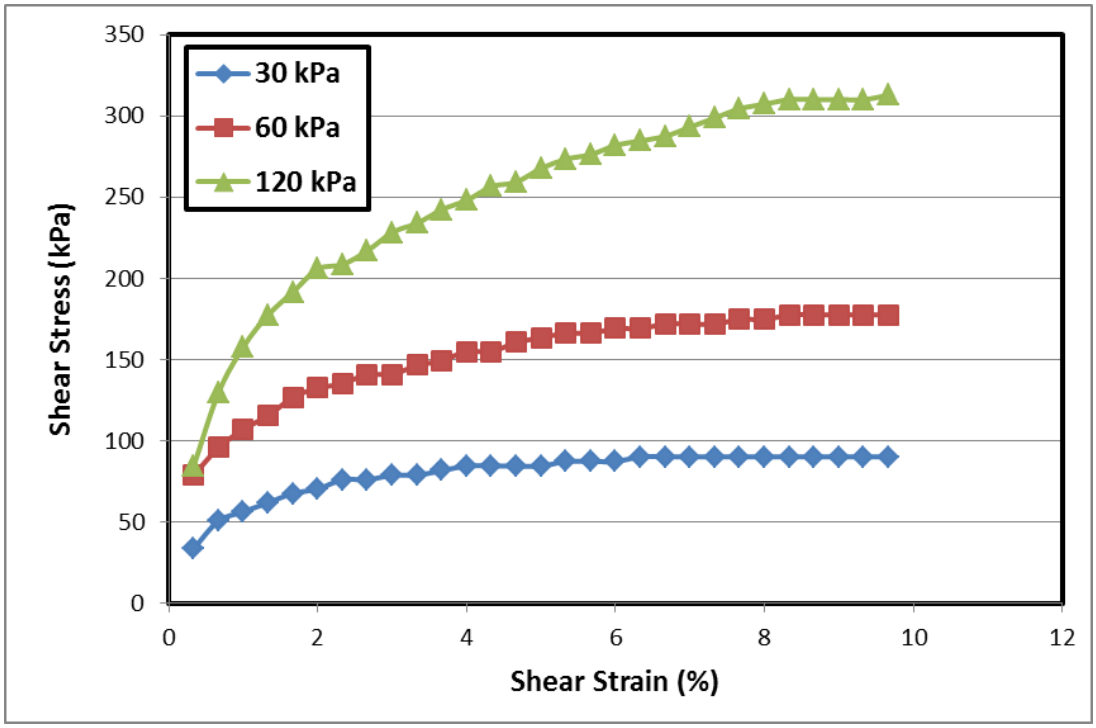


Figure 4.11: Shear stress-shear strain curves at 40% sand content for rough steel-organic soil with respect to crushed sand

#### 4.2.1.3 Smooth steel-Organic soil with respect to crushed sand

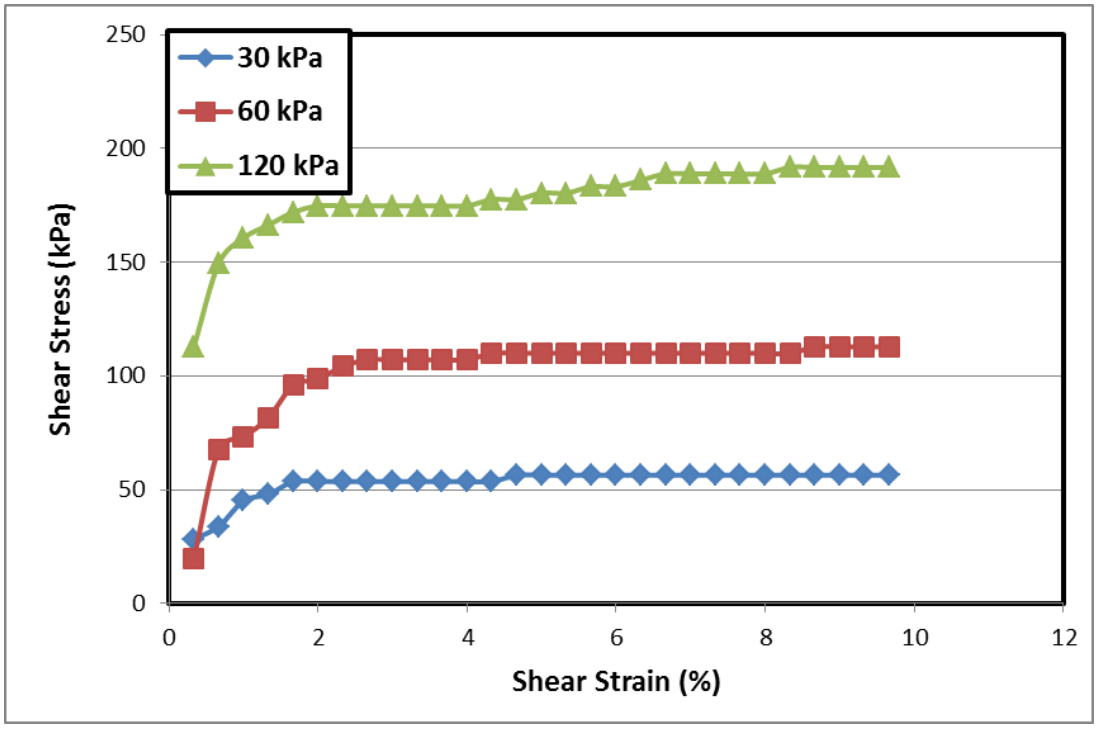


Figure 4.12: Shear stress-shear strain curves at 0% sand content for smooth steel-organic soil with respect to crushed sand

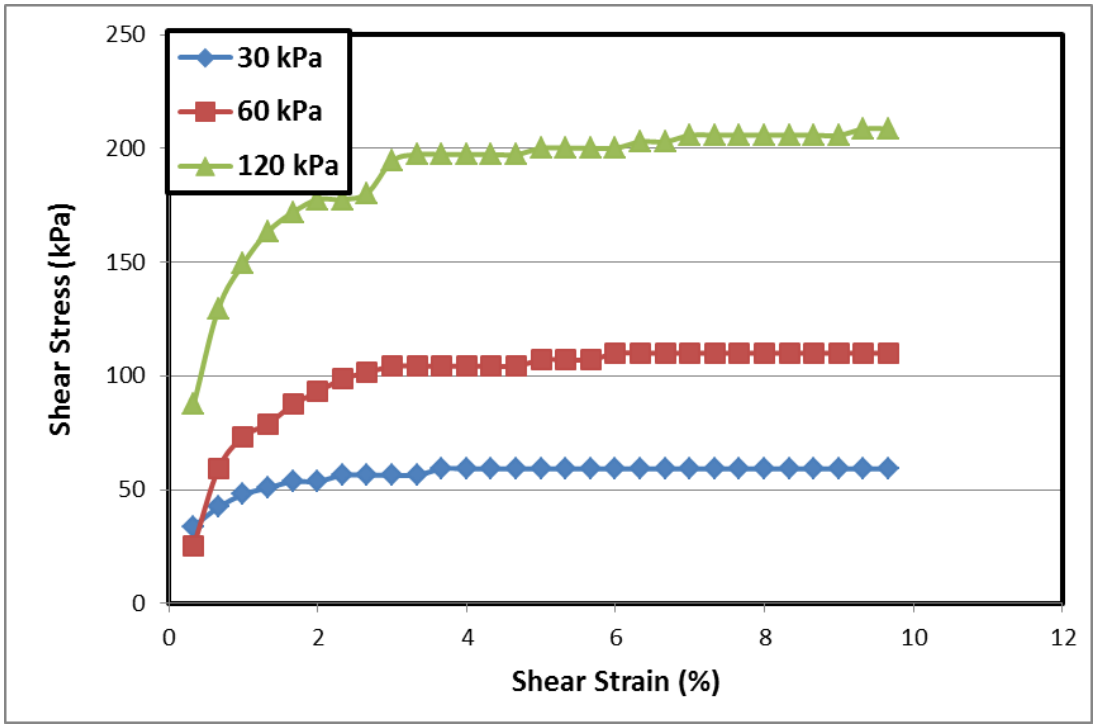


Figure 4.13: Shear stress-shear strain curves at 10% sand content for smooth steel-organic soil with respect to crushed sand

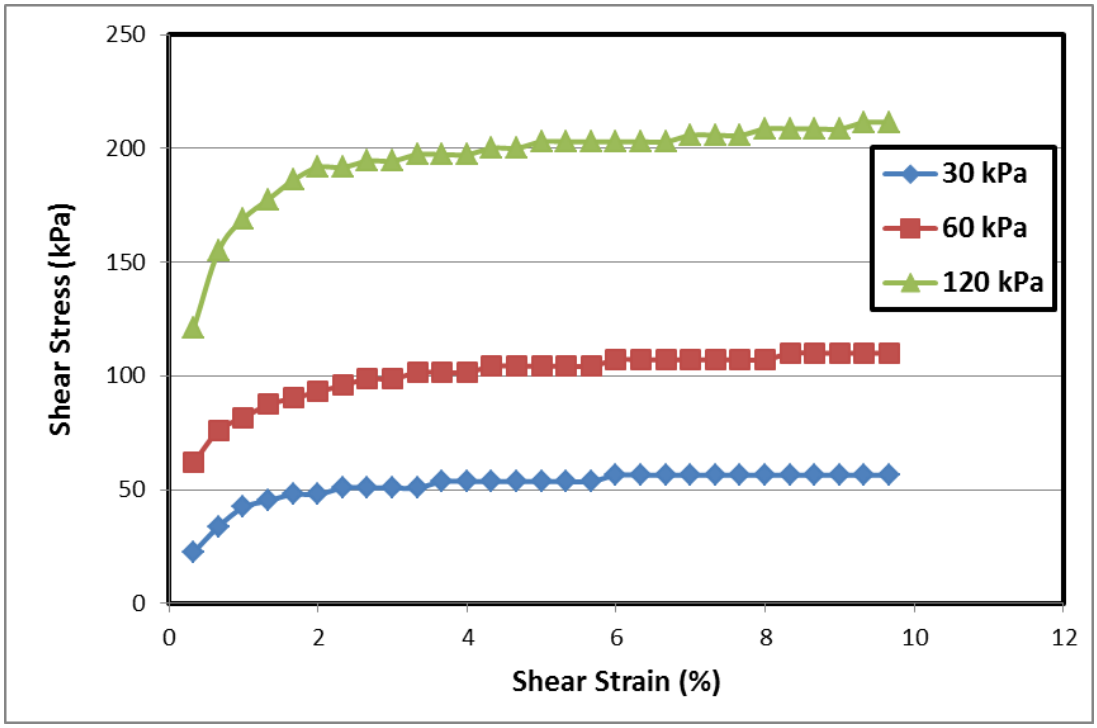


Figure 4.14: Shear stress-shear strain curves at 20% sand content for smooth steel-organic soil with respect to crushed sand

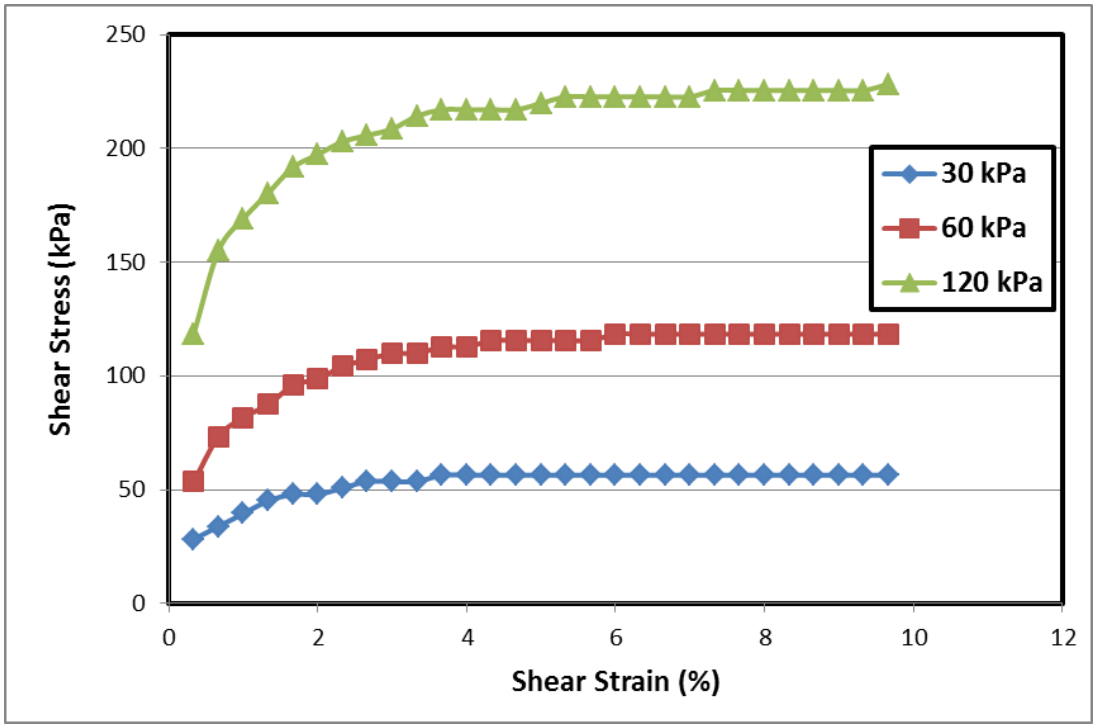


Figure 4.15: Shear stress-shear strain curves at 30% sand content for smooth steel-organic soil with respect to crushed sand

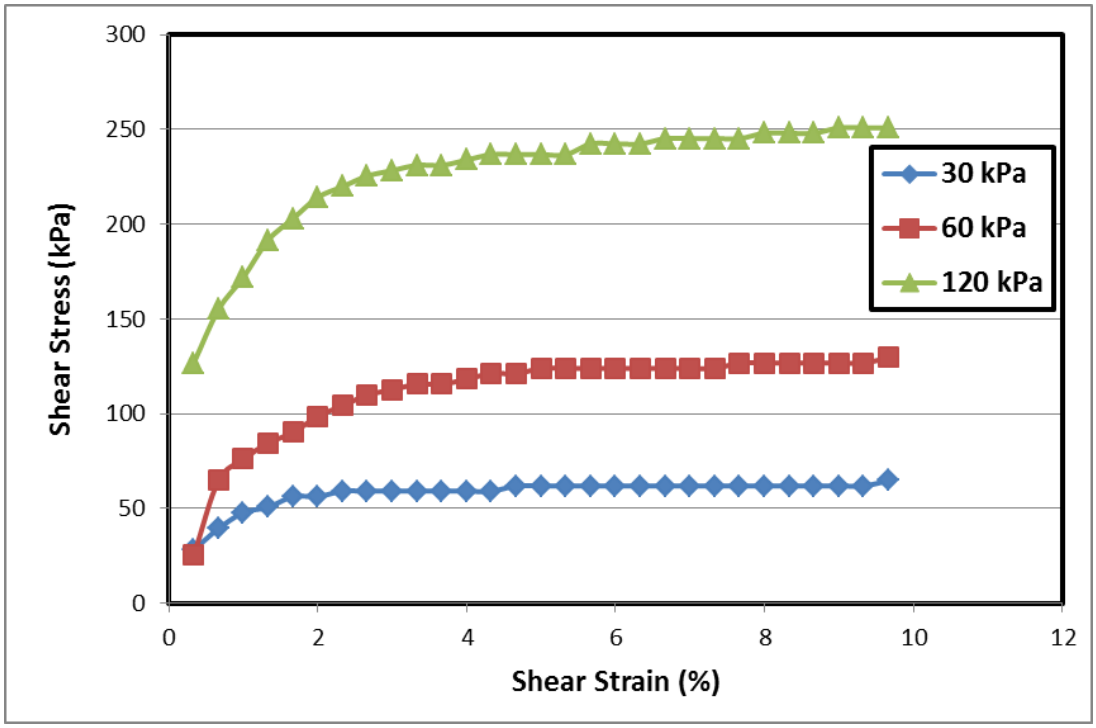


Figure 4.16: Shear stress-shear strain curves at 40% sand content for smooth steel-organic soil with respect to crushed sand

#### 4.2.1.4 Wood-Organic soil with respect to crushed sand

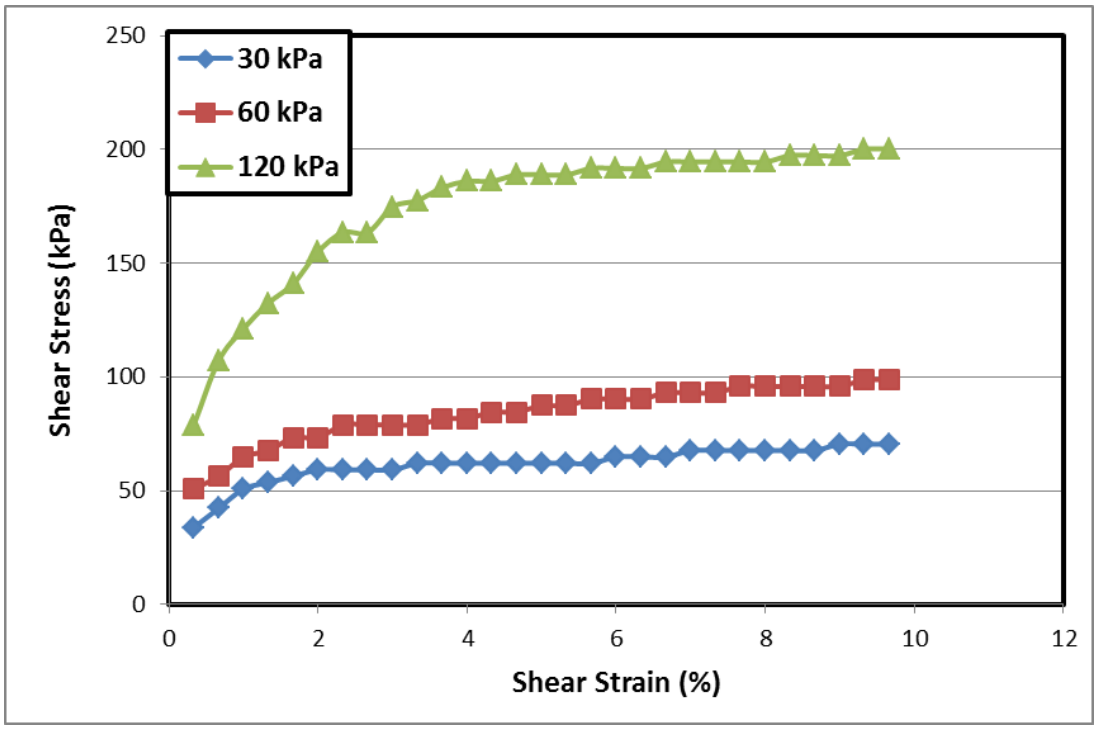


Figure 4.17: Shear stress-shear strain curves at 0% sand content for wood-organic soil with respect to crushed sand

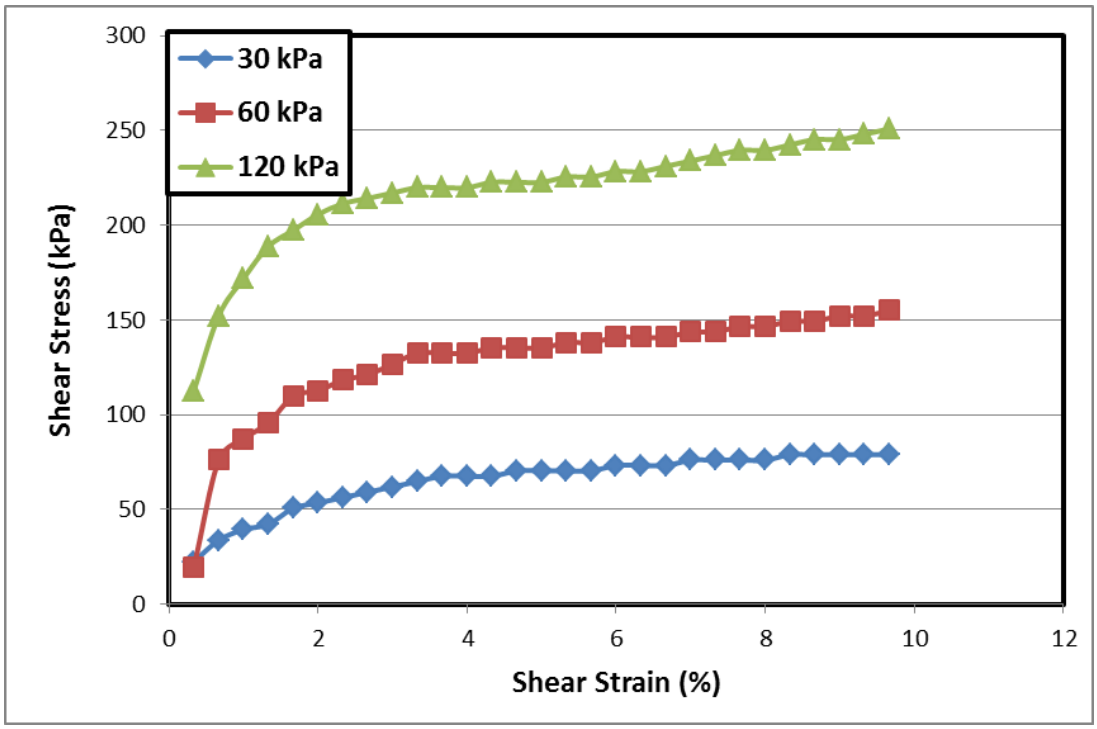


Figure 4.18: Shear stress-shear strain curves at 10% sand content for wood-organic with respect to crushed sand soil

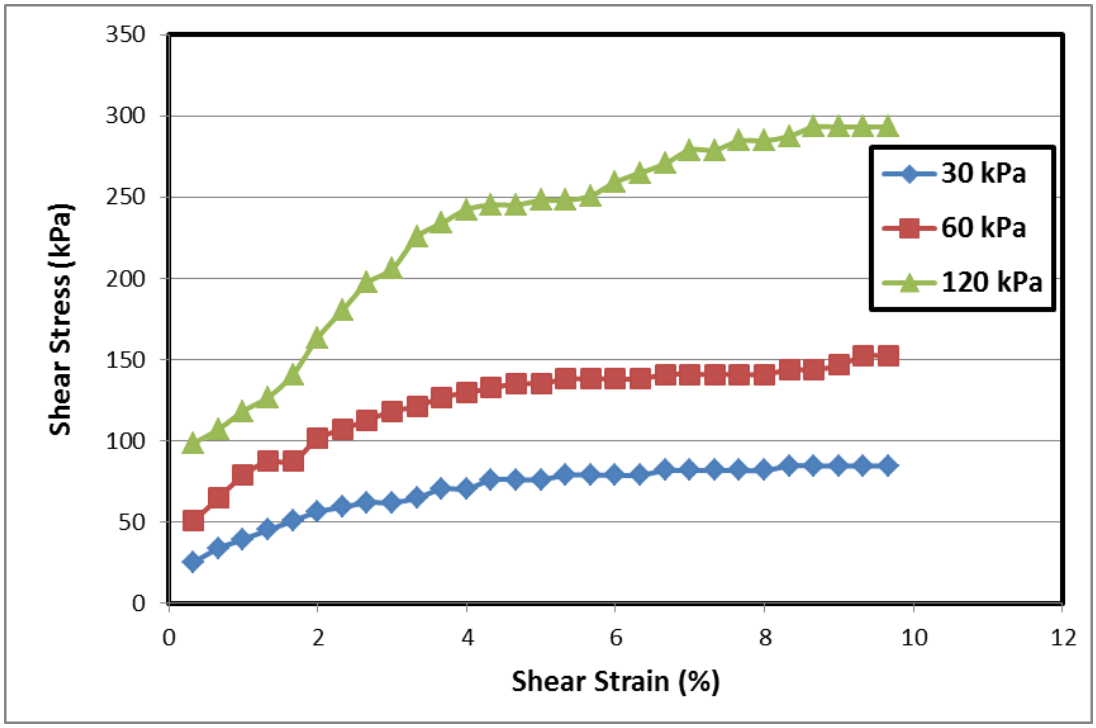


Figure 4.19: Shear stress-shear strain curves at 20% sand content for wood-organic soil with respect to crushed sand

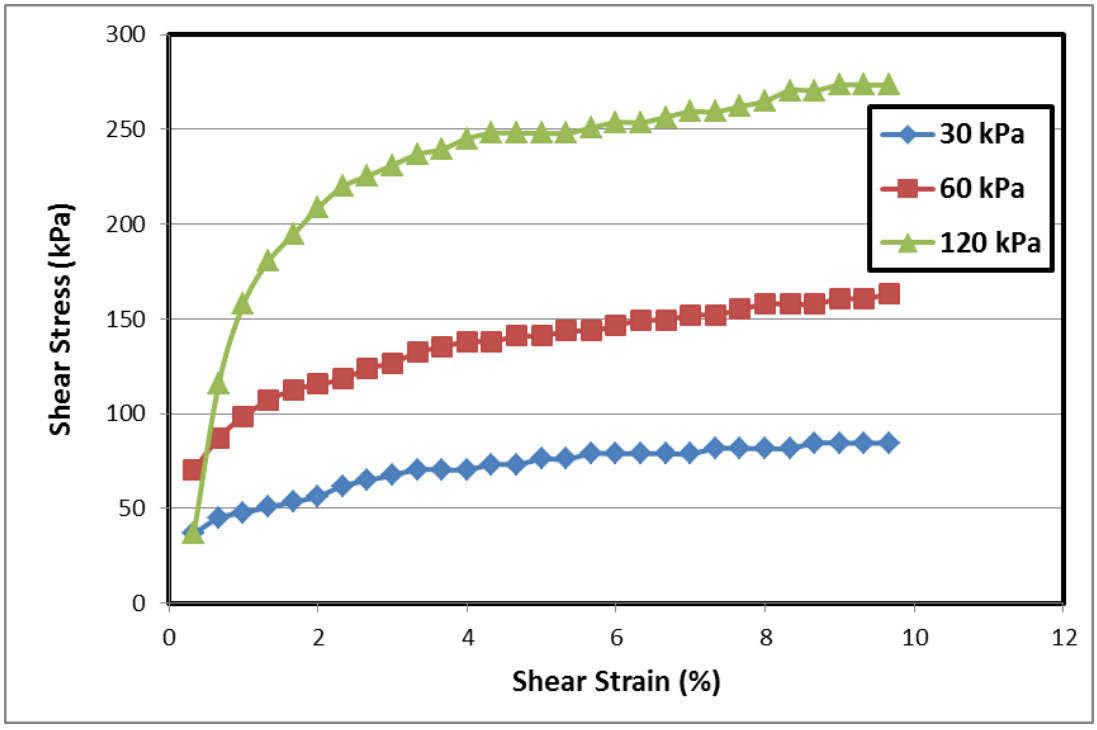


Figure 4.20: Shear stress-shear strain curves at 30% sand content for wood-organic soil with respect to crushed sand

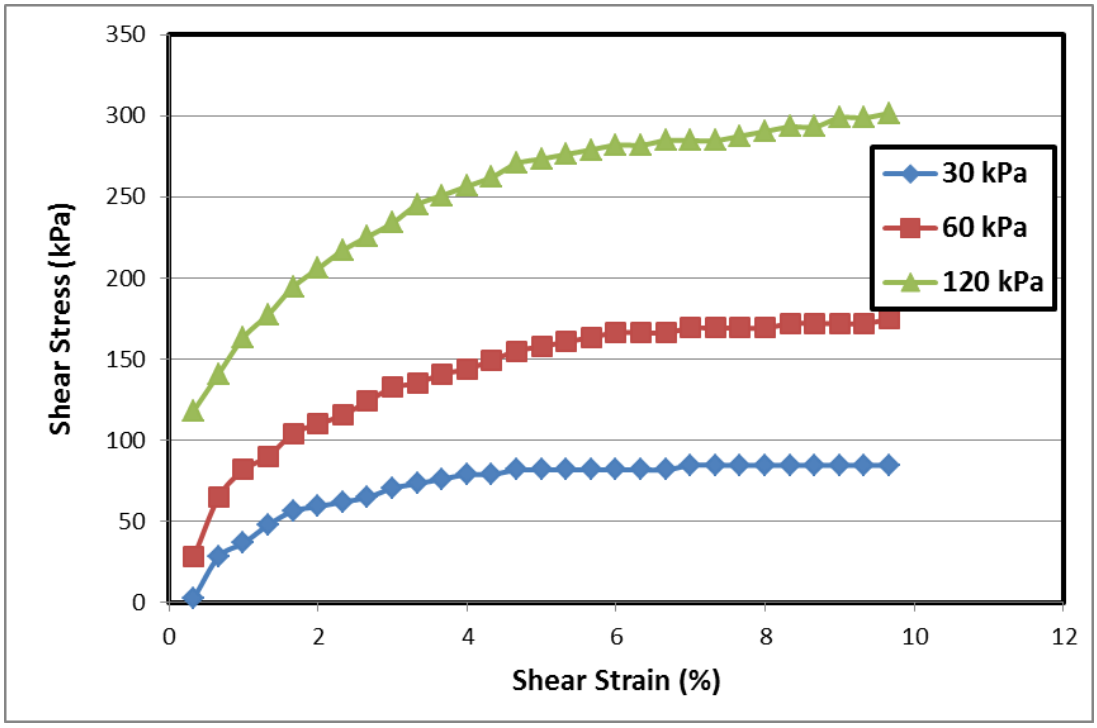


Figure 4.21: Shear stress-shear strain curves at 40% sand content for wood-organic soil with respect to crushed sand

### 4.2.2 Shear stress–shear strain for rounded sand

Typical shear stress versus shear strain performed on the organic soil containing 0%-40% rounded sand with construction materials (concrete, rough steel, smooth steel and wood) under 30 kPa, 60 kPa and 120 kPa normal stresses are shown in figures 4.22–4.41. These figures show a relatively similar trend and shape. In addition, it can be seen from the figures that interface shear stress increases gradually with horizontal displacement until certain deformation, beyond which it becomes relatively constant. The curves showed slight strain softening behavior. Since maximum horizontal deformation reached for all the tests was 10% shear deformation, residual shear condition could not be achieved in the tests.

