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CHARACTERIZATION OF PERMANENT DEFORMATION OF SUBGRADE SOILS USING CYCLIC LOADING TEST

A THESIS

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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سورة يوسف / آية 76

*To My Family
with All of My Love
and Respect*

CERTIFICATION

We certify that this thesis, entitled "**CHARACTERIZATION OF PERMANENT DEFORMATION OF SUBGRADE SOILS USING CYCLIC LOADING TEST**" was prepared by "Anmar Faleh Degan" under our supervision at Babylon University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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ABSTRACT

Permanent deformation of subgrade soils is the accumulation of plastic deformation in soils due to continuous repeated loads from traffic. An accurate estimation of the permanent deformation in pavement materials leads to the better design of pavement materials and their thicknesses in the design of flexible pavement systems. The design excluded the permanent strain would lead to cracking of the pavement surface materials and this distress increases the rehabilitation costs annually. Permanent deformation of subgrade soils still poses a great challenge to highway engineers. The primary reason is that the deformation behavior of subgrade soils has not been adequately addressed in today's design methods.

The main objective of this study is to investigate some of the factors that affect the permanent deformation of subgrade soils such as soil types, compaction moisture content, applied stress and dry density. Also, to formulate regression models which have been obtained to predict the permanent strain in subgrade soils as related to moisture content , time of loading, dry density and applied stress by using **STATISTICA** software.

This research also established a test procedure to use cyclic load test to measure the permanent strain of subgrade soils. The permanent strains were monitored during 60 load cycles, and the accumulated permanent deformations were determined. The test procedure and test results conducted on two types of soils that cover an important geographical area of Iraq, A4 and A6 soils are presented.

The results indicate that compaction moisture content and applied stress are the major factors governing the permanent deformation. The increase of moisture content from 90% to 110% of optimum moisture content will increase the permanent strain by 270% (dry densities corresponding to 95% of maximum dry density with stress of 28 KPa) for soil A4. While the increase of applied

stresses from 28 KPa to 63 KPa, will increase the permanent strain by 81% (dry densities corresponding to 95% of maximum dry density with 90% moisture content).

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NOMENCLATURE

SYMBOL	DESCRIPTION
AASHTO	American Association of State Highway and Transportation Officials
AC	Percent Asphalt Content by Weight of Total Mix
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
DD	Dry Density (gm/cm ³)
DUR	Applied Stress Duration (second)
EP	Cumulative Permanent Microstrain at N Load Repetition
ESAL	18-Kip Equivalent Single Axle Loads
GWT	Ground Water Table
KENLAYER	<u>K</u> entucky <u>M</u> ultilayer Flexible Pavement Analysis Program
LL	Liquid Limit
LVDT	Linearly Variable Differential Transformer
Mr	Resilient Modulus
MC	Moisture Content
MDD	Maximum Dry Density (gm/cm ³)
N	Number of Stress Application
NCHRP	National Cooperative Highway Research Program.
PD	Axial Permanent Deformation (mm)
PSI	Present Serviceability Index
PL	Plastic Limit
PI	Plasticity Index
R²	Coefficient of Determination
OMC	Optimum Moisture Content (%)
OECD	Organization for Economic Cooperation and Development
SCRB	State Corporation of Roads and Bridges

ST	Applied Stress (KPa)
T	Time of Loading in Second
U.S.C.S	Unified Soil Classification System
Ep	accumulated permanent strain (mm/mm)
ϵ_p	Permanent Strain (mm/mm).
δ_p	Total Rut Depth
λ	(Decay Constant) From Regression of Test Data
$\dot{\epsilon}$	strain rate
α	Log(Strain Rate at Unit Time)
e	Void Ratio
w	Molding Water Content (%)
$\sigma_1, \sigma_2, \sigma_3$	Major Principal Stresses
σ_{atm}	Reference Stress (Atmospheric Pressure of 100 Kpa)
ϵ_{pz}	Vertical Plastic Strain in Microstrain at Depth z
ϵ_z	Vertical Resilient Strain in Microstrain

Note: Any other notation may be explained where it appears in the thesis.

CHAPTER ONE

INTRODUCTION

1.1: General

Flexible roadway pavements have four basic components: subgrade, base, surfacing and a drainage system. The convention in flexible structure pavement design is to use successively a stiffer layer from the subgrade up to the surfacing.

Pavements fail is due to many reasons; the factors which include poor construction, poor design or poor materials are some of the primary causes. However, one of the very important cause of failure lies in the pavement foundation, subgrade layer which represents the pavement foundation is the key importance in the pavement structure.

The major function of subgrade soils is to provide support to pavement structures. Under heavy traffic loads, subgrade soils may deform and contribute to distress in the overlying pavement structure. In asphalt pavement, this distress normally takes the form of cracking and rutting. It has been well documented that the subgrade soils plays a critical role in the initiation and propagation of permanent deformation of pavement structures and directly influences the pavement performance [**Huang, 1993**].

The subgrade soils, in particular the weak soft subgrades, contribute a significant portion (above 40 %) of the total pavement rutting [**Majidzadeh, et al. 1978**]. Therefore, an excessive plastic deformation on the top of subgrade layer may deteriorate the pavement in the form of rutting or cracking, and it is important to consider the permanent deformation aspects of subsoils while estimating the total rutting magnitudes in a pavement section.

Deformation of subgrade soils can be divided into two parts: the recoverable elastic deformation that is a measure of the resilient behavior and the non-recoverable plastic deformation that indicates the absorbing behavior. Current pavement design procedures consider soil support characteristics in

terms of its resilient behavior. These procedures ignore permanent deformation behavior even that it may be a very important component in the pavement performance. All pavement layers contribute to the permanent deformation of the pavement structure. Yet, subgrade does not attract as much attention as do the asphalt surface and granular base. The last are man-made products in some sense and their properties are relatively well known and have been extensively studied for several decades. Actually, with the implementation of (super level I mixture design method), the rutting of asphalt concrete can be minimized through the proper selection of materials. As a result, subgrade becomes a weak point in the pavement structure [Elliott, et al. 1998].

The permanent deformation in the subgrade is related to the plastic strain. Subgrade soil could cause unrecoverable deformation under repeated load, and then pavement will be damaged rapidly.

An accurate estimation of the permanent deformation response of the subsoils under traffic loads generally helps in either modifying the pavement design by changing the asphalt, base and subbase thicknesses or by selecting an appropriate subgrade stabilization procedure for improving the subsoil permanent deformation resistance [Puppala, et al., 1999].

This work represents the first attempt to study and evaluate the subject of permanent deformation of subgrade soils in Iraq because all earlier works deals with the permanent deformation of asphalt concrete and granular materials.

1.2: The Research Objectives

The main objective of the research is to study the permanent deformation characteristics of two types subgrade soils in Iraq. Several specific objectives are outlined below:

1. Investigate the main factors related to the permanent deformation of two Iraqi subgrade soils including the compaction moisture content, applied stress, dry density and some soil types.

2. Develop models for the permanent deformation prediction of two kinds of Iraqi subgrade soils. Also, Presenting a procedure for the prediction of the permanent deformation of some subgrade soils.

1.3: layout of Thesis

The presentation of the research work and the results are spread into five chapters as summarized below:

1. The definition of the permanent deformation problem of subgrade soils and objectives with the layout of thesis are presented in chapter one.
2. Chapter two focused on a review of the literature that related to the permanent deformation problem of subgrade soils, the definition and the specification of subgrade layer, a typical subgrade distresses, the mechanism of permanent deformation, the factors that affect and pervious methods to predict the permanent deformation.
3. Chapter three gives a detailed explanation with supporting photos of the experimental work carried out including sampling, testing program, description of testing apparatus and procedures of tests.
4. In chapter four, the results of classification tests, cyclic load tests and the graphs obtained from the experimental work for subgrade soils were analyzed and discussed. The effects of the considered variables (moisture content, dry density, stress and subgrade soils types) on the permanent deformation are shown. Based on the performed cyclic load test results, statistical models were developed for the permanent strain. Diagnostic plots to check the suitability of these models from the statistical point of view were also presented in this chapter.
5. Finally, the main conclusions and recommendations are presented in chapter five.

CHAPTER TWO

REVIEW OF LITERATURE

2.1: Introduction

The function of a pavement is to carry traffic safely, smoothly and economically from one location to another [**Yoder & Witczak, 1975**].

Typically, a flexible pavement section may consist of three or more layers; an asphaltic concrete surface layer, a granular base course, and an underlying soil subgrade [**Barksdale, 1972 & Drumm, et. al., 1990**].

Pavements may reach failure when they experience fatigue cracking or undergo excessive plastic deformation (also known as rutting). There are two types of fatigue cracking: the bottom-up fatigue cracking which gets initiated at the bottom of the asphalt concrete layer where the tensile bending stresses are the greatest and then it progresses up to the surface, and the top-down fatigue cracking that is initiated near the surface. The accumulated plastic deformations in base, subbase, and subgrade layers contribute to a total rutting at the surface, which causes discomfort to travelers and even fail the pavement structures when the rutting exceeds certain values [**Muhanna, et. al., 1999**].

According to the AASHTO design equation for flexible pavements, a (1.1) inch rut depth will reduce the Present Serviceability Index (PSI) of a relatively new pavement, having no other distress, from (4.2) to (2.5). With this amount of drop in serviceability, the entire life of the pavement has in effect been lost. [**Albayati, 2006**].

Also rutting gives problems to users by increasing the consumption of fuel and the risk of skidding (on water or on ice), it also gives problems to the owner as ruts encourage water to soak the pavement instead of draining off the surface. Water that enters the pavement in this way may collect in a (buried) rut in the subgrade and/or reduce the load carrying capacity of the granular layers [**Dawson & Kolisoja, 2004**].

Both rutting and fatigue cracking explain the importance of understanding stresses and strain responses of subsoils and asphalt materials, which in turn can help in the better design of flexible pavements.

Current studies show that asphalt materials can be modified by the addition of polymers to improve their fatigue resistance. However, very little focus has been shown on subsoil behavior and its contribution to pavement rutting. Recognizing this deficiency, in 1986, the American Association of State Highway and Transportation Officials (AASHTO) proposed a new test protocol for the pavement design. They suggested using the resilient modulus (M_r) characteristic of subsoil, which replaced the California Bearing Ratio (CBR), to characterize and understand the behavior of pavement materials including subgrades subjected to moving traffic loads. AASHTO's practice for designing flexible pavements requires resilient modulus of subgrade soils. The resilient characteristics are assumed to account for permanent deformation of soils. However, this approach can provide misleading characterizations. Soils such as silty sand, silty clays and sandy clays possess good resilient characteristics. Nevertheless, they still undergo large plastic deformation under traffic loads [Puppala, et. al., 1999].

The research study mentioned in the Organization for Economic Cooperation and Development (OECD) report [Resistance, 1975] as cited by [Puppala, et. al., 1999] describes the plastic deformation in pavement layers at various number of commercial vehicle passes. Figure (2-1) shows the predicted plastic deformation in millimeters of asphalt, base, subbase and subgrade layers versus the number of passes. This Figure shows that the subgrade soils have not exhibited any shear strength failure during loading. However, at the same time, the rutting magnitudes are continuously increasing at a steady rate. The subgrade contribution to the total rut in the pavements is more than 30% at 10^8 cycles. This explains the significance of subgrade contribution to the total rut on the pavements. This means that the plastic strain results of the first few cycles can

be used reasonably, if not accurately, to extrapolate plastic strain at a large number of cycles.

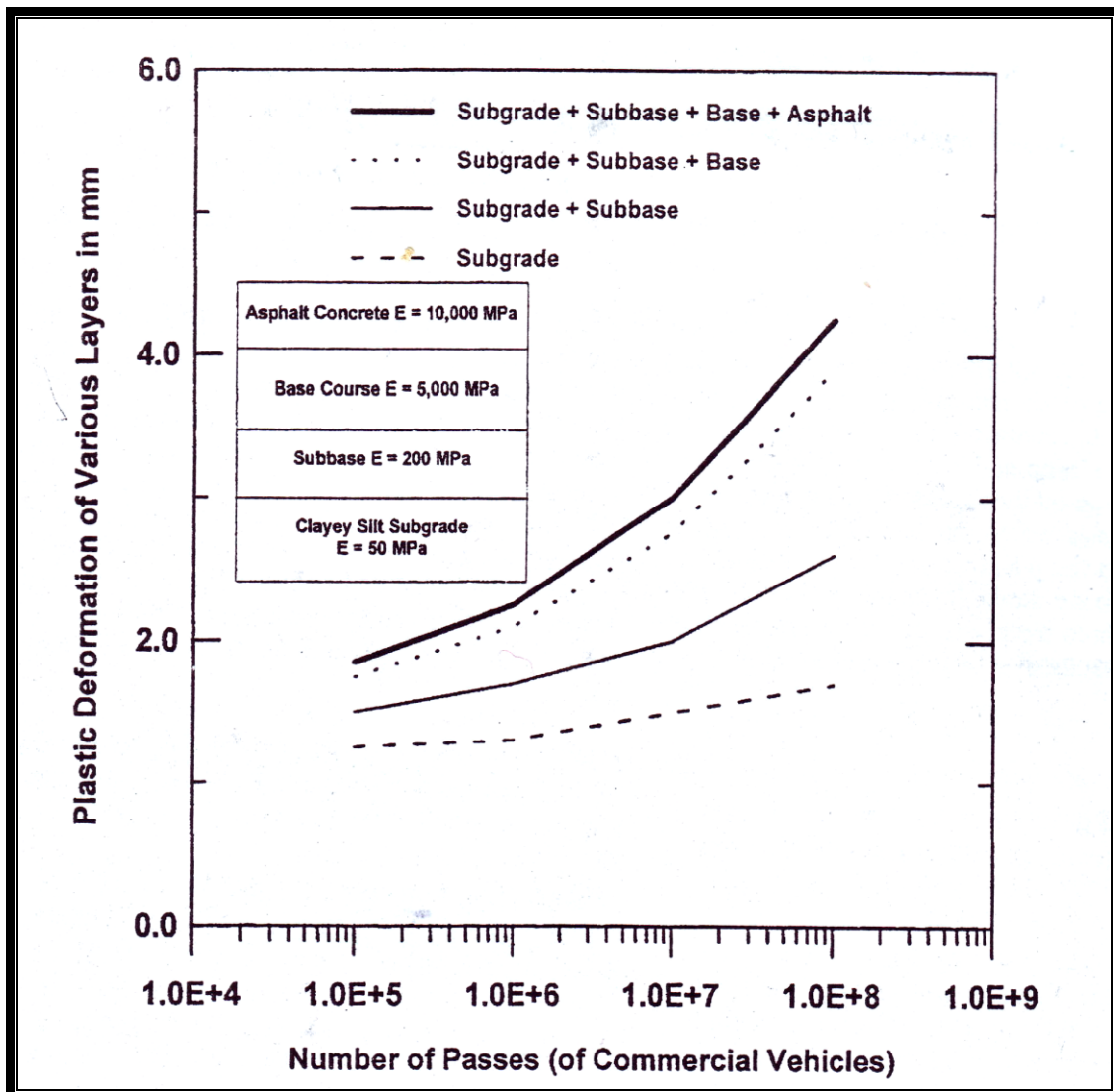


Figure (2-1) Plastic Deformation of Various Layers in OESD Study (after Puppala, et. al., 1999)

In addition, the data of the first few number of cycles can provide the rate of plastic deformation or rut rates [Thompson & Neumann, 1993]. The rut rate details, which depend on soil type and loading conditions, are beneficial for pavement design because they can be used for evaluating the rut potential of subgrade.

Flexible pavements are designed to withstand a limiting horizontal tension at the bottom of the asphalt layer and a limiting vertical compression strain (or

stress) at the top of subgrade. These maximum strain values limit the fatigue damage of the asphalt layer and the rutting (permanent deformation) of the subgrade, respectively as shown in Figure (2-2) [Khasawneh, 2005].

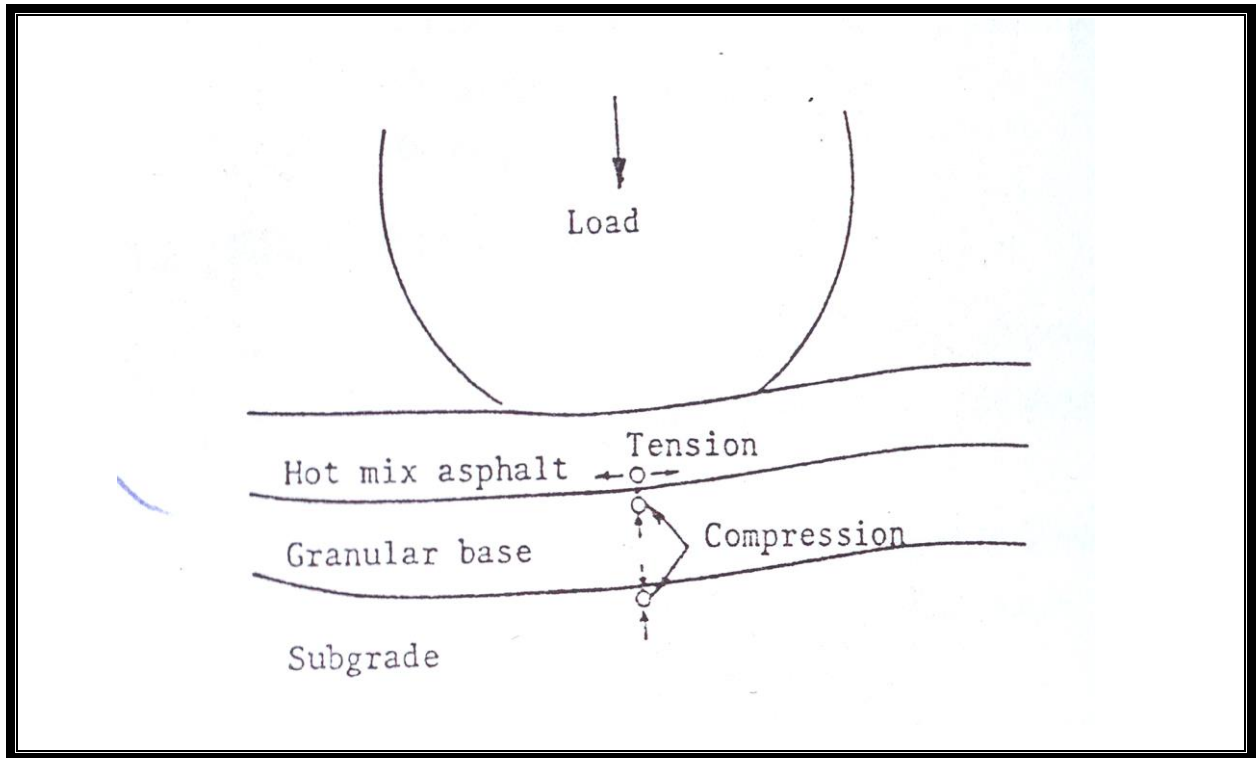


Figure (2-2) Tensile and compressive strains in flexible pavements
(after Huang, 1993)

2.2: Definition of Subgrade Layer

The subgrade is the foundation layer and must eventually support all the loads, which come into the pavement. This layer in some cases will simply be the natural earth surface. In other instances, it is compacted soil that exists in a cut section or the upper layer of an embankment section. The principle concept of the flexible pavement's action is that the combined thickness of subbase, base and wearing surface must be great enough to reduce the stresses in subgrade to the values that are not sufficiently great to cause excessive distortion of the

subgrade soil layer, [Wright & Paquette, 1987] as cited by [AL-Mumaiz, 2002].

[AL-

2.3: Iraqi Specification for Active Soil Layer

The SCRB (State Corporation of Roads and Bridges) specifications, specify that the active soil layer of subgrade (30 cm below the formation) should be compacted to minimum of 95% of the maximum density as determined by AASHTO (American Association of State Highway and Transportation Officials) T180-74 (modified AASHTO compaction test) in all parts of the embankment and cut areas throughout the whole length & width of section. A maximum dry density (modified compaction) of not less than 1.7 gm/cm³ and a minimum CBR of not less than 4% at 95% relative modified AASHTO compaction are also required by SCRB specification for the active layer, and the liquid limit and plasticity index should be less than 55 and 30 respectively, otherwise the soil shall not be regarded as a suitable to be used for subgrade [SORB, 1983].

In such cases, the 30-cm soil layer immediately below the surface of the subgrade shall be replaced with suitable soil or granular material. It is also worthwhile mentioning that salty or gypsiferous soil containing more than 10% of soluble salts is considered unsuitable material when used in the top 20 cm of the embankment and 20% in the rest of the embankment (not for express ways).

2.4: Typical Subgrade Distresses

Hawaii Asphalt Paving Industry, [2003] propose that poor subgrade level can cause various pavement distresses as:

1. Fatigue cracking: The fatigue crackings are a series of interconnected cracks caused by a fatigue failure of the hot mix asphalt surface under a repeated traffic loading. As the number and magnitude of loads become too great, longitudinal cracks begin to form (usually in the wheel paths). After repeated loading, these longitudinal cracks connect forming multi-sided sharp-

angled pieces that develop into a pattern resembling the back of an alligator or crocodile as shown in Figure (2-3). Fatigue cracking can be caused by poor subgrade support.



Figure (2-3) Fatigue Cracking

2. Potholes: Potholes are small, bowl-shaped depressions in the pavement surface that penetrate all the way through the hot mix asphalt layer down to the base course as shown in Figure (2-4). They generally have sharp edges and vertical sides near the top of the hole. Potholes can result in serious vehicular damage and moisture infiltration. One of the possible causes for potholes formation is weak subgrade layer.



Figure (2-4) Pothole

3. Depressions: Depressions are localized pavement surface areas with slightly lower elevations than the surrounding pavement as shown in Figure (2-5). This type of distress is very noticeable after the rain when they are filled with water. Depressions result in the problems of roughness and the depressions filled with substantial water can cause vehicle hydroplaning. The major reason for depressions is subgrade settlement resulting from inadequate compaction during construction.



Figure (2-5) Depression

4. Rutting: Rutting is the surface depression in the wheel path as shown in Figure (2-6). Pavement uplift (shearing) may occur along the sides of the rut. Ruts are particularly evident after the rain when they are filled with water. There are two basic types of rutting: mix rutting and subgrade rutting. Mix rutting occurs when the subgrade does not rut yet the pavement surface exhibits wheel path depressions as a result of compaction/mix design problems. Subgrade rutting occurs when the subgrade exhibits wheel path depressions due to loading. In this case, the pavement settles into the subgrade ruts causing surface depressions in the wheel path. Ruts filled with water can cause vehicle hydroplaning and can be hazardous because ruts tend to pull a vehicle towards the rut path as it is steered across the rut.



Figure (2-6) Pavement Rutting

2.5: Mechanism of Permanent deformation

When a shear stress is sustained on a soil specimen the stress will be carried in the first place by the non-rigid clay matrix which exhibits translations and rotations of the particles. As a result the load will be transferred to the more rigid contacts causing significant decrease in creep rates. Important changes in the structure happen during this stage, the number and size of voids are reduced, fabric defects partially closed, spacing between clay size particles decreases. As a result the structure grows stronger leading to a stable equilibrium. After this stage, the soil structure is behaving macroscopically as a viscous material with a viscosity which increases with time due to a stiffening of the contact bonds [Waker, 1969] as cited by [Kemmonr, 1986].