#### 4.2.2.1 Concrete-Organic soil with respect to rounded sand

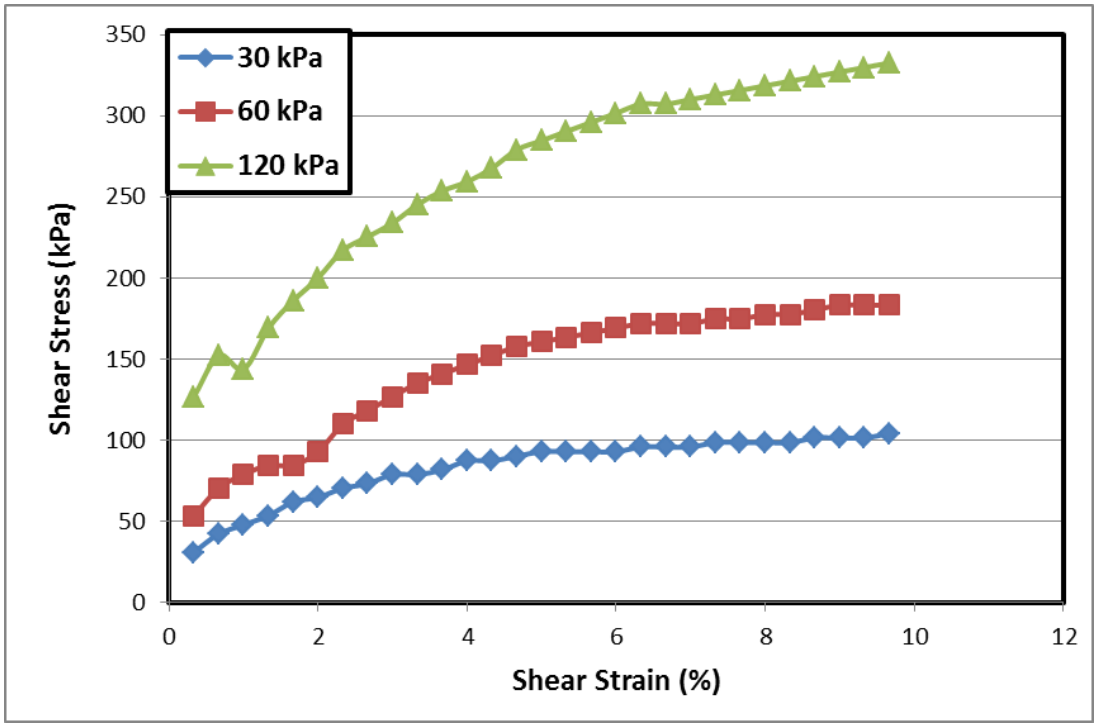


Figure 4.22: Shear stress-shear strain curves at 0% sand content for concrete-organic soil with respect to rounded sand

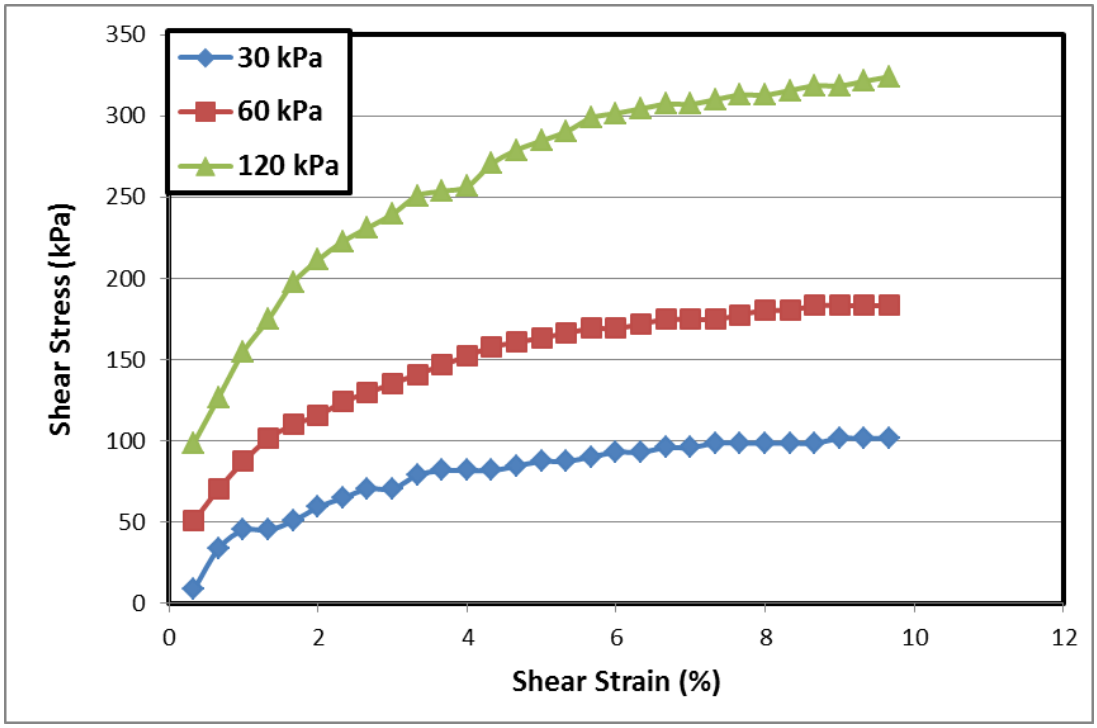


Figure 4.23: Shear stress-shear strain curves at 10% sand content for concrete-organic soil with respect to rounded sand

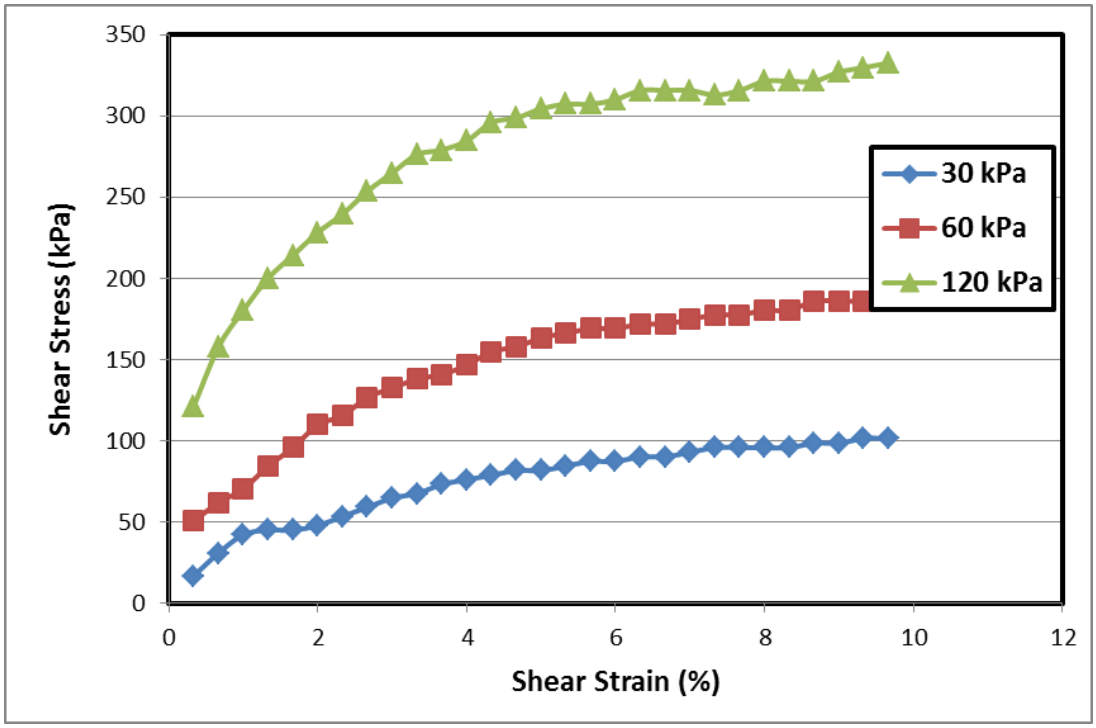


Figure 4.24: Shear stress-shear strain curves at 20% sand content for concrete-organic soil with respect to rounded sand

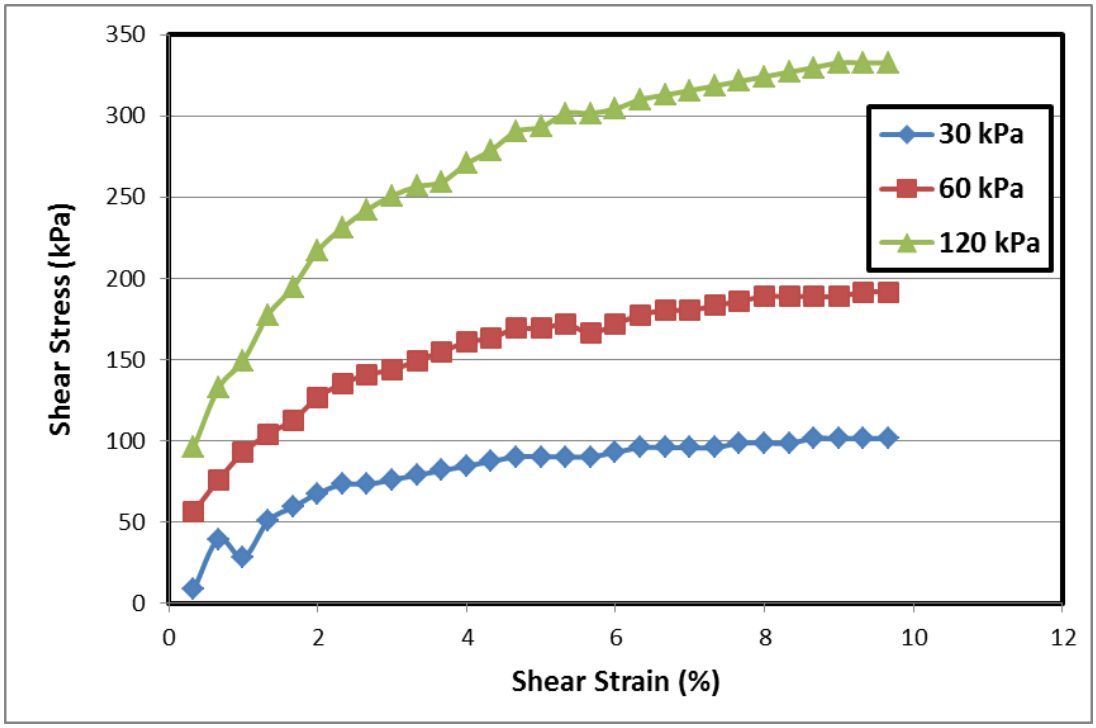


Figure 4.25: Shear stress-shear strain curves at 30% sand content for concrete-organic soil with respect to rounded sand

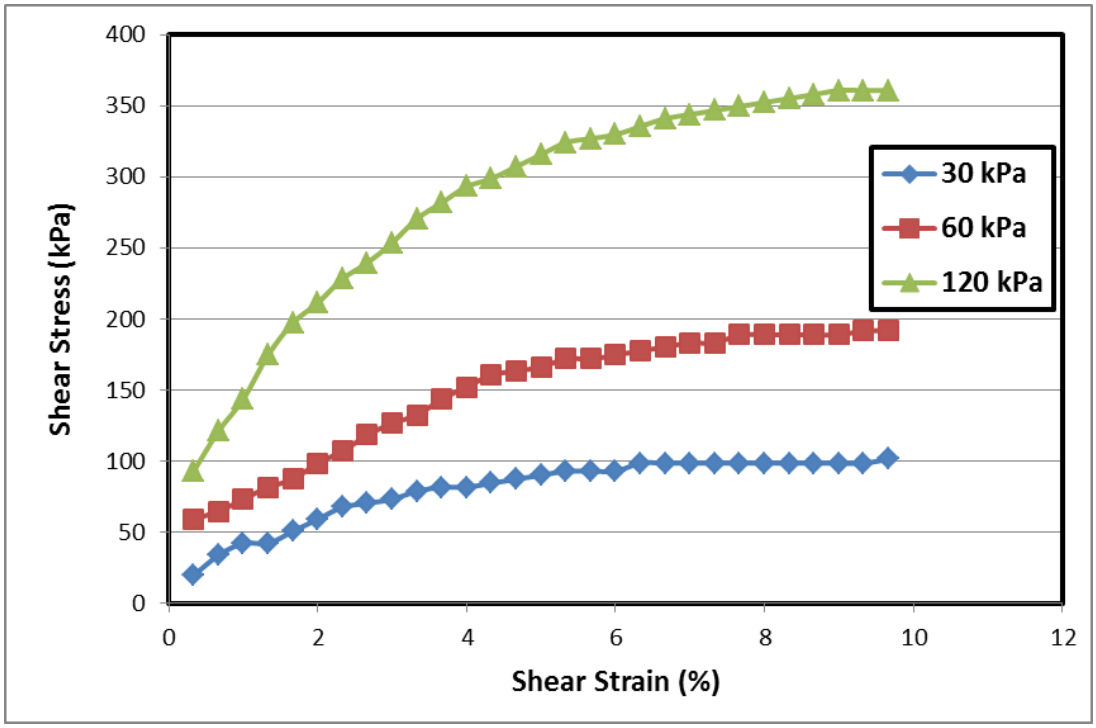


Figure 4.26: Shear stress-shear strain curves at 40% sand content for concrete-organic soil with respect to rounded sand

#### 4.2.2.2 Rough steel-Organic soil with respect to rounded sand

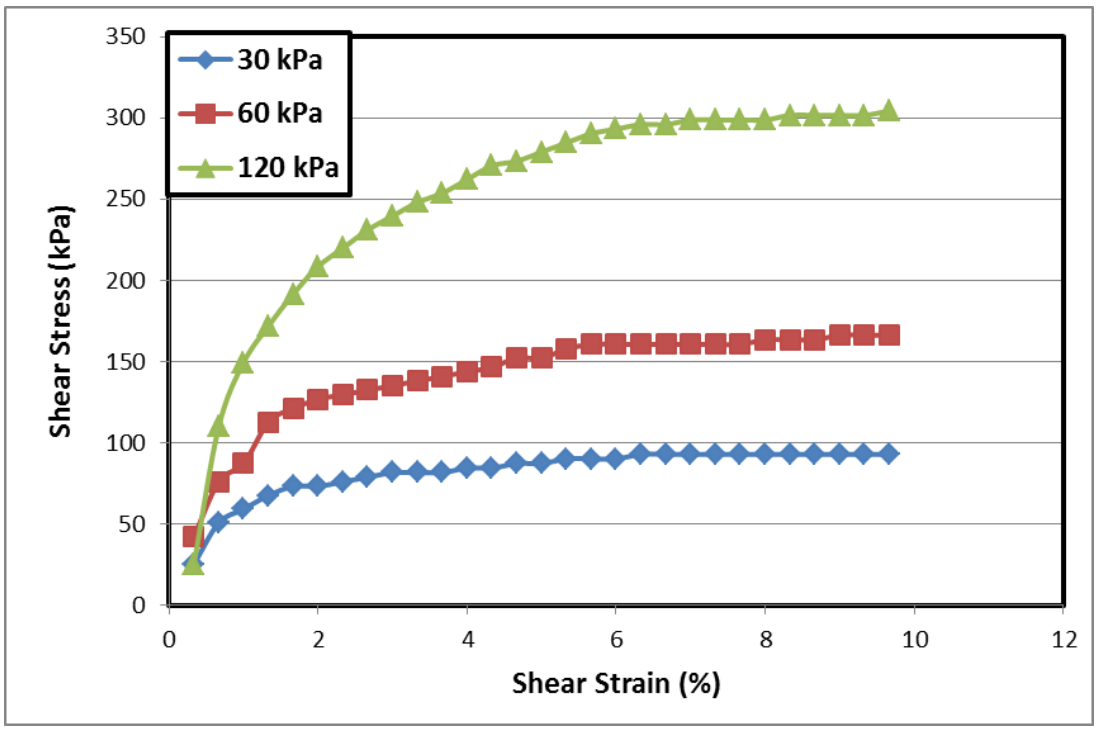


Figure 4.27: Shear stress-shear strain curves at 0% sand content for rough steel-organic soil with respect to rounded sand

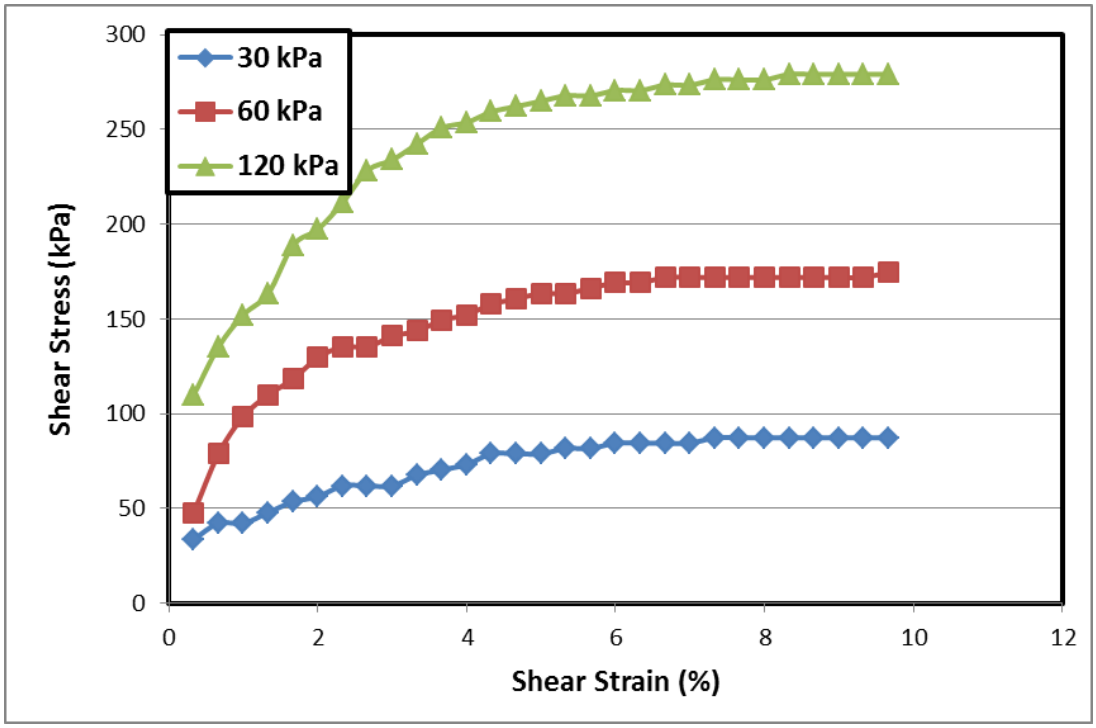


Figure 4.28: Shear stress-shear strain curves at 10% sand content for rough steel-organic soil with respect to rounded sand

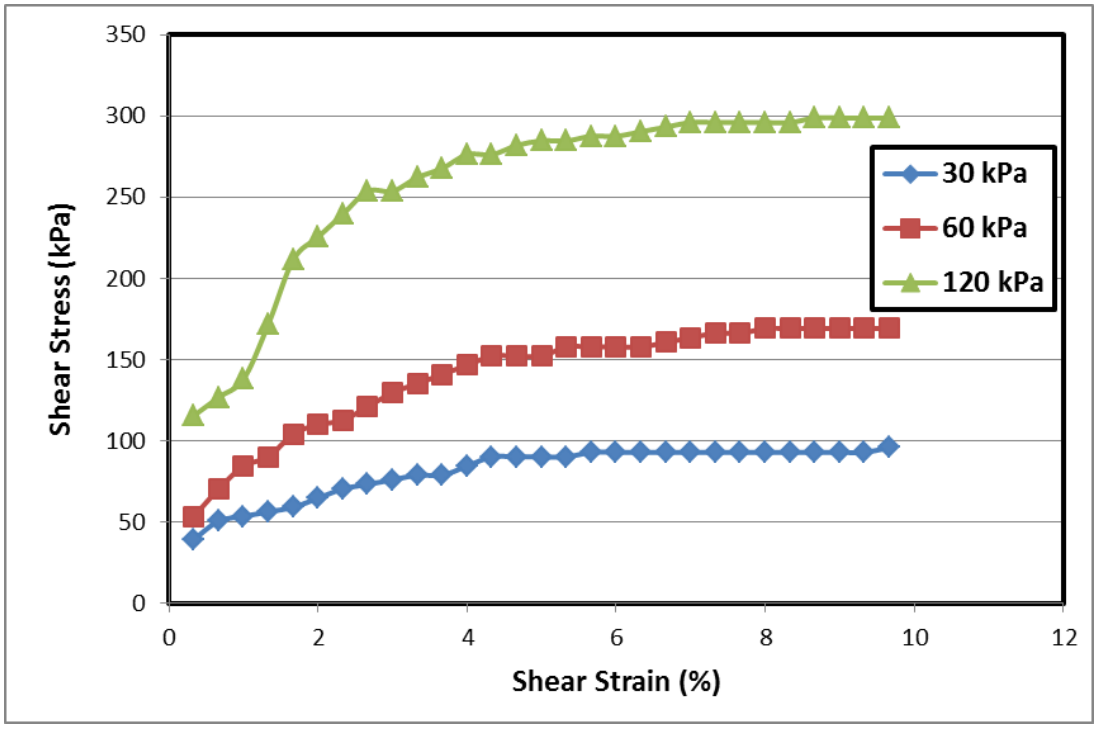


Figure 4.29: Shear stress-shear strain curves at 20% sand content for rough steel-organic soil with respect to rounded sand

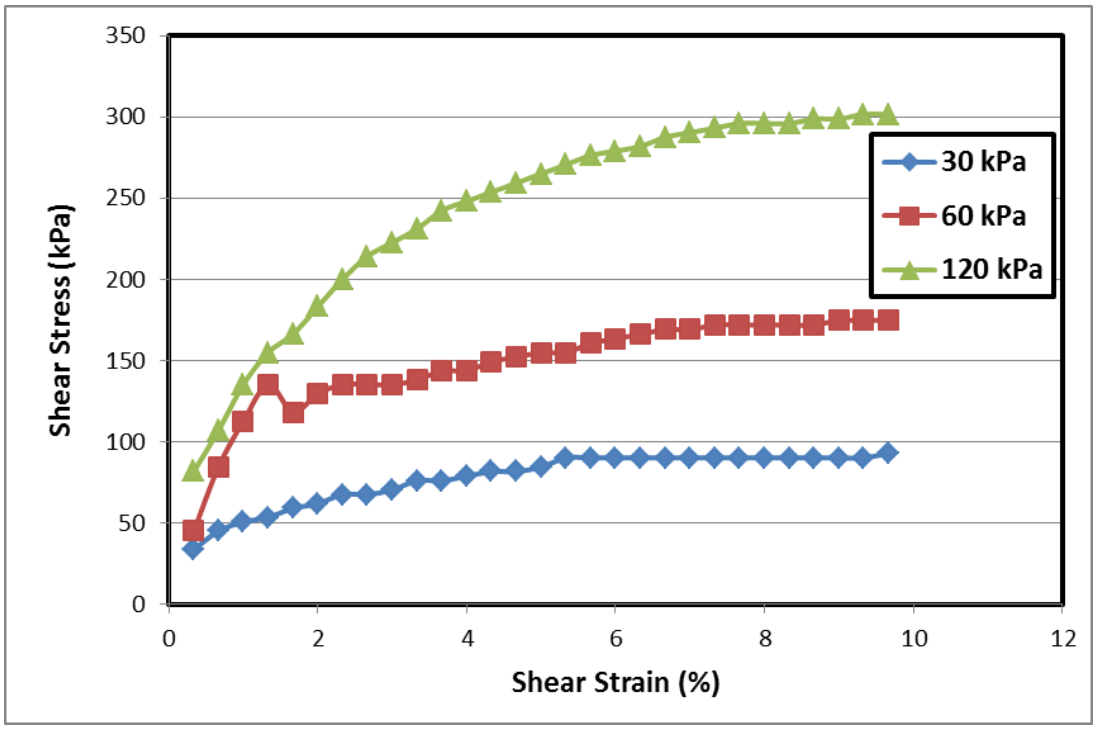


Figure 4.30: Shear stress-shear strain curves at 30% sand content for rough steel-organic soil with respect to rounded sand

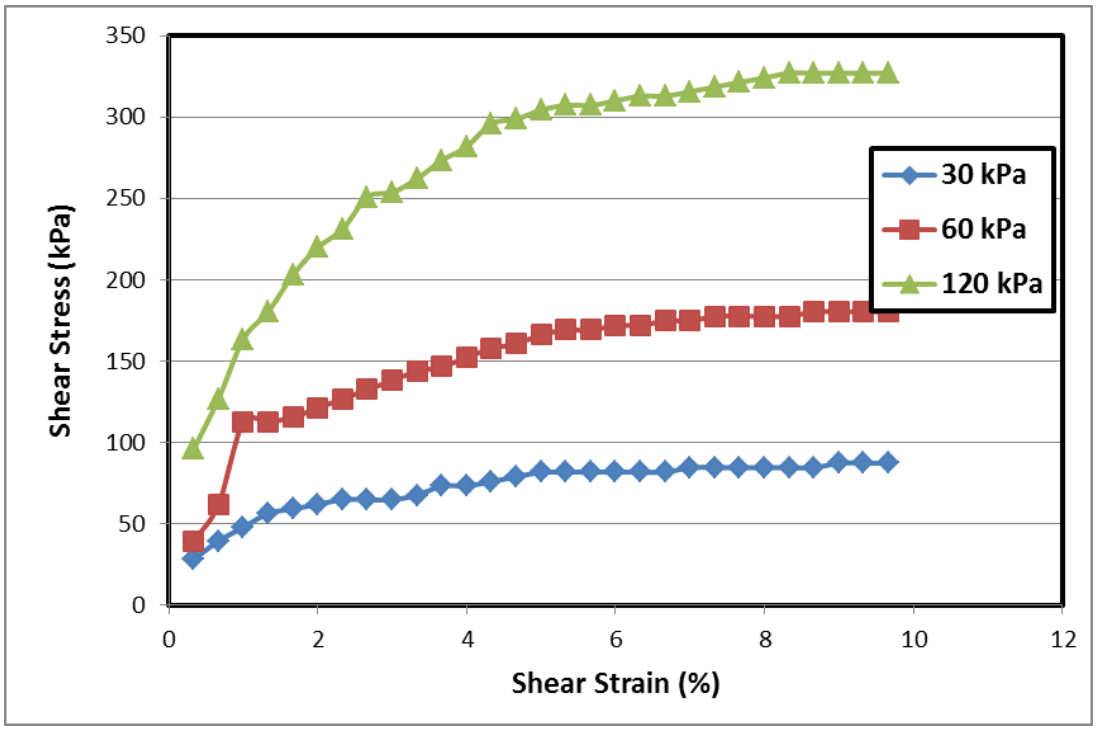


Figure 4.31: Shear stress-shear strain curves at 40% sand content for rough steel-organic soil with respect to rounded sand