At low and moderate stress levels, the deformational energy stored in the specimen during the loading process is of a small order, and dissipated within a short period of time. Under high stress levels, the specimen exhibits greater primary and secondary creep. The stresses will be so high that microcracks of

different orientation are liable to develop, old fissures grow and new ones appear. As a result, the specimen undergoes accelerating creep at a considerable rate leading to failure [Pusch & Felthan, 1980].

2.6: Stages of Permanent deformation

Regardless of the material type considered, there are generally three distinct stages for the permanent deformation that reported by the National Cooperative Highway Research Program [NCHRP, 2004] and can be described as follows:

Primary Stage: high initial level of rutting, with a decreasing rate of plastic deformation, predominantly associated with volumetric change.

Secondary Stage: small rate of rutting exhibiting a constant rate of change of rutting that is also associated with volumetric changes; however, shear deformation starts to increase at increasing rate.

Tertiary Stage: high rate (level) of rutting predominantly associated with plastic (shear) deformation under no volume change conditions. These typical stages are shown in Figure (2-7).

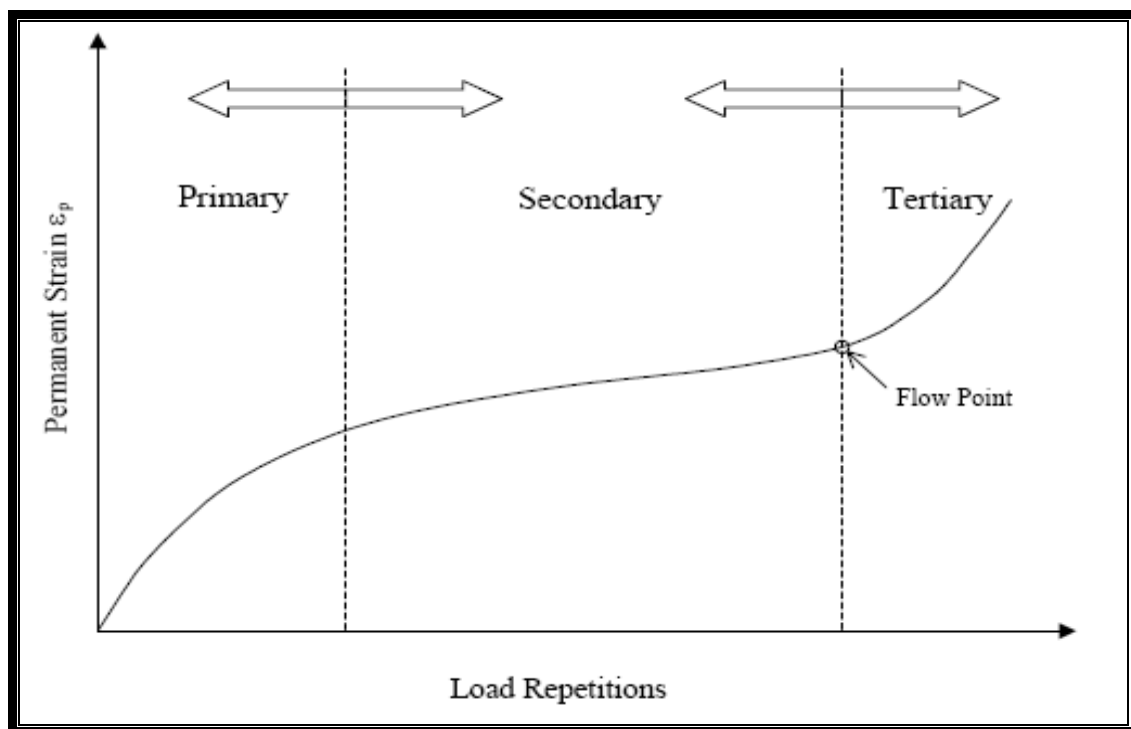


Figure (2-7) Typical Repeated Load Permanent Deformation Behavior of Pavement Materials (after NCHRP, 2004)

Permanent deformation has been less studied [Gidel, et. al., 2001] as cited by [Khasawneh, 2005]. Gidel, et. al., [2001] attributed this unsatisfactory concern of permanent deformation to three reasons:

1. The complexity of the tests in view of the strong influence of the stress history.
2. The difficulty in making the transition from the laboratory test results to predicting in-pavement behavior.
3. The test results exhibit a significant amount of dispersion due to the large number of test specimens needed.

Elliott, et. al., [1998] reported that permanent deformation has not received much attention because:

1. Tests are tedious, time-consuming and expensive.
2. Most research efforts and expenses have gone to resilient behavior of subgrade soils during the last decade and at the same time people have a high expectation that flexible pavement design will be improved by better understanding of resilient modulus of soils.
3. Pavement distresses are thought to be highly dependent on resilient behavior rather than plastic behavior of subgrade soils.
4. Highway research has been mostly devoted to high-volume road ways where thick AC layer and/or base layer are generally used in design and subgrade permanent deformation is believed to be insignificant.

2.7: Factors Affecting Permanent Deformation

Permanent deformation of subgrade soils is affected by the following soil and loading conditions:

2.7.1: Moisture content

It is apparent that as the moisture content increases, the permanent deformation also increases. Elliott, et. al., [1998] found that the moisture content

is a significant factor contributing to the accumulation of permanent deformation. He examined the influence of moisture content on the permanent deformation of four representative Arkansas cohesive subgrade soils and found that as moisture content increased (especially for specimens compacted above the optimum), for the same deviator stresses, permanent strains increased as shown in Figure (2-8). This result is expected since the presence of water results in a decrease of the resistance to deformation and therefore, strains (recoverable or permanent) are consequently increased.

Also [**Puppala, et. al., 2005**] as cited by [**Khasawneh, 2005**] found that in the case of wet of optimum moisture content the following three factors induced high plastic strain:

- a. High water content in sand causes a lubrication effect at the soil particle contact points, thereby increasing the plastic deformation or rutting in wet soils under continuous loading.
- b. Strengths of soil specimens were lower at wet of optimum moisture conditions and hence continuous deviatoric loading induces more damage to the soil specimen, which was recorded in the form of high rutting.
- c. Though not measured, positive pore pressures in near saturated soil specimens at wet of optimum conditions increase with the number of cycles and hence result in softening and high permanent deformation in soils.

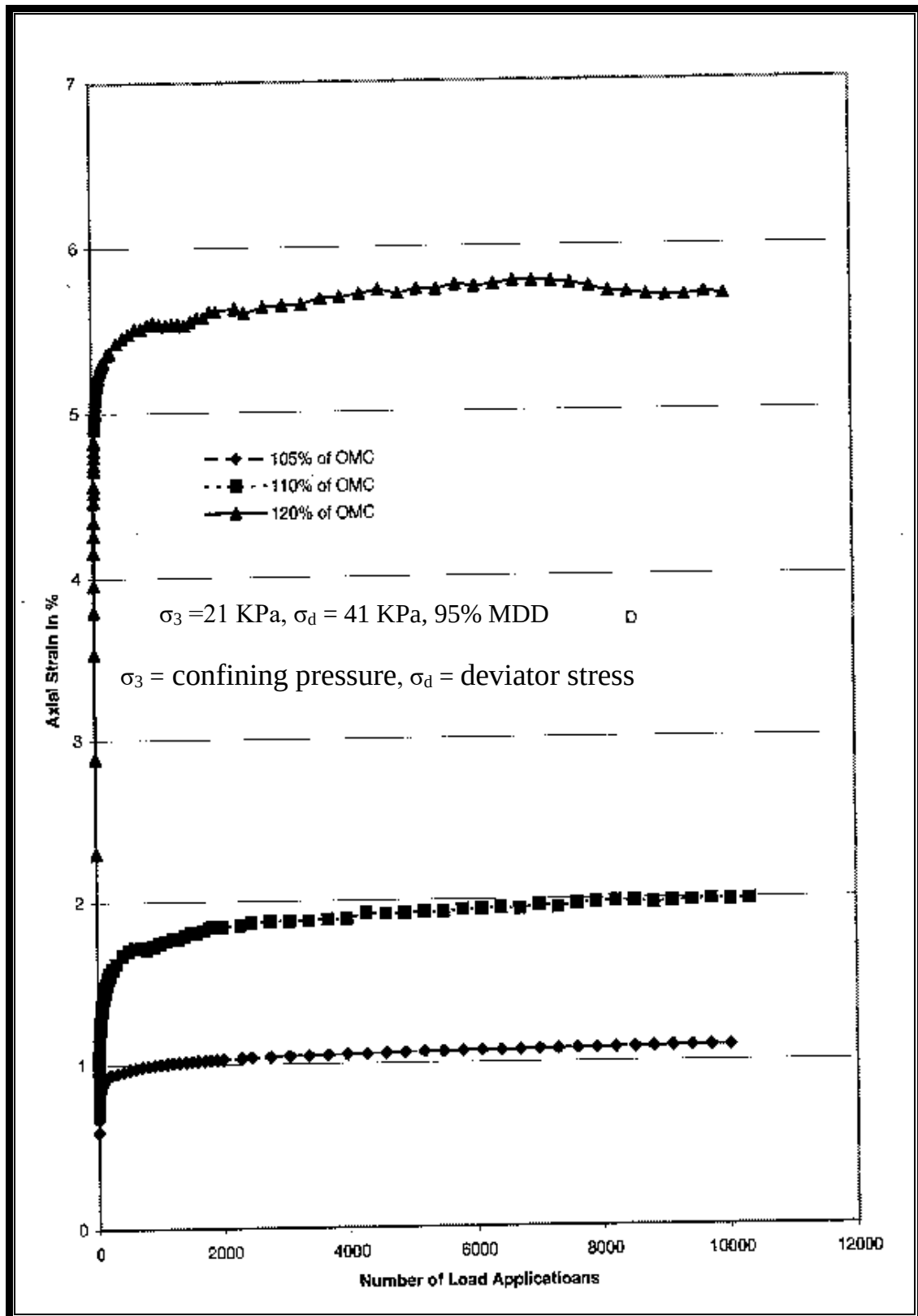


Figure (2-8) Effects of Moisture Content on Axial Strain
(after Elliott, et. al., 1998)

2.7.2: Deviatoric stress

It was found by Elliott, et. al., [1998] that the deviator stress plays a major role in the development of permanent deformation, especially on the first cycle deformation as show in Figure (2-9). Also Puppala, et. al., [2005] and Gidel, et. al., [2001] as cited by **Khasawneh, 2005]** found that an increase in deviatoric load resulted in high plastic strain at the same compaction conditions.

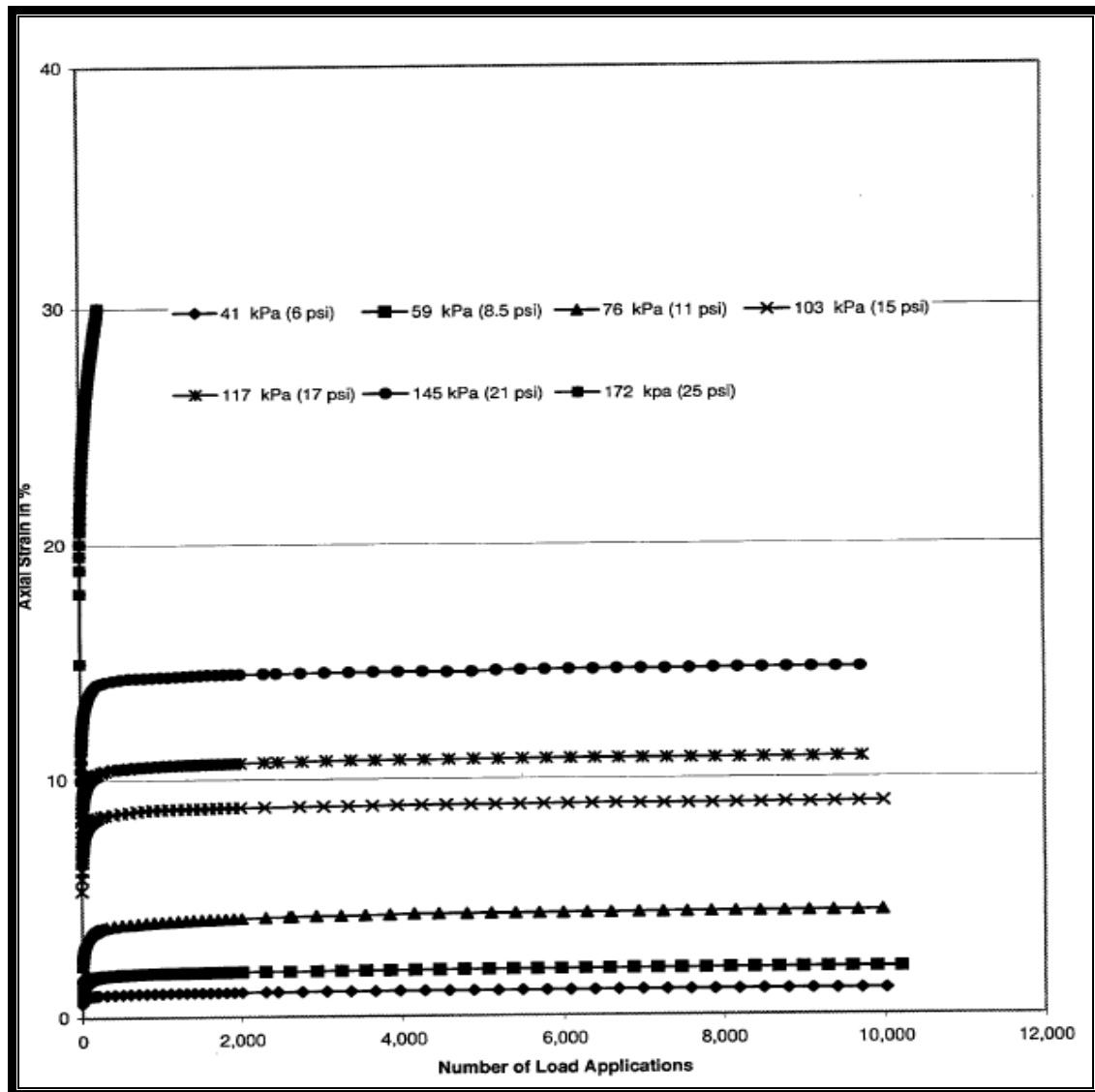


Figure (2-9) Effects of Deviatoric Stress on Deformation
(after Elliott, et. al., 1998)

2.7.3: Density

The more packed the material is, the less plastic deformation it will exhibit, but the influence of this property is very slight over the density range generally encountered in pavements [Khasawneh, 2005]. Yanjun, et. al., [1999] found that the density plays a minor role in contributions to permanent deformation as shown in Figure (2-10).

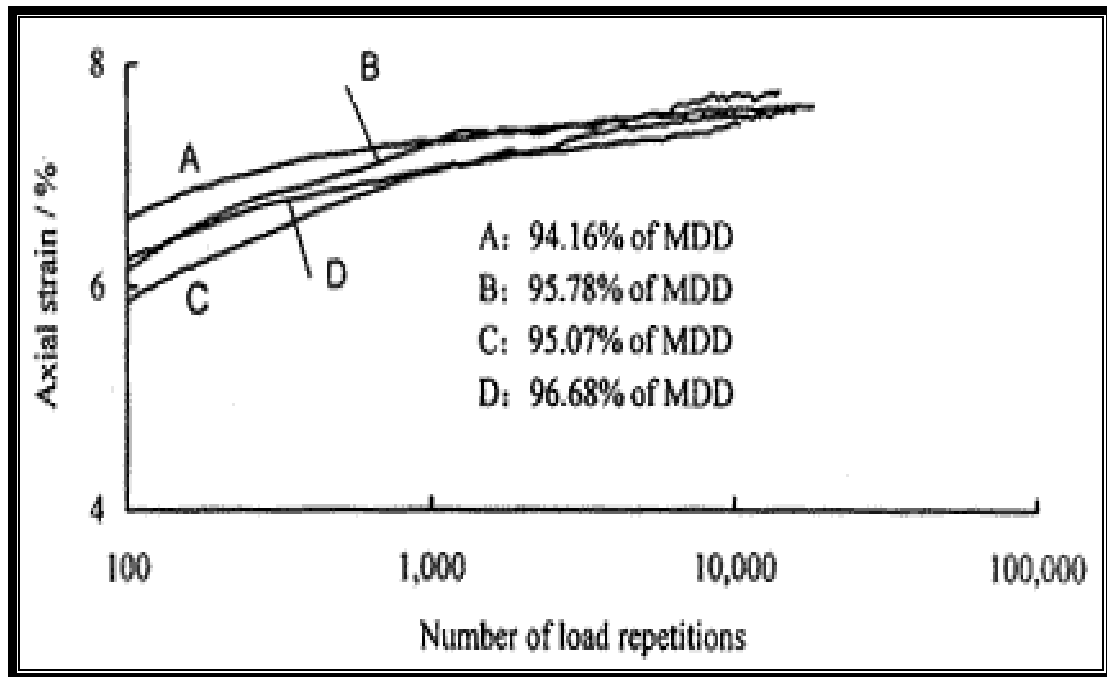


Figure (2-10) Effect of Density on Permanent Deformation of Soil A4 (after Yanjun, et. al., 1999)

2.7.4: Confining pressure

Elliott, et. al., [1998] found that confining pressure plays a minor role in contribution to permanent deformation and it is not a critical factor in influencing permanent deformation as shown in Figure (2-11). Also Khasawneh, [2005] found that all around pressure was found to slightly, if any, affect the permanent deformation of soil.

On the other hand, Gidel, et. al., [2001] as cited by [Khasawneh, 2005] indicated that the experimental results show permanent deformation diminishes when the mean stress or lateral pressure is increased.

Normally, the static confining pressure in the upper part of the subgrade will be in the range of 1 PSi (6.9 KPa) to 1.5 PSi (10.35 KPa). [Monismith, et. al., 1973].

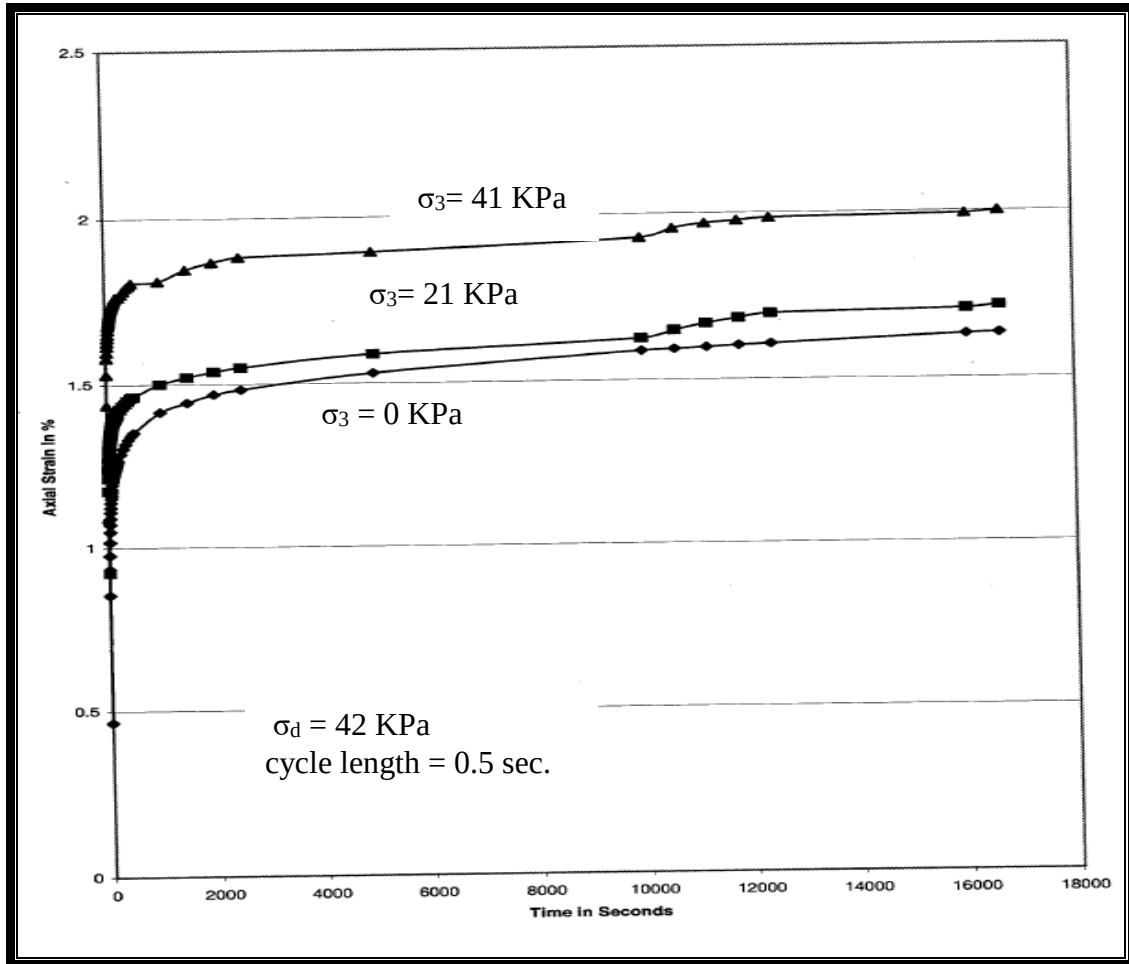


Figure (2-11) Effects of Confining Pressure on Deformation
(after Elliott, et. al., 1998)

2.7.5: Stress history

Monismith, et. al., [1975] performed a series of undrained triaxial compression tests on a silty clay (liquid limit = 35, plasticity index 15). Specimens were prepared at dry densities from 90 to 95 percent of the maximum value obtained in the modified AASHTO compaction test and at water content from 16 to 20 percent. The effect of stress history on the permanent deformation accumulation is presented in Figure (2-12). These are the results of the repeated load test of specimens at a constant confining pressure of 5 PSi and at the

repeated deviator stresses of 10 and 20 PSi. In the two cases, the specimens were subjected to 10000 applications of these stresses, followed by an unloading and a reload to the same number and level of stress applications. The data shows that specimens with the previous stress applications exhibited lower axial permanent strains than the specimens that were not previously subjected to stress applications. These results attributed to a considerable stiffening and a consequent increase in the resistance to the deformation that is generated by the previous stress applications.

Also Puppala, et. al., [1999] found that the behavior of cohesive soils is controlled by the previous stress history. According to their test result, dilatational or negative plastic strains are measured at testing stress levels that are smaller in magnitude than those measured at the previous stress levels.

Elliott, et. al., [1998] found that the previous loading at lower deviator stresses increased the soil's resistance to deformation under repeated loads at high deviator stress. The work hardening of previous load application made the specimen more solid and less prone to permanent deformation.