#### 4.2.2.3 Smooth steel-Organic soil with respect to rounded sand

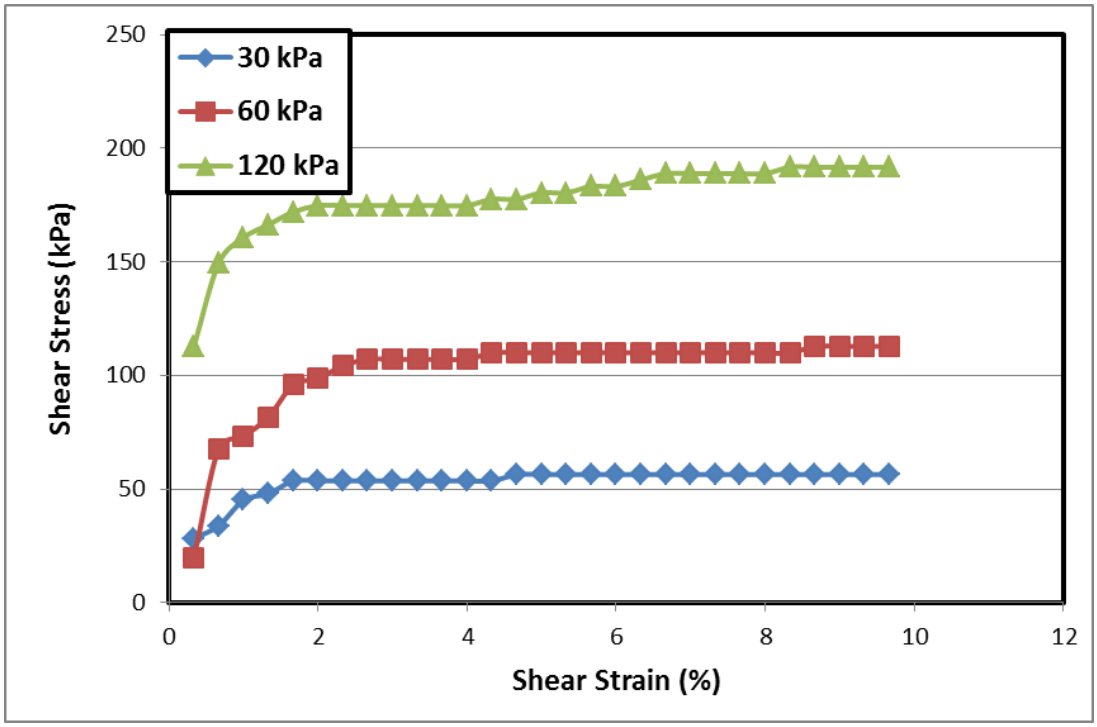


Figure 4.32: Shear stress-shear strain curves at 0% sand content for smooth steel-organic soil with respect to rounded sand

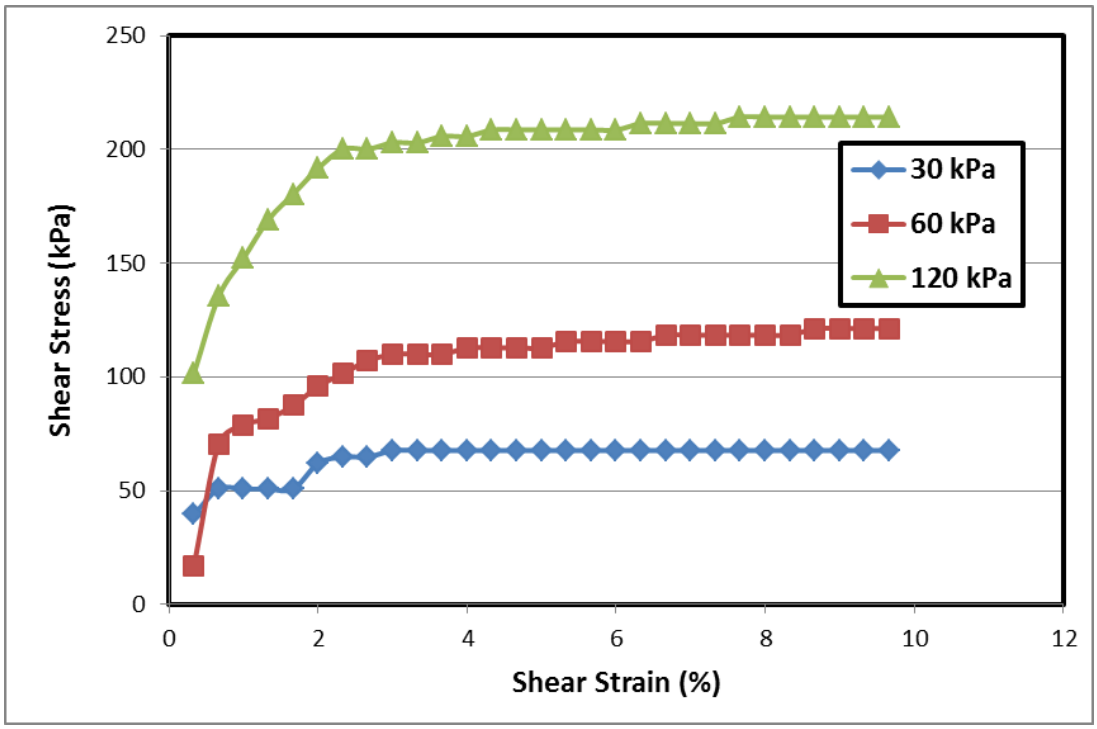


Figure 4.33: Shear stress-shear strain curves at 10% sand content for smooth steel-organic soil with respect to rounded sand

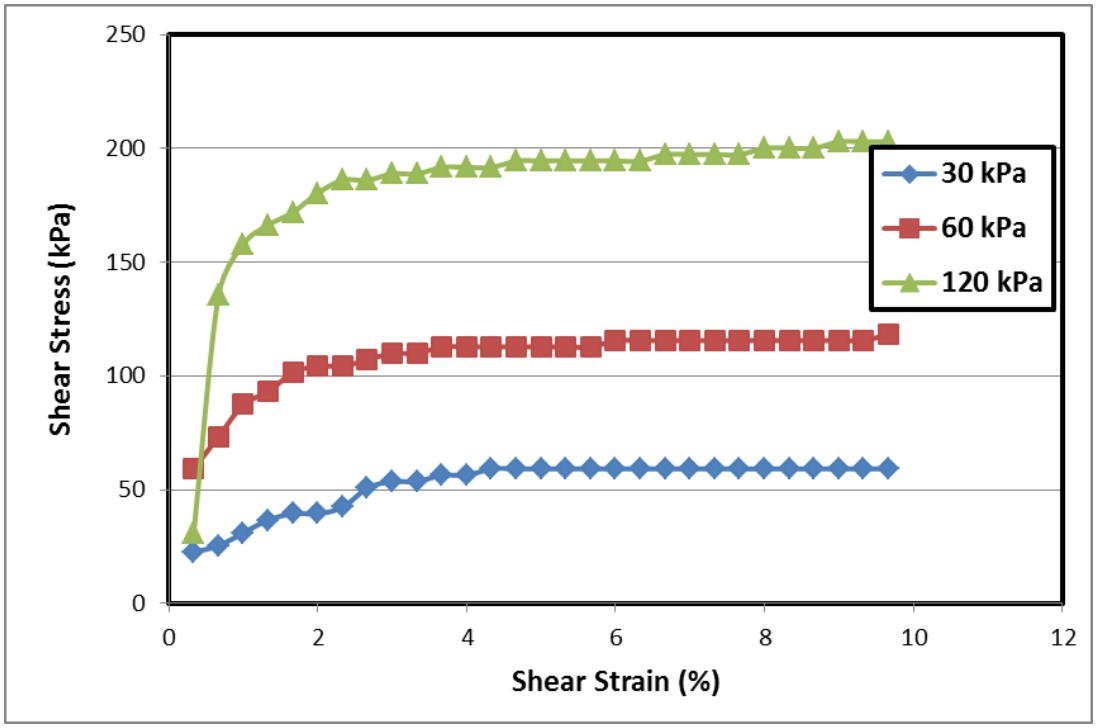


Figure 4.34: Shear stress-shear strain curves at 20% sand content for smooth steel-organic soil with respect to rounded sand

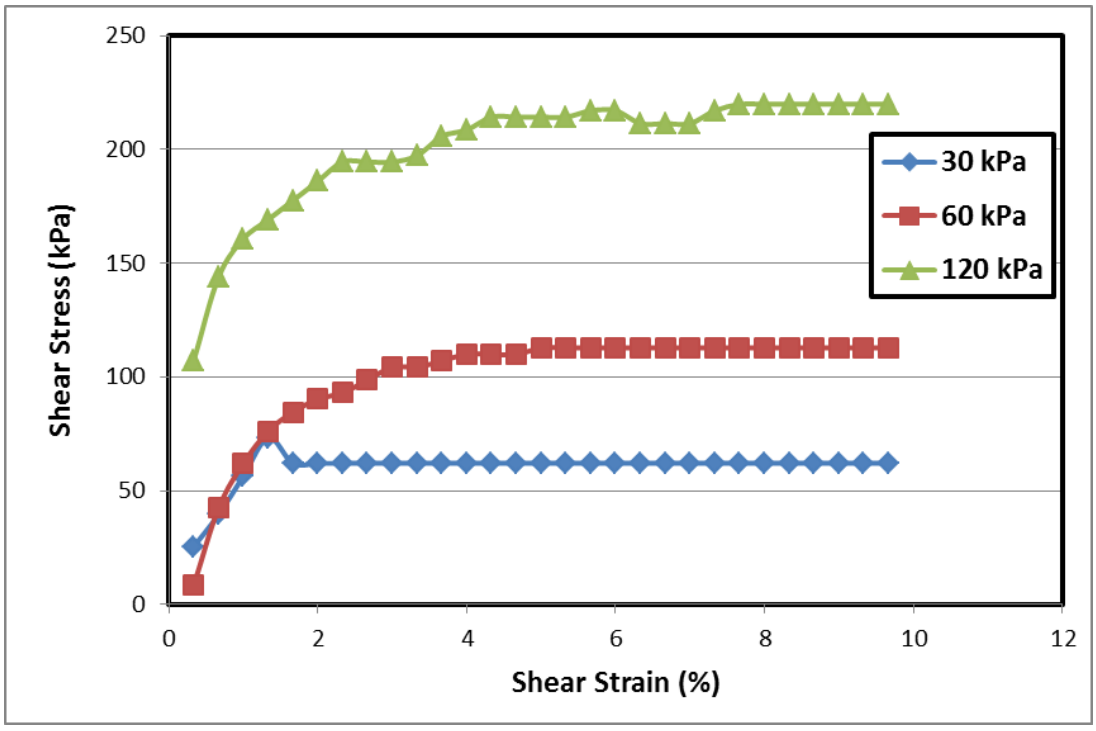


Figure 4.35: Shear stress-shear strain curves at 30% sand content for smooth steel-organic soil with respect to rounded sand

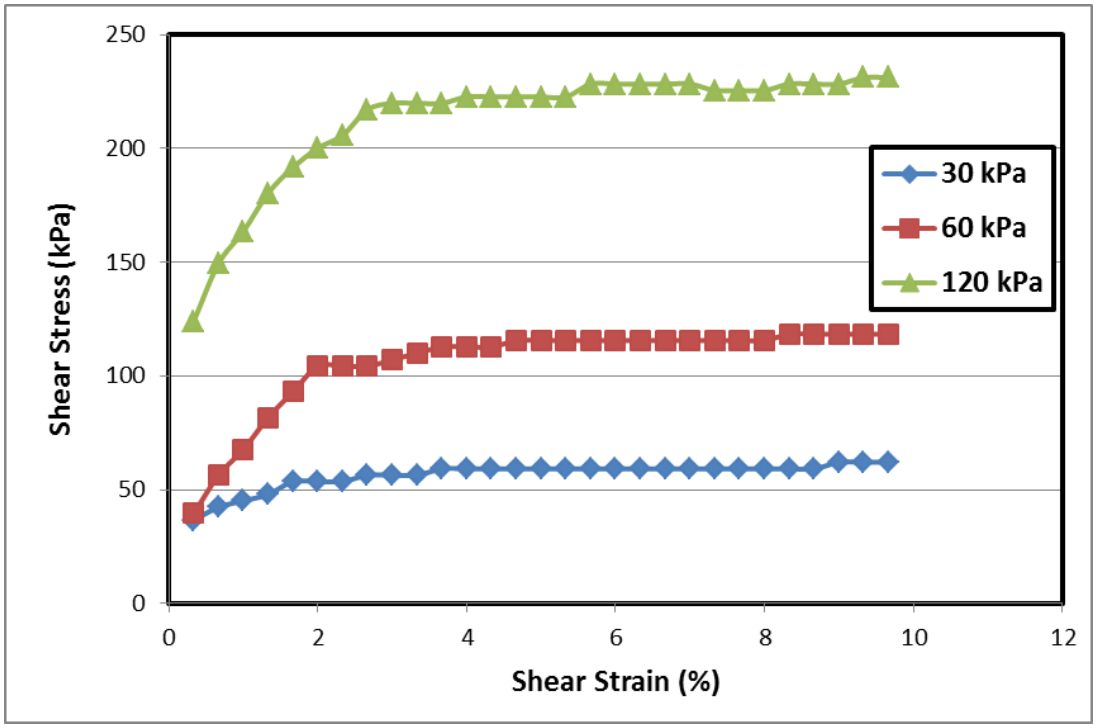


Figure 4.36: Shear stress-shear strain curves at 40% sand content for smooth steel-organic soil with respect to rounded sand

#### 4.2.2.4 Wood-Organic soil with respect to rounded sand

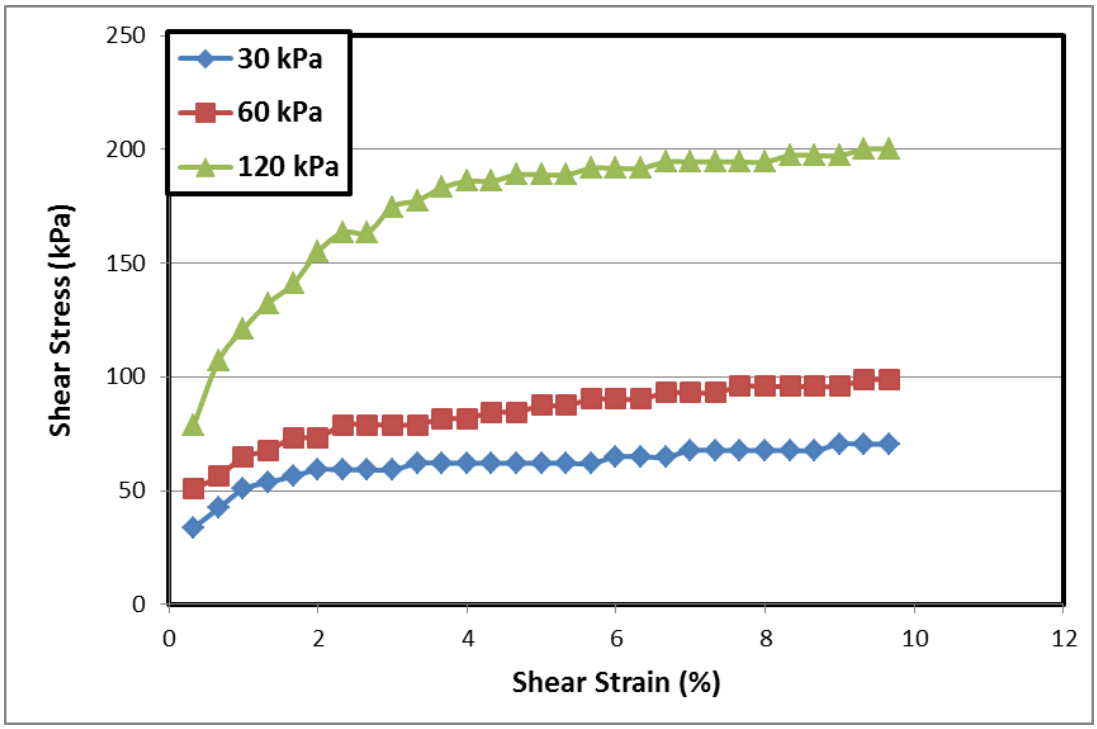


Figure 4.37: Shear stress-shear strain curves at 0% sand content for wood-organic soil with respect to rounded sand

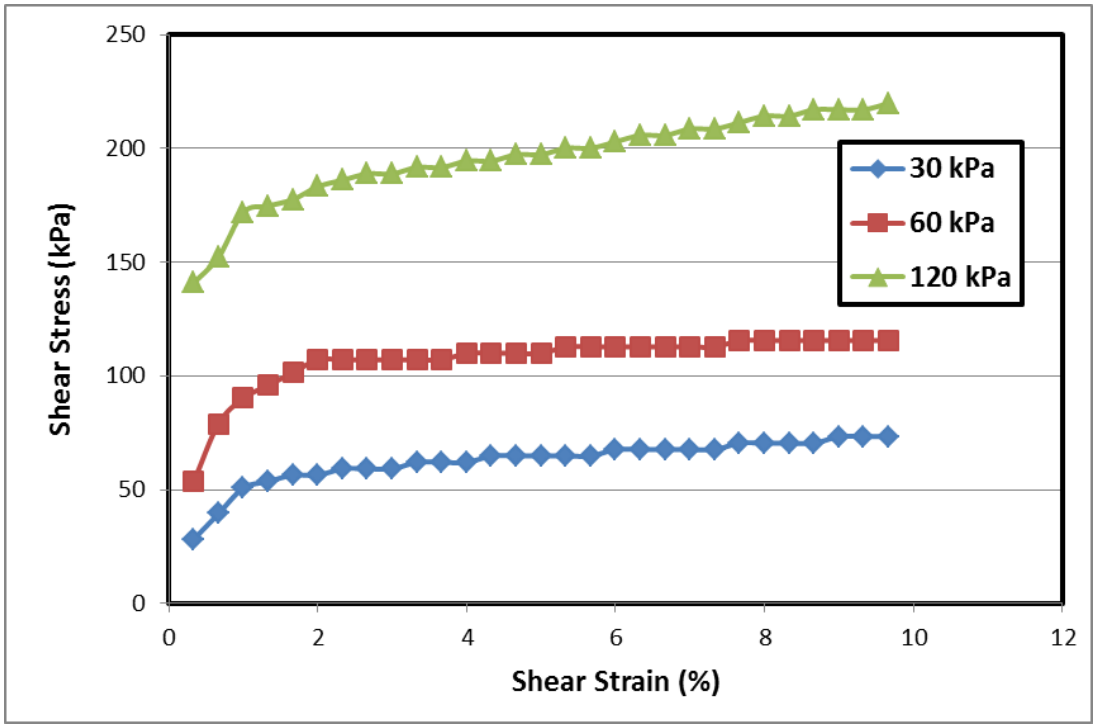


Figure 4.38: Shear stress-shear strain curves at 10% sand content for wood-organic soil with respect to rounded sand

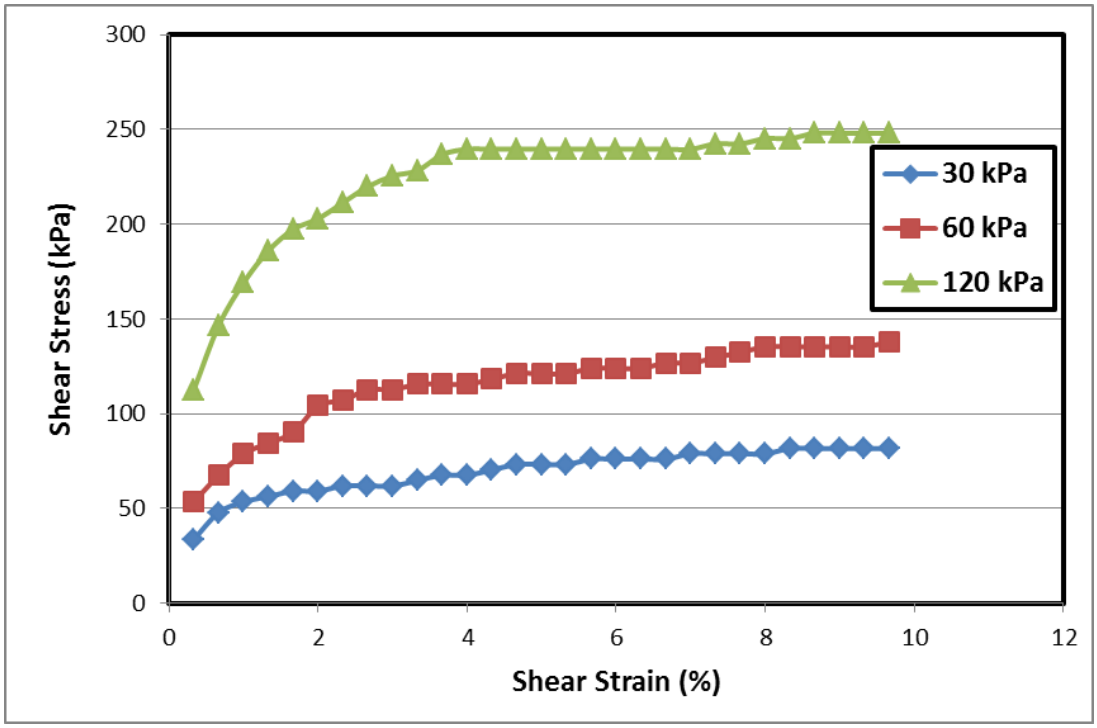


Figure 4.39: Shear stress-shear strain curves at 20% sand content for wood-organic soil with respect to rounded sand

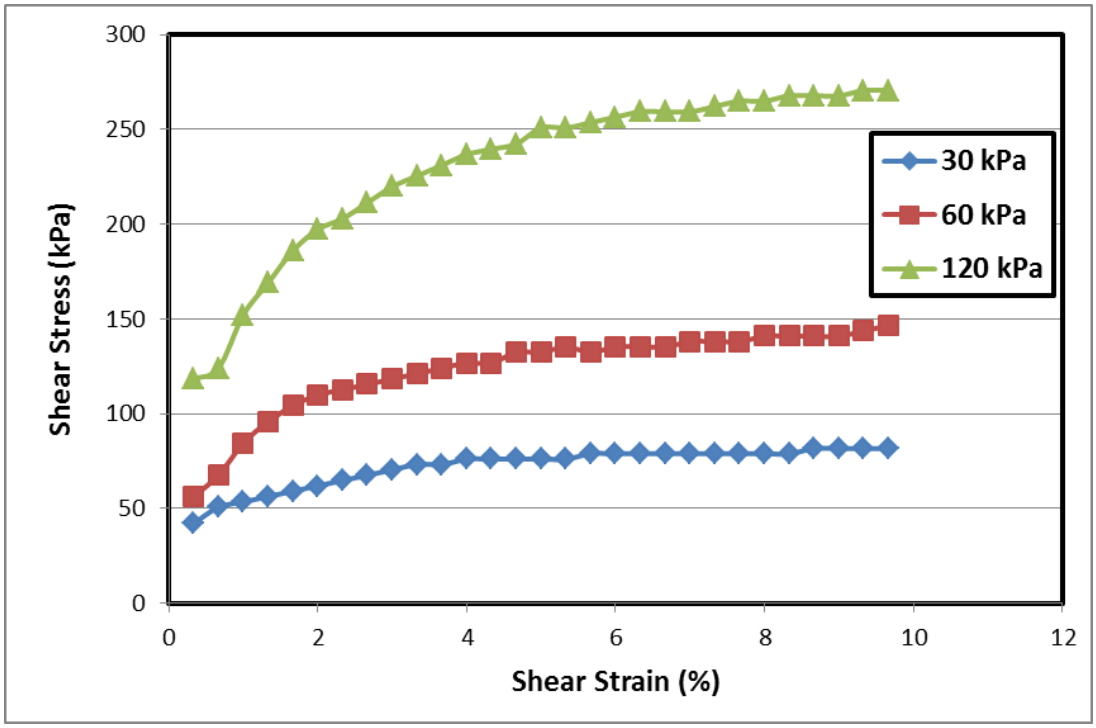


Figure 4.40: Shear stress-shear strain curves at 30% sand content for wood-organic soil with respect to rounded sand

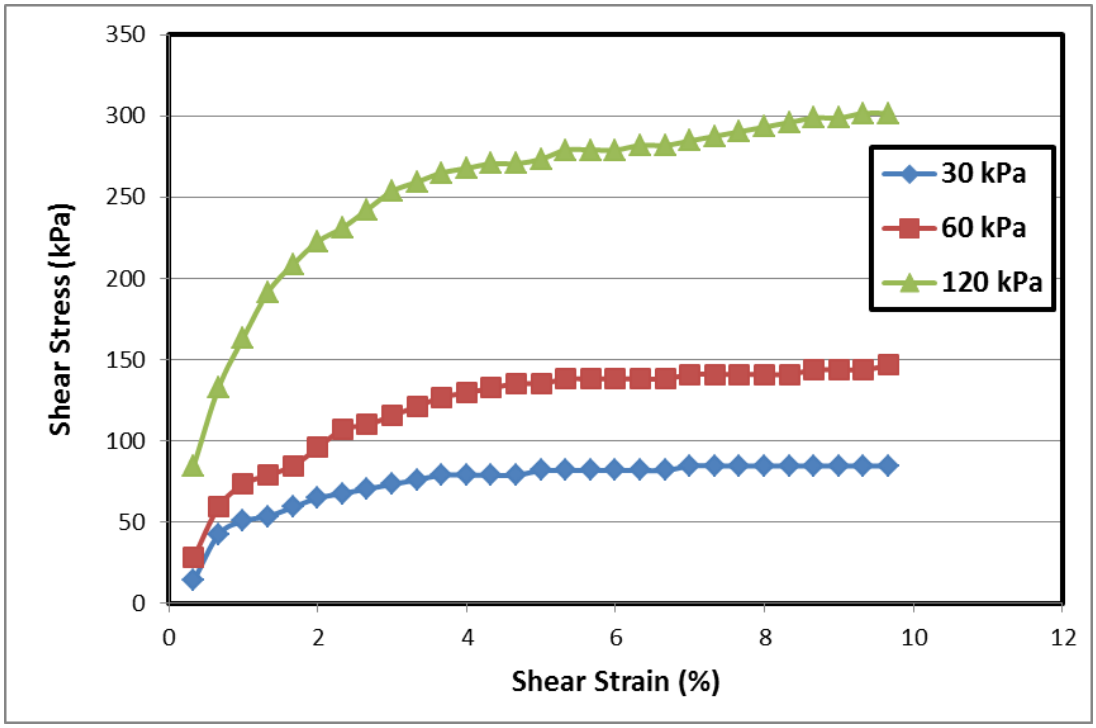


Figure 4.41: Shear stress-shear strain curves at 40% sand content for wood-organic soil with respect to rounded sand

### 4.3 The horizontal shear displacement –vertical deformation

Figure 4.42a-b shows typical results of horizontal shear displacement versus vertical displacement of the interface between organic soil containing 40% crushed and rounded sand and construction materials under 120 kPa normal stress. The larger vertical displacement was observed for the specimens under an applied normal stress of 120 kPa due to higher reduction of local voids associated with higher applied normal stress for all interface surfaces (Plesha, 1987; Kamari and Stead, 2008). The possible reason for this behavior is that the relatively high applied normal stresses degraded the organic soil and thus, underwent high vertical deformation during shearing. The effect of granular content in the organic soil has very little effect on the vertical displacement during shearing on construction material interface. This may be due to embedment of sand particles in to the soft organic soil at the interface, which thus did not reduced vertical deformation. Typical results of horizontal shear displacement versus vertical displacement of the interface between organic soil containing 0%-40% crushed and rounded sand and construction materials (concrete, rough steel, smooth steel and wood) under 30 kPa, 60 kPa and 120 kPa normal stresses are given in Appendix-A.