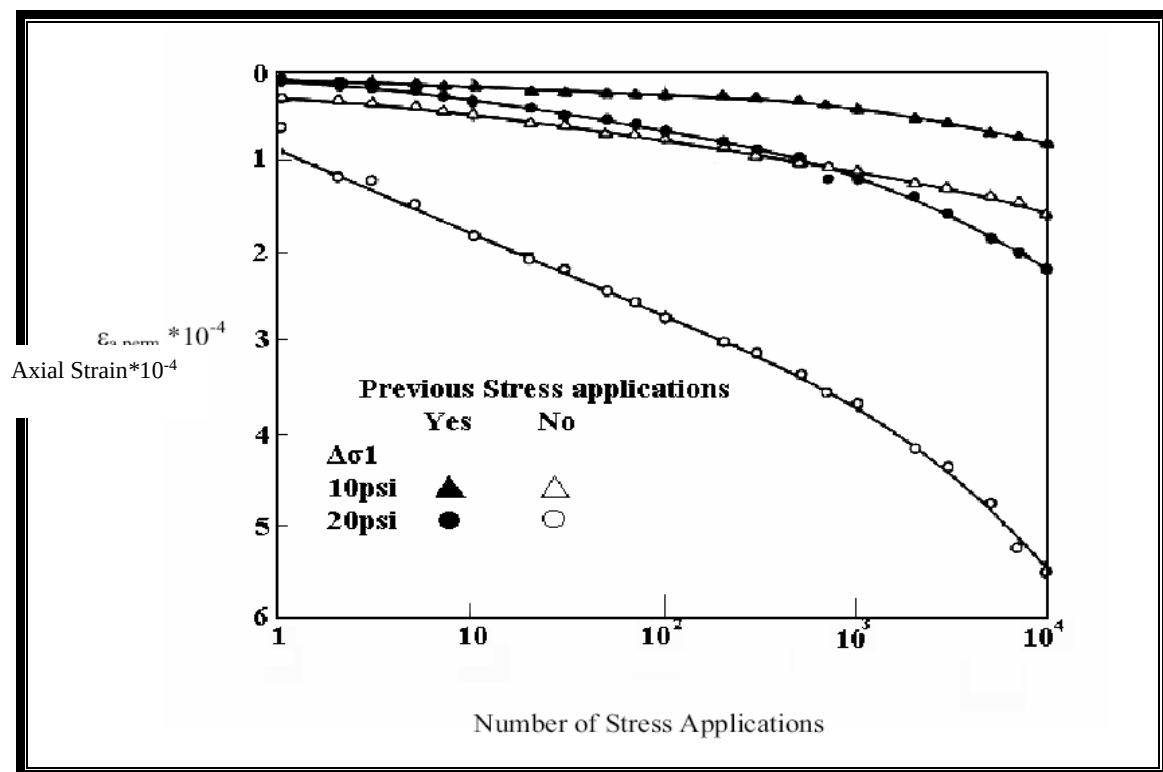


Figure (2-12) Influence of Stress History on Permanent Strains
(after Monismith et. al., 1975)

2.7.6: Frequency of load

Seed & Chan, [1958] as cited by [Salgado & Kim, 2002] found that the influence of the frequency of load was significant on clays with a high degree of saturation, while clays with low degree of saturation were not influenced at all. Figure (2-13) presents the effect of the load frequency using stress controlled tests for identical silty clay specimens compacted to an initial degree of saturation of 95 percent and subjected to the repeated stress applications of the same magnitude and duration, but with varying frequencies. There is a large difference in the number of application required to cause a certain amount of strain. Specimens subjected to high load frequencies developed a certain amount of axial strain sooner than specimens subjected to low load frequencies.

Also Elliott, et. al., [1998] found that the higher load frequency would increase the potential of soils to deform under repeated load, especially under high deviator stress. One reason might be that the rest period is not long enough for soils to develop an increasing resistance to succeeding load applications.

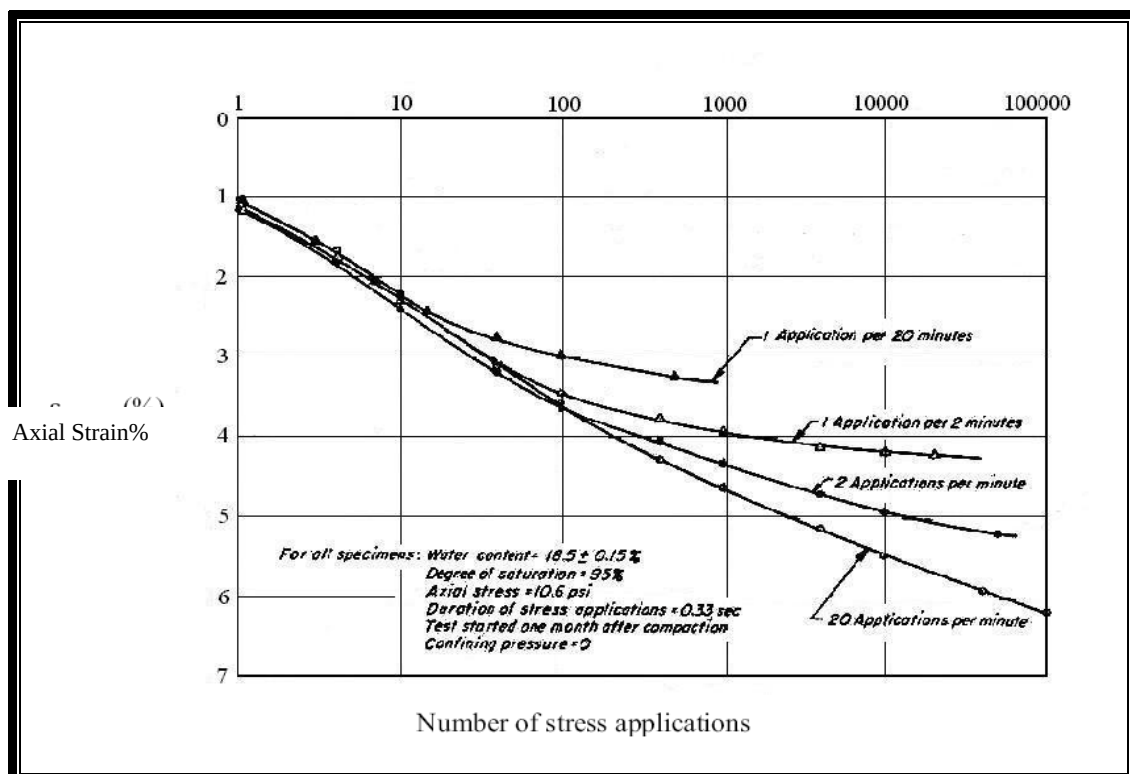


Figure (2-13) Effect of Frequency of Stress Application on Deformation of Silty Clay with High Degree of Saturation (after Seed & Chan, 1958)

2.7.7: Particle size and shape

The best resistance to permanent deformation is obtained with a continuous grading and a fairly high fines content (between 6 and 10% of fines), which turns out to enhance the density. On the other hand, the best performance being achieved with crushed granular material with angular particles [Khasawneh, 2005].

2.7.8: Influence of Asphalt Concrete Thickness upon Permanent Deformation

Figure (2-14) illustrates that for all levels of AC thickness, the magnitude of rutting in the subgrade is increased as the subgrade support is decreased. When the asphalt concrete layer gets thicker, the subgrade rut decreases. However, increasing the asphalt layer thickness also protects the subgrade layer and reduces the rutting in it. While in a very small AC layer, the stress states in subgrade are quite large and will tend to increase the probability of rutting in it. Also, Subgrade rutting will be increased as the subgrade support becomes weaker [NCHRP, 2004].

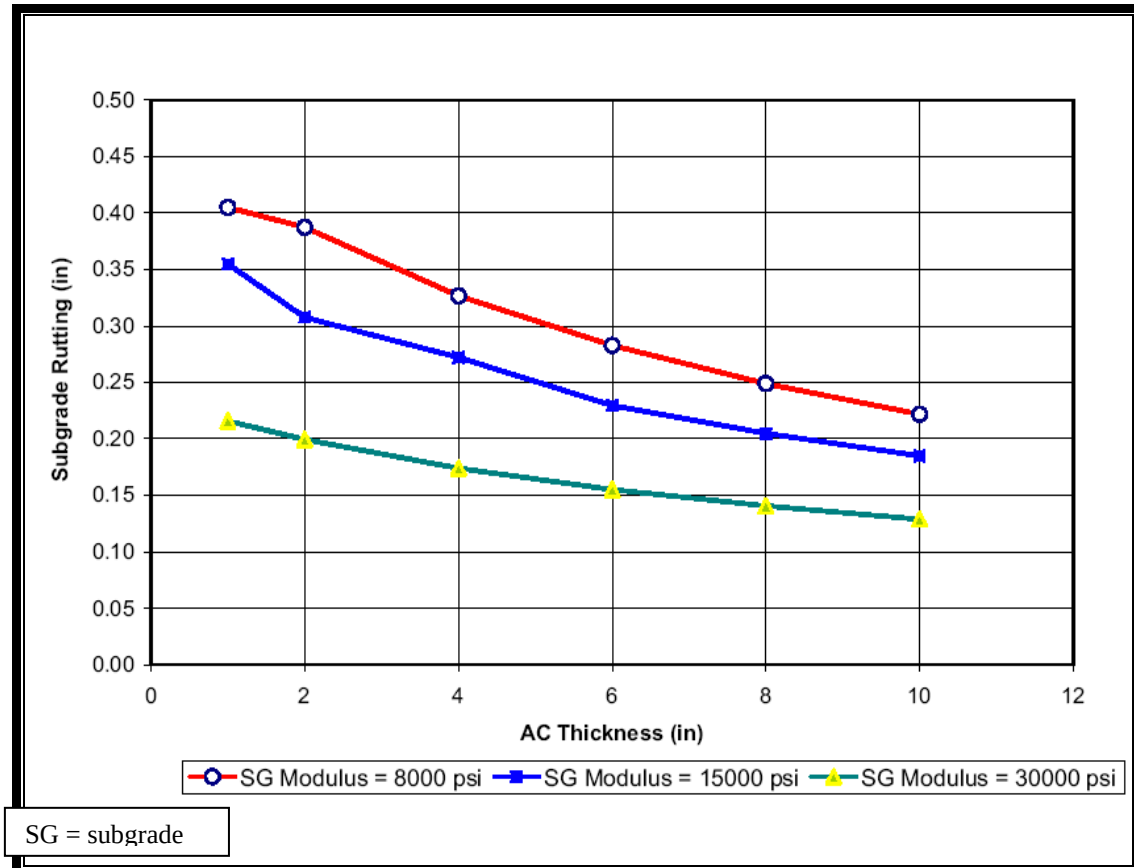


Figure (2-14) Effect of AC Layer Thickness on Subgrade Rut Depth (after NCHRP, 2004)

2.7.9: Influence of Base Thickness upon Permanent Deformation

The most significant impact of increasing the base thickness is that it will tend to protect the subgrade layer from a higher stress state and it, will tend to cause a large resilient strain, plastic strain and eventually rutting. As the thickness of base is increased, the subgrade rut depth will decrease [NCHRP, 2004]. The amount of base thickness required to bring the subgrade into a tolerable rut depth range is a direct function of the quality of the subgrade being used, as shown in Figure (2-15).

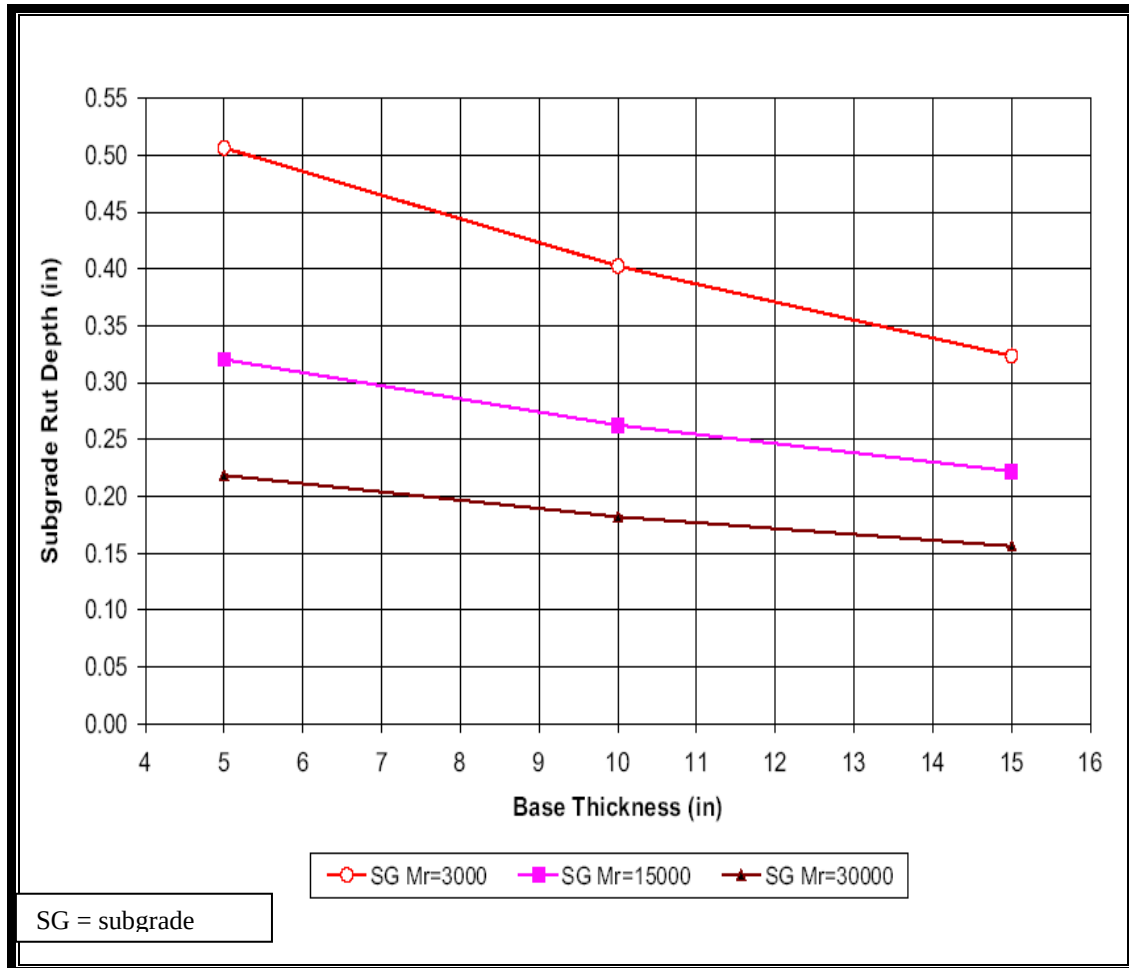


Figure (2-15) Effect of Base Thickness on Subgrade Rut Depth at Different Subgrade Moduli (after NCHRP, 2004)

2.7.10: Influence of Depth to Ground Water Table (GWT) on Permanent Deformation

The influence of the ground water table depth, as observed in Figure (2-16) is more pronounced on subgrade rutting, compared to the other pavement layers.

The presence of ground water table within a flexible pavement cross-section will influence the magnitude of rut depth that may occur in the subgrade [NCHRP, 2004]. In general, the closer the ground water table is to the surface, the more subgrade rutting that will occur. As the subgrade gets soft (low modulus) the influence of the GWT depth on the subgrade becomes more and the changes in the rutting are very significant.

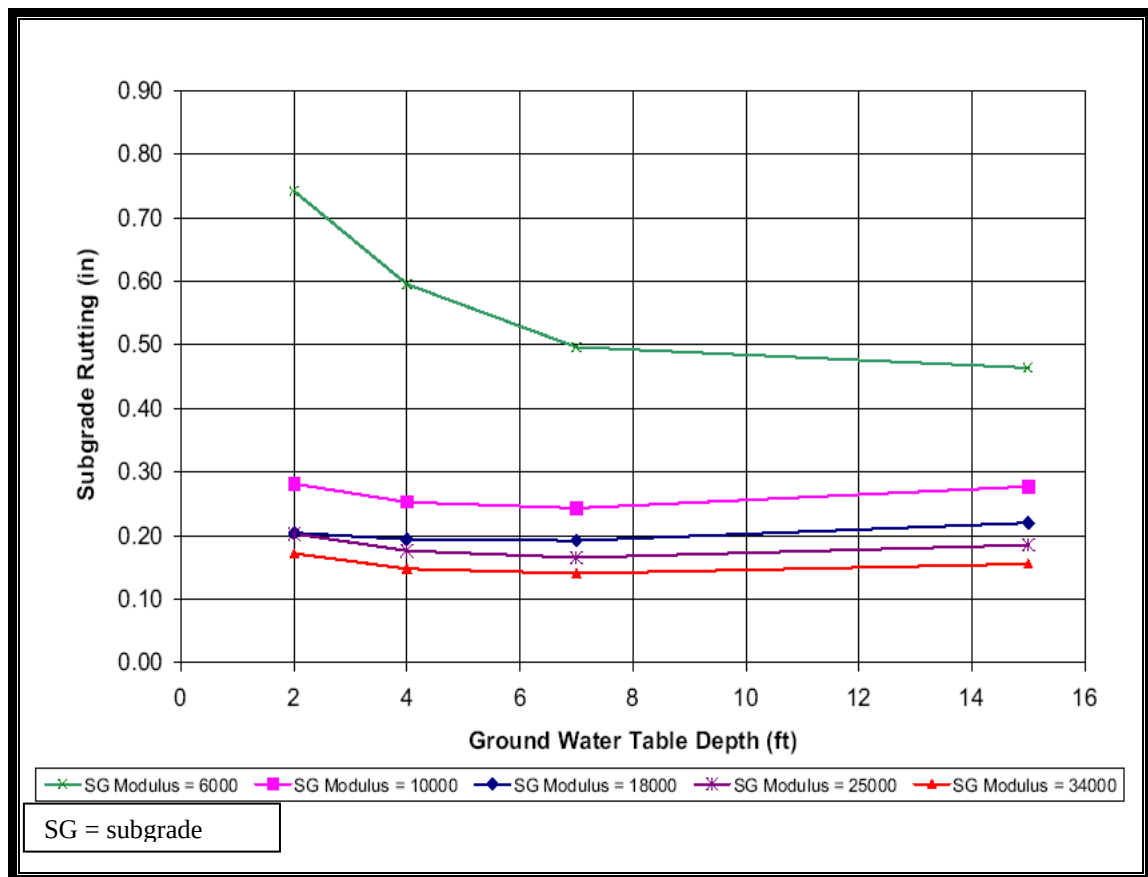


Figure (2-16) Effect of Depth to GWT on Subgrade Rut Depth
(after NCHR, 2004)

2.8: Repeated or Cyclic loading

Currently, there are no clear U.S. standards or established test procedures for determining the plastic strain response of subgrade soils [Puppala, et. al., 1999] and [Majidzadeh, et. al., 1978]. Although several test methods were used that are similar to the ones developed for asphalt mixes and bases, none are standardized [Ullditz, 1993].

Repeated loading or cyclic loading has been the well accepted test method in analyzing elastic and plastic deformation behavior of subgrade soils [Behzadi & Yandell, 1996] as cited by [Puppala, et. al., 1999].

Hyde and Brown, [1976] found that the behavior of a silty clay under creep loading has been shown to be very similar to that under repeated loading, and there is a linear relationship between the logarithm of the strain rate and the applied deviator stress.

It is well known that most paving materials are not elastic but experience some permanent deformation after each load application. However, if the load is small compared to the strength of the material and is repeated for a large number of times, the deformation under each load repetition is nearly completely recoverable and proportional to the load and can be considered as elastic. Figure (2-17) shows the straining of a specimen under a repeated load. At the initial stage of load applications, there is a considerable permanent deformation, as indicated by the plastic strain in the figure. As the number of repetitions increases, the plastic strain due to each load repetitions decreases [Huang, 1993].

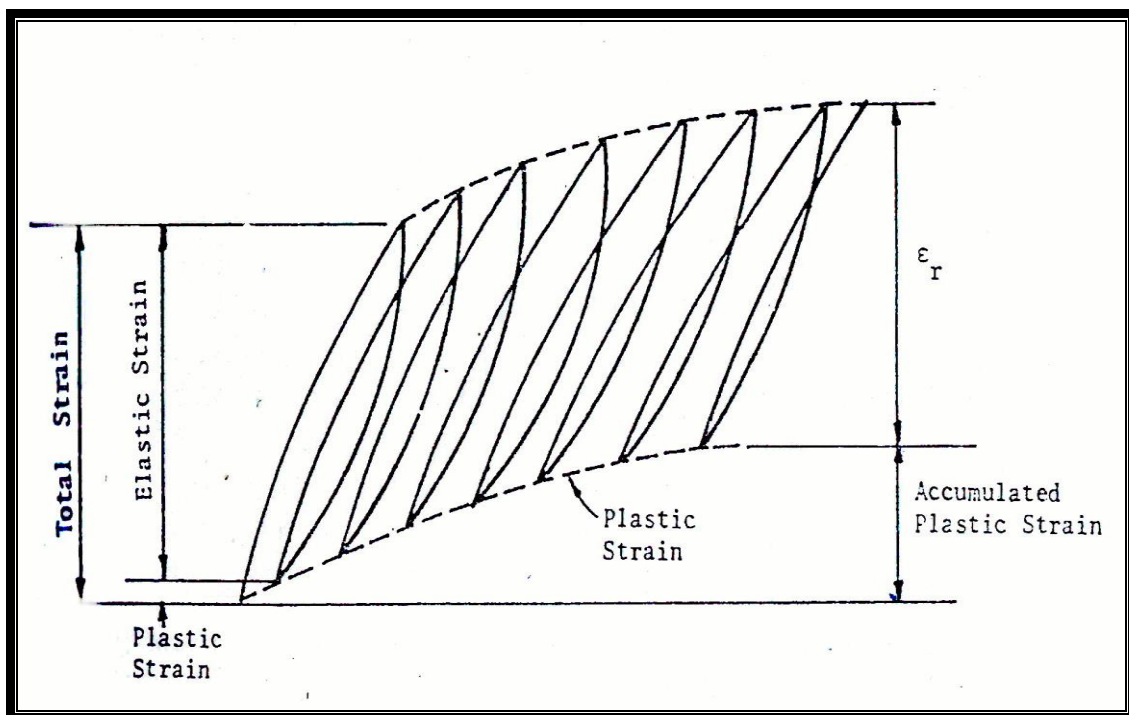


Figure (2-17) Strain under Repeated Loads (after Huang, 1993)

2.9: Permanent Deformation Models

For predicting permanent deformation in subgrade layers, several researchers have proposed different models, theories and testing procedures.

The total rut depth in a pavement is a summation of various layers in a multilayer pavement system [Puppala, et. al., 1999], and it is given by

$$\delta_p = \sum \epsilon_{pi} h_i \quad \dots\dots\dots 2 - 1$$

Where:

δ_p = total rut depth

ϵ_{pi} = plastic strain of each layer

h_i = thickness of the layer

The permanent deformation of road material is generally expressed as the product of two functions [Romain, 1972], as cited by [Puppala, et. al., 1999]

$$\epsilon_p = f(s). F(n) \quad \dots\dots\dots 2 - 2$$

Where:

ϵ_p = permanent strain.

$f(s)$ = function of stress condition characterized by the deviatoric stress magnitudes.

$F(n)$ = function of number of load repetitions.

Monismith, et. al., [1973] proposed a rutting model that is well accepted in predicting the amount of rutting contributed by the subgrade.

$$\epsilon_p = AN^b \quad \dots\dots\dots 2 - 3$$

Where:

ϵ_p = permanent strain

N = number of stress application

A, b = experimentally determined coefficients

Monismith used a silty clay soil to develop this model with liquid limit and plasticity index are 35% and 15%. The specimens have a diameter 2.8 in

(71.12 mm) and height 6 in (152.4 mm). A load duration 0.1 sec. followed by a rest period created a cyclic frequency of 20 repetitions per minute and most of the specimens were subjected to 10000 load repetitions with some specimens receiving up to 100000 applications. Exponent b is dependent only on soil type while the coefficient A is a function of stress level and placement conditions.

Hyde & Brown, [1976] found that the accumulation of plastic strain could be predicted by using a relationship between strain rate and time:

$$\text{Log } \dot{\epsilon} = \alpha - \lambda \log T \quad \dots\dots\dots 2 - 4$$

Where:

λ = (decay constant) from regression of test data

$\dot{\epsilon}$ = strain rate

T= time in second

α = log (strain rate at unit time)

They tested silty clay with a liquid limit of 32 and a plastic limit of 18. The soil was tested under the creep loading and the repeated loading. It was found that no significant change in the strain rate could be expected from the inclusion of test periods of different lengths. And by comparing the test data from the repeated load and the creep load, it was concluded that a permanent deformation could be predicted with confidence from the creep test data.

Another popular rutting model has been termed the Ohio Model [Majidzadeh, 1978]

$$\epsilon_p / N = A N^{-m} \quad \dots\dots\dots 2 - 5$$

Where

A, m = rutting parameters

Five soils were tested in the development of this model (three silty sands and two low-plasticity clays). The test specimens were created by using a drop-hammer compaction technique that yielded specimens with a constant diameter of 71 mm (2.78 in) but with a variable height of 145-152 mm (5.7-6.0 in). Specimens were subjected to loading by using a uniaxial dynamic testing technique. The accumulation rate of permanent deformation was related to the number of load applications.

Diyaljee & Raymond, [1983] suggest the following model which is widely used, the equation is as follows

$$\epsilon_p (N) = IN^S \quad \dots\dots\dots 2 - 6$$

Where:

I = permanent strain that occurs during the first cycle of load

S = slope of the plot between permanent strain and number of load cycles (N).

Thompson & Neumann, [1993] used a logarithmic permanent strain--logarithmic load repetitions phenomenological model in the modeling of plastic strains of soils. The expression for this model is given as follows:

$$\text{Log } \epsilon_p = a + b \text{ log } N \quad \dots\dots\dots 2 - 7$$

Where:

ϵ_p = the accumulation permanent strain

N = the number of load repetitions

a and b = model constants.

They show that a term varies and depends on the soil type and stress level while b term varies between 0.12 and 0.2 for the cohesive and granular soils, respectively.

Li, et. al., [1996] as cited by [Elliot, et. al. 1998] proposed a rutting model to predict cumulative plastic deformation of subgrade soils. It was found that the measured settlements of the subgrade were consistent with the predicted settlements given by the equation:

$$\epsilon_p = a N^b \beta^m \dots\dots\dots 2 - 8$$

Where:

a, b, m = material constants. The parameter b is relatively constant for the same soils and could be considered a function of the soil type alone.

β = deviator stress/ static strength. And it was introduced to account for the influence of factor such as moisture content, density and soil structure.

Muhanna, et. al., [1998] as cited by [Salgado, et. al. 2002] proposed the following model to predict the cumulative plastic deformation of subgrade soils:

$$\text{Log} [\Sigma \epsilon_p^* / (SL^{7/4} . e^3)] = 1.3 + 2.476. (w-w_o) / w_o \dots\dots\dots 2 - 9$$

Where:

$\Sigma \epsilon_p^*$ = accumulated plastic strain (%) at the state of apparent shakedown (shakedown can be defined as the switch of material response from plastic to purely elastic behavior after a few cycles of loading)

SL = stress level

e = void ratio obtained by T-99 compaction at molding water content (w)

w = molding water content (%)

w_o = T-99 optimum moisture content (%)

Puppala, et. al., [1999] derived the following model to predict the cumulative plastic deformation of subgrade soils by using three types of soils (well-graded sand, silty clay and heavy clay):

$$\text{Log } \epsilon_p = \log A + a \log N + \beta \log [\sigma_{\text{oct}} / \sigma_{\text{atm}}] \quad \dots\dots 2 - 10$$

Where:

ϵ_p = the accumulation permanent strain

A , a and β = constant

N = the number of load repetitions

$$\sigma_{\text{oct}} = [\sigma_1 + \sigma_2 + \sigma_3] / 3$$

$\sigma_1, \sigma_2, \sigma_3$ = major principal stress

σ_{atm} = reference stress (atmospheric pressure of 100 KPa)

The log A value of the three soils depends on the moisture content and dry unit weight levels at which the soil samples are tested. Also the value appears to depend on the moisture content and dry unit weight levels of the soils while the β value appears to be dependent on the soil type.

Zhang, W. and Macdonald, R. A., [1999] proposed the following model to estimate the plastic strain in subgrade soils. The assumption made in the model is that the vertical plastic strain, ϵ_{pz} , can be written as a function of the number of load repetitions, N , and of the vertical resilient strain, ϵ_z , with the following relationship:

$$\epsilon_{pz} = A * N^a * \epsilon_z^\beta \quad \dots\dots\dots 2 - 11$$

Where:

ϵ_{pz} : is the vertical plastic strain in microstrain at depth z .

ϵ_z : is the vertical resilient strain in microstrain.

A , a and β are constants, obtained in an incremental-recursive procedure by minimizing the difference between the measured and estimated values.

It can be seen that the previous models are depended on the repeated load testing equipments that allow for load duration of (0.1) [which would represent the time of loading for a moving vehicle at (88) km/h (55 mph)] to (0.5) second and rest duration of (0.4) to (2.7) second. In fact this equipment is not available in Iraq, so it is difficult to apply these models on Iraqi soils.

CHAPTER THREE

EXPERIMENTAL WORK

3.1: Introduction

In this chapter the sampling, testing program, simple description of testing apparatus and the adopted test procedures which are adopted for the laboratory test program are explained in detail. Cyclic load tests include four test series to investigate the effect of moisture content, stress, dry density, and subgrade soil types on permanent deformation.

3.2: Sampling

The subgrade soil samples that are used in this research were collected from two sites that cover an important geographical area of Iraq. The first subgrade soil sample was taken from the north shoulder of Kerbala-Hilla roadway near new Kerbala university as shown in Figure (3-1), while the second subgrade soil sample was taken from Al-jadrreya in Baghdad near university of Baghdad as shown in Figure (3-2) .

When the samples are taking, the superficial soil was scraped off in order to dispose the organic materials and roots and then disturbed soil samples were taken from the two sites. The two samples were obtained at a depth of (30 cm) from the natural ground surface.

The subgrade soil samples were put in plastic bags, labeled and transported to the soil mechanics laboratory, in the college of engineering at the University of Babylon, also transported to the soil mechanics laboratory, in the college of engineering at the University of Baghdad for testing.



Figure (3- 1) Site View Showing the site of Kerbala-Hilla roadway

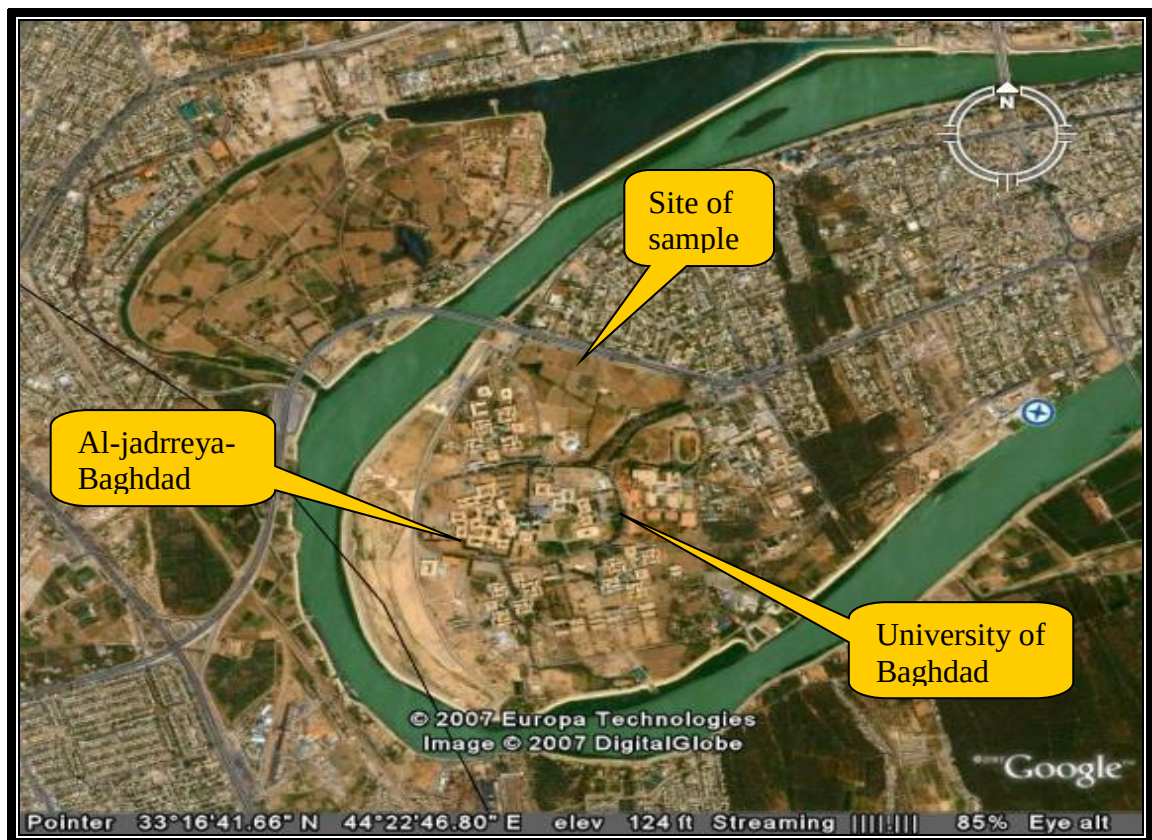


Figure (3- 2) Site View Showing the site of Al-jadrreya

3.3: Testing program

The testing program in this research can be summarized in the following groups:

- 1:** Classification tests include physical tests which comprised the water content, specific gravity, Atterberg limits, grain size analysis and maximum dry density.
- 2:** Cyclic load tests include four test series as follows:
 - a. **First series:** to investigate the effect of compaction moisture content on permanent deformation of subgrade soils.
 - b. **Second series:** to investigate the effect of stress on permanent deformation of subgrade soils.
 - c. **Third series:** to investigate the effect of dry density on permanent deformation of subgrade soils.
 - d. **Fourth series:** to investigate the effect of subgrade soil types on permanent deformation.

3.4: Classification Tests – Physical Tests

3.4.1: Water Content:

The water content of the soils was determined after the sampling according to the ASTM D-2216.

3.4.2: Specific Gravity:

The specific gravity of the soils was determined according to the ASTM D-854.

3.4.3: Atterberg Limits:

The liquid limit and the plastic limit tests were carried out according to the ASTM D-4318.

3.4.4: Grain Size Analysis:

Grain size analysis was determined by the sieve analysis and hydrometer according to ASTM D-422.

3.4.5: Classification of Soil:

The classification of soil was carried out according to AASHTO soil classification and also to unified soil classification system (u.s.c.s.) ASTM D - 2487.

3.4.6: Maximum Dry Density:

Maximum dry density test was performed according to ASTM D-698 standard Proctor test. These tests were used to establish a various moisture content and dry unit weight levels at which soil samples were prepared and tested with cyclic load tests.

3.5: Fabrication of Specimens

3.5.1: Mixing

The soils were mixed with the desired amount of water to control the moisture content and dry density. This means that the compacted soil specimens were prepared at a various moisture content to simulate the range of moisture expected in the subgrade within a pavement.

The first step was to put the samples in oven before (24) hours from the beginning of the test in (105) C° in order to remove all the humidity in soil samples, and then the samples will be taken out from the oven and allowed to cool at a room temperature and then added the water to the soil samples.

3.5.2: Compaction

At first, the standard Proctor compaction tests were conducted on the two soil types. These tests yielded dry unit weight versus moisture content relationships. The results of the standard Proctor compaction test used to establish a various moisture content and dry unit weight levels at which soil samples prepared and tested with the cyclic load tests.

A special split of three pieces of steel mold with (50.8 mm) in diameter and (101.6 mm) in height was designed as shown in Figure (3-3) to prepare specimens that can be used for a cyclic load testing.

The use of split mold is to get specimens of the same desired density because the use of a hydraulic extractor to remove the specimens from the mold will change the density of the specimens.



Figure (3-3) Steel split Mold and the Additional Part

Thus, the impact compaction method was used during the experimental work. Compaction is performed in five layers using a special hammer in order to give a compactive effort equivalent to the standard Proctor compaction test, until the desired density was achieved.

In order to achieve the target density, a trial and error approach is used to determine the number of blows per layer which is changed for different soils and even for the same soil under a different moisture content. Several trials were normally required before the correct blows per layer could be achieved.

A filmy tape is put inside the mold in order to decrease the cohesion between the mold and the soil specimens, thus, the specimens will be without disturbs.

3.6: Cyclic Loading Test

Due to the limitation of the available testing equipments, the possible local method which could be used to characterize the subgrade soils permanent deformation is the uniaxial cyclic load compression test. The consolidation apparatus for soils manufactured by (Geonor, Oslo - Norway) as shown in Figure (3-4) is employed to perform this test. The tests were performed on cylindrical specimens, 50.8 mm (2 in) in diameter and 101.6 mm (4 in) in height, giving a height to diameter ratio of (2) [**Puppala, et. al., 1999**].

This apparatus provides a cyclic loading for the subgrade specimens and the nature of projecting the load is perpendicular to the specimens, and this provides a gradual accumulation of small plastic deformation or permanent strains.

Three stresses are used for the cyclic load tests : 28 KPa, 42 KPa and 63 KPa. Each test consists of sixty cycle, the periods of each cycle consists of sixty second , ten seconds for loading and fifty second for unloading. The deformation is measured for each cycle at the end of ten second and at the end of sixty second.

The total number of cycles during tests is 60 cycles . The number of cycles is small compared with the actual number of cycles that causes a permanent deformation in the field conditions. However, for practical considerations, the plastic strain test data obtained from a small number of load cycles is assumed to be sufficient for extrapolating the permanent deformation results explored as a large number of cycles [**Puppala, et. al., 1999**] .



Figure (3-4) The Consolidation Apparatus for Soils

In this research only the subgrade strain criterion was considered. In the repeated creep test the sample is subjected to a number of load applications at different stress conditions to allow for the gradual accumulation of small plastic deformation or permanent strains. This test simulates the long-term loading condition of pavements in order to allow for prediction of the amount of permanent strain generated at any given number of load cycles at any stress

level. Three specimens for each combination are tested and the average results are reported.

Because the LVDT (linearly variable differential transformer) which convert the mechanical signal (displacement) to electrical signal appeared in the digital readout connected to the LVDT, was not available, a dial gauge of (0.002 mm) readability manufactured by ELE (Engineering Laboratory Equipment, Limited) are used in repeated creep tests as shown in Figure (3-5). The dial gauge was attached to the loading plate to measure the deformation of soil specimen.



Figure (3-5) The Dial Gauge that are used in tests

The strain (ϵ_p) is calculated by applying the following equation:

$$\epsilon_p = \frac{p_d}{h} \dots\dots\dots (3 - 1)$$

Where:

ϵ_p = axial strain (mm/mm)

P_d = axial deformation (mm)

h = specimen height (mm)

A typical relationship between permanent strain and the time of loading is shown in Figure (3-6) and the data are presented in Table (3-1), while the complete summary of repeated load tests data are shown in appendix A.

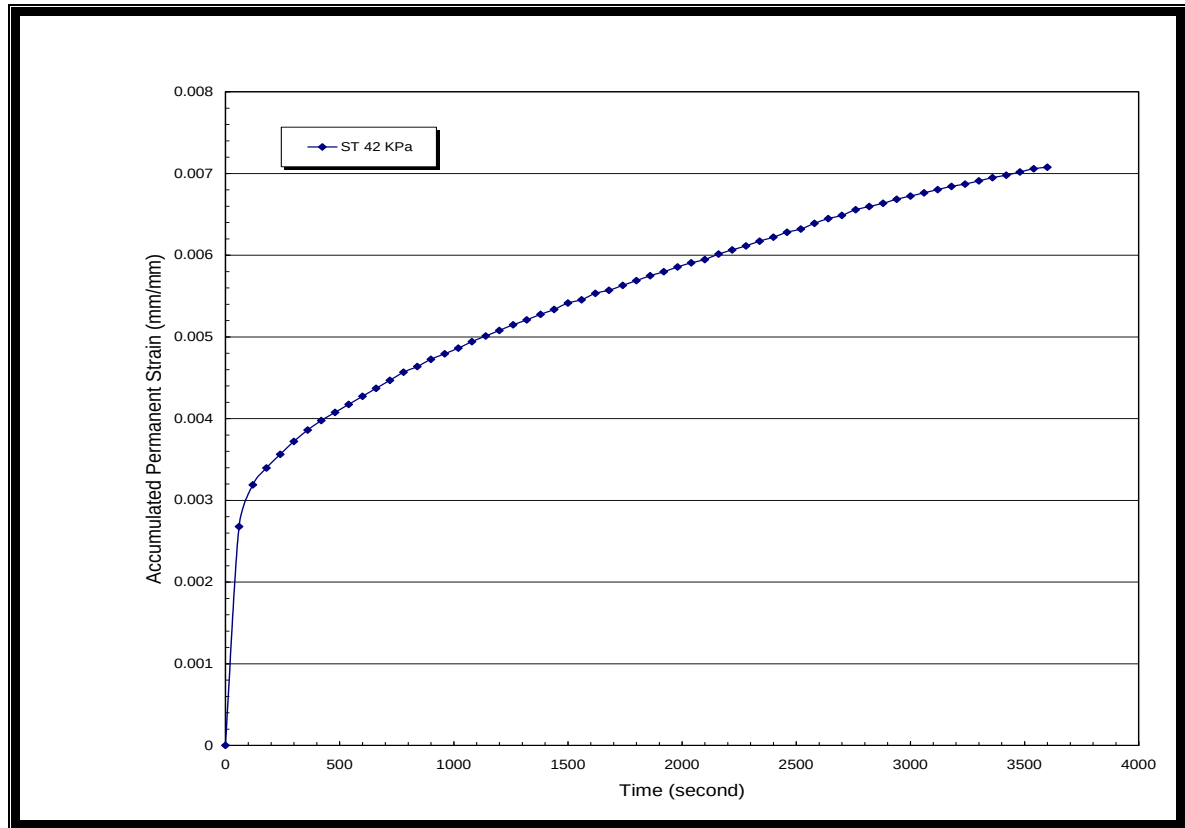


Figure (3-6) Typical Relationship between Permanent Strain and the Time of Loading

Table (3-1) Typical Record of Permanent Deformation Test Data

Date: **25 Oct 2006....** Loading Time **10 sec....** Rest Time **50 sec....**

Stress..... **42 KPa.....** Dial gauge readability...**0.002 mm....**

Notes...**Soil type A6, dry density = 95% of the maximum dry density,**
moisture content = 105% of the optimum moisture content.

Load			Unload			Permanent Strain (mm/mm)	Accumulation permanent strain (mm/mm)
Gauge reading	deformation (mm)	strain (mm/mm)	Gauge reading	deformation (mm)	strain (mm/mm)		
260	0.52	0.00511811	124	0.248	0.002440945	0.002677165	0.002677165
140	0.28	0.002755906	114	0.228	0.002244094	0.000511811	0.003188976
121	0.242	0.00238189	110.5	0.221	0.002175197	0.000206693	0.003395669
115.5	0.231	0.002273622	107	0.214	0.002106299	0.000167323	0.003562992
110	0.22	0.002165354	102	0.204	0.002007874	0.00015748	0.003720472
106	0.212	0.002086614	99	0.198	0.001948819	0.000137795	0.003858268
102	0.204	0.002007874	96	0.192	0.001889764	0.00011811	0.003976378
99	0.198	0.001948819	94	0.188	0.001850394	9.84252E-05	0.004074803
98	0.196	0.001929134	93	0.186	0.001830709	9.84252E-05	0.004173228
95	0.19	0.001870079	90	0.18	0.001771654	9.84252E-05	0.004271654
94	0.188	0.001850394	89	0.178	0.001751969	9.84252E-05	0.004370079
92	0.184	0.001811024	87	0.174	0.001712598	9.84252E-05	0.004468504
54	0.108	0.001062992	49	0.098	0.000964567	9.84252E-05	0.004566929
53	0.106	0.001043307	49.5	0.099	0.000974409	6.88976E-05	0.004635827
52.5	0.105	0.001033465	48	0.096	0.000944882	8.85827E-05	0.004724409
51	0.102	0.001003937	47.5	0.095	0.000935039	6.88976E-05	0.004793307
50.5	0.101	0.000994094	47	0.094	0.000925197	6.88976E-05	0.004862205
50	0.1	0.000984252	46	0.092	0.000905512	7.87402E-05	0.004940945
49	0.098	0.000964567	45.5	0.091	0.000895669	6.88976E-05	0.005009843
48.5	0.097	0.000954724	45	0.09	0.000885827	6.88976E-05	0.00507874
47	0.094	0.000925197	43.5	0.087	0.000856299	6.88976E-05	0.005147638
47.5	0.095	0.000935039	44.5	0.089	0.000875984	5.90551E-05	0.005206693
46.5	0.093	0.000915354	43	0.086	0.000846457	6.88976E-05	0.005275591
46	0.092	0.000905512	43	0.086	0.000846457	5.90551E-05	0.005334646
46	0.092	0.000905512	42	0.084	0.000826772	7.87402E-05	0.005413386
44	0.088	0.000866142	42	0.084	0.000826772	3.93701E-05	0.005452756
44	0.088	0.000866142	40	0.08	0.000787402	7.87402E-05	0.005531496
43	0.086	0.000846457	41	0.082	0.000807087	3.93701E-05	0.005570866
43	0.086	0.000846457	40	0.08	0.000787402	5.90551E-05	0.005629921
42	0.084	0.000826772	39	0.078	0.000767717	5.90551E-05	0.005688976
42	0.084	0.000826772	39	0.078	0.000767717	5.90551E-05	0.005748031
41	0.082	0.000807087	38.5	0.077	0.000757874	4.92126E-05	0.005797244

Table (3-1) Typical Record of Permanent Deformation Test Data (Continued)

41.5	0.083	0.000816929	38.5	0.077	0.000757874	5.90551E-05	0.005856299
41	0.082	0.000807087	38.5	0.077	0.000757874	4.92126E-05	0.005905512
41	0.082	0.000807087	39	0.078	0.000767717	3.93701E-05	0.005944882
41	0.082	0.000807087	37.5	0.075	0.000738189	6.88976E-05	0.00601378
39.5	0.079	0.000777559	37	0.074	0.000728346	4.92126E-05	0.006062992
39	0.078	0.000767717	36.5	0.073	0.000718504	4.92126E-05	0.006112205
39.5	0.079	0.000777559	36.5	0.073	0.000718504	5.90551E-05	0.00617126
38.5	0.077	0.000757874	36	0.072	0.000708661	4.92126E-05	0.006220472
38	0.076	0.000748031	35	0.07	0.000688976	5.90551E-05	0.006279528
37	0.074	0.000728346	35	0.07	0.000688976	3.93701E-05	0.006318898
37.5	0.075	0.000738189	34	0.068	0.000669291	6.88976E-05	0.006387795
37	0.074	0.000728346	34	0.068	0.000669291	5.90551E-05	0.00644685
36	0.072	0.000708661	34	0.068	0.000669291	3.93701E-05	0.00648622
36.5	0.073	0.000718504	33	0.066	0.000649606	6.88976E-05	0.006555118
35	0.07	0.000688976	33	0.066	0.000649606	3.93701E-05	0.006594488
35	0.07	0.000688976	33	0.066	0.000649606	3.93701E-05	0.006633858
35.5	0.071	0.000698819	33	0.066	0.000649606	4.92126E-05	0.006683071
34	0.068	0.000669291	32	0.064	0.000629921	3.93701E-05	0.006722441
33	0.066	0.000649606	31	0.062	0.000610236	3.93701E-05	0.006761811
33	0.066	0.000649606	31	0.062	0.000610236	3.93701E-05	0.006801181
32	0.064	0.000629921	30	0.06	0.000590551	3.93701E-05	0.006840551
31.5	0.063	0.000620079	30	0.06	0.000590551	2.95276E-05	0.006870079
31	0.062	0.000610236	29	0.058	0.000570866	3.93701E-05	0.006909449
31	0.062	0.000610236	29	0.058	0.000570866	3.93701E-05	0.006948819
30.5	0.061	0.000600394	29	0.058	0.000570866	2.95276E-05	0.006978346
30	0.06	0.000590551	28	0.056	0.000551181	3.93701E-05	0.007017717
30	0.06	0.000590551	28	0.056	0.000551181	3.93701E-05	0.007057087
29	0.058	0.000570866	28	0.056	0.000551181	1.9685E-05	0.007076772

In order to investigate the effects of moisture content on the accumulation of permanent deformation , specimens were fabricated at six different moisture contents corresponding to 90% , 100% , 105% , 110% , 115% and 120% of optimum moisture content to simulate the field conditions of pavement subgrades.