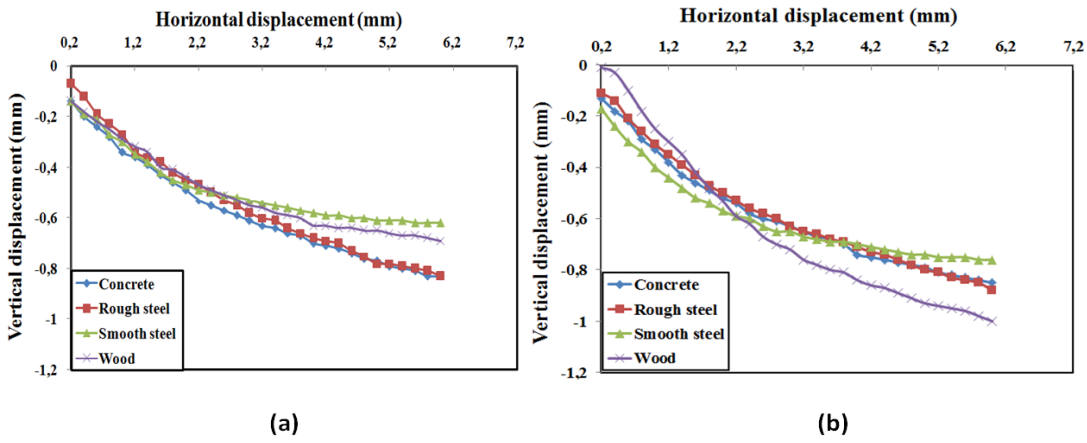


Figure 4.42: Vertical displacement-horizontal displacement curve for 120 kPa normal load; a) Crushed sand-%40 sand content, b) Rounded sand-%40 sand content.

### 4.4 The shear strength envelopes

Figure 4.43-4.48 show typical interface shear strength envelopes for construction material and organic soil mixed with rounded and angular sand. These envelopes were

drawn by using three normal stresses and corresponding shear stresses for each test. A linear regression line was fitted through the set of interface shear stress vs. normal stresses data. The strength values of all the tests were taken at 10% shear deformation and they provide an excellent straight line fit with $R^2$ values around 0.99. For each regression line, values of interface friction angles and adhesions were obtained from linear curves shown in figure 4.43-4.48. The results are reliable with expected trends in behavior where the shear strength increases with increasing normal stress. It can be seen from figure 4.43-4.46, that regardless of the type of construction material, the strength data can be well described by a Mohr–Coulomb failure criterion. It can also be seen from this figure that organic soil mixed with two types of sand showed relatively similar adhesion value, which were very small. As it is clearly seen from figure 4.43-4.46, the highest shear strength values were observed between organic soil and the concrete at all normal stresses. On the other hand, the smallest one was obtained when smooth steel was used. This can be explained by surface roughness of the construction materials used in the study. These results indicate that the values of shear stress are directly related to surface roughness. This finding concurs with the findings reported in existing literature (Potyondy 1961; Gireesha and Muthukkumaran 2011).

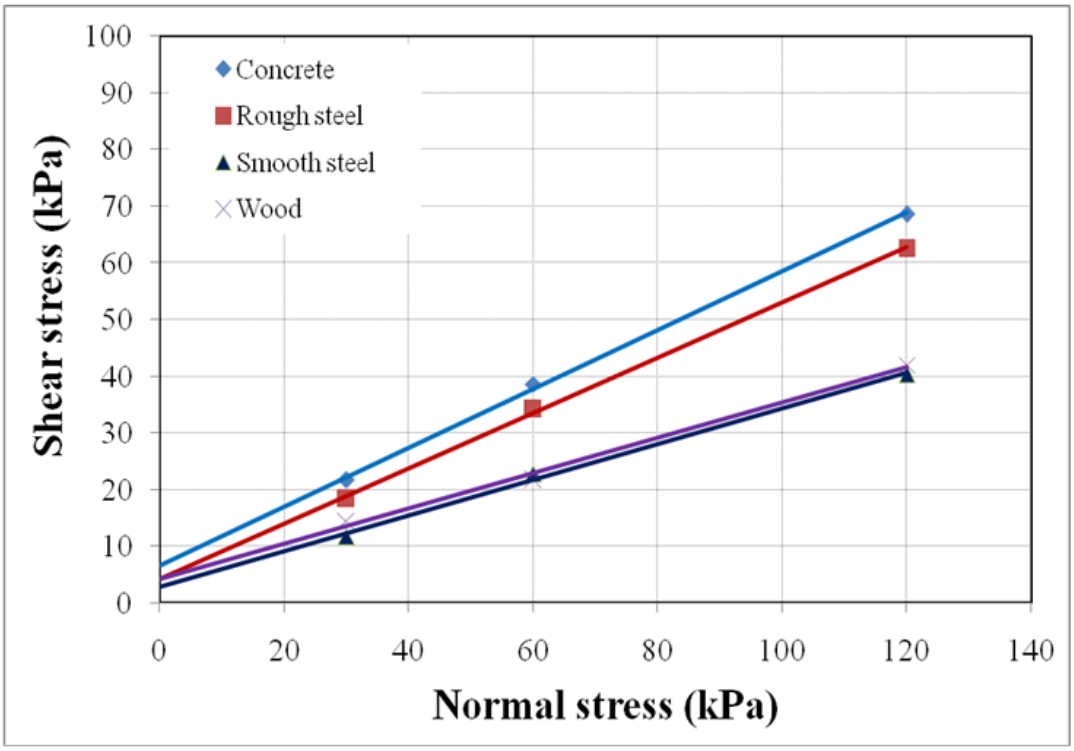


Figure 4.43: Shear envelopes for the organic soil–construction materials interfaces for 0% crushed sand content

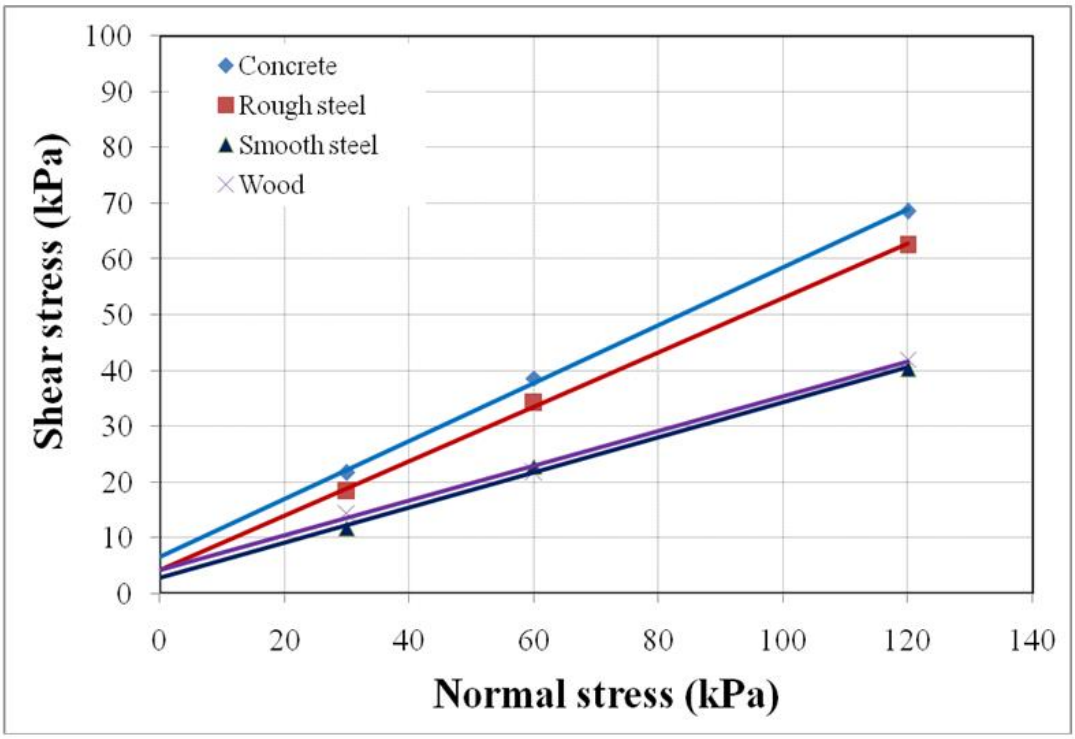


Figure 4.44: Shear envelopes for the organic soil–construction materials interfaces for 40% crushed sand content

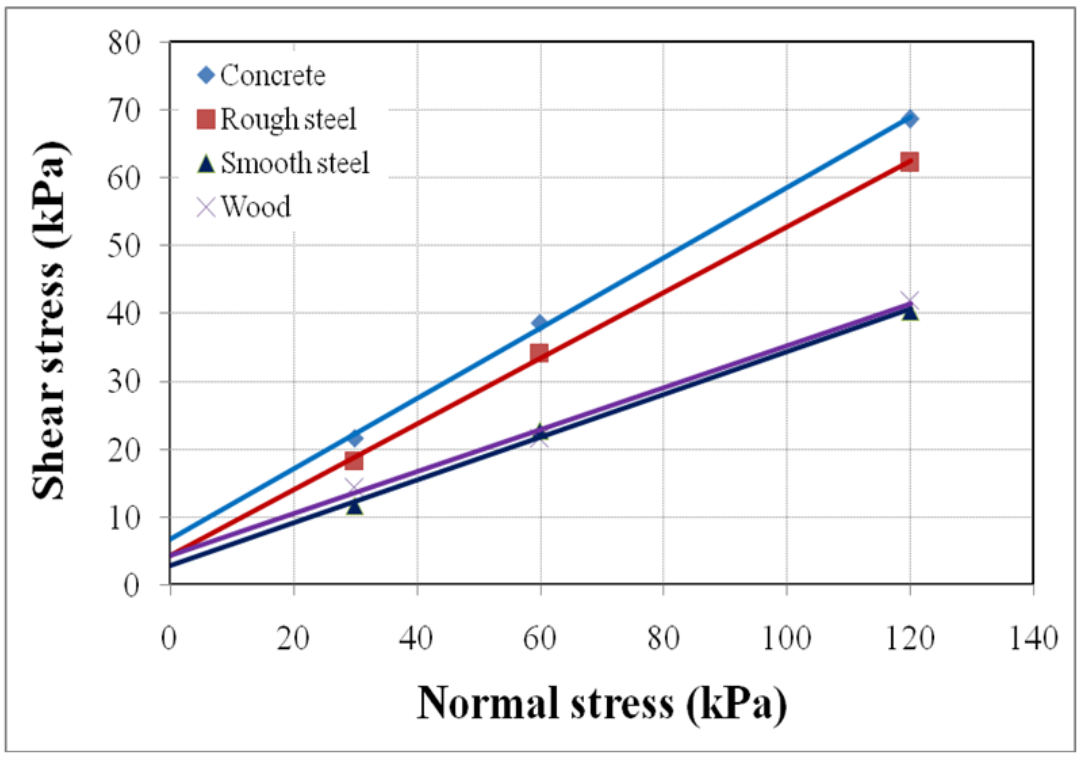


Figure 4.45: Shear envelopes for the organic soil–construction materials interfaces for 0% rounded sand content

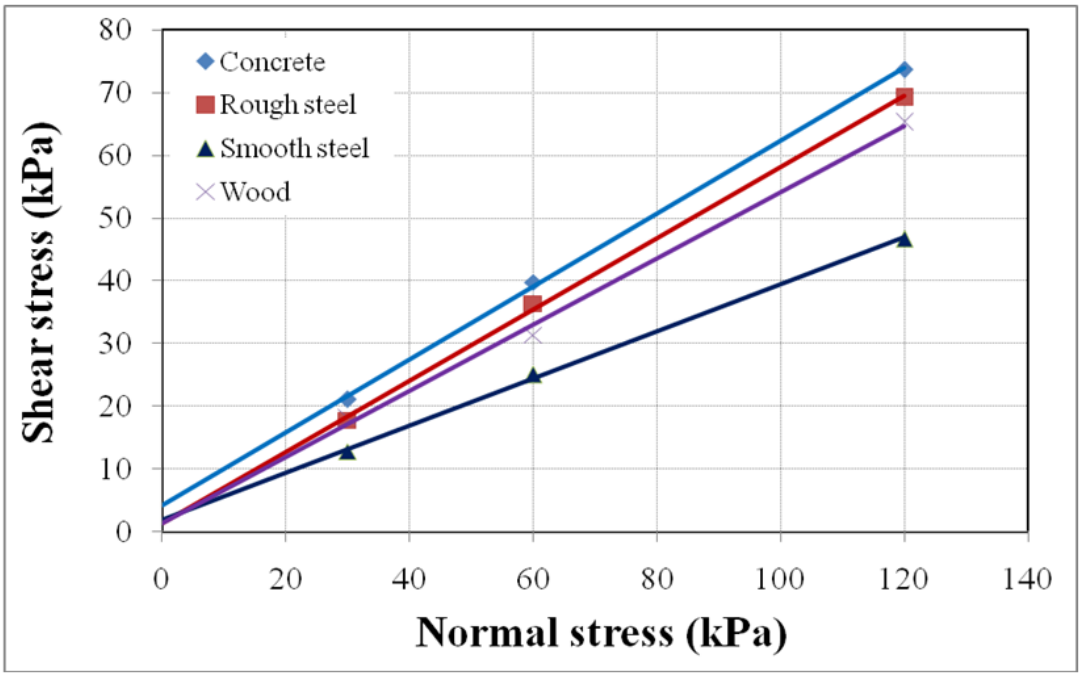


Figure 4.46: Shear envelopes for the organic soil–construction materials interfaces for 40% rounded sand content

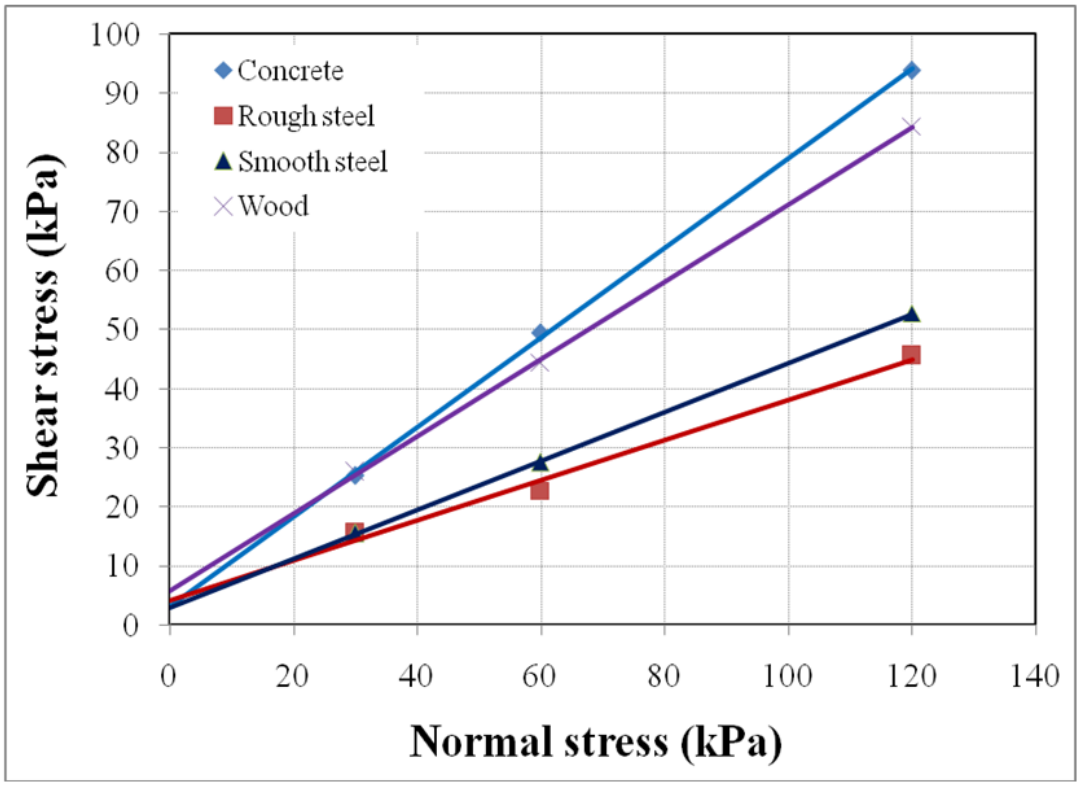


Figure 4.47: Shear envelopes for the organic soil–construction materials interfaces for 40% granular soil at dry condition

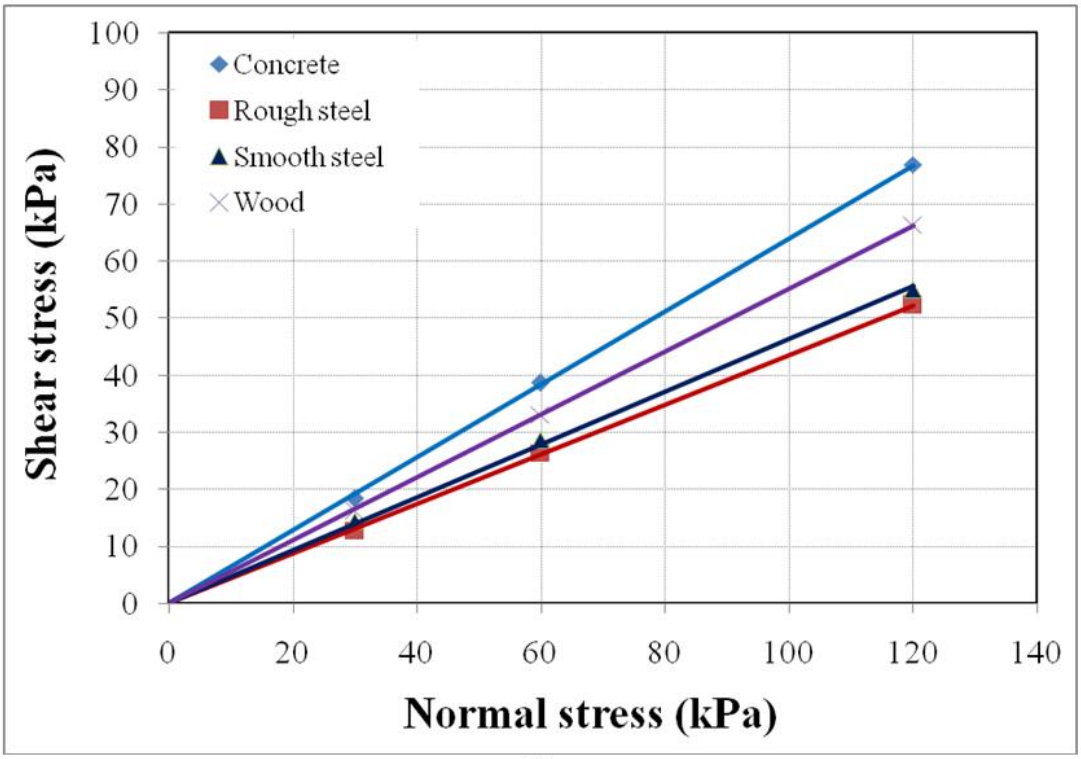


Figure 4.48: Shear envelopes for the organic soil–construction materials interfaces for 40% granular soil at 40% water content

Figure 4.47-4.48 clearly shows that the increase of water content decreases the interface shear strength between the soil-concrete and soil-wood. On the other hand, water has very limited effect on the interface shear strength between soil-steel. This can be explained by the addition of water in organic soil increasing the slipperiness of the surface of construction materials and thus reducing shear stress in the interface.

### 4.5 The interface friction angle-sand content relations on construction materials

The comparison of the results of interface shear tests presented above suggest that the sand and water content of organic soil have a significant impact on the mechanical behavior at the interface between organic soil-sand mixtures and construction materials (Figures 4.49-4.50). The results also show that there is a general trend of increase of interface friction angle of organic soil having granular soil and construction materials interface with increasing sand content. The frictional resistance between the construction materials and individual sand particles can explain this. The highest interface friction angles at different sand contents were observed in concrete interface. On the other hand, the smallest ones were observed for smooth steel at same condition (Tiwari and Al-Adhadh, 2014). Moreover, as it is clearly seen from figures 4.49-4.50, the shape of sand in the organic soil (crushed or rounded) does not have so much effect on the interface friction angle.

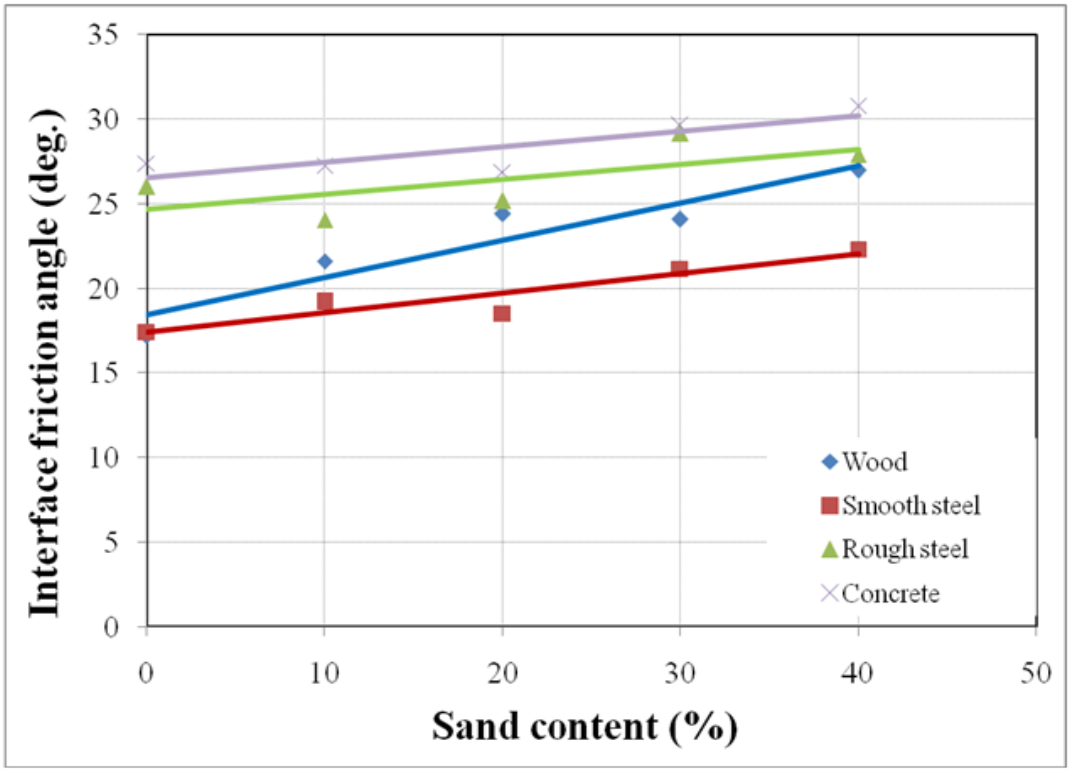


Figure 4.49: Changes in interface friction angle with respect to shape of sand (w=75%) for crushed sand

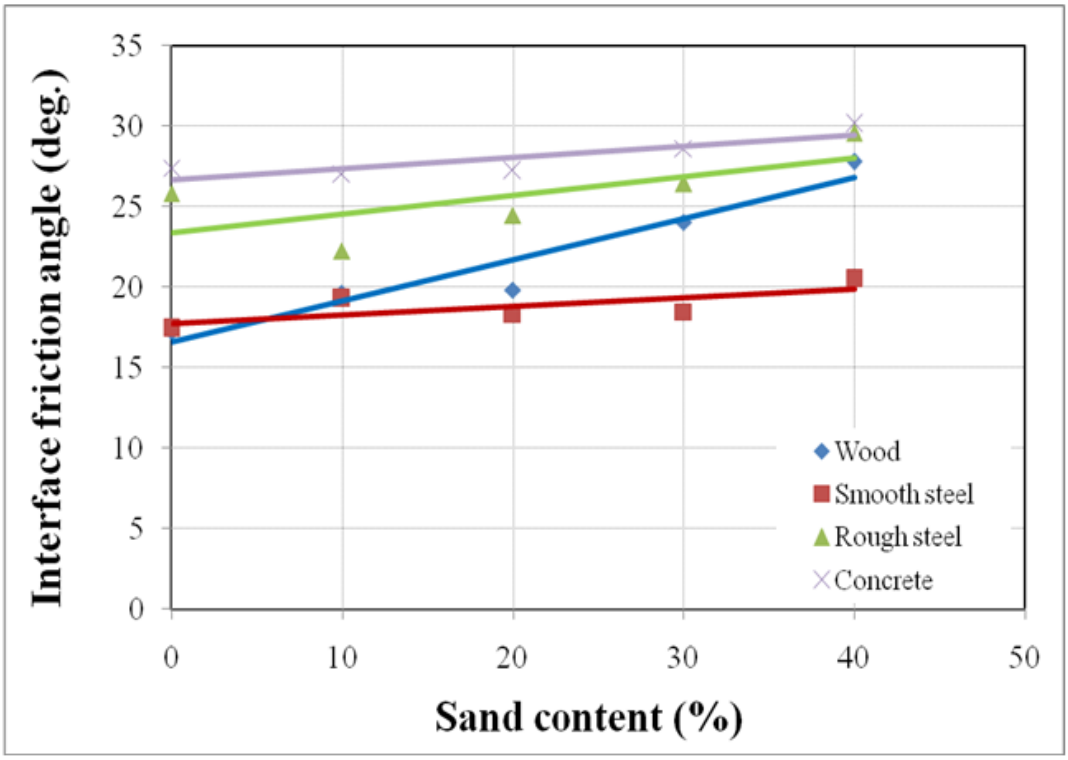


Figure 4.50: Changes in interface friction angle with respect to shape of sand (w=75%) for rounded sand

### 4.6 The interface friction angle-water content relations on construction materials

Figure 4.51 shows the effect of water content on interface friction angle between organic soil and construction materials. As it is seen from the graph, concrete and wood were affected by the water content. Increase in water content of the organic soil caused reduction in interface friction in these two materials. On the other hand, water has very limited effect on interface friction angle in steel.

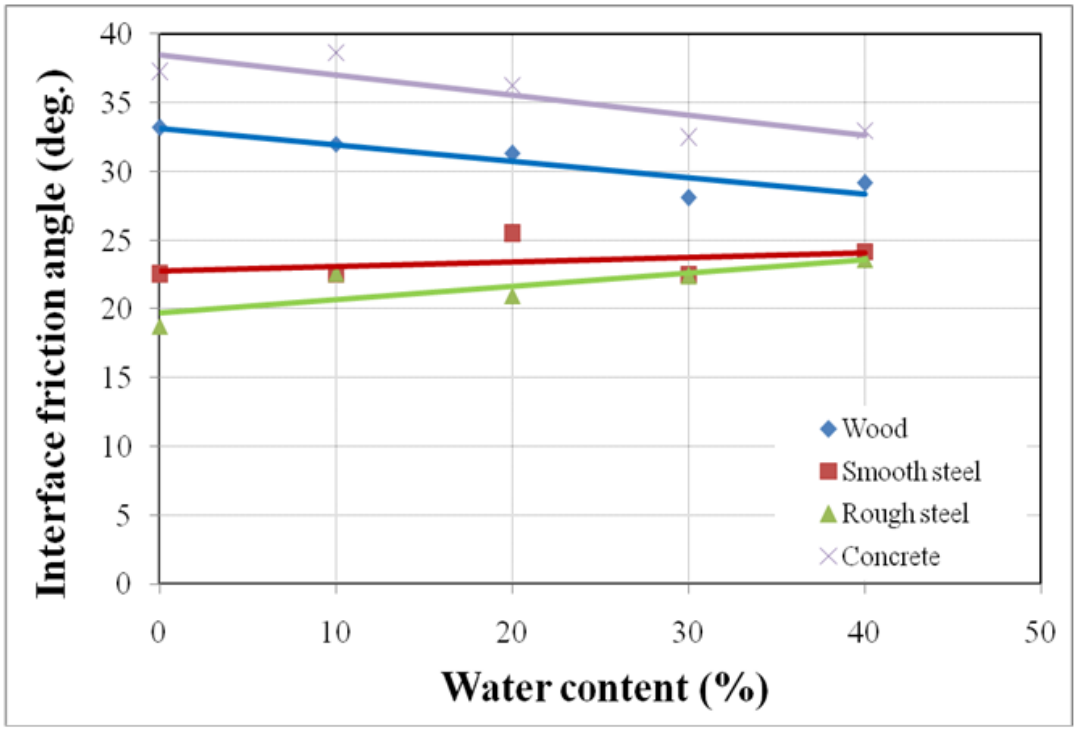


Figure 4.51: Effect of water content on interface friction angle

### 4.7 Coefficient of friction and surface roughness (Ra)

Coefficient of friction and surface roughness values (Ra) for construction materials are shown in figure 4.52a-b. As it is seen from the figures that the highest coefficient of friction (0.67) and surface roughness (330 µm) values were obtained in the concrete compared to the other construction materials. On the other hand, the smallest coefficient of friction (0.39) and surface roughness (35 µm) values were measured in smooth steel. The results showed that the coefficient of friction value was directly related to surface roughness (Ra) for organic soil.