Specimens with the same moisture content and dry density were subjected to various levels of axial stress (28 KPa, 42 KPa and 63 KPa) to explore the role of stresses in the development of subgrade deformation. The effect of limited variation in density on deformation behavior was also investigated where the

specimens are compacted in different degree of dry density to investigate the effects of dry density on a permanent deformation.

Three soil compaction conditions representing dry of the optimum moisture content (corresponding to 95 % of maximum dry unit weight), optimum moisture content and wet of optimum moisture content levels (corresponding to 95 % of maximum dry unit weight) were investigated

In all tests of repeated load, a digital video camera was used to record the subgrade specimen's displacement. The test procedure is recorded, and then the results will be analyzed after the film transfer to the computer. A new computer program was established to calculate the results.

A digital camera was used in the tests because it is extremely difficult to take the reading of the dial gauge in the process of loading and unloading with the high speed movement of the dial gauge in a short time and the difficulty to control reading.

3.7: Stress Determination

The vertical stress is determined by using the KENLAYER program developed by Huang, [1993]. In this program, the pavement system is assumed to be an elastic multi-layers system with each layer being isotropic, homogeneous with specified resilient modulus and Poisson ratio. Each layer is to extend to infinity in the horizontal direction and has, except for the bottom layer; a finite thickness. The backbone of the KENLAYER program is the solution for a multi-layer elastic system (up to 19 layers) under a circular loaded area and the determination of the pavement response (stress, strain and deflection) at the predetermined points within the pavement structure.

The same study that are used by [Albayati, 2006] to determine the vertical stress in the neutral axis are used in this research (but here) to determine the vertical stress at the top of subgrade surface as shown in Figures (3- 7) and (3-8).

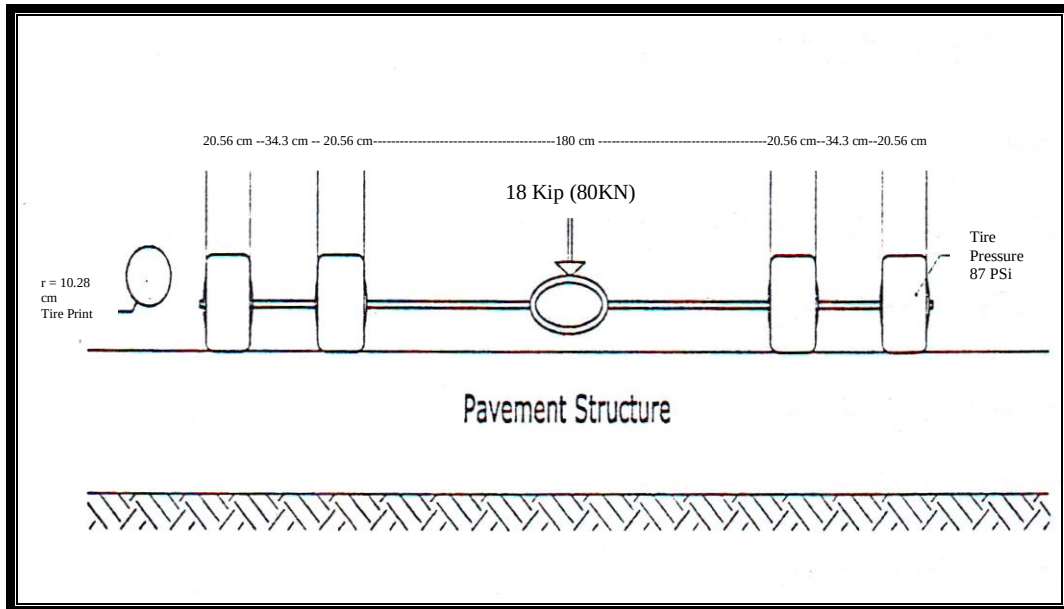


Figure (3- 7) 18-Kip ESAL Configuration (after Albayati, 2006)

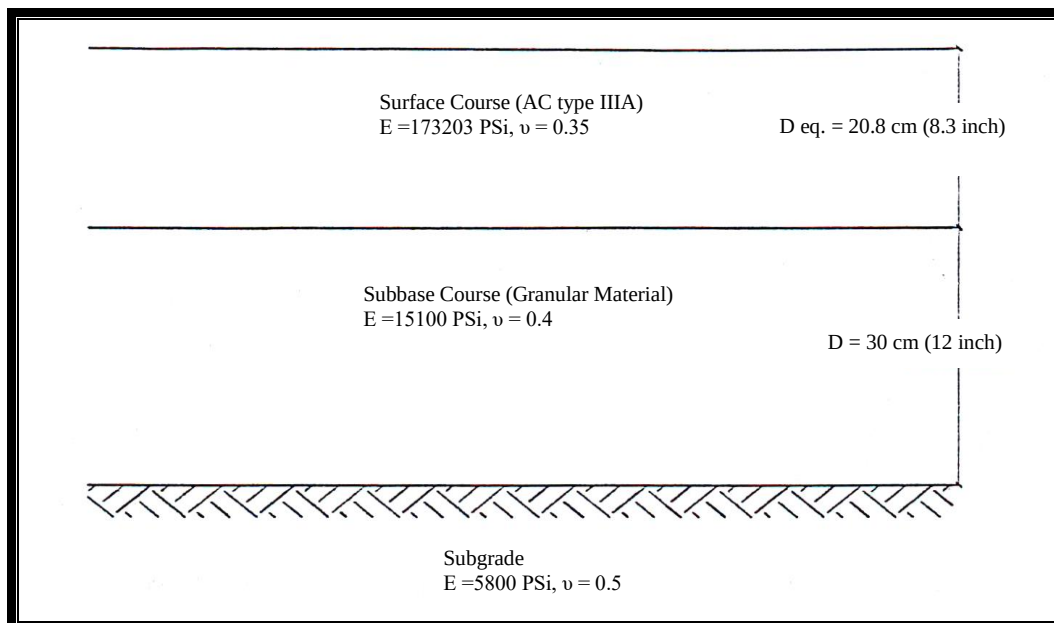


Figure (3- 8) Geometry of the Transformed Pavement Section
(after Albayati, 2006)

The obtained output results of the KENLAYER program are shown in Figures (3- 9) and (3-10). The stress value at the top of the subgrade soil under the wheel load axis symmetry is shown to be equal of 3 PSi (21 KPa). Therefore, the stresses that will use in this research will be approached to this value.

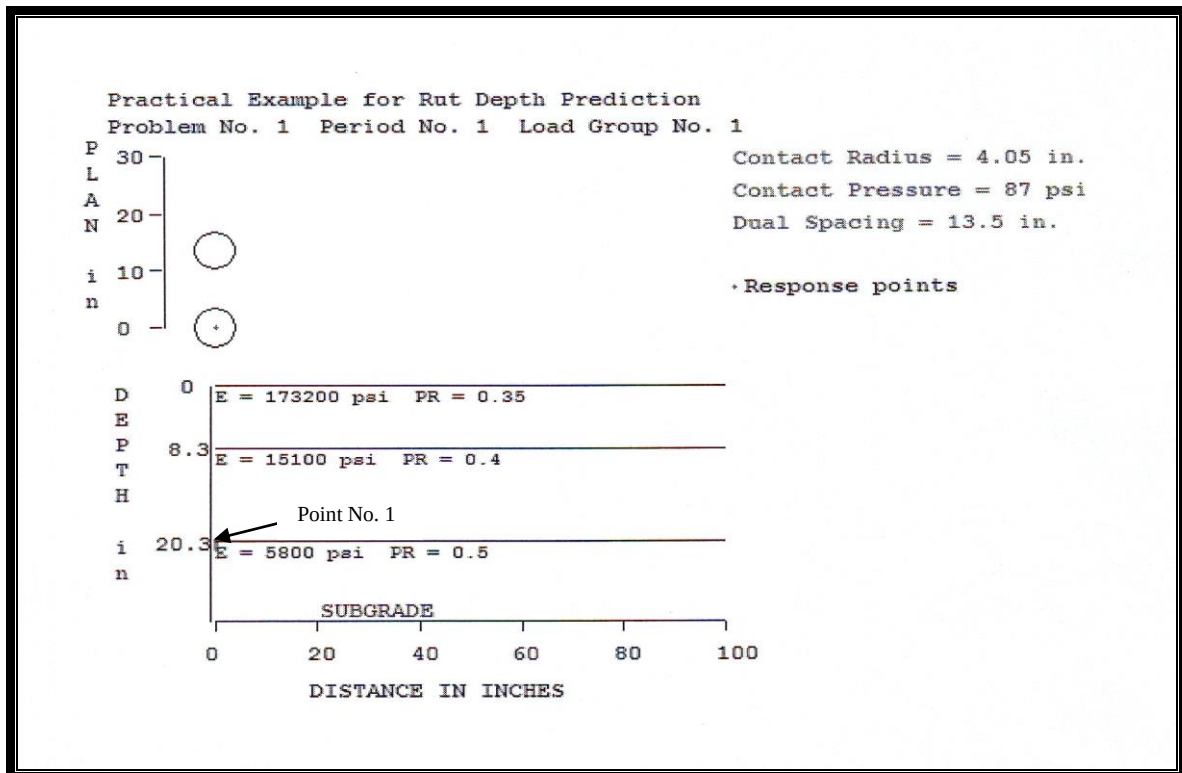


Figure (3- 9) Output results No (1) of KENLAYER Computer Program

```

NUMBER OF PROBLEMS TO BE SOLVED = 1

TITLE - Practical Example for Stress Determination

MATL = 1 FOR LINEAR ELASTIC LAYERED SYSTEM
NDAMA = 0, SO DAMAGE ANALYSIS WILL NOT BE PERFORMED
NUMBER OF PERIODS PER YEAR (NPY) = 1
NUMBER OF LOAD GROUPS (NLG) = 1
TOLERANCE FOR INTEGRATION (DEL) -- = 0.001
NUMBER OF LAYERS (NL)----- = 3
NUMBER OF Z COORDINATES (NZ)----- = 1
LIMIT OF INTEGRATION CYCLES (ICL)- = 80
COMPUTING CODE (NSTD)----- = 9
SYSTEM OF UNITS (NUNIT)----- = 0

Length and displacement in in., stress and modulus in psi
unit weight in pcf, and temperature in F

THICKNESSES OF LAYERS (TH) ARE : 8.3 12
POISSON'S RATIOS OF LAYERS (PR) ARE : 0.35 0.4 0.5
VERTICAL COORDINATES OF POINTS (ZC) ARE: 20.3
ALL INTERFACES ARE FULLY BONDED

FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE :   1 1.732E+05   2 1.510E+04
        3 5.800E+03

LOAD GROUP NO. 1 HAS 2 CONTACT AREAS
CONTACT RADIUS (CR)----- = 4.05
CONTACT PRESSURE (CP)----- = 87
NO. OF POINTS AT WHICH RESULTS ARE DESIRED (NPT)-- = 1
WHEEL SPACING ALONG X-AXIS (XW)----- = 0
WHEEL SPACING ALONG Y-AXIS (YW)----- = 13.5

RESPONSE PT. NO. AND (XPT, YPT) ARE: 1 0.000 0.000

PERIOD NO. 1   LOAD GROUP NO. 1

POINT   VERTICAL   VERTICAL   VERTICAL   MAJOR   MINOR   INTERMEDIATE
NO.     COORDINATE   DISP.     STRESS     PRINCIPAL PRINCIAL P. STRESS
        (STRAIN)   (STRAIN)   (STRAIN)   (STRAIN) (STRAIN) (HORIZONTAL
1       20.30000   0.02015   3.039      3.068    -3.569    P. STRAIN)
        (STRAIN)   3.761E-04 3.788E-04 -2.365E-04 -2.365E-04

```

Figure (3- 10) Output results No (2) of KENLAYER Computer Program

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF THE RESULTS

4.1: Introduction

In this chapter, the results of the classification tests and the cyclic loading test of the two subgrade soil types are analyzed and discussed. The effect of moisture content, stress, dry density and subgrade soil types on permanent deformation are analyzed and discussed. By using statistical analysis, models are developing relating a criterion variable to the predicted variables.

4.2: Classification Tests

The results of Atterberg limits tests conducted on fractions passing sieve No. 40 indicate that the Kerbala-Hilla roadway soil samples are Low plastic soils while Al-jadrreya soil samples are Medium plastic soils. Table (4-1) describes the classification of soils according to the plasticity index.

The grain size distribution curves of the soil samples are shown in Figures (4-1) and (4-2). From these results, the soil specimens can be classified according to the unified soil classification system (u.s.c.s) as (clayey silt soil) for both Kerbala-Hilla roadway soil sample and Al-jadrreya soil sample. While the AASHTO classification indicates that Kerbala-Hilla roadway soil sample is (A4) soil and Al-jadrreya soil sample is (A6) soil.

Table (4-1) Soil Classification according to the plasticity (Al-Ashwo, 1991)

plasticity index	Soil description
0	Non plastic soil
1-5	Some kind plastic soil
5-10	Low plastic soil
10-20	Medium plastic soil
20-40	High plastic soil
More than 50	Soil with very high plasticity

The physical properties of the two soils are summarized in Table (4-2). The results of the standard Procter tests of the two samples are shown in Figures (4-3) and (4-4), from these Figures, the optimum moisture content and maximum dry density of Kerbala-Hilla roadway soil sample are (18.25%), (1.75 gm/cm³) and for Al-jadrreya soil sample (20%), (1.71 gm/cm³) respectively.

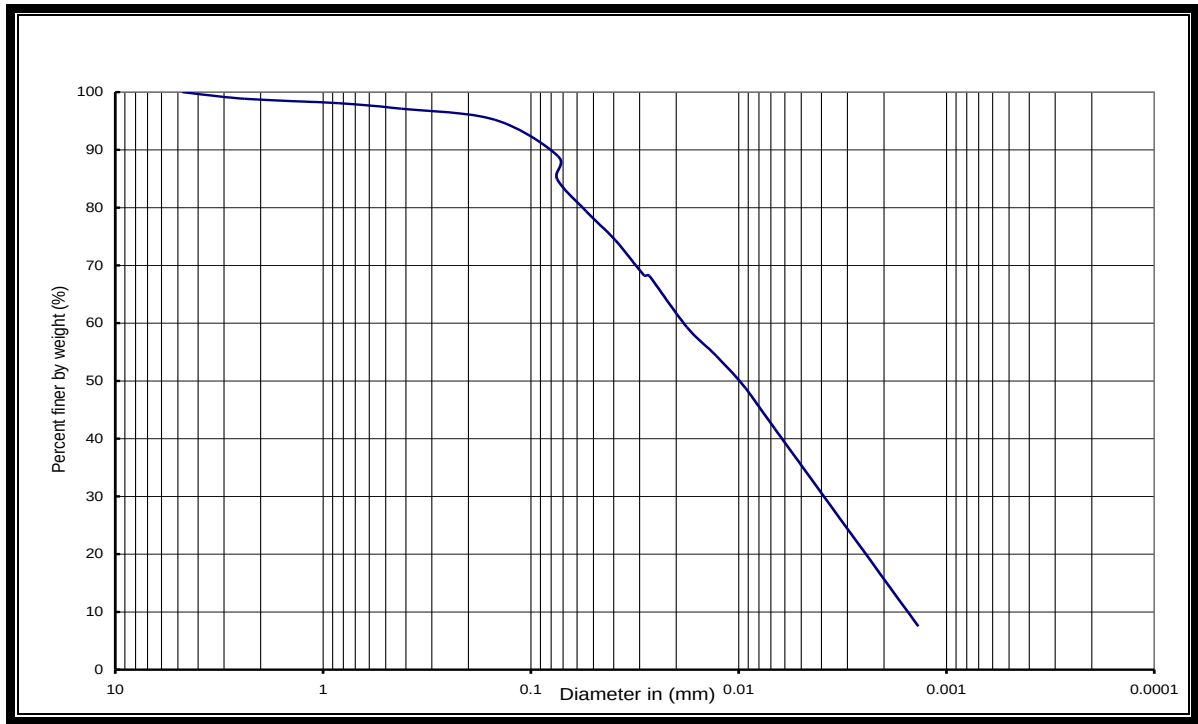


Figure (4-1) Grain size distribution of Kerbala-Hilla roadway soil

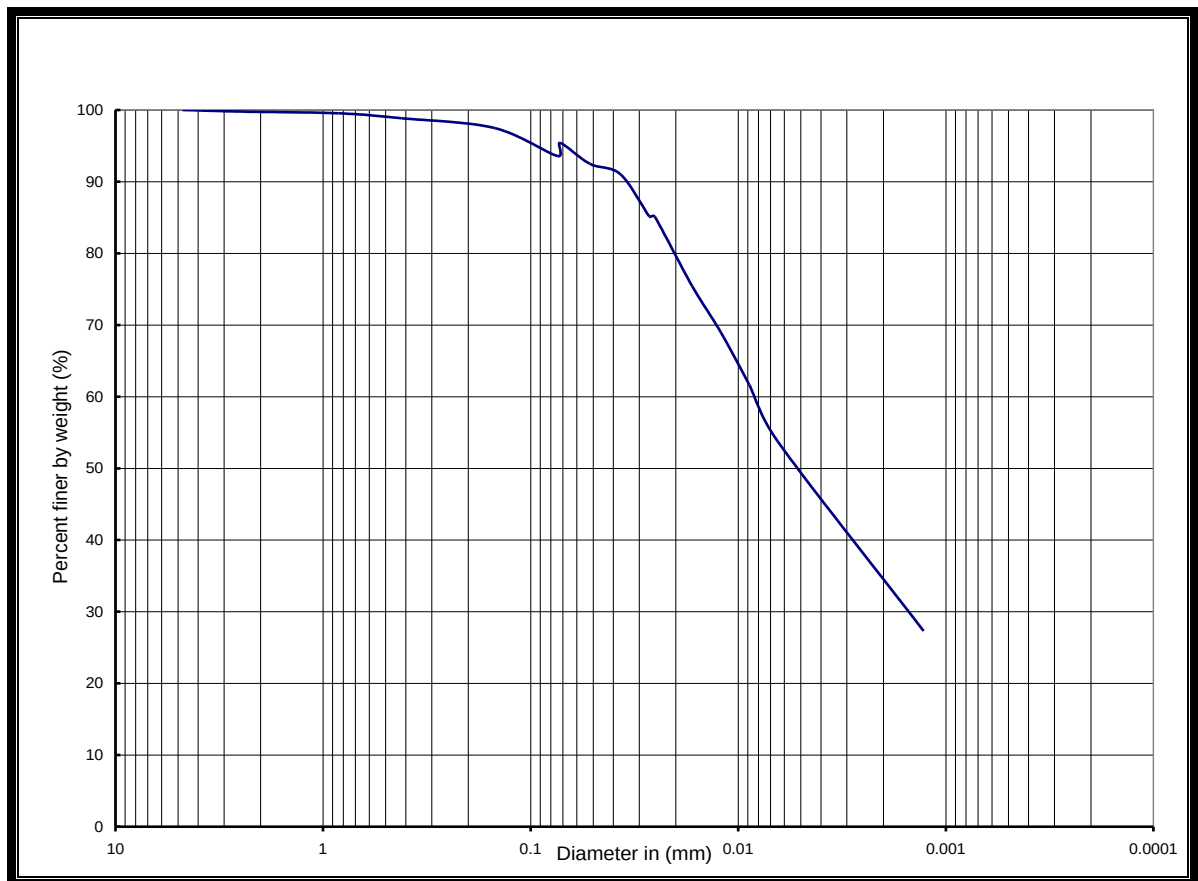


Figure (4-2) Grain size distribution of Al-jadrreya soil

Table (4-2) Summary of Soil Properties

Soil	Kerbala-Hilla	Al-jadrreya
Sampling	Kerbala-Hilla Roadway	Al-jadrreya - Baghdad
Location	Near New University of Kerbala	Near University of Baghdad
LL	30.7	35.5
PL	23.6	24.25
PI	7.1	11.25
Water Content (%)	26	20
Specific Gravity	2.69	2.73
OMC (%)	18.25	20
MDD (gm/cm³)	1.75	1.71
% of Fines	88.4	93.6
AASHTO Classification	A4	A6
Unified Classification	Clayey Silt	Clayey Silt

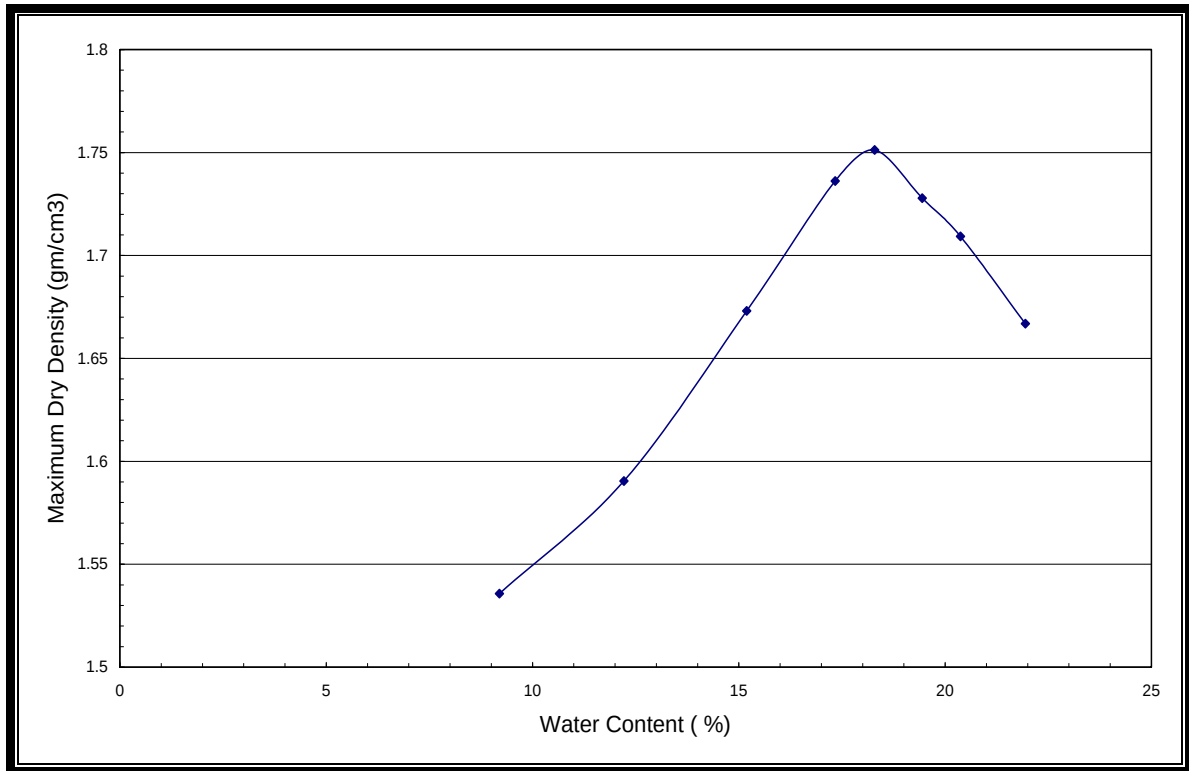


Figure (4- 3) Compaction curve for Kerbala-Hilla roadway soil

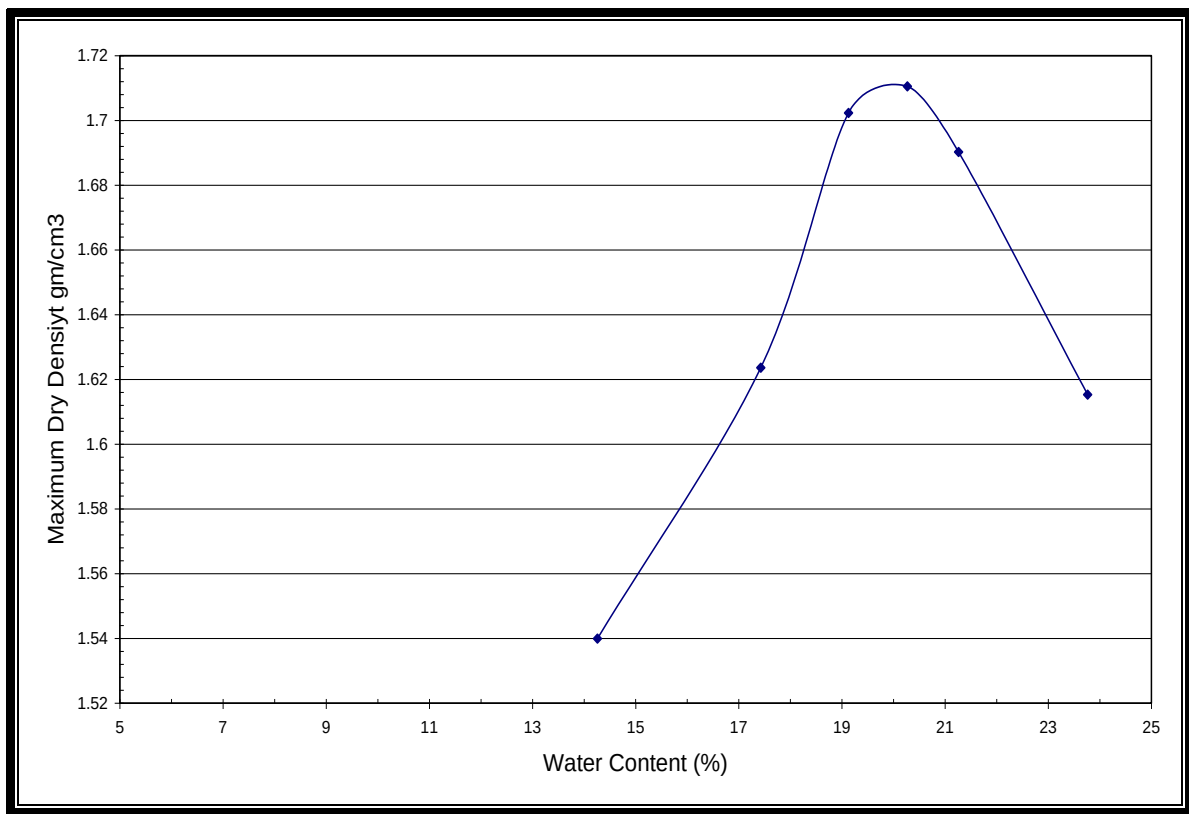


Figure (4-4) Compaction curve for Al-jadrreya soil

4.3: Cyclic Loading Test

The experimental data were analyzed to determine the effect of the variables considered in this investigation on the permanent deformation of laboratory subgrade samples.

4.4: Test Results and Discussion

In this section, test results from the cyclic loading tests are discussed. Since all these tests were performed on six different moisture contents at various stress and dry density, much more emphasis shall be placed on the results of the cyclic loading tests. The test results for all uniaxial cyclic load testing are presenting in Appendix A.

All soil samples exhibited plastic deformations. Also, specimens did not show any failure during the present repeated loading since the loads are quite small when compared to failure loads.

Permanent deformation of subgrade soils is characterized by a rapid increase in deformation during the first cycle, followed by gradual stabilization. The amount of deformation depends on the characteristics of the material and the applied load.

The results which were obtained by conducting uniaxial repeated load test on the sample according to tests program are discussed in chapter three. The relationships between times of loading against permanent strain are plotted from the test results.

4.4.1: Effect of Moisture Content on Permanent Deformation

In order to investigate the effect of the moisture content on the accumulation of permanent deformation, specimens were fabricated at six different moisture contents corresponding to 90%, 100%, 105%, 110%, 115%,

120% of optimum moisture content to simulate field conditions of pavement subgrades.

The obtained results are presented in Figures (4-5) to (4-10). In these Figures, the permanent strain is plotted against the time of loading for all degrees of the moisture content under several levels of stress (28 KPa), (42 KPa) and (63 KPa).

Cyclic load testing results for Kerbala-Hilla roadway soil (A4 soil), are presented in Figure (4-5) to (4-7). Figure (4-5) illustrates test results with moisture contents corresponding to (90%, 100%, 105%, 110%, 115%, and 120%) of optimum moisture content and dry densities corresponding to 95% of maximum dry density with stress of 28 KPa. In this Figure it can be seen that when moisture content increases from 90% to 110% of optimum, the permanent strain increases by 270%.

While cyclic load testing results for Al-jadrreya soil (A6 soil), are presented in Figure (4-8) to (4-10). Figure (4-8) illustrates test results with moisture contents corresponding to (90%, 100%, 105%, 110%, 115%, and 120%) of optimum moisture content and dry densities corresponding to 95% of maximum dry density with stress of 28 KPa. In this Figure it can be seen that when moisture content increases from 90% to 110% of optimum, the permanent strain increases by 220%.

Also a simple comparison between Figure (4-5) and Figure (4-7), it was found that the specimen having a moisture content of (120%) of optimum moisture content and subjected (28) KPa developed more deformation (about 575%) than a specimen having a moisture content of (100%) of optimum moisture content and subjected to (63) KPa. The same results are showing by soil A6 with an increase of 166% .

The maximum permanent strain was measured for both soils when compacted at the wet side of the optimum moisture content. Where, for A4 soil when moisture content increases from 90% to 100% with the same stress (63 KPa) and the same dry density, the permanent strain increases by (14%), but for

the same conditions when moisture content increases from 100% to 110%, the permanent strain increases by (214)%. While for soil A6 when moisture content increases from 90% to 100% with the same stress (63 KPa) and the same dry density, the permanent strain increases by (39%), but for the same conditions when moisture content increases from 100% to 110%, the permanent strain increases by (101.5%). This permanent strain variation attributed to the strength variations at these moisture contents high strength properties at dry and optimum conditions provided more resistances to the applied stresses and hence, low permanent strains were recorded at those moisture conditions.

There are two interesting aspects from all of these Figures, the first one is that the plastic deformation was high in wet of optimum moisture conditions, which indicates the need to compact and preserve moisture in subgrade close to optimum moisture content conditions.

The second one is that the plastic deformation, if interpolated to high number of cycles close to several thousands, will be quite high and may exceed allowable rutting values.

This may signifies the need to a complement plastic deformation test and their results in the characterization of subgrade for a flexible pavement design.

The compaction of soil means the increase of soil density by decreasing the gaps among soil particles with forcing air from these gaps. The compaction of soil aims to decrease the permanent deformation, to decrease the permeability of soil, to increase the soil bearing capacity and also to decrease the settlement in pavement.

With the add of amount of moisture content to the dry soil, the particles of soil will envelope with the thin membrane of water, and with the increase of water content that add to the soil, the water membrane thickness (that envelope the soil particles) will be increased and this membrane will easy the process of slipping of soil particles above them and this process called lubrication and it has a great effect in the compaction of soil.

lubrication phenomenon causes that with the addition of a limited amount of moisture to dry soil will easy and help its compaction, because water will drive away the air from the gaps that was found between soil particles and settled there, but when the soil arriving the high degree of saturation then the access water will take an additional part that must be taken by the soil particles.

In all these tests it seems that moisture content is a significant factor contributing to the accumulation of deformation, where an increase in compaction moisture content has raised the permanent strain.

Elliott, et. al., [1998] found similar results in his analysis for Arkansas soils, also [Puppala, et. al., 2005] and [Khasawneh, 2005] found similar results.

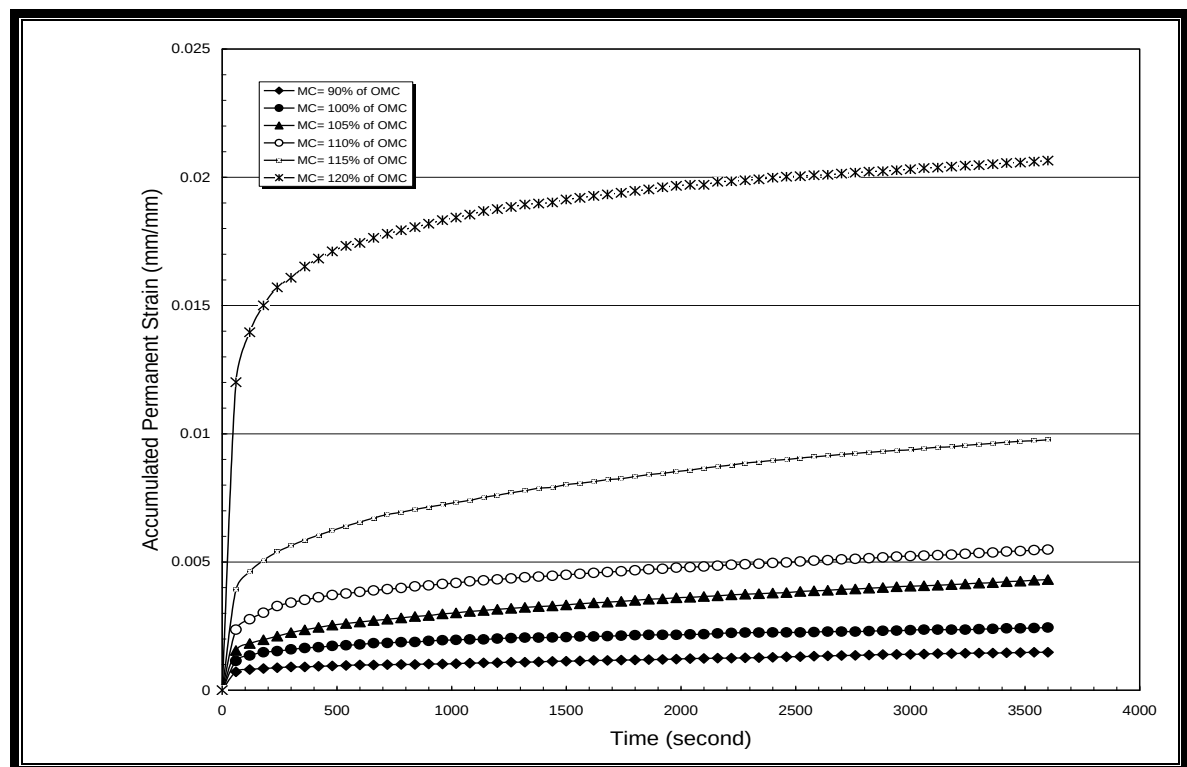


Figure (4- 5) Effect of Moisture Content on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, stress: 28 KPa)

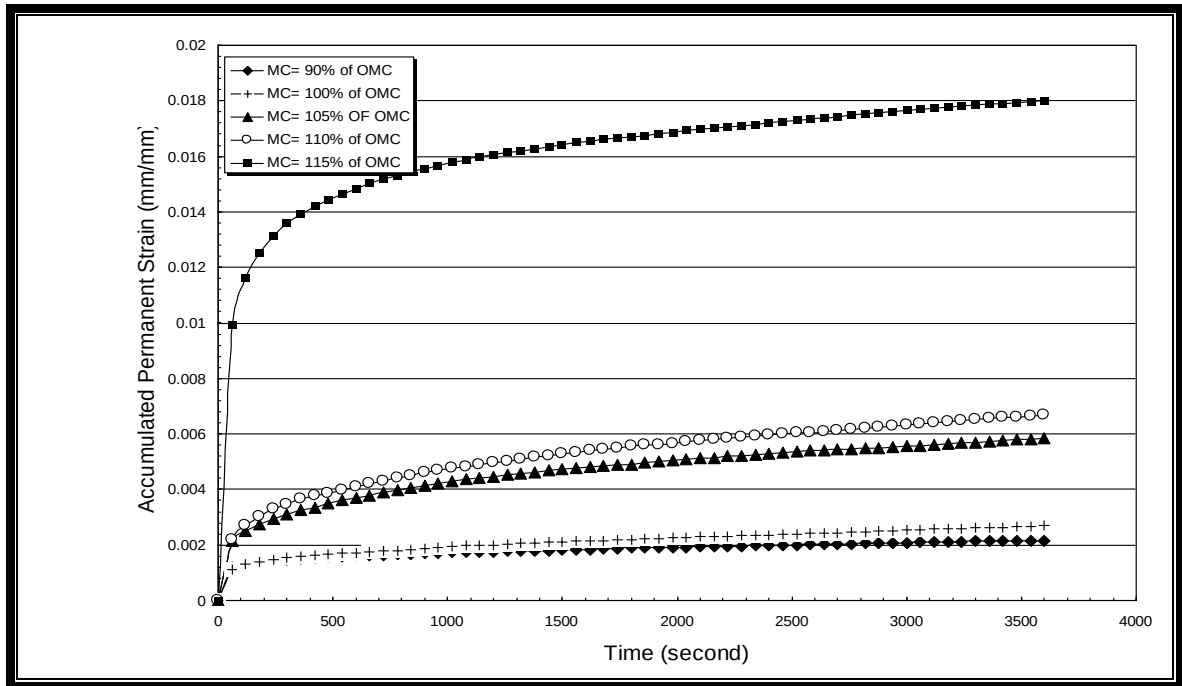


Figure (4- 6) Effect of Moisture Content on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, stress: 42 KPa)

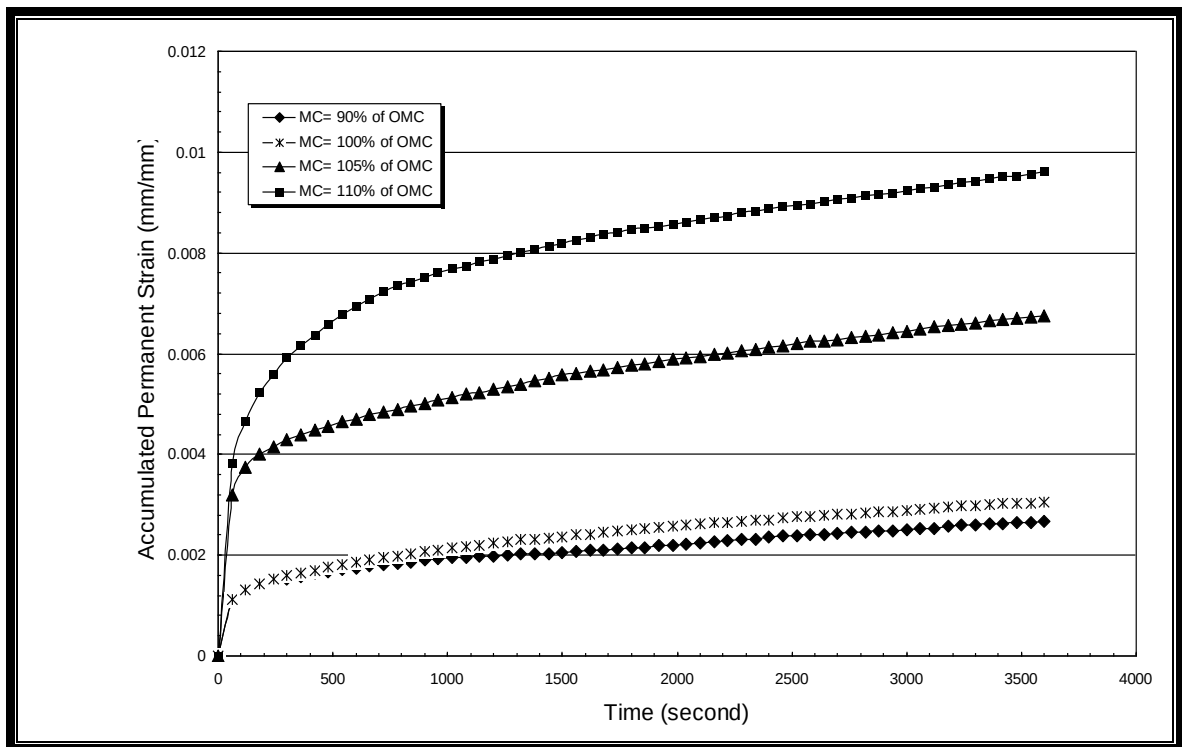


Figure (4- 7) Effect of Moisture Content on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, stress: 63 KPa)

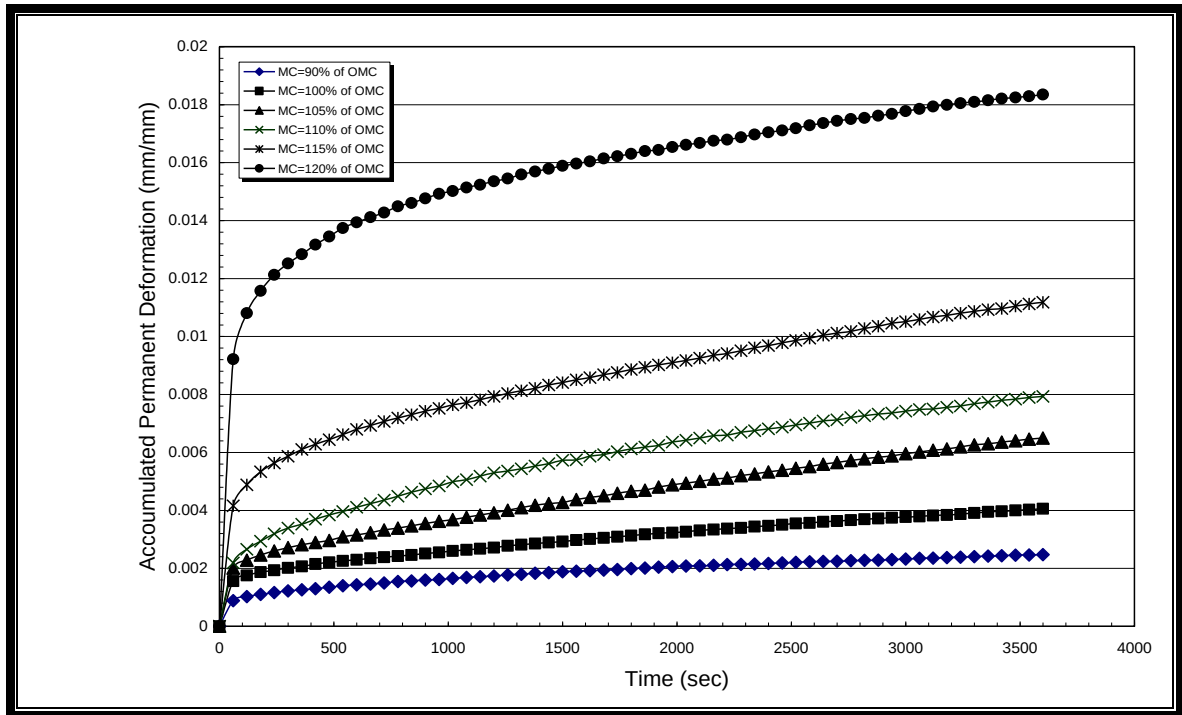


Figure (4- 8) Effect of Moisture Content on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, stress: 28 KPa)