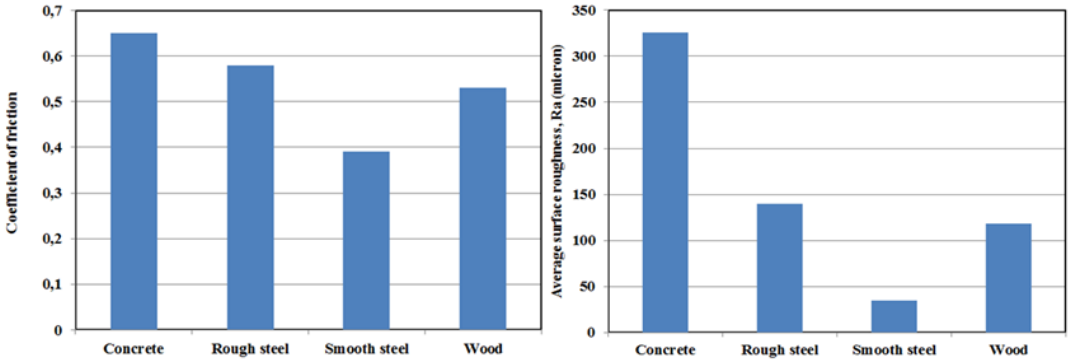


Figure 4.52: Friction parameters of the construction materials
a) coefficient of friction b) surface roughness

# CHAPTER 5

# CONCLUSION

In this study, the interface shear behavior of the organic soil and construction material was evaluated by using a direct shear test apparatus: following conclusions were drawn.

Test results showed that the highest interface friction angle was between organic soil and concrete when compared to other construction materials independent on the shape of granular soil in it. On the other hand, the lowest interface friction angle was observed in smooth steel. It was also found that the sand shape has no affect on interface friction for all construction material with added content for this study. Increase in water content of organic soil decreases the interface friction angle for the concrete and the wood. The study also showed that surface roughness (Ra) of the construction material and coefficient of interface friction angle are strongly related for organic soil.

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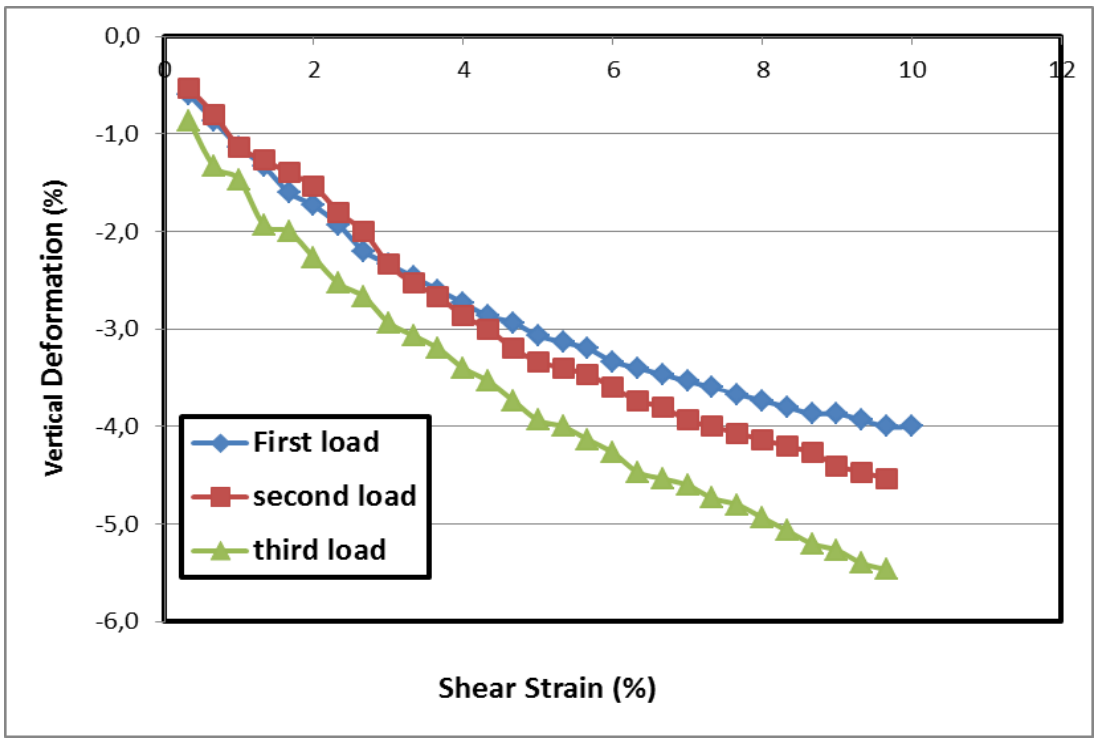
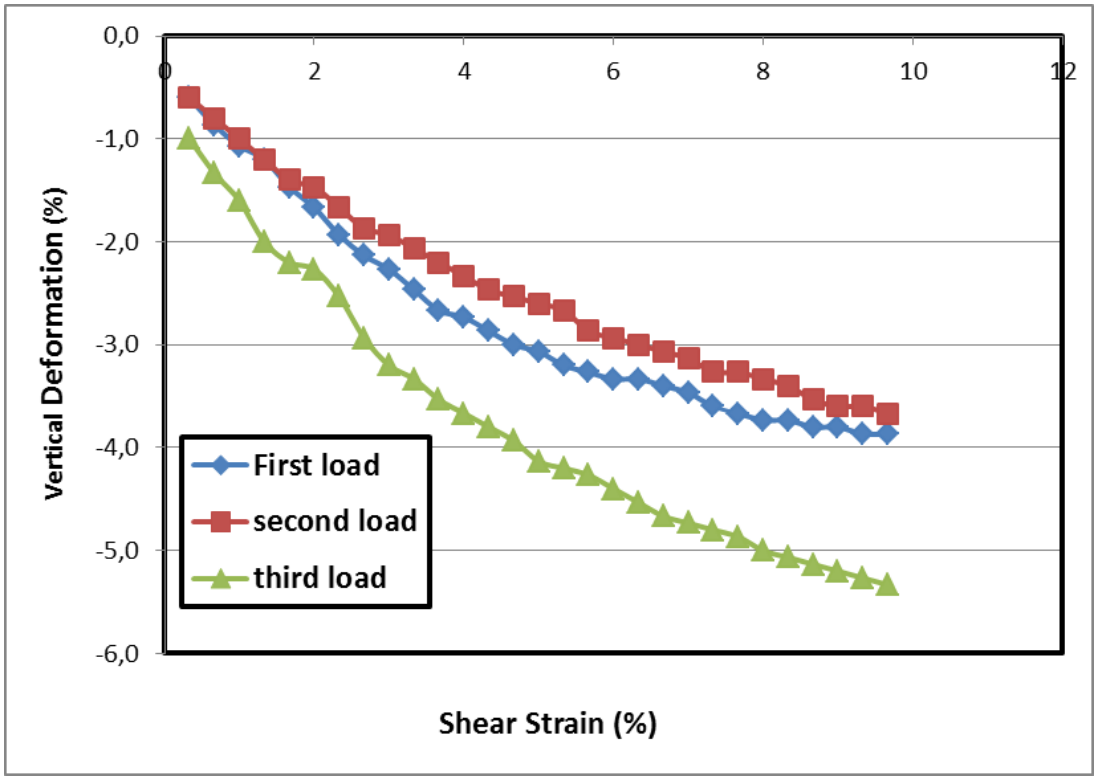
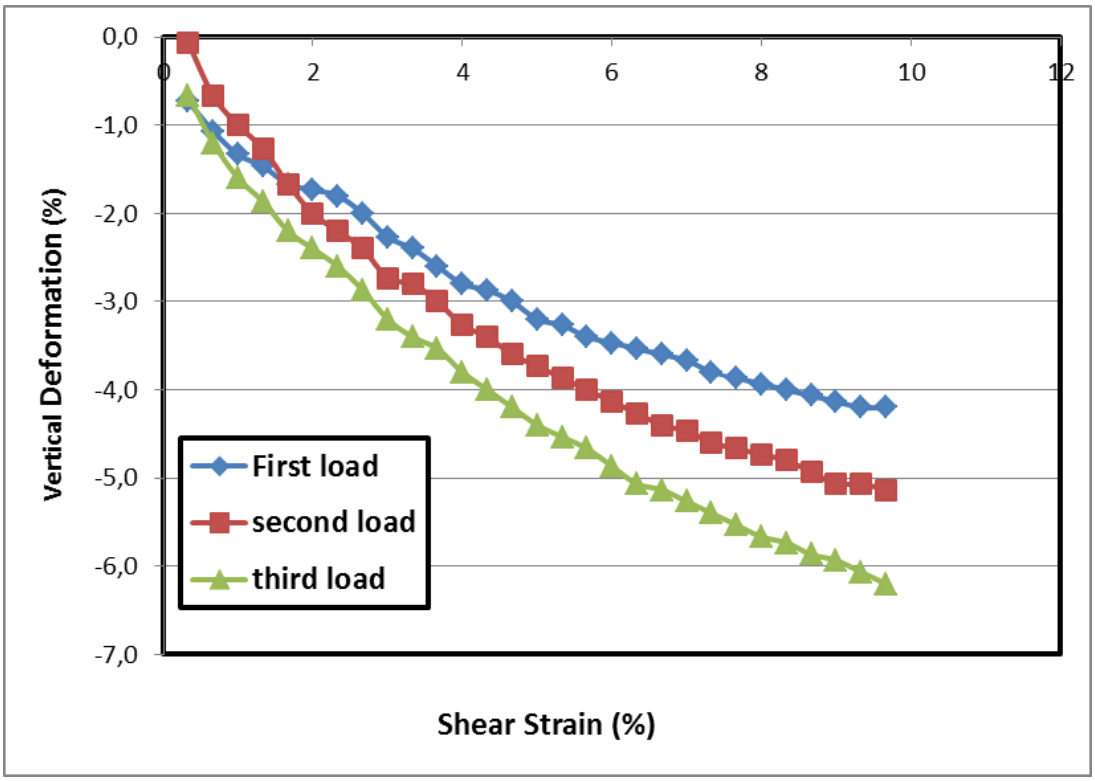
# Appendix A



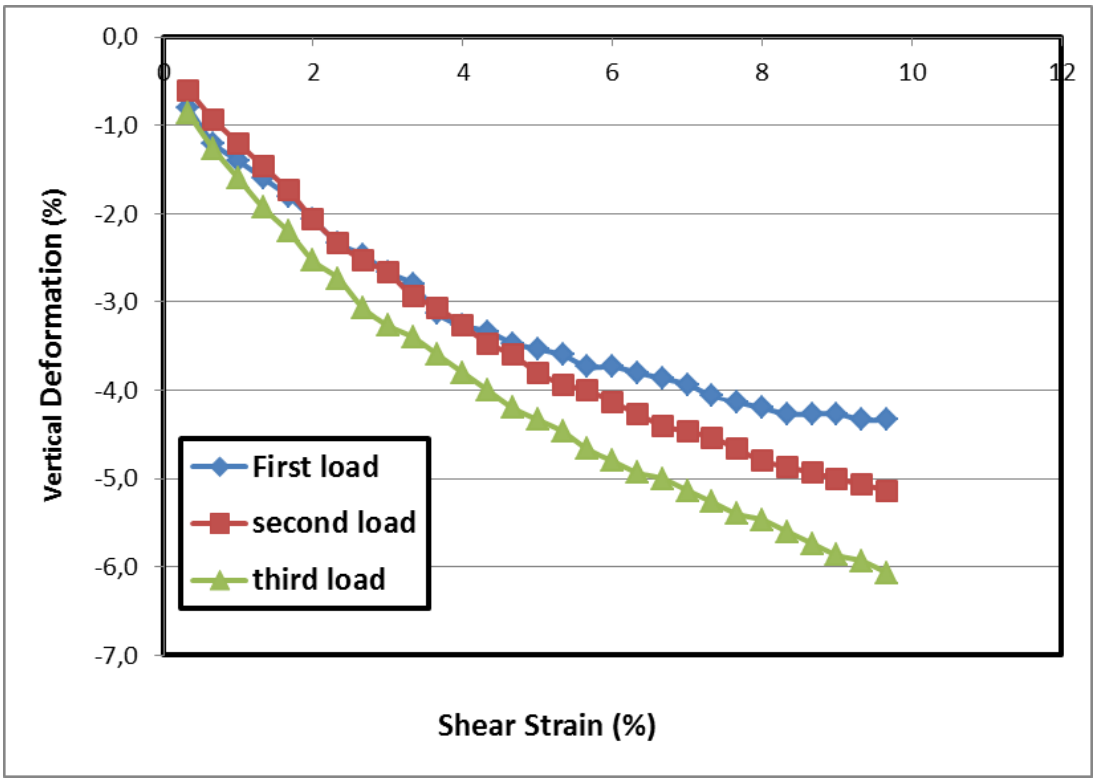

Apendix-A1: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %0 sand content.



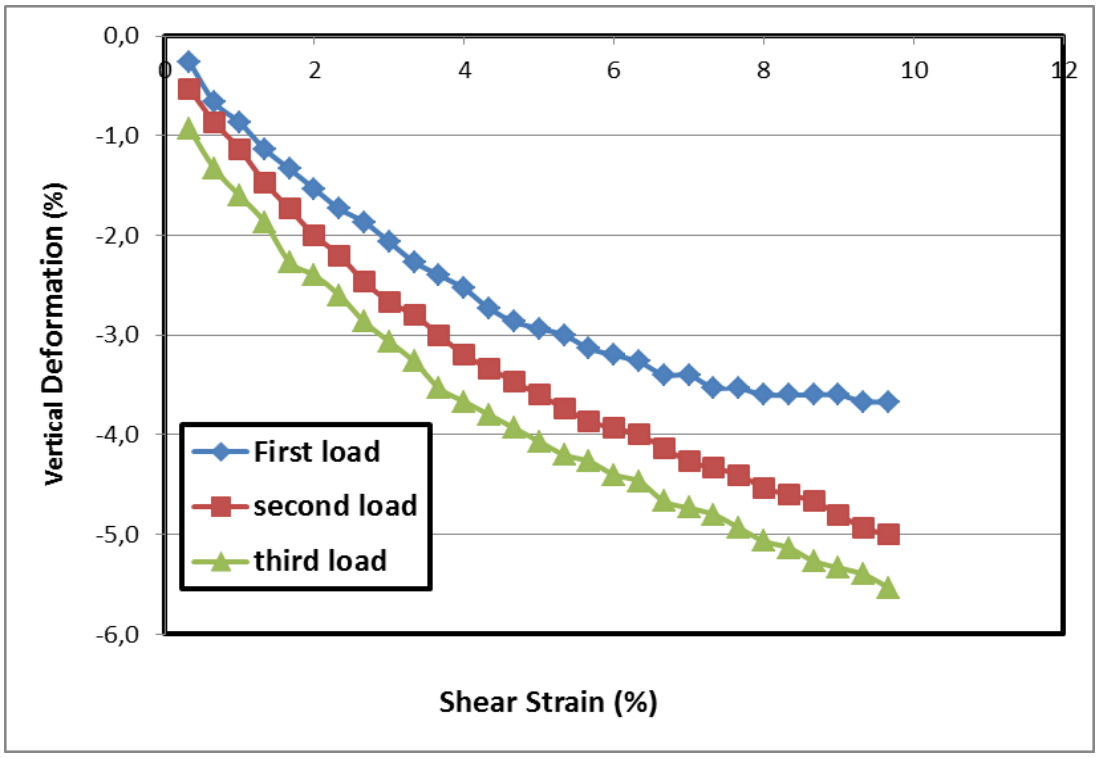

Apendix-A2: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %10 sand content.



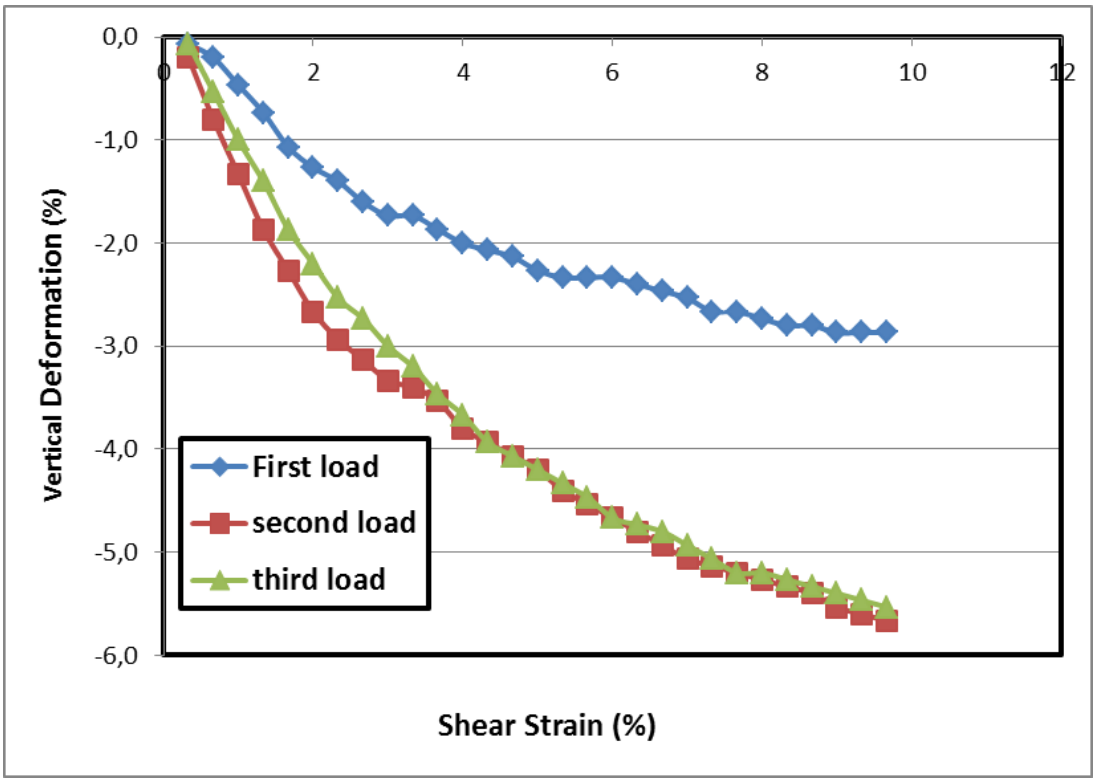

Apendix-A3: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %20 sand content.



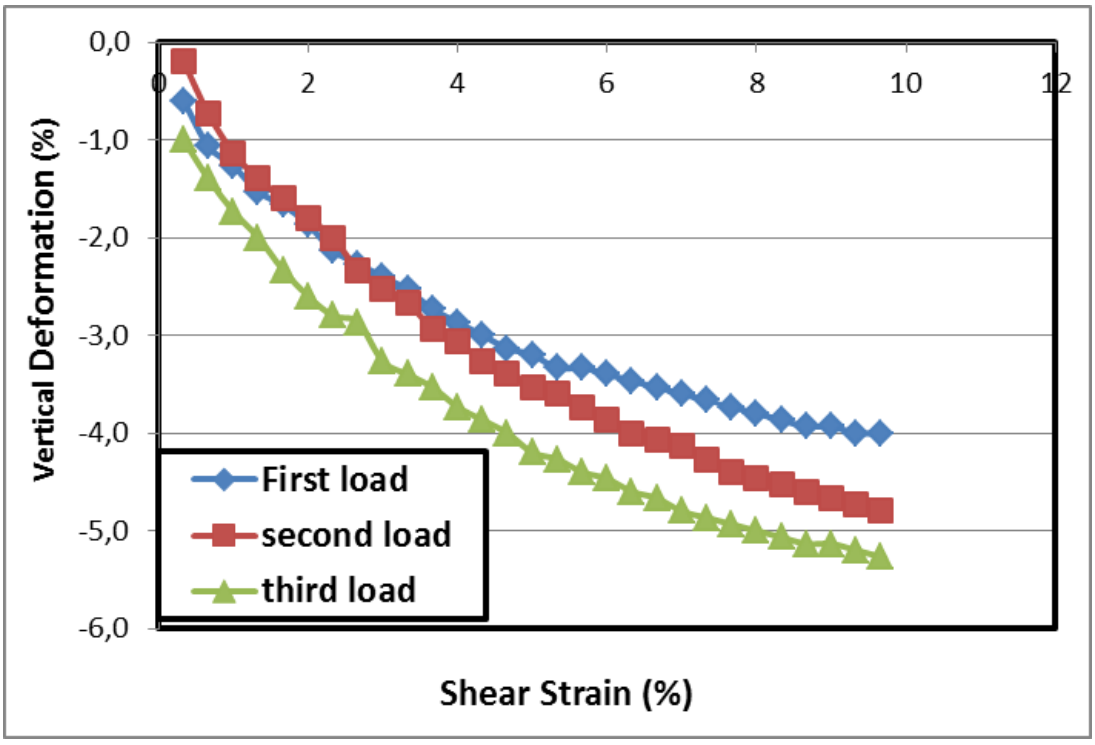

Apendix-A4: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %30 sand content.



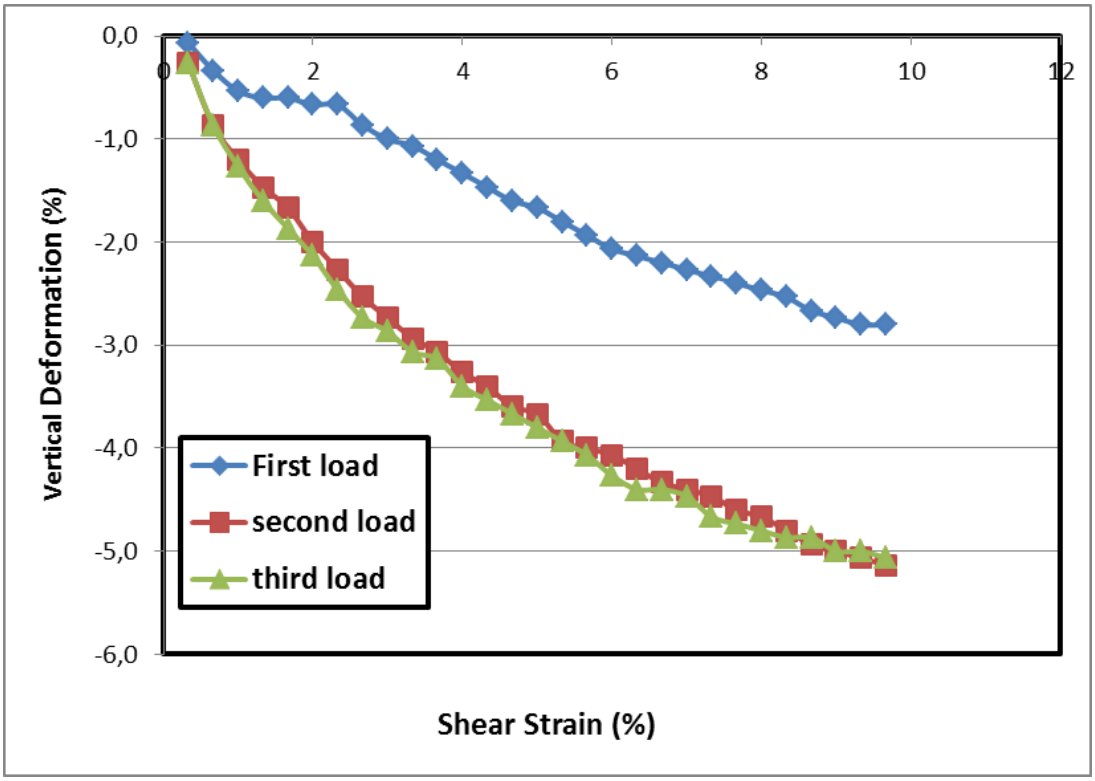

Apendix-A5: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %40 sand content.



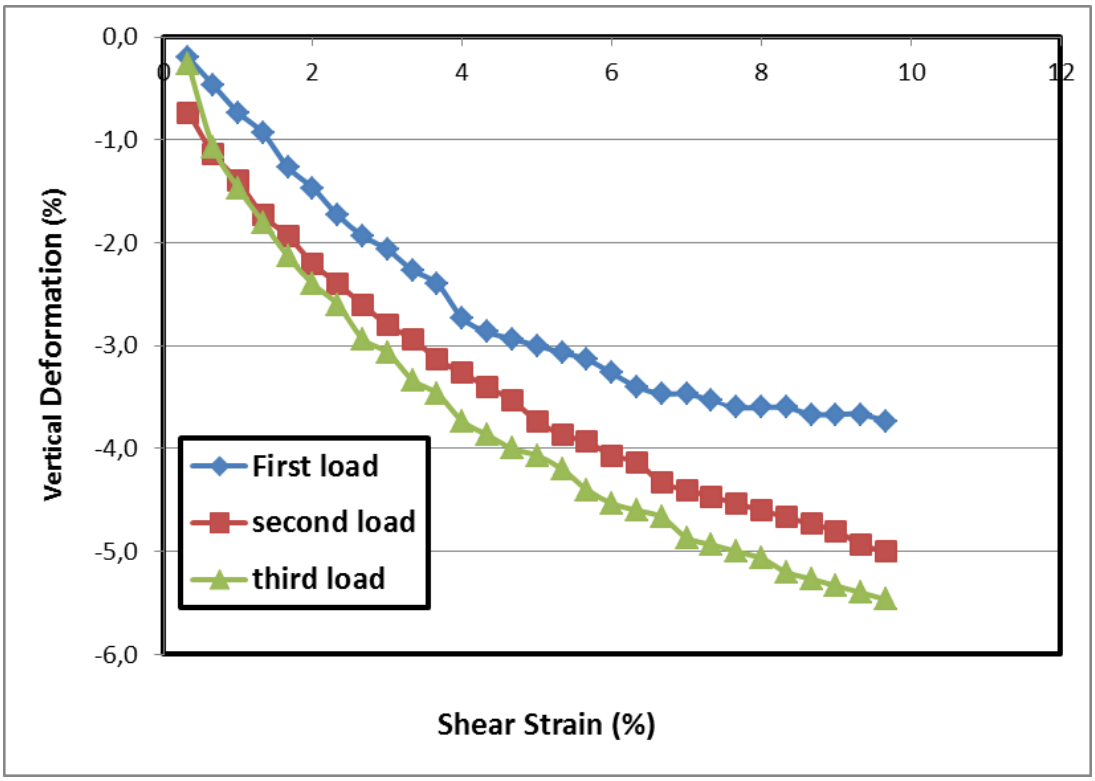

Apendix-A6: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %0 sand content.