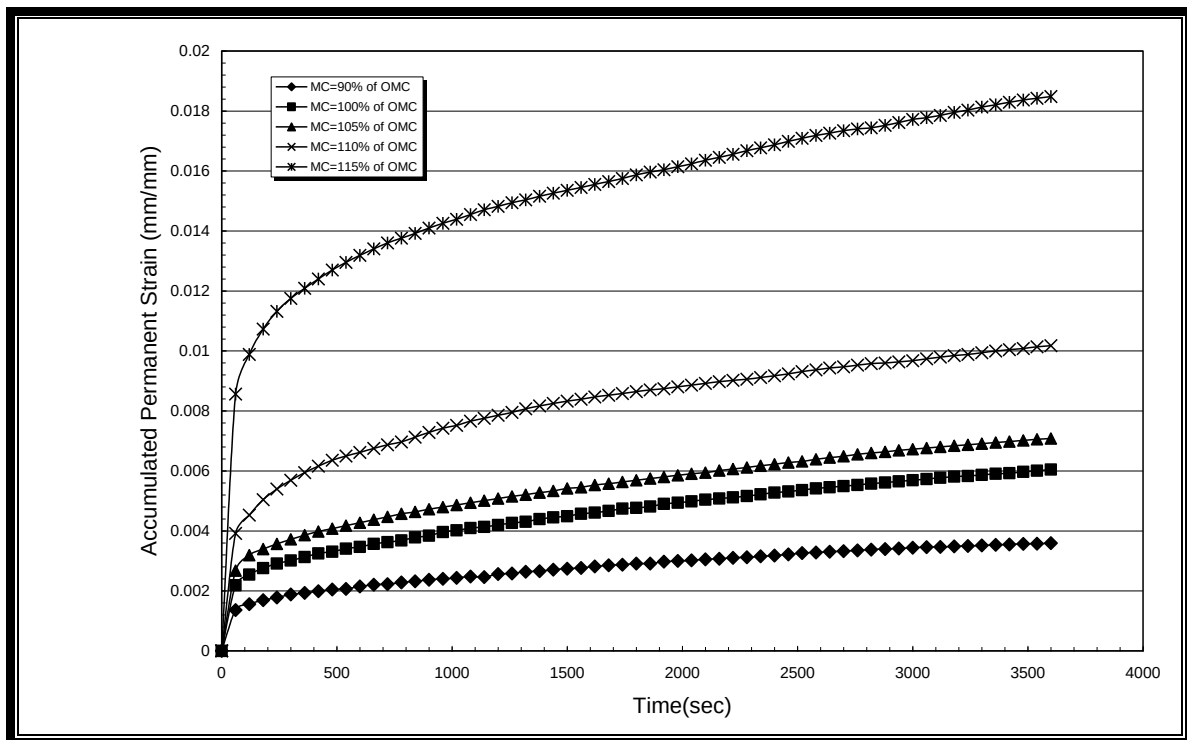


Figure (4- 9) Effect of Moisture Content on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, stress: 42 KPa)

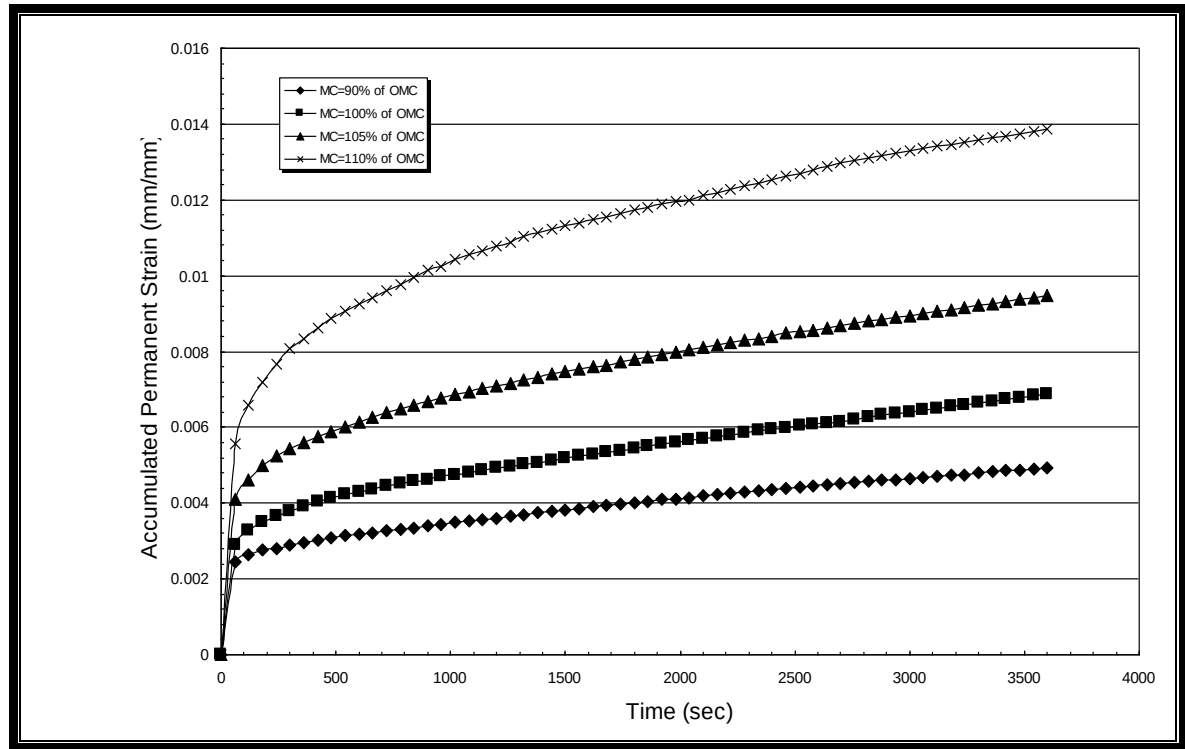


Figure (4- 10) Effect of Moisture Content on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, stress: 63KPa)

4.4.2: Effect of Stress on Permanent Deformation

Specimens with the same moisture content and dry density were subjected to various levels of stresses to explore the role of stress in the development of subgrade deformation.

The applied stress showed a considerable influence on the measured plastic strains.

The obtained results are presented in Figures (4-11) to (4-20) for both soils A4 and A6. In these Figures, the permanent strain is plotted against the time of loading. Figure (4-11) shows the accumulated permanent strain of A4 soil at 90% of the optimum moisture content at different stages of loading procedure for three levels of applied stress (28 KPa), (42 KPa) and (63 KPa). Similar plots (4-12), (4-13), (4-14) and (4-15) are developed for A4 soil at the optimum moisture content and at 105%, 110%, and 115% of the optimum moisture content. Likewise, Figures (4-16) to (4-20) show plots of A6 soil at 90%, 100%, 105%, 110% and 115% of the optimum moisture content.

From Figure (4-11) it can be seen that when the applied stresses increased from 28 KPa to 63 KPa, the permanent strain increased (81%) for soil A4, while in Figure (4-16), when the applied stresses increase from 28 KPa to 63 KPa, the permanent strain increased (100%), for soil A6.

It can be seen from Figures (4-12) and (4-17) that soil A6 showed more permanent deformation than soil A4, (about 125%) for the same moisture content (100% of optimum moisture content), the same stress (63 KPa) and the same dry density (95% of maximum dry density), but this percent will be decreased to (66%) when the stress decreased to 28 KPa for the same soils with the same conditions.

From all these Figures it can be seen that at a lower applied stress there is a gradual stabilization, while at a higher applied stress, a rapid increase in strain is observed for both soils used in this research, indicating possibility of rutting accumulation over time.

Elliott, et. al., [1998] found similar results for Arkansas soils. Also, similar results were found by [Khasawneh, 2005].

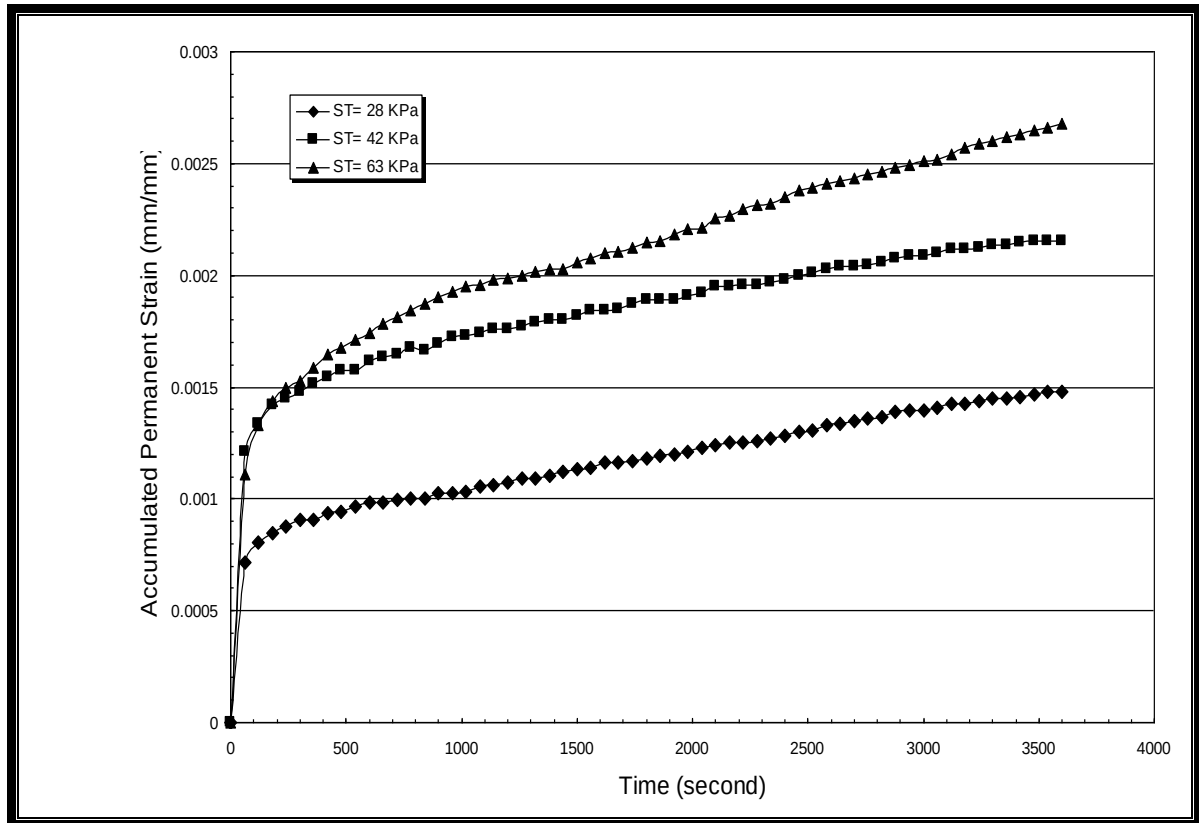


Figure (4- 11) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, Moisture Content 90%)

Figure (4-12) shows an important conclusion, it can be seen that the soil A4 when compacted at the optimum moisture content, whatever the applied stress is increased, the rate of permanent strain will be increased slightly.

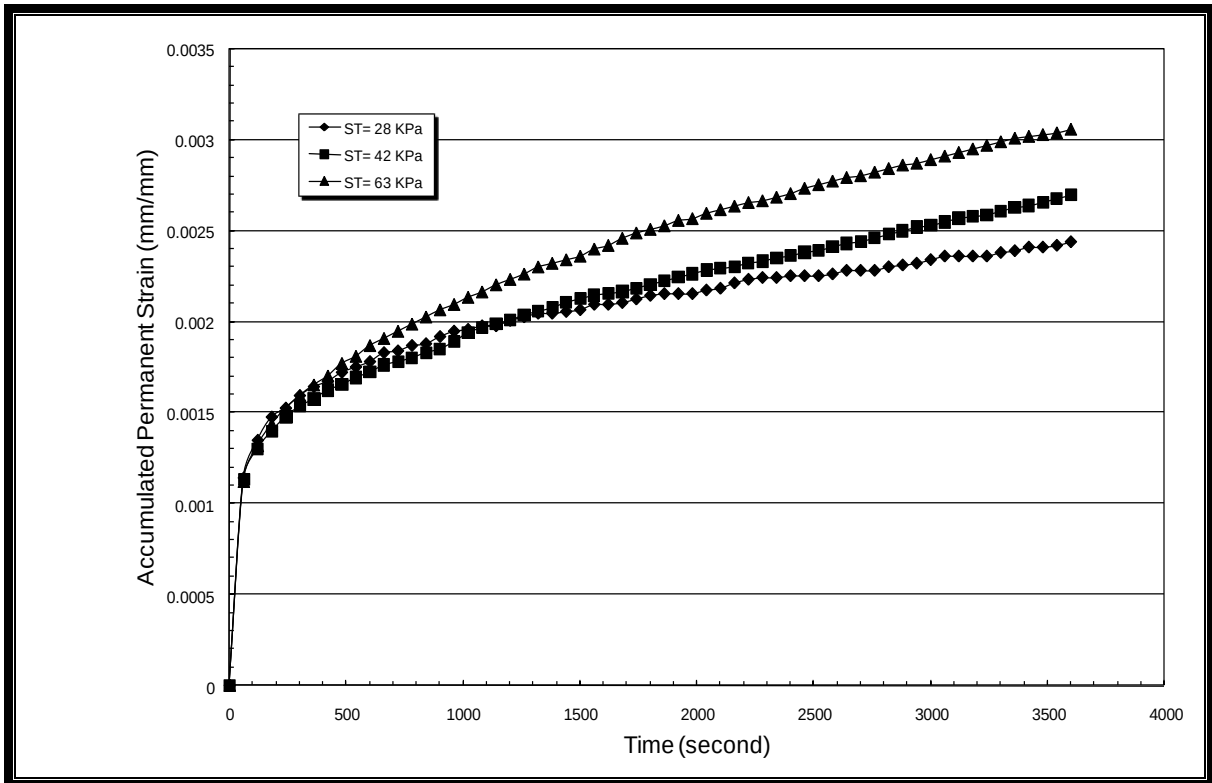


Figure (4- 12) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, Moisture Content 100%)

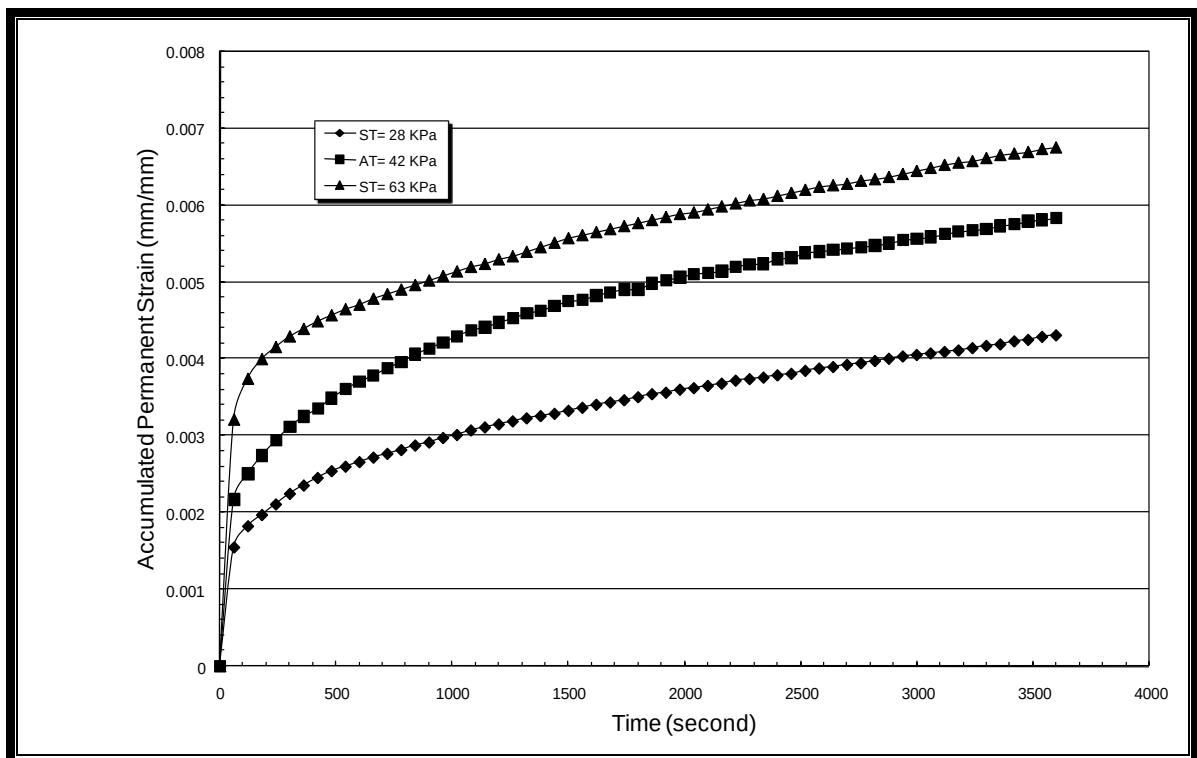


Figure (4-13) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, Moisture Content 105%)

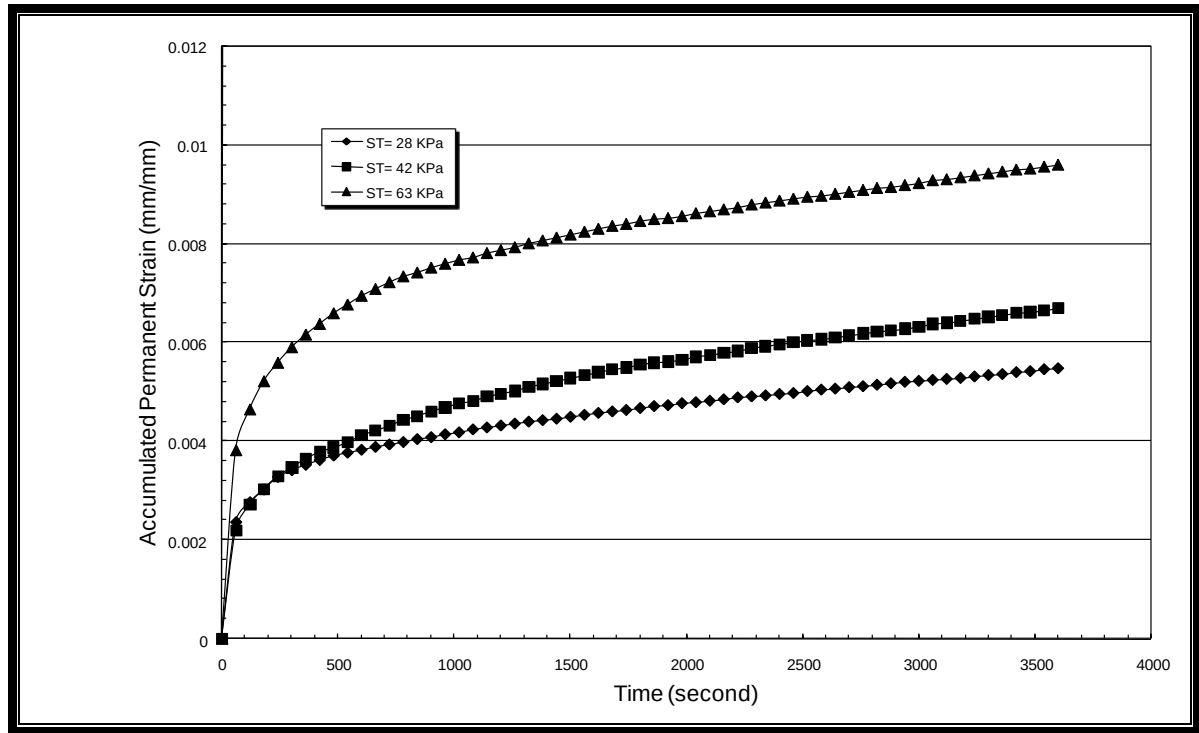


Figure (4-14) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, Moisture Content 110%)

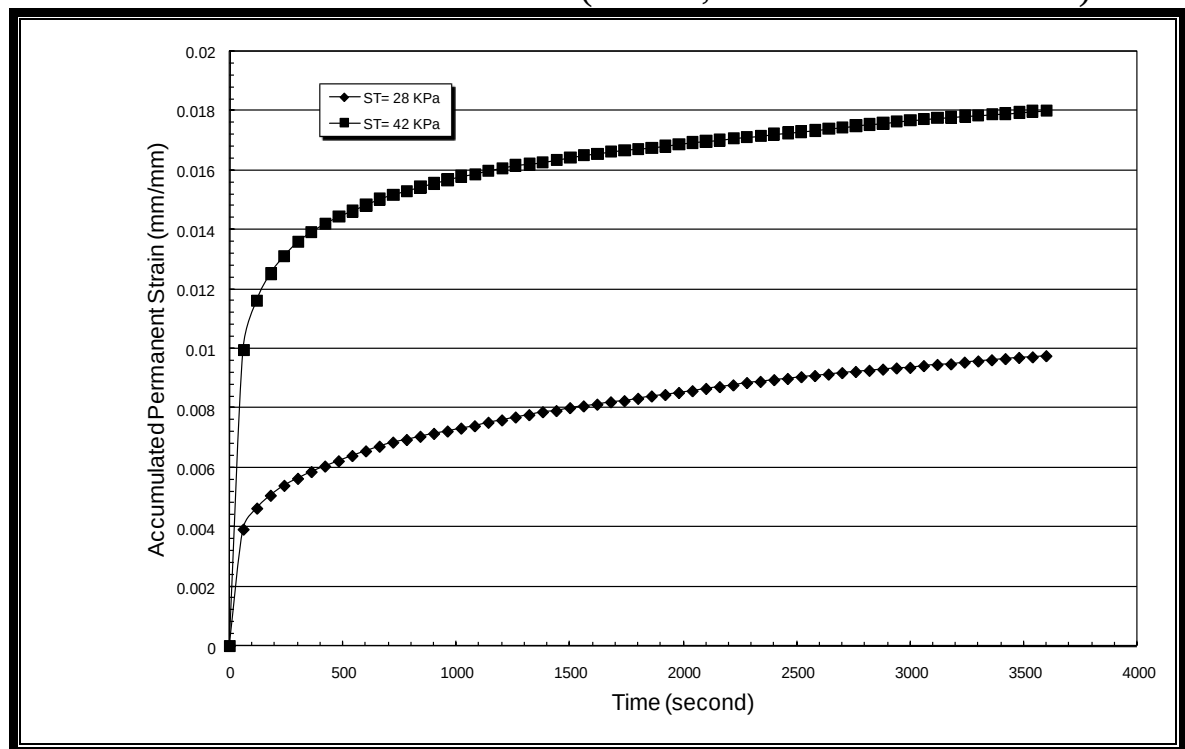


Figure (4-15) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, Moisture Content 115%)