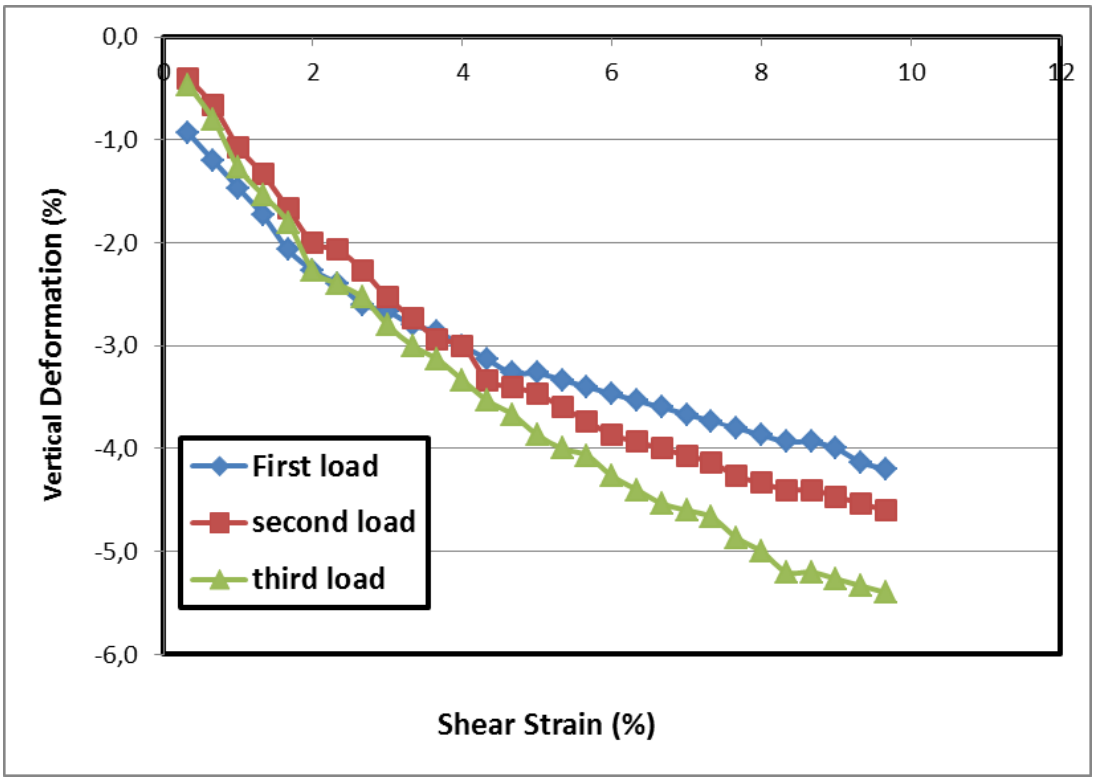

Apendix-A7: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %10 sand content.



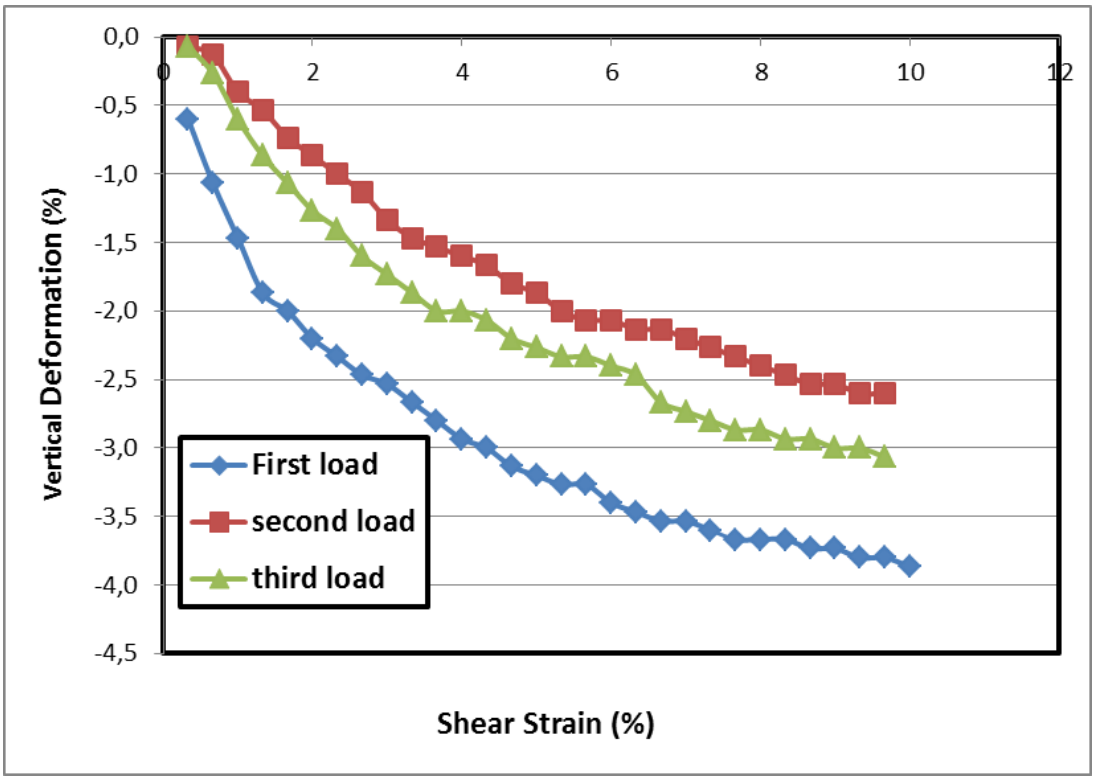

Apendix-A8: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %20 sand content.



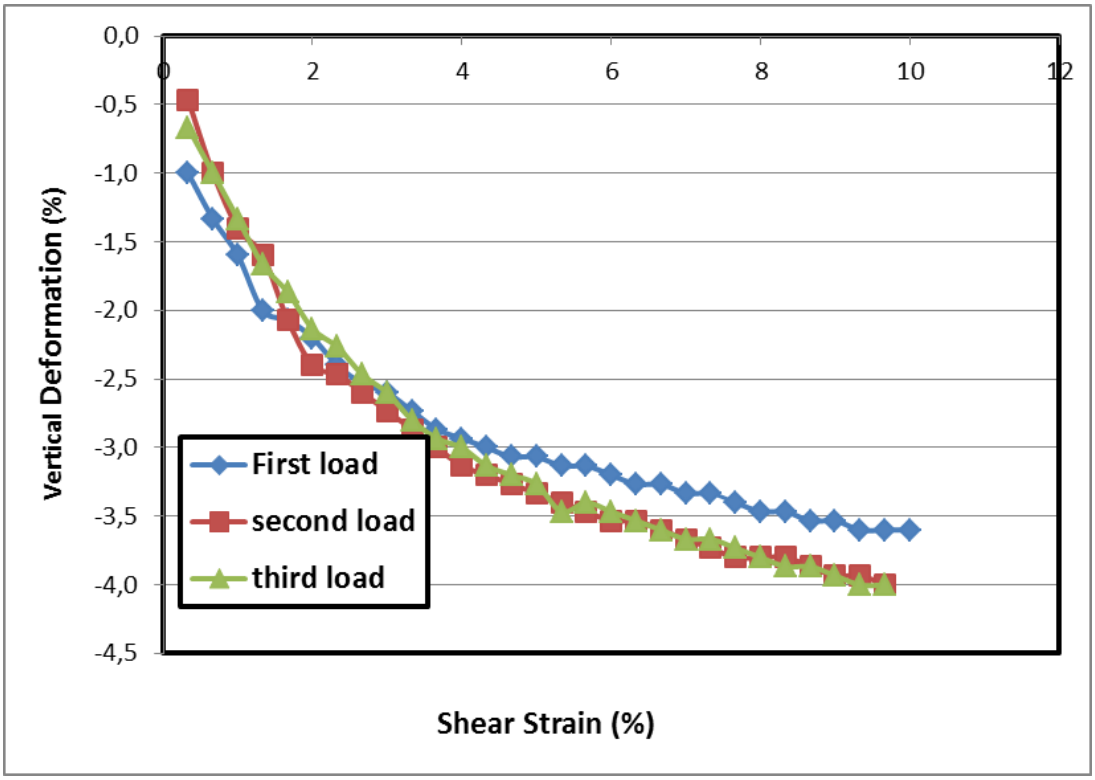

Apendix-A9: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %30 sand content.



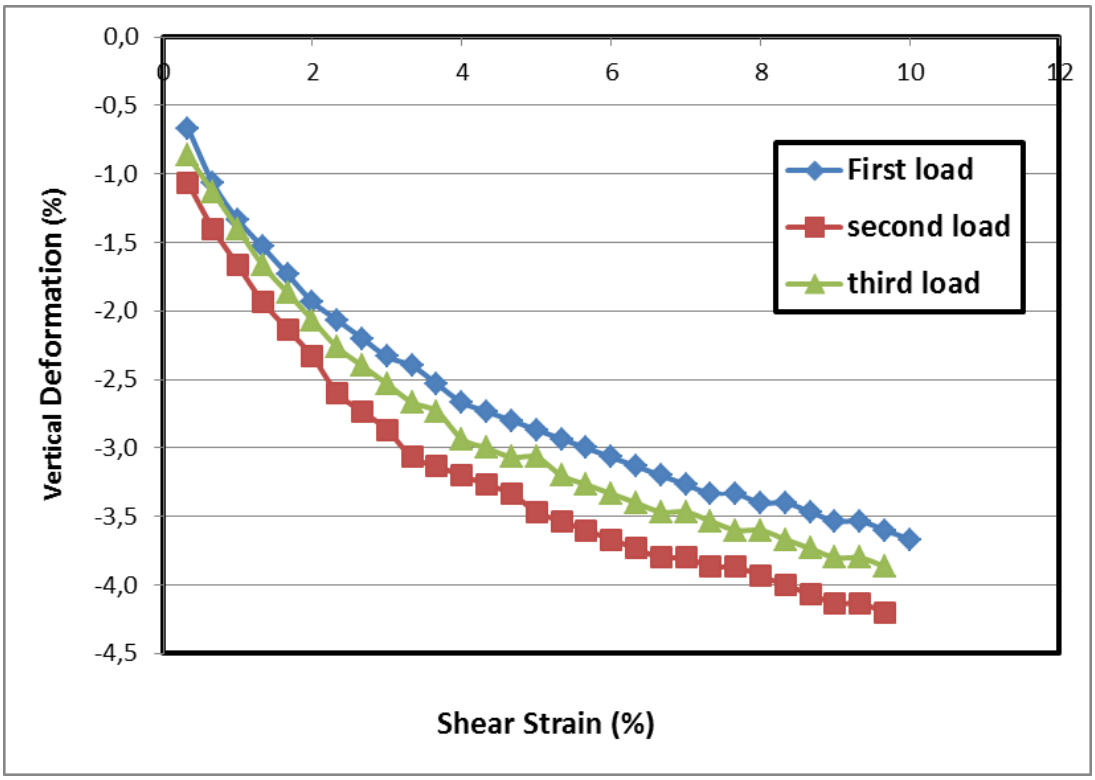

Apendix-A10: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %40 sand content.



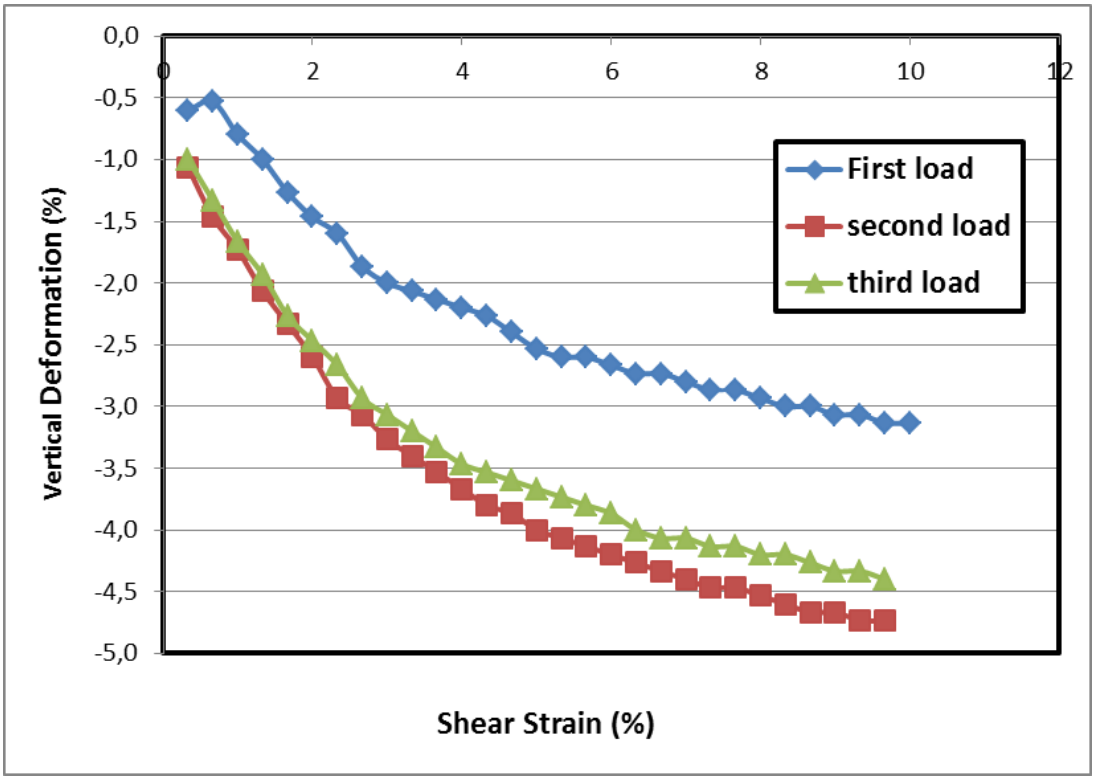

Apendix-A11: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %0 sand content.



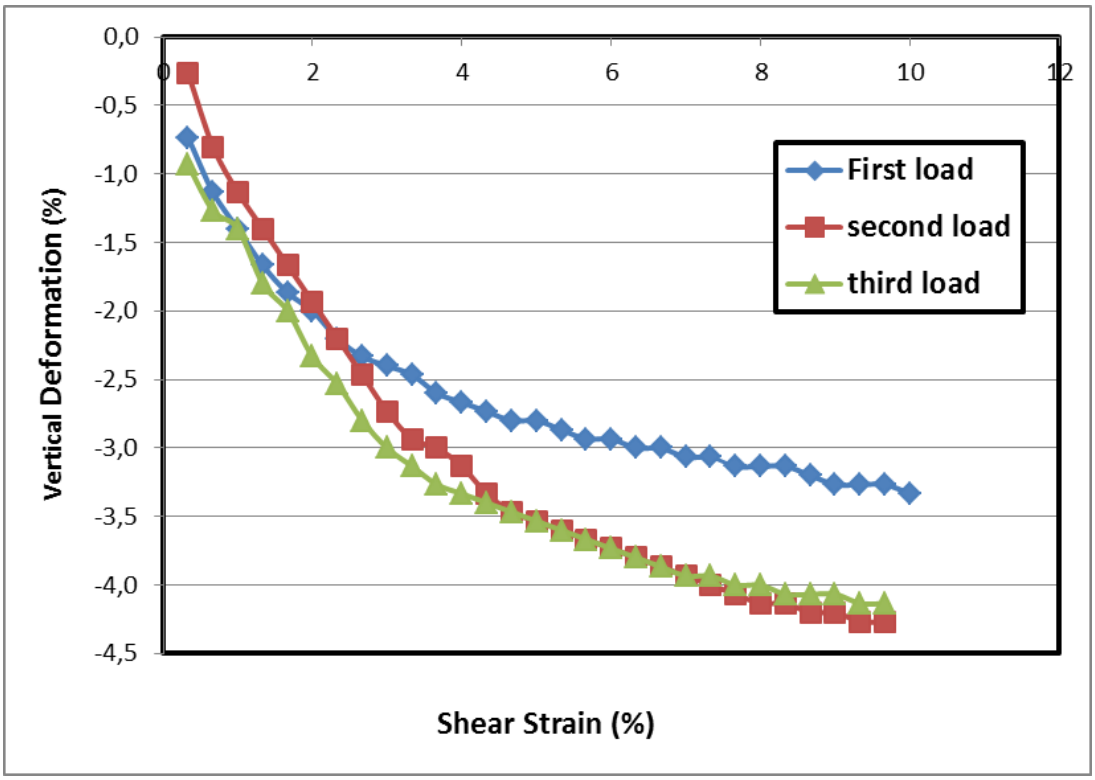

Apendix-A12: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %10 sand content.



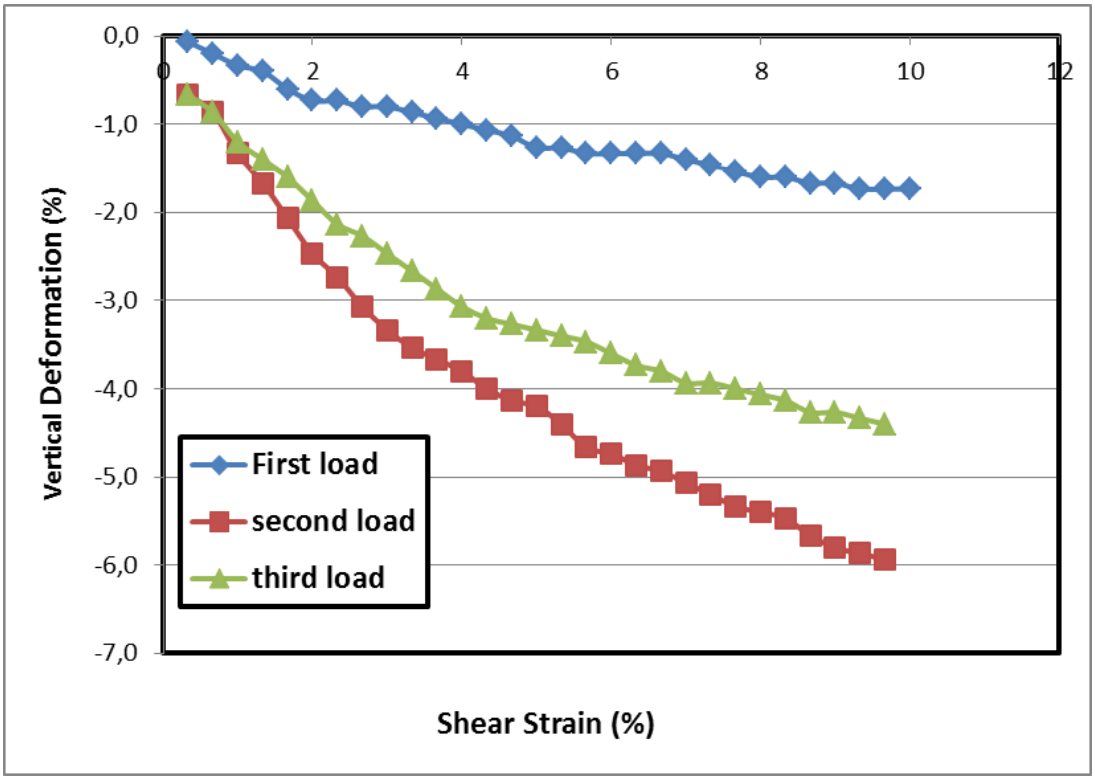

Apendix-A13: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %20 sand content.



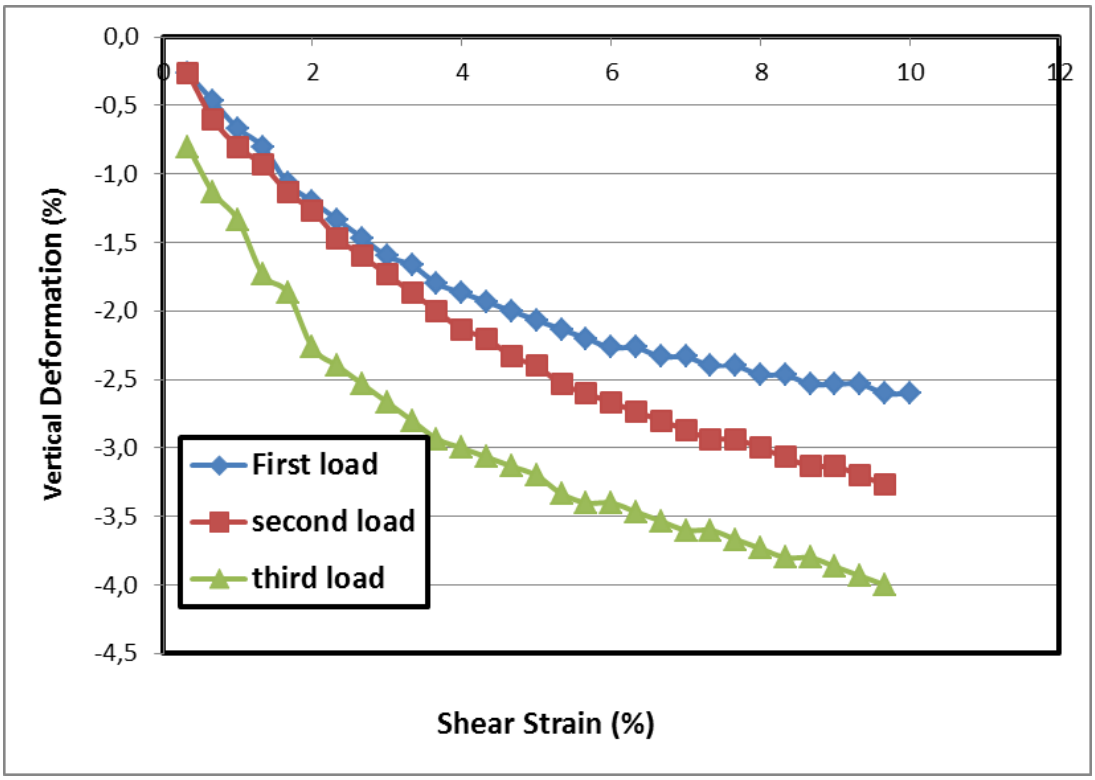

Apendix-A14: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %30 sand content.



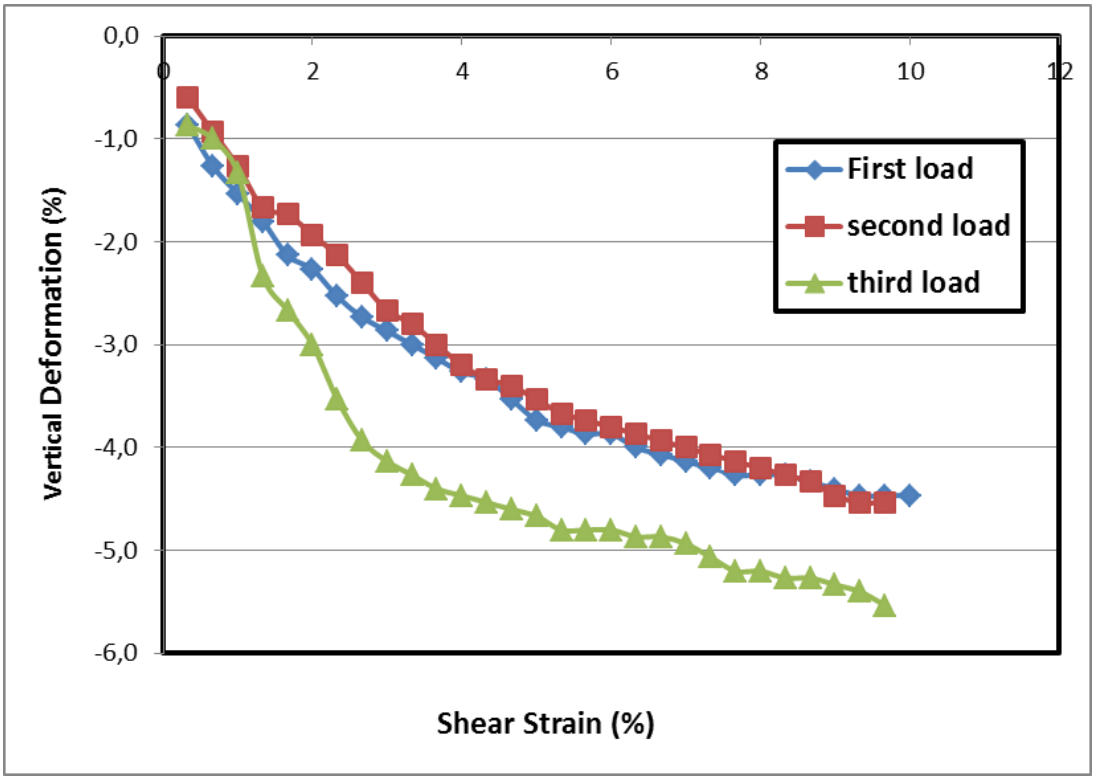

Apendix-A15: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %40 sand content.



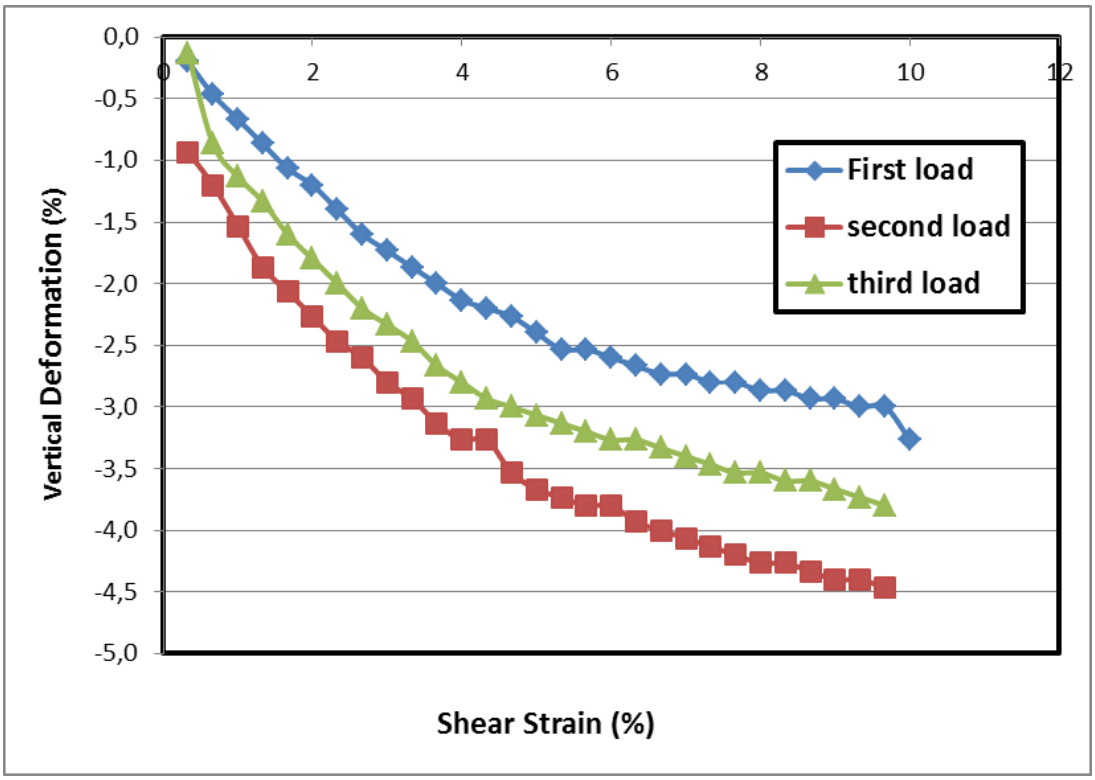

Apendix-A16: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %0 sand content.



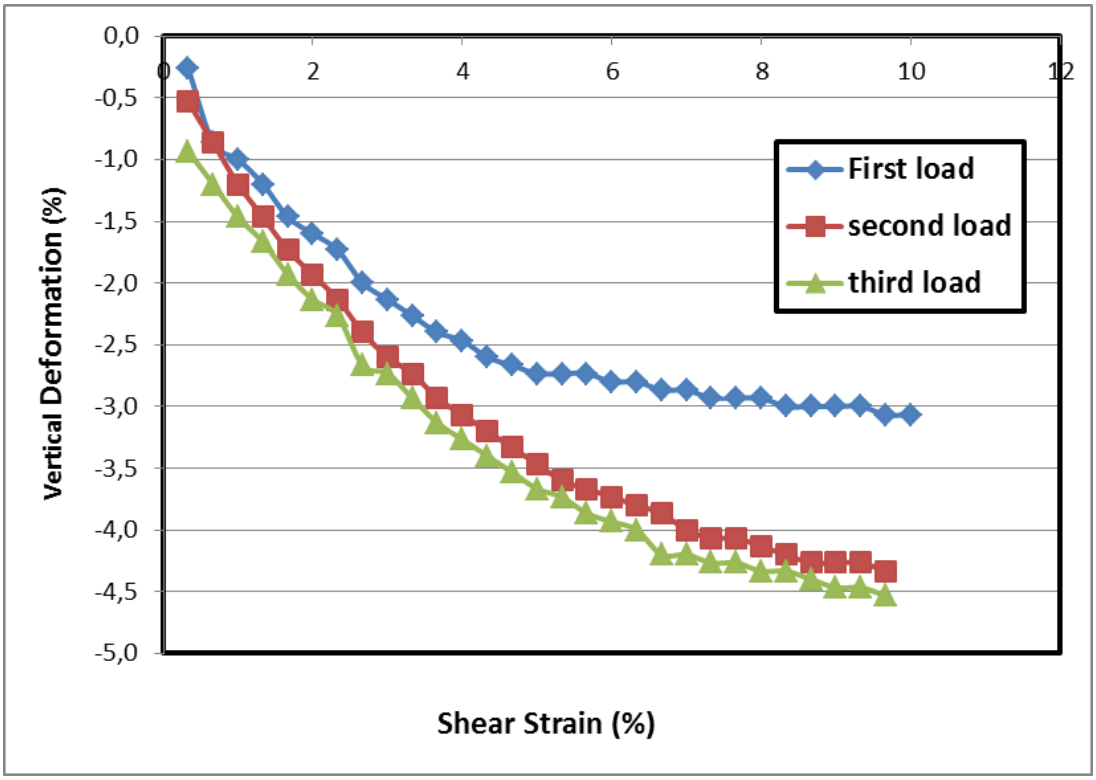

Apendix-A17: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %10 sand content.



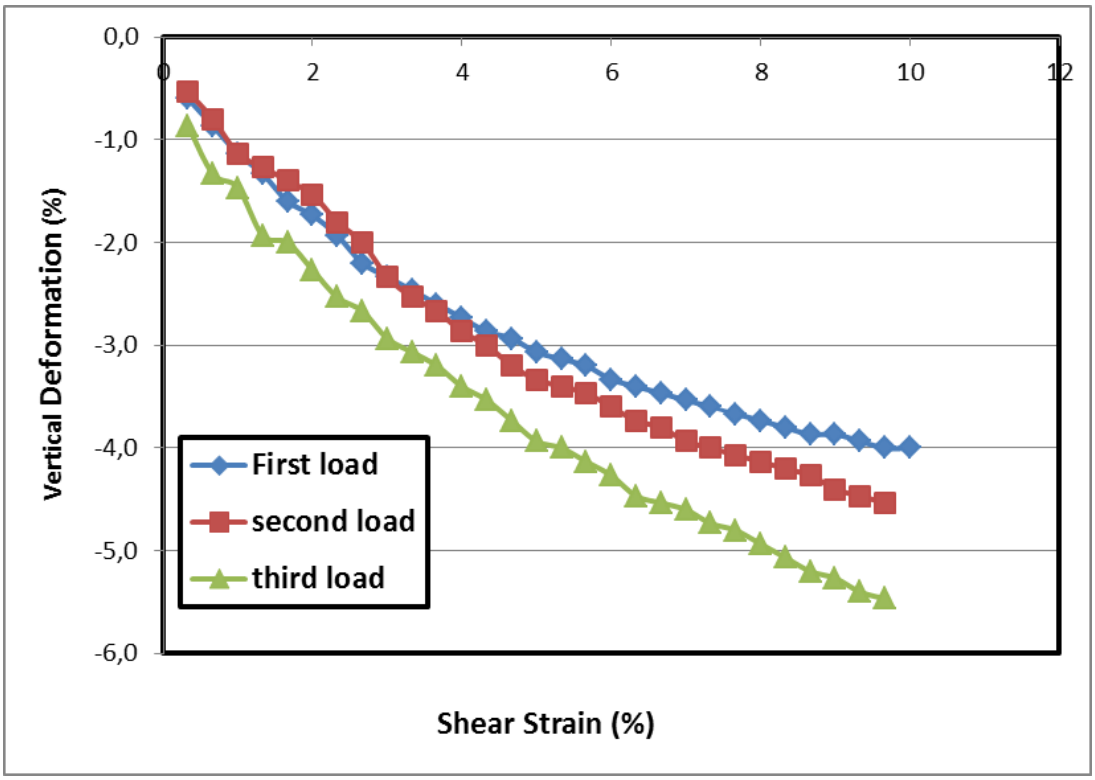

Apendix-A18: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %20 sand content.



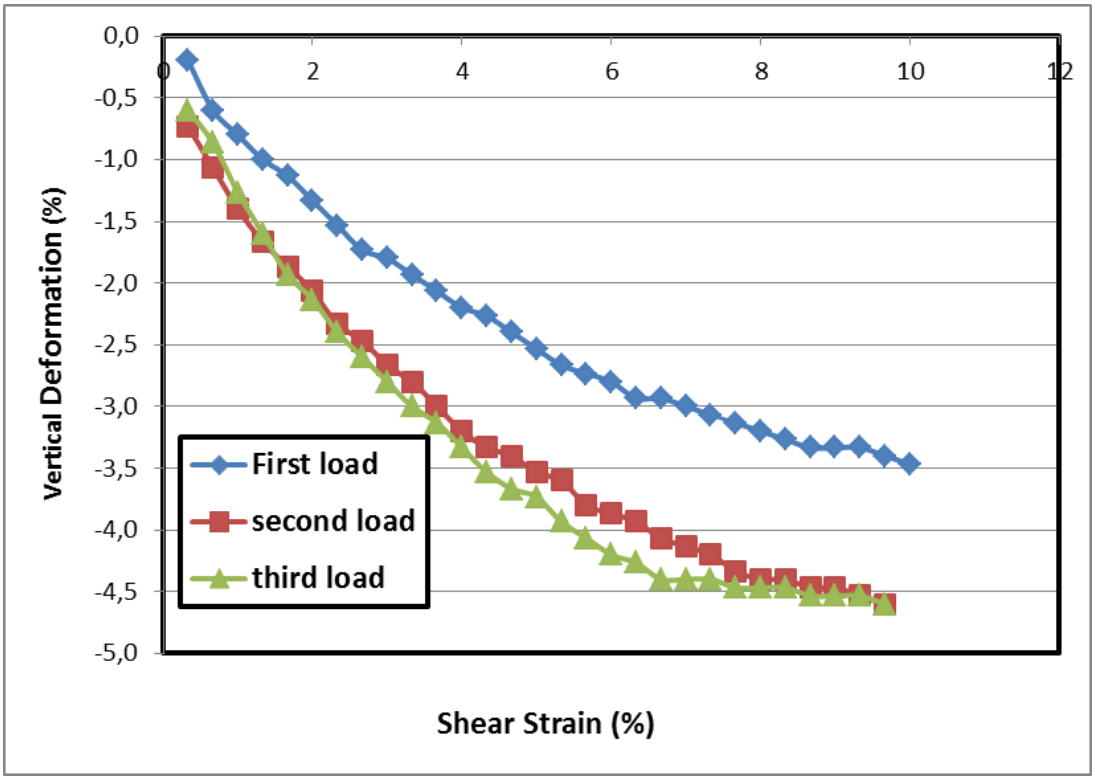

Apendix-A19: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %30 sand content.



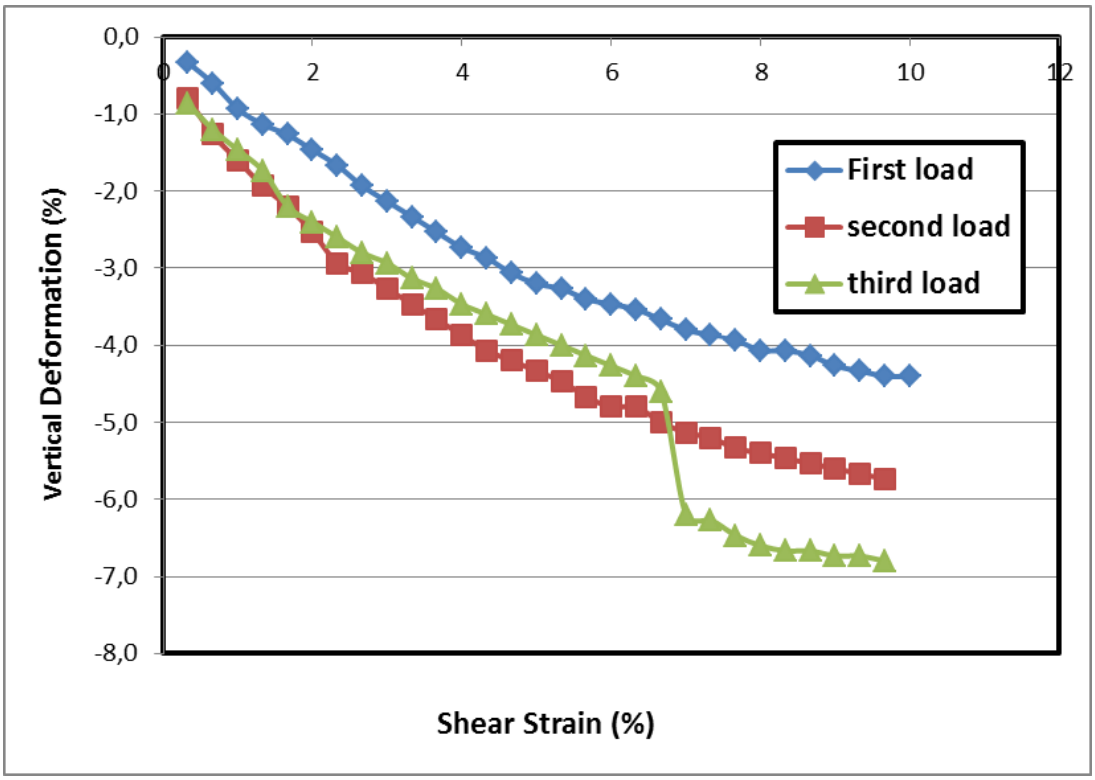

Apendix-A20: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to crushed sand at %40 sand content.



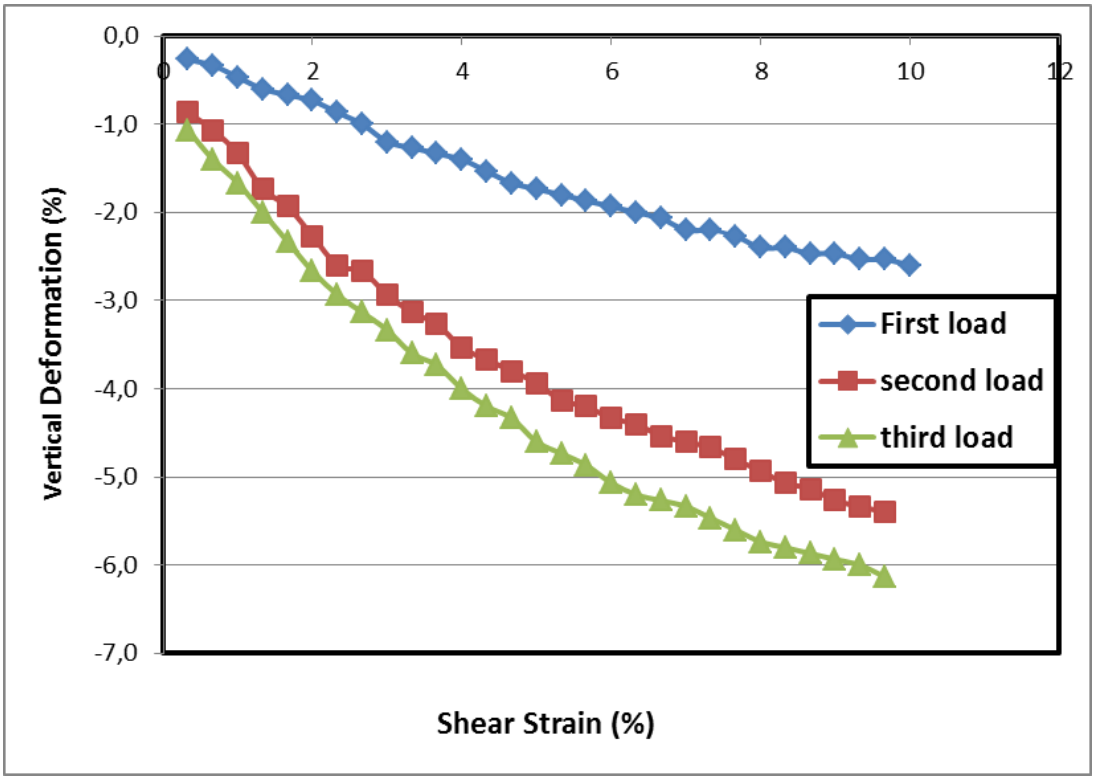

Apendix-A21: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %0 sand content.



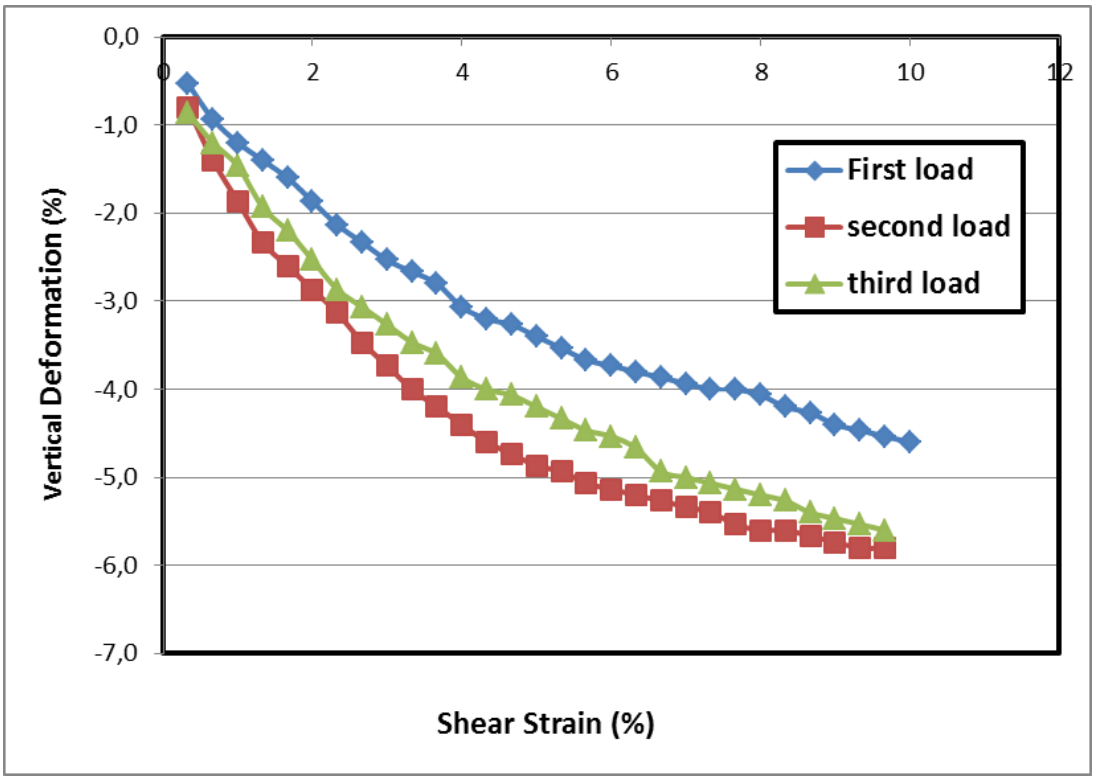

Apendix-A22: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %10 sand content.



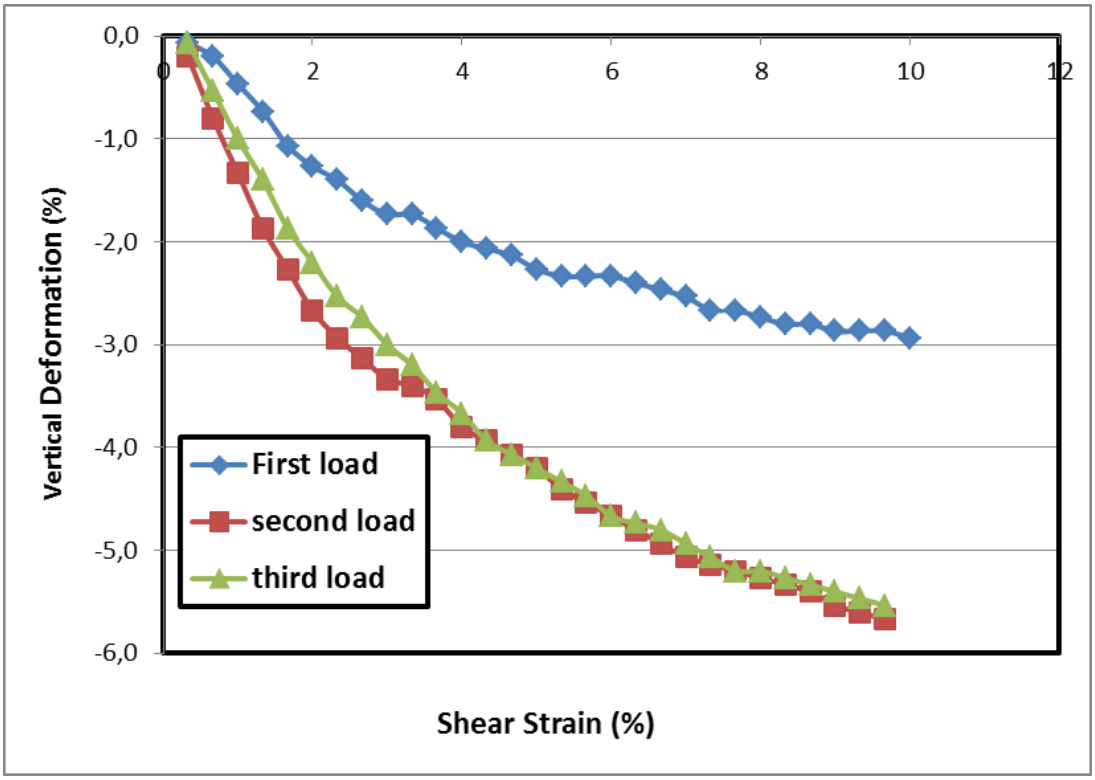

Apendix-A23: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %20 sand content.



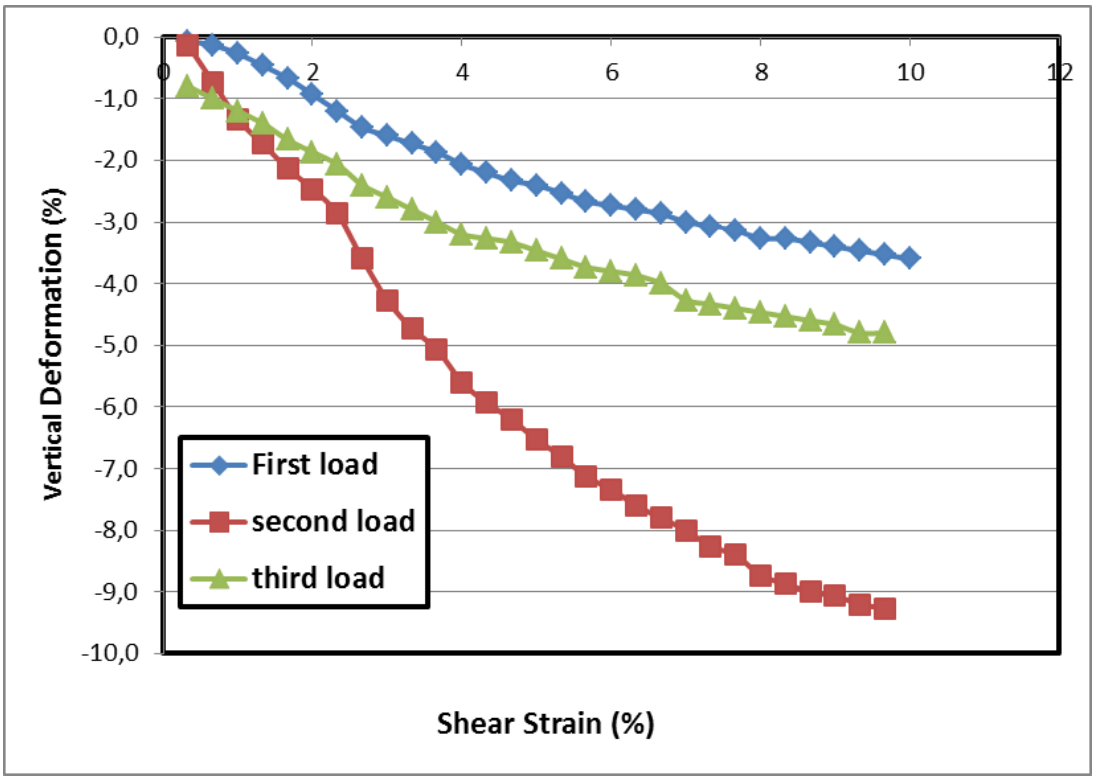

Apendix-A24: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %30 sand content.



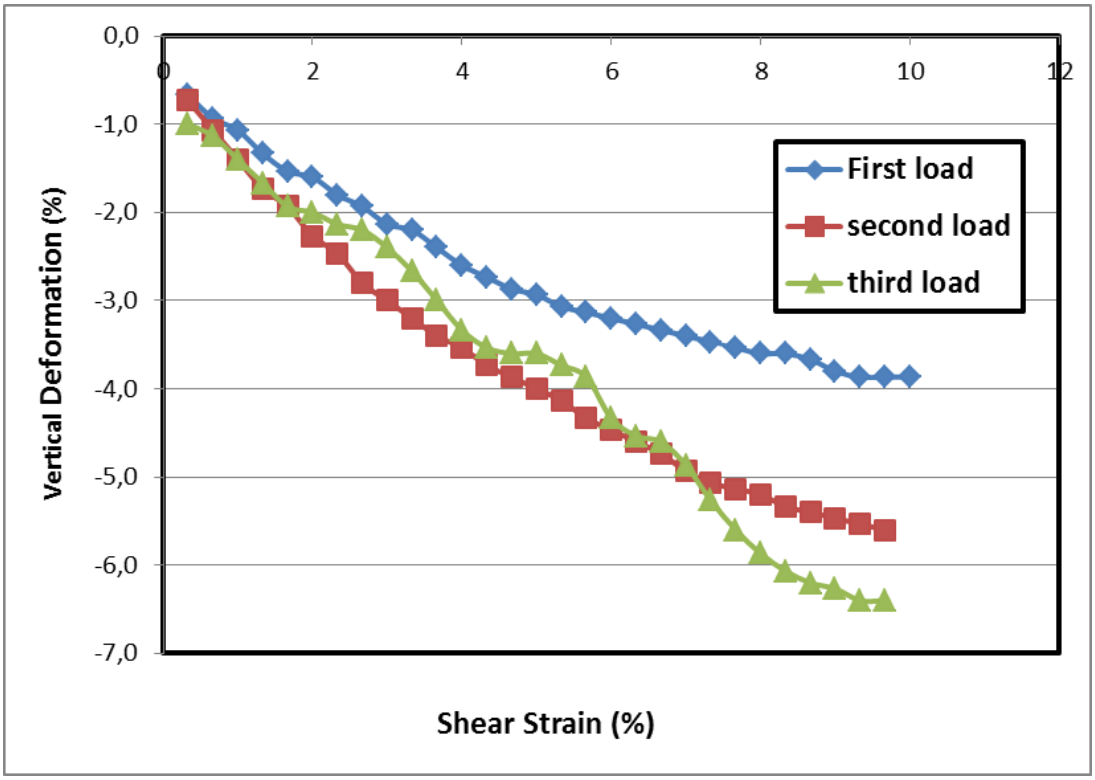

Apendix-A25: Vertical displacement-horizontal displacement curve instead of concrete-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %40 sand content.



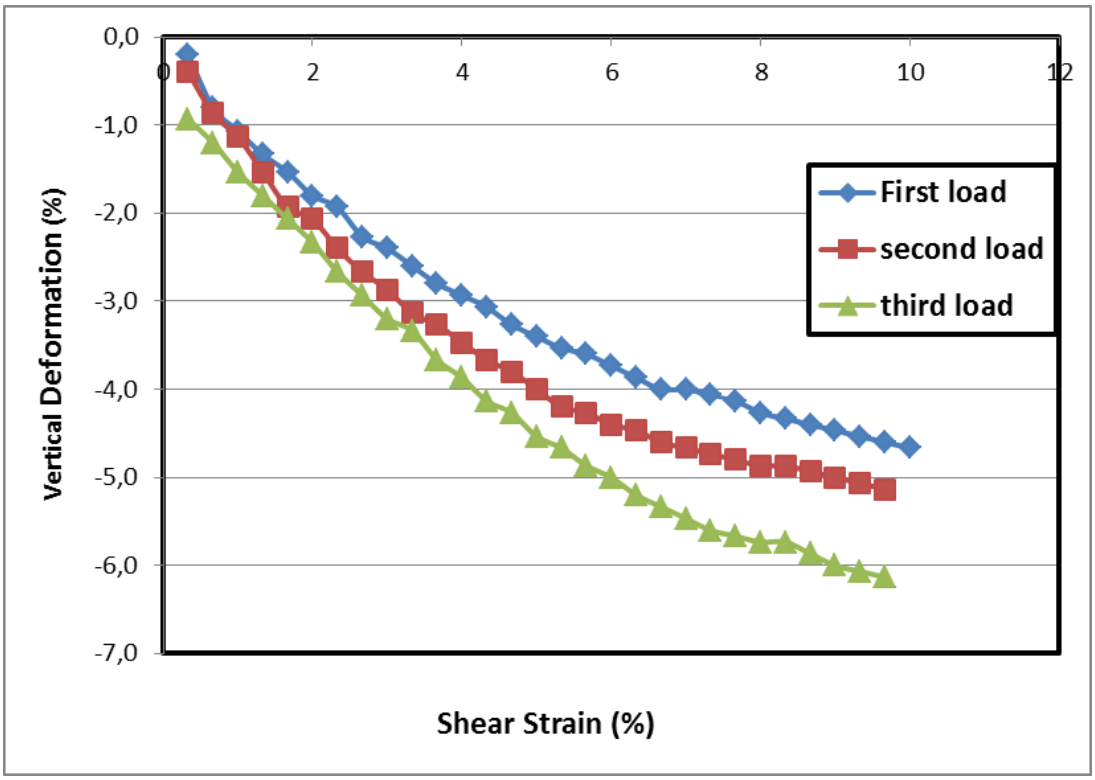

Apendix-A26: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %0 sand content.



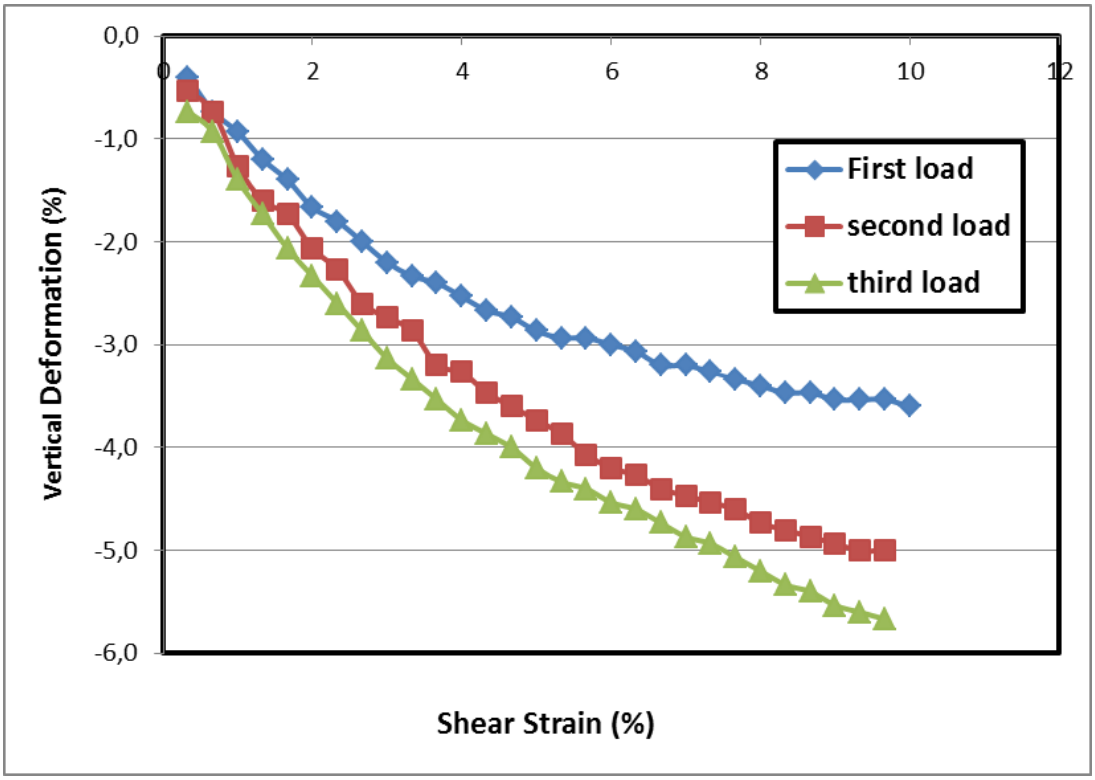

Apendix-A27: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %10 sand content.



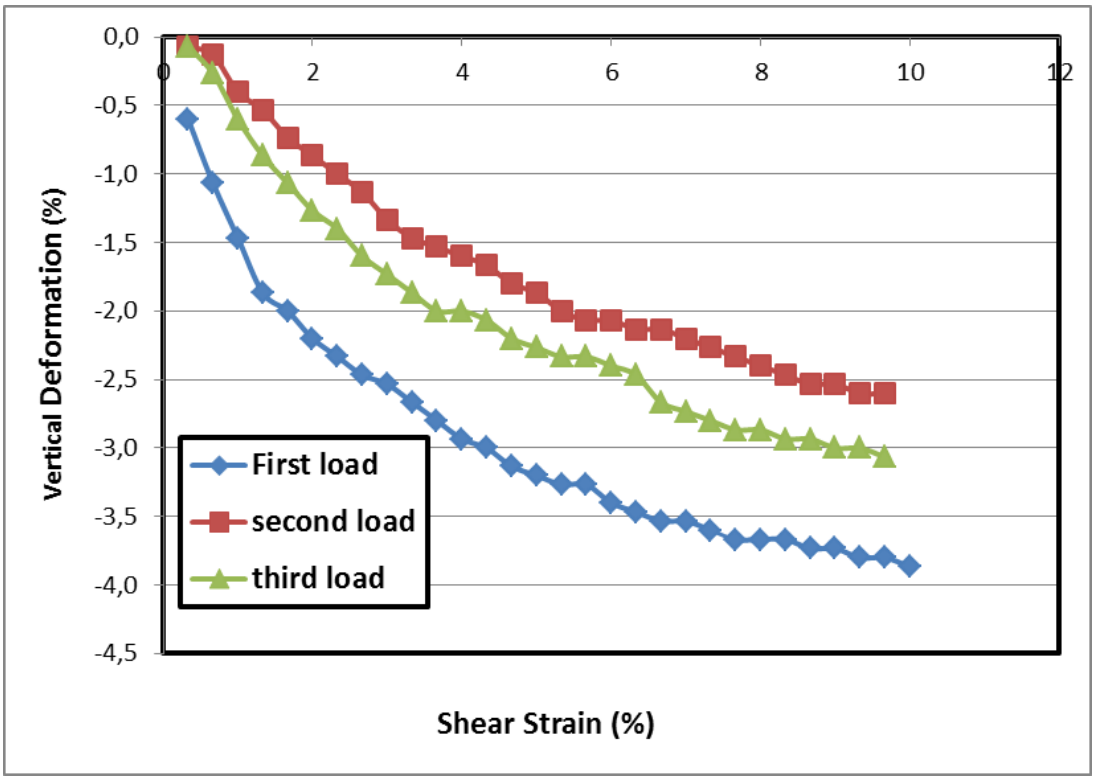

Apendix-A28: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %20 sand content.



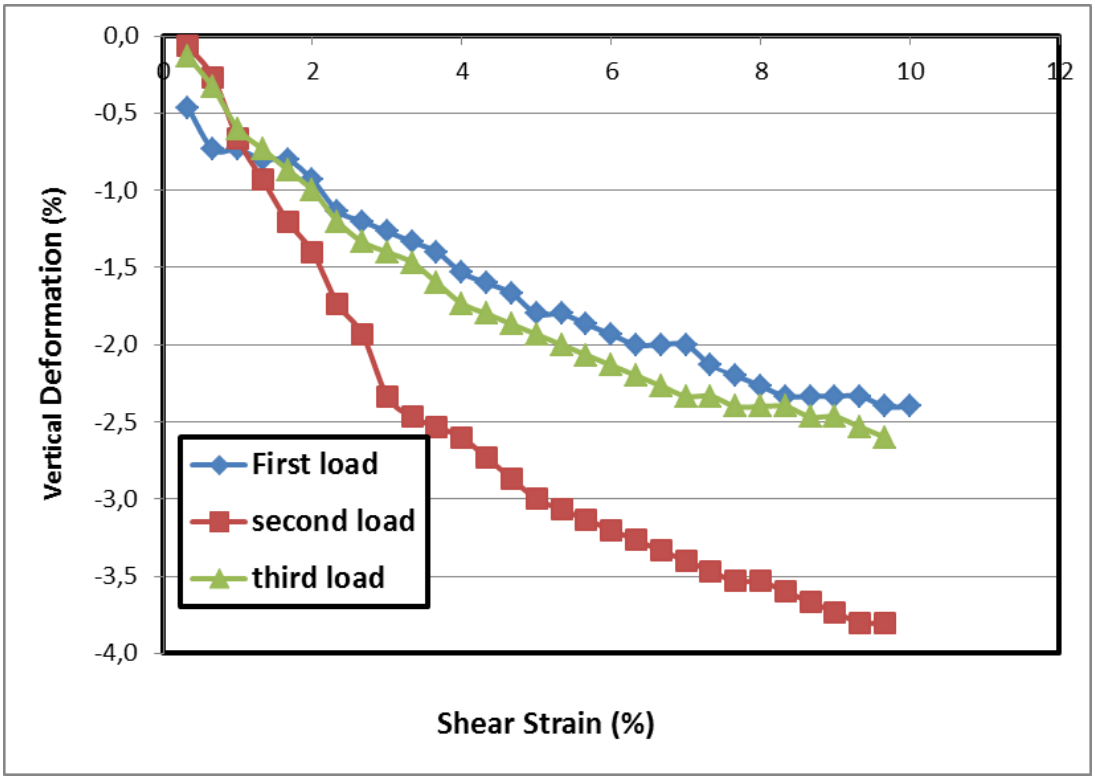

Apendix-A29: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %30 sand content.



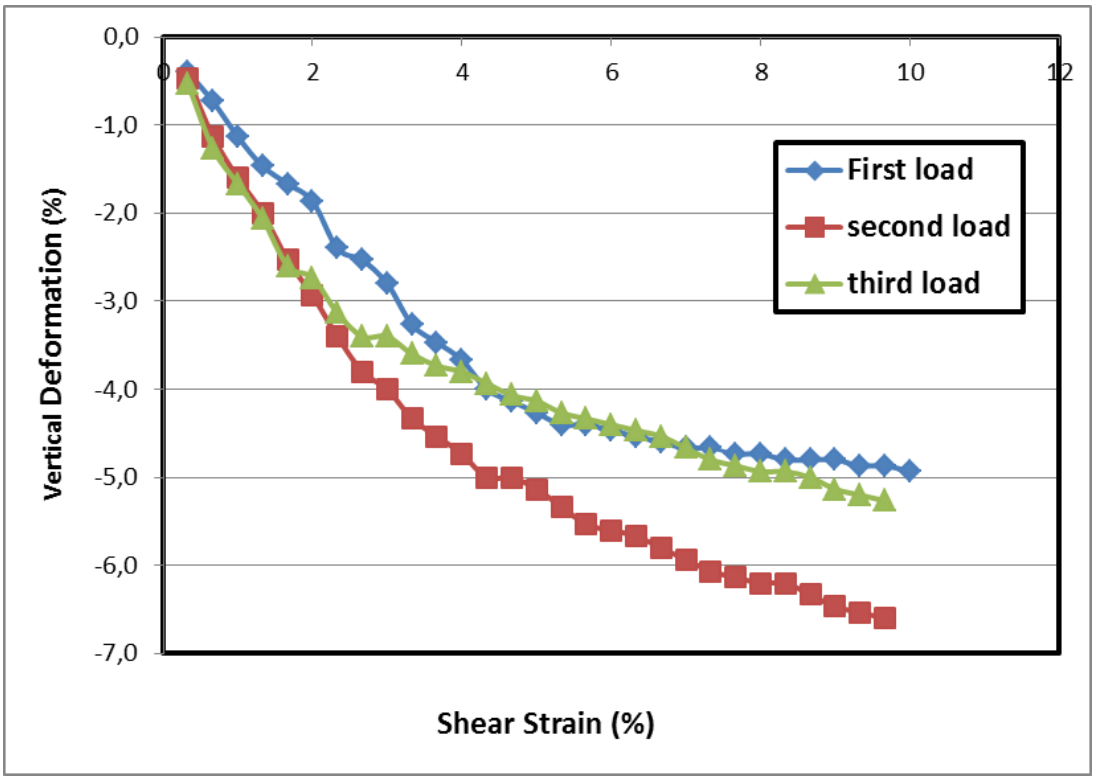

Apendix-A30: Vertical displacement-horizontal displacement curve instead of rough steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %40 sand content.



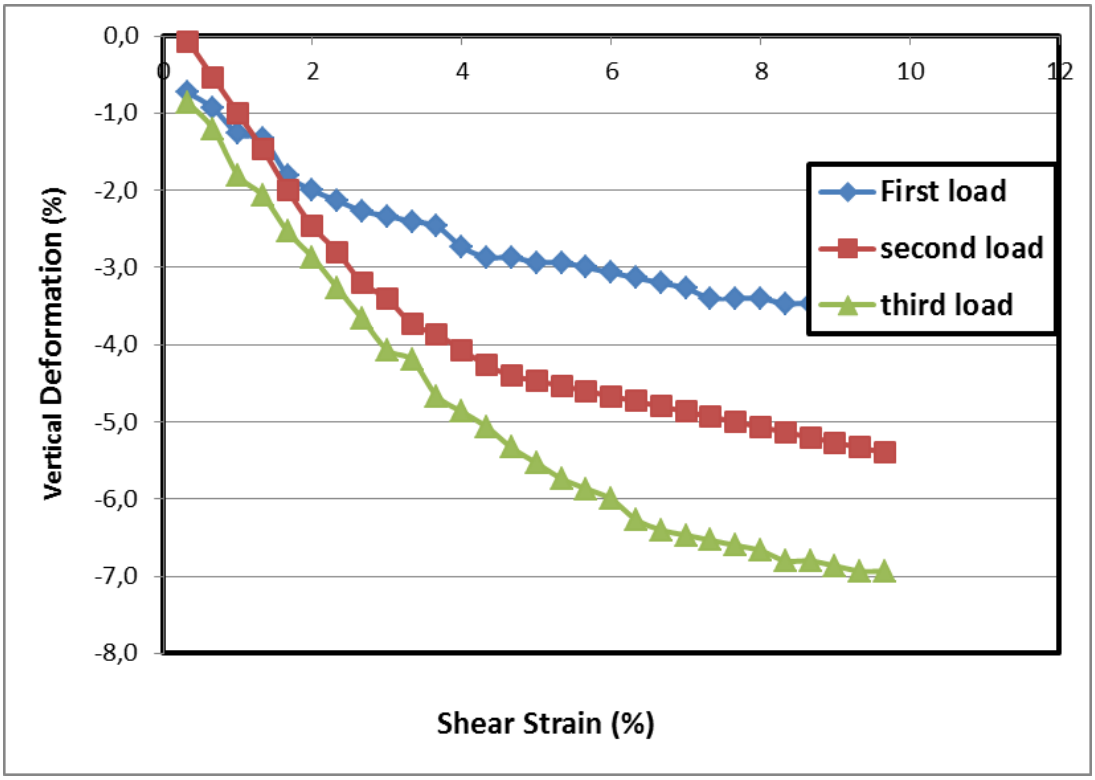

Apendix-A31: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %0 sand content.



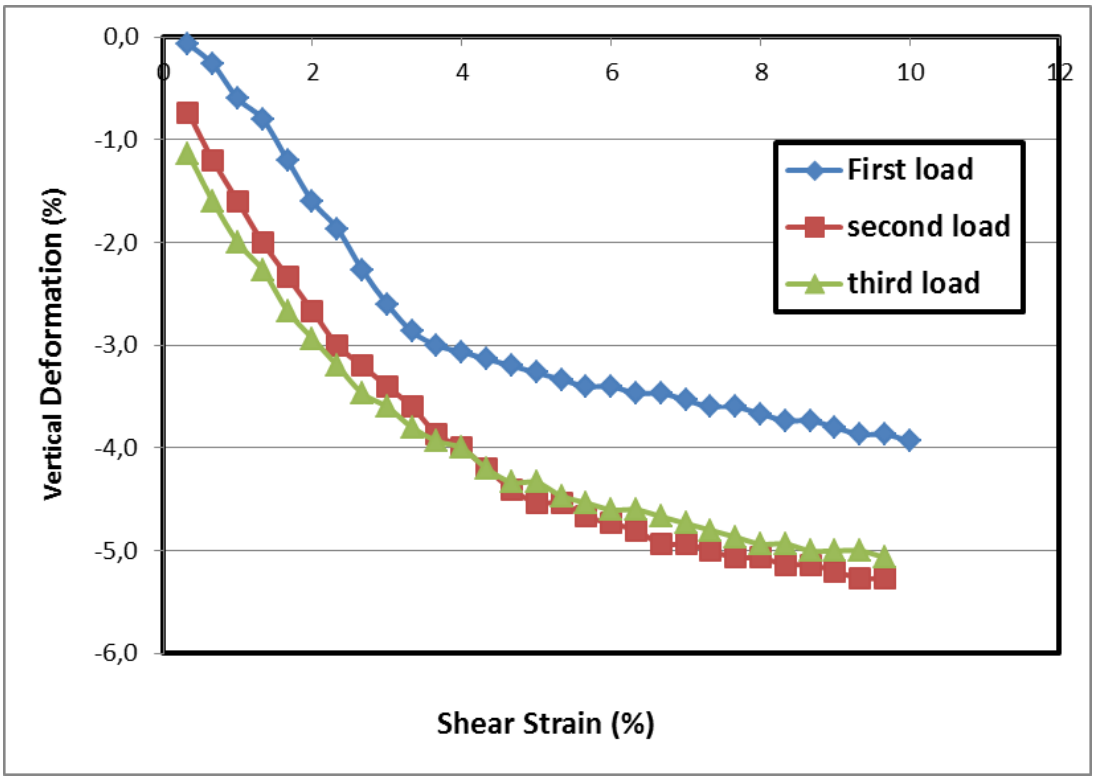

Apendix-A32: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %10 sand content.



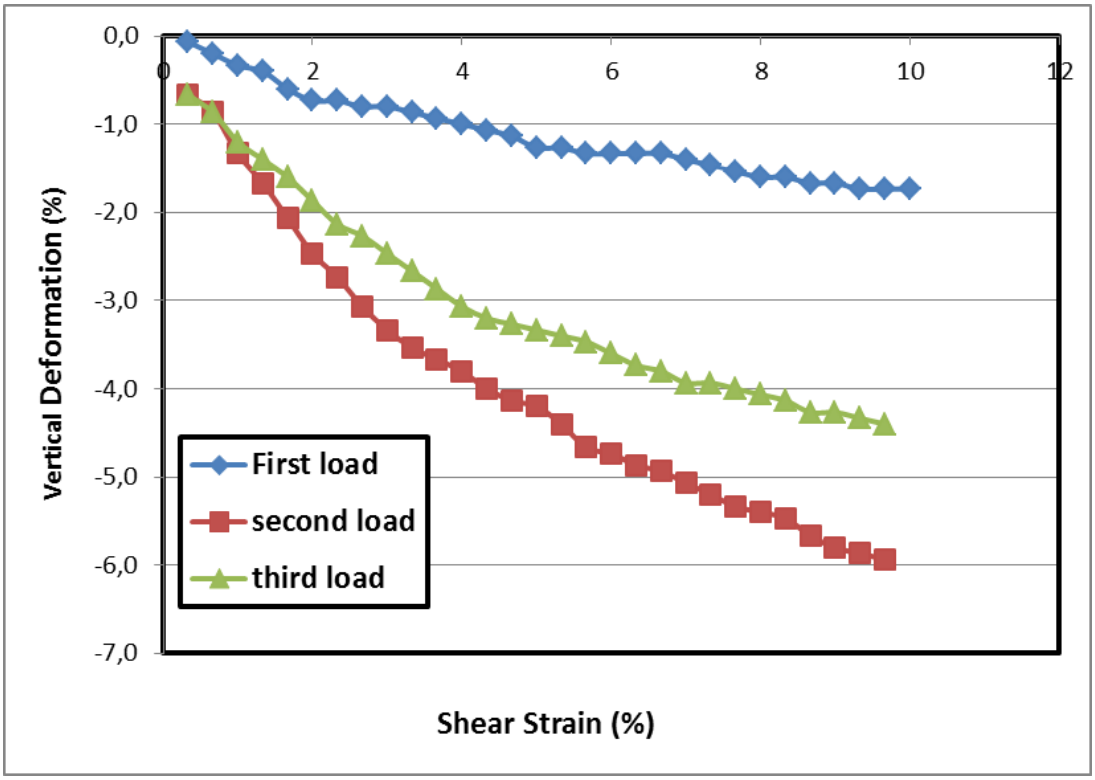

Apendix-A33: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %20 sand content.



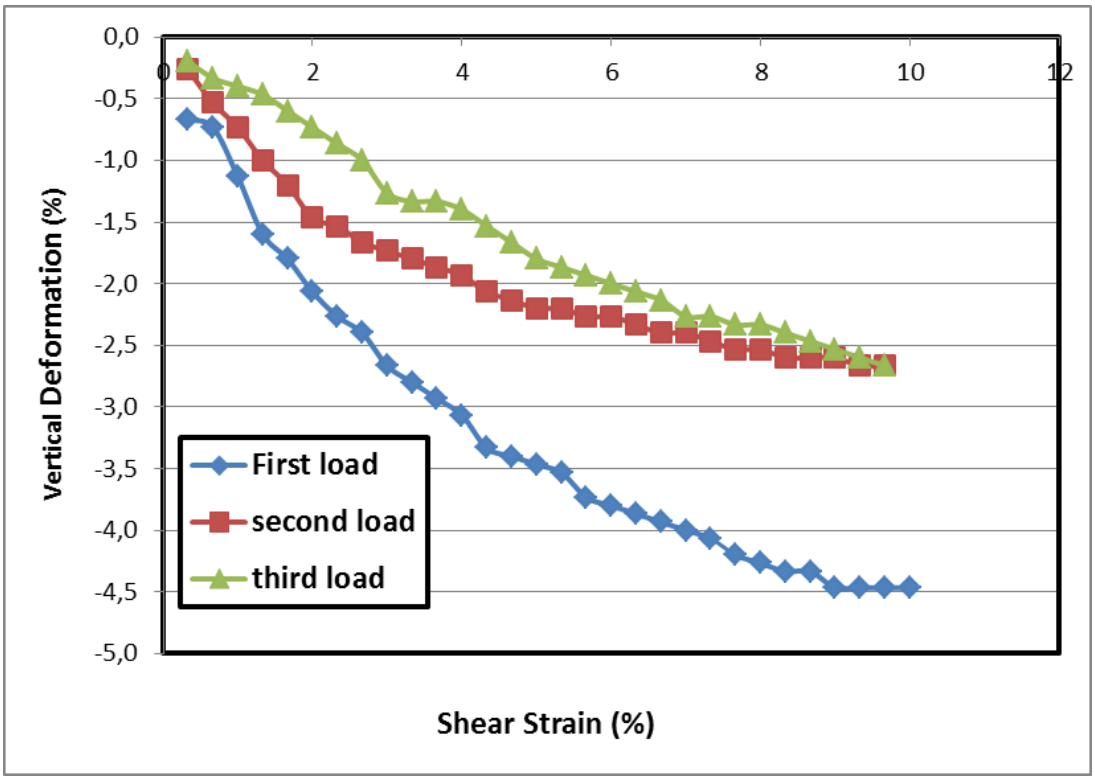

Apendix-A34: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %30 sand content.



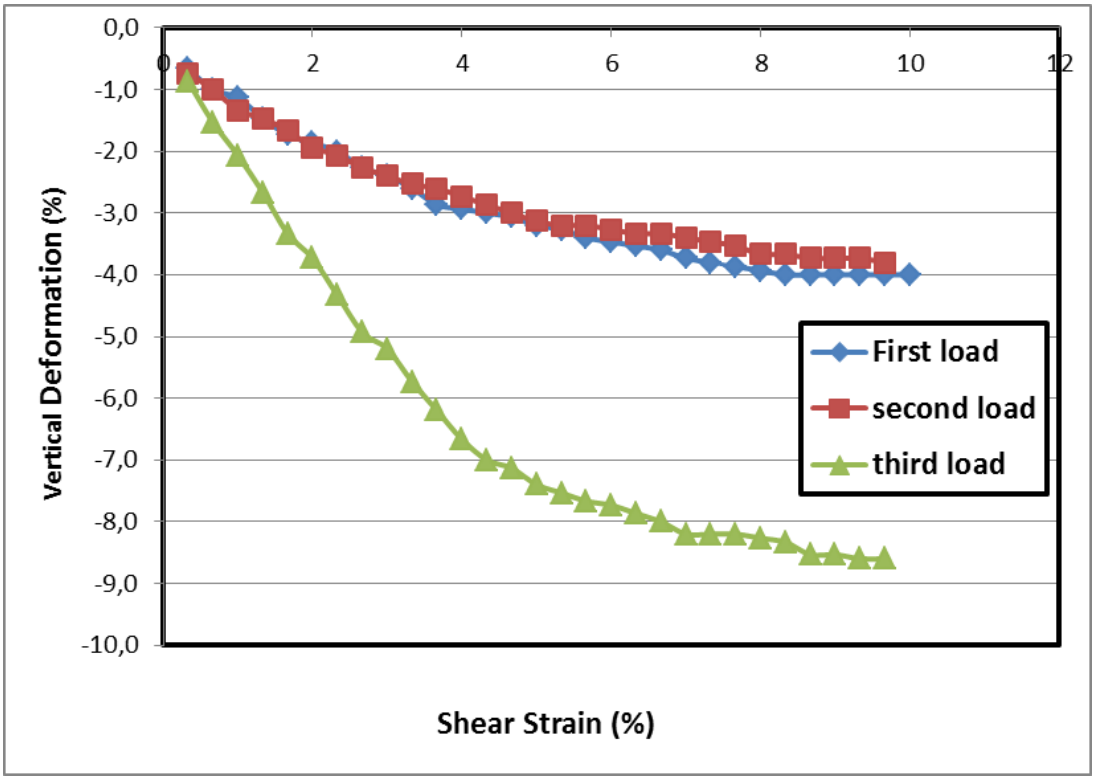

Apendix-A35: Vertical displacement-horizontal displacement curve instead of smooth steel-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %40 sand content.



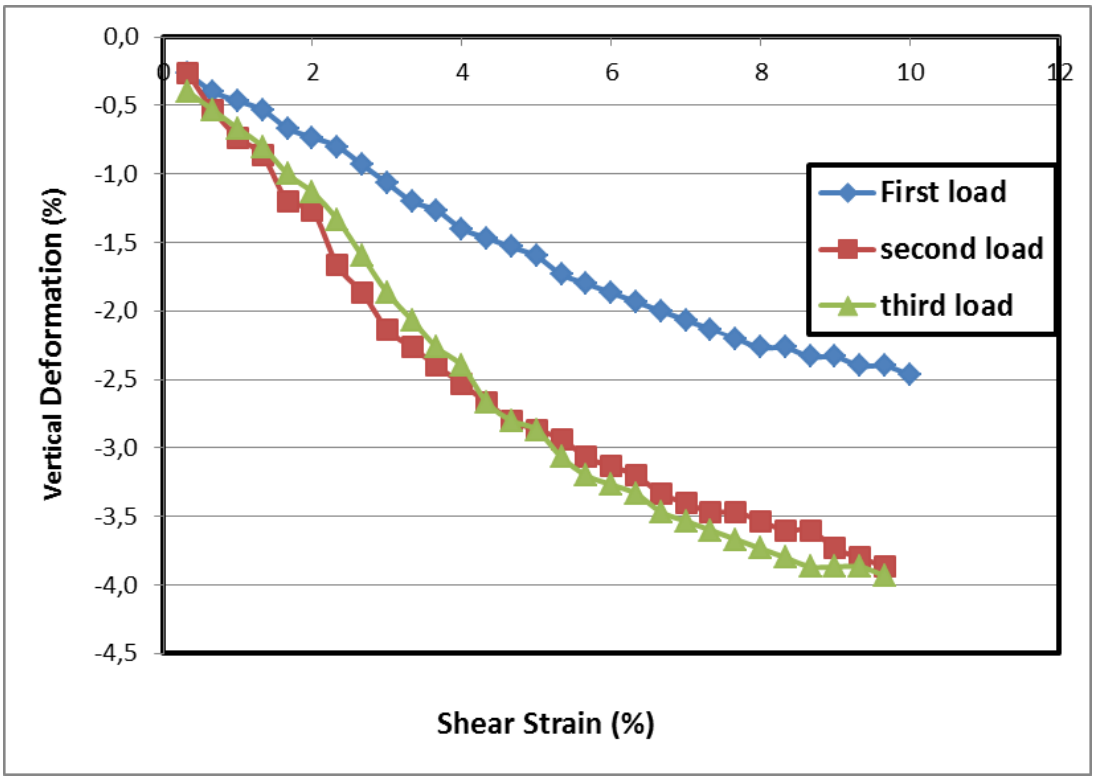

Apendix-A36: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %0 sand content.



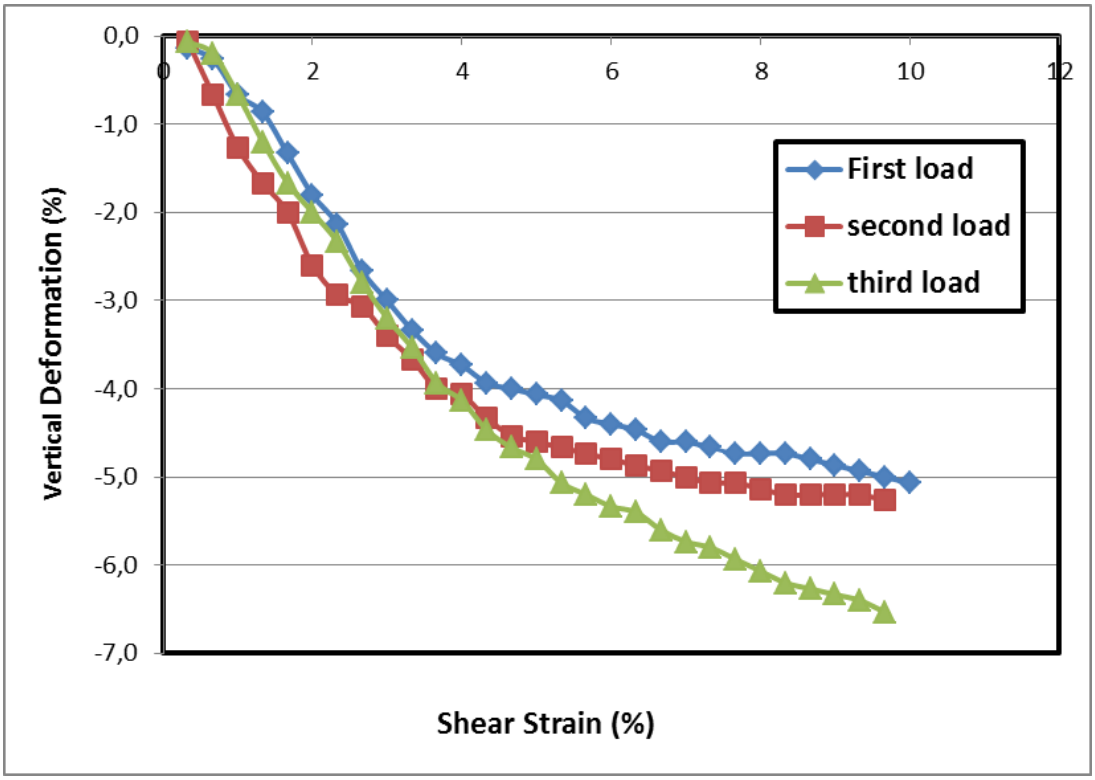

Apendix-A37: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %10 sand content.




Apendix-A38: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %20 sand content.




Apendix-A39: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %30 sand content.




Apendix-A40: Vertical displacement-horizontal displacement curve instead of wood-organic soil for 30kPa, 60 kPa and 120 kPa normal load with respect to rounded sand at %40 sand content.