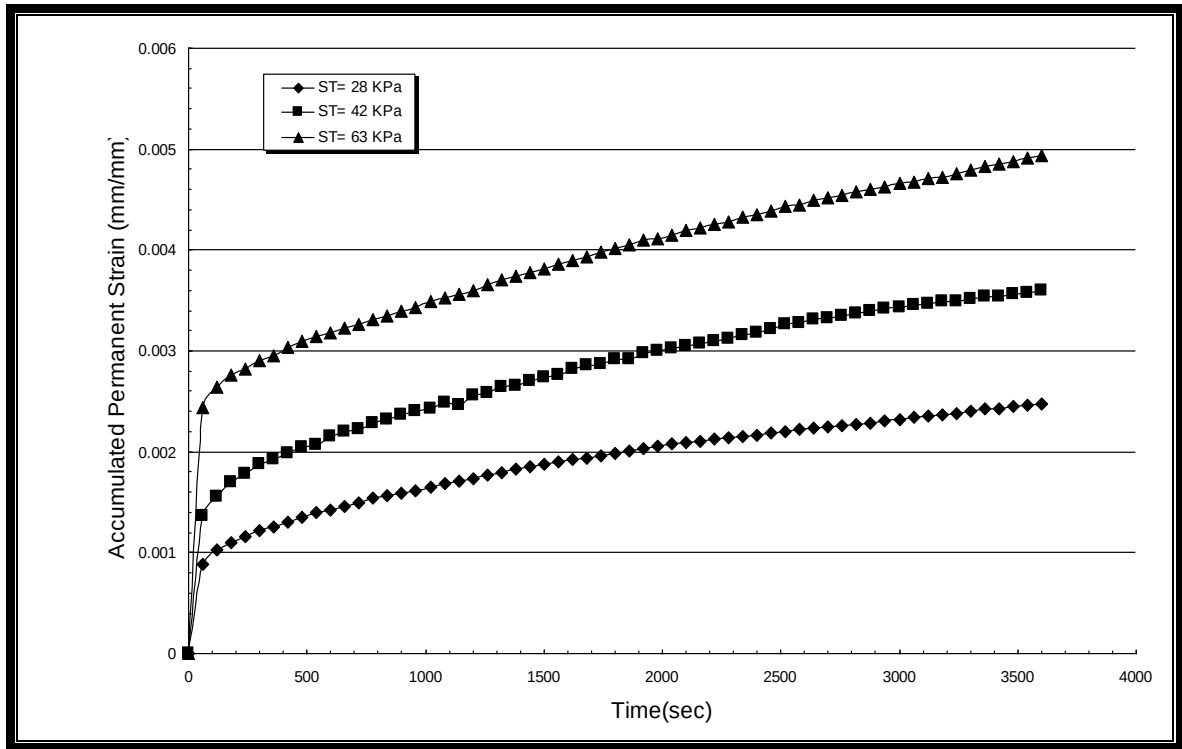


Figure (4- 16) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, Moisture Content 90%)

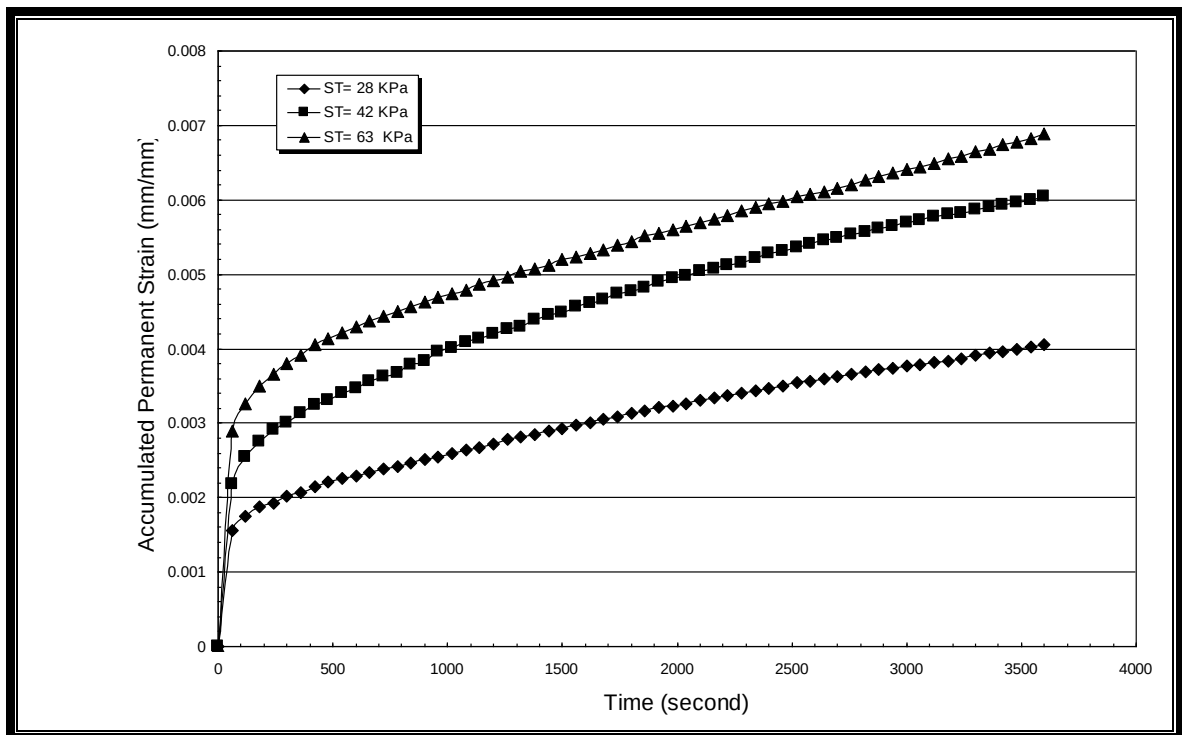


Figure (4-17) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, Moisture Content 100%)

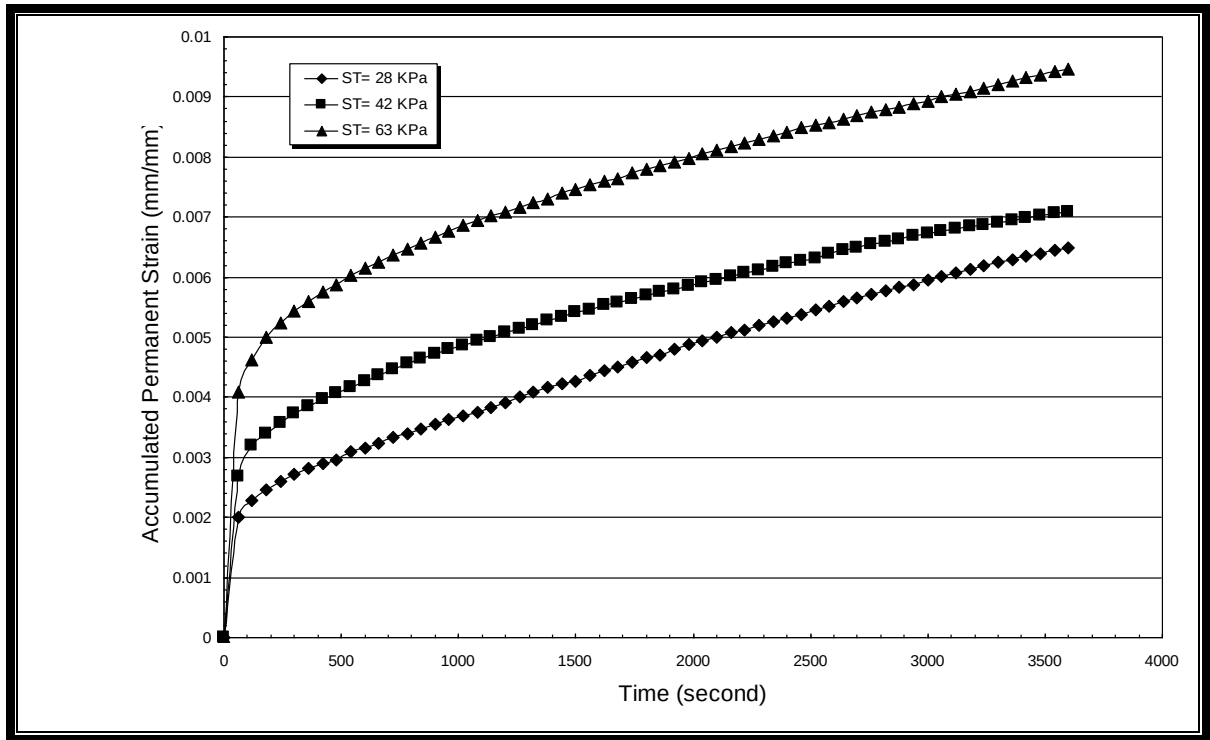


Figure (4-18) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, Moisture Content 105%)

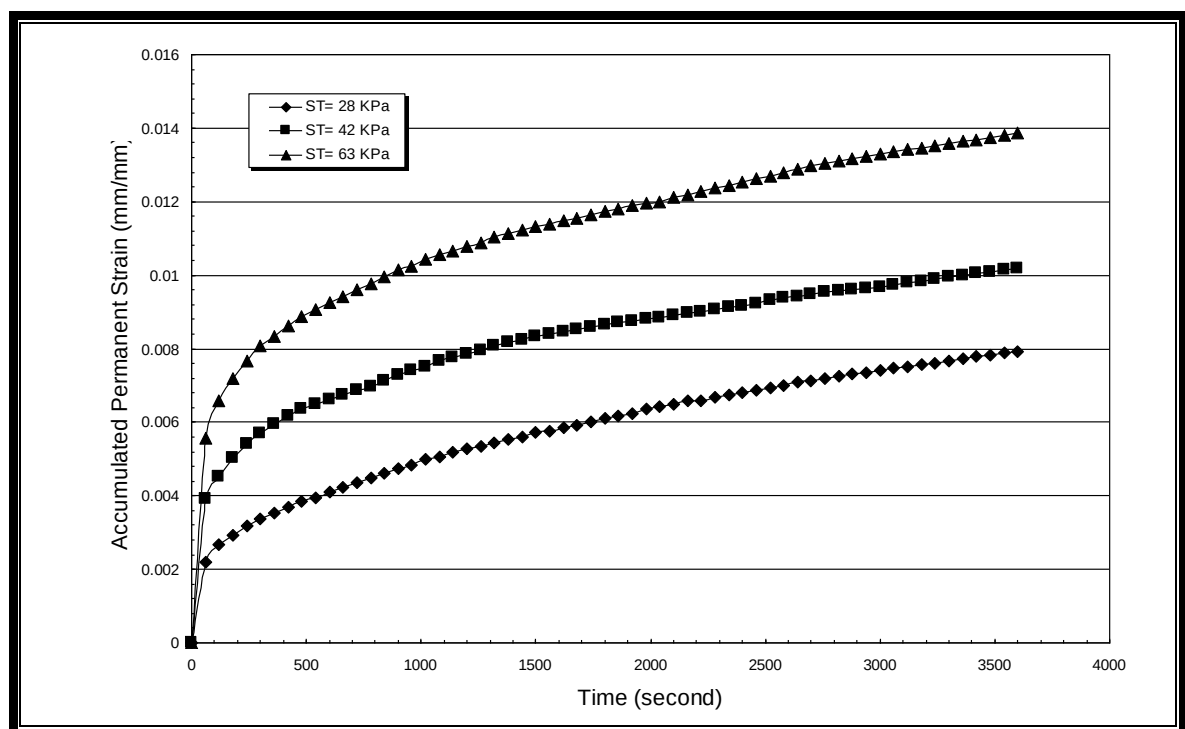


Figure (4-19) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, Moisture Content 110%)

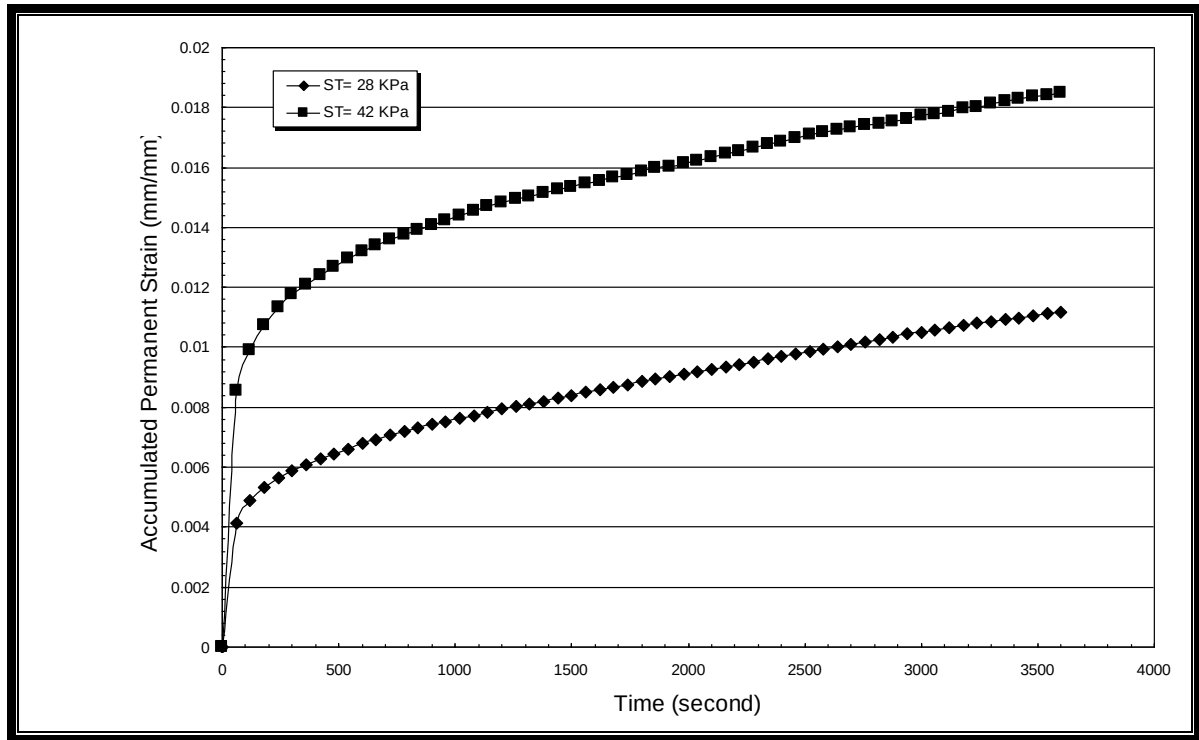


Figure (4- 20) Effect of Stress on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, Moisture Content 115%)

4.4.3: Effect of Dry Density on Permanent Deformation

Figure (4-21) demonstrates the effect of the dry density on the accumulation of the permanent deformation for soil A4. Specimens are fabricated to moisture content at 100% of the optimum moisture content and the dry density increased from 93% to 96.6% of maximum with applied stress of 42 KPa, it can be seen that the permanent strain is decreased by 34%.

The effect of dry density on the accumulation of the permanent deformation for soil A6 is presented in Figure (4-22). Specimens are fabricated to moisture content at 100% of the optimum moisture content and the dry density increased from 94% to 96.4% of maximum with applied stress of 42 KPa, it can be seen that the permanent strain is decreased by 17%.

Therefore, it can be seen that the limited decrease in the dry density produces slight increase in permanent strain for both soils.

Similar results were found by [Elliott, et. al., 1998], [Yanjan, et. al., 1999] and [Khasawneh, 2005].

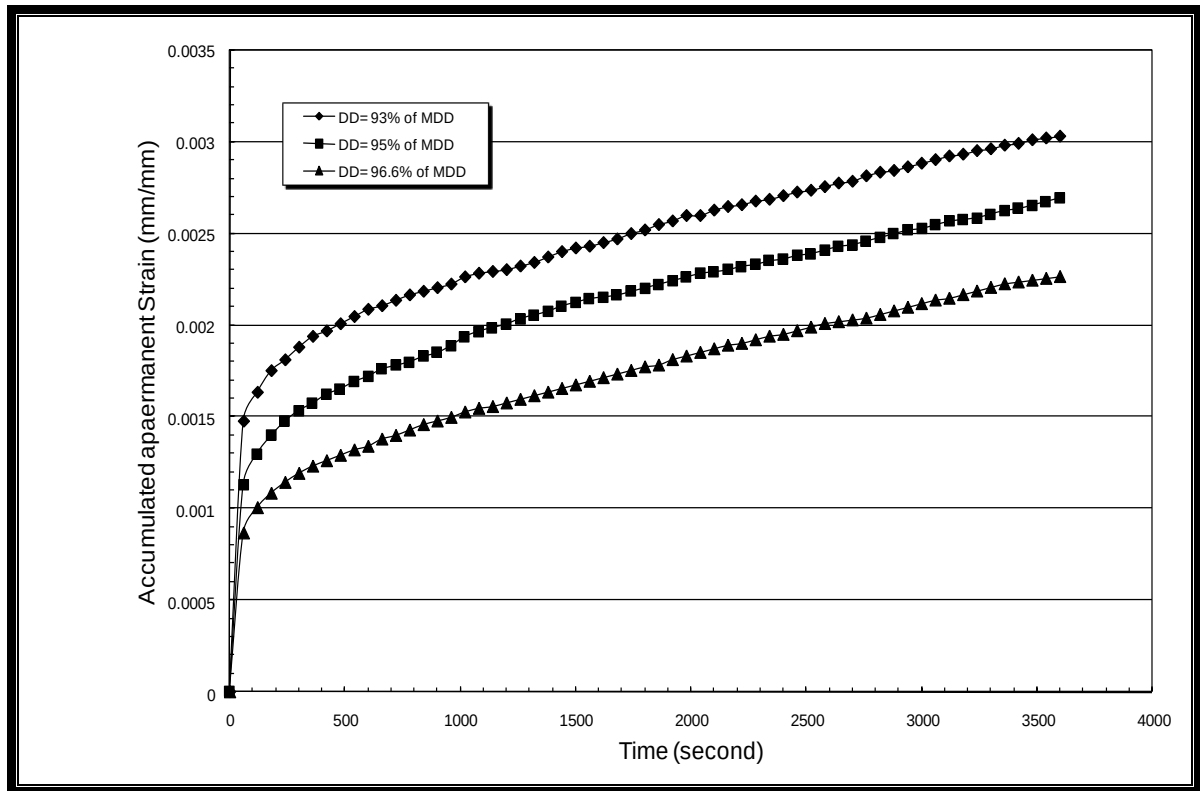


Figure (4- 21) Effect of Dry Density on the Relationship between Loading Time and Accumulated Permanent Strain (A4 soil, Stress: 42 KPa)

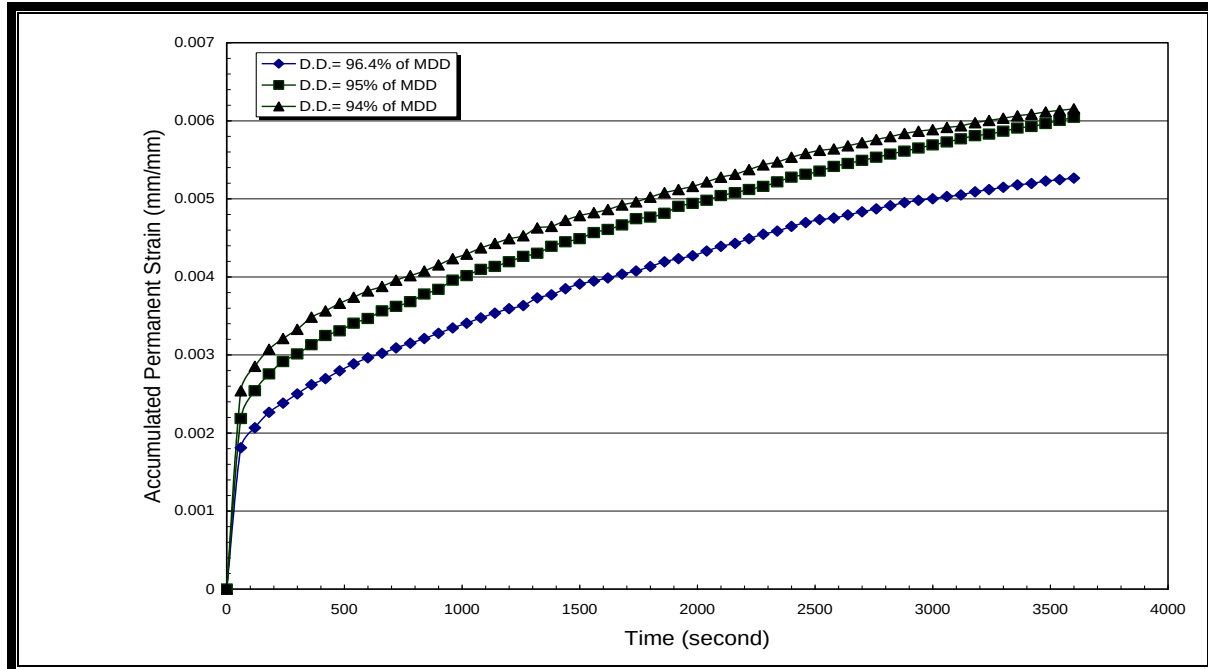


Figure (4-22) Effect of Dry Density on the Relationship between Loading Time and Accumulated Permanent Strain (A6 soil, Stress: 42 KPa)

4.4.4: Effect of Type of Soil on Permanent Deformation

From Figures (4-5), (4-6), (4-7) and Figures (4-8), (4-9), (4-10), it can be observed that soil A4 has more resistance to the permanent deformation than soil A6, specially for the moisture content near to the optimum with all degree of stresses. But when the moisture content increased up to more than 110% of the optimum moisture content, the permanent deformation of the two soils was approximately convergent.

By a simple comparison between the permanent deformation of the two soils (A4 and A6) for the Figures (4-5) and (4-8) with moisture content 100% and 28 KPa applied stress, it can be seen that soil A6 showed more permanent deformation than soil A4, (about 66%).

Also from Figure (4-21) and Figure (4-22), it can be observed that soil A4 with optimum moisture content has more resistance to permanent deformation from soil A6, for all degrees of dry density with the same applied stress (about 120%).

This may be due to the fact that soil A4 contents less finer particles than Soil A6 and the maximum dry density for soil A4 is higher than for soil A6 and the optimum moisture content of soil A4 is less than the optimum moisture content of soil A6.

4.5 General Trend of Deformation Behavior

From cyclic load testing results for (A4) soil and (A6) soil it can be seen that a large part of the permanent samples deformation were developed during the first seven cycles of the tests.

It can be seen that the permanent deformation under the first load application for the two subgrade soils (A4 and A6) constituted between (27.5% to 50%) of the total permanent deformation for all tests that was accumulated after 60 cycles. Table (4-3) and (4-4) indicate that the accumulated permanent strain expressed as a percent of the total permanent strain during the first, tenth, twenty five and fifty cycles for soil A4 and for soil A6 with the moisture

content of 105% of the optimum moisture content and applied stresses of 28 KPa, 42 KPa and 63 KPa with dry density 95% of maximum dry density.

If the log of the axial strain is plotted against the log of time of loading, the relationship will be approximately linear for the two soils as shown in Figure (4-23), (4-24).

Table (4- 3) Accumulation of Permanent Strain at Various Load Cycles Expressed as a Percentage of Deformation at 60 Cycles for A4 Soil (MC=105% of OMC, DD =95% of MDD)

Stress (KPa)	1st	10th	25th	50th
28	35.8	61.6	77.2	94
42	37.2	64.8	81.4	95.4
63	47.5	69.7	82.5	95.5
Average	40.1	65.4	80.4	95

Table (4-4) Accumulation of Permanent Strain at Various Load Cycles Expressed as a Percentage of Deformation at 60 Cycles for A6 Soil (MC=105% of OMC, DD= 95% of MDD)

Stress (KPa)	1st	10th	25th	50th
28	31	48	65.7	91.6
42	37.8	60.3	76.5	95
63	43.2	64.8	78.8	94.4
Average	37.3	57.7	73.7	93.7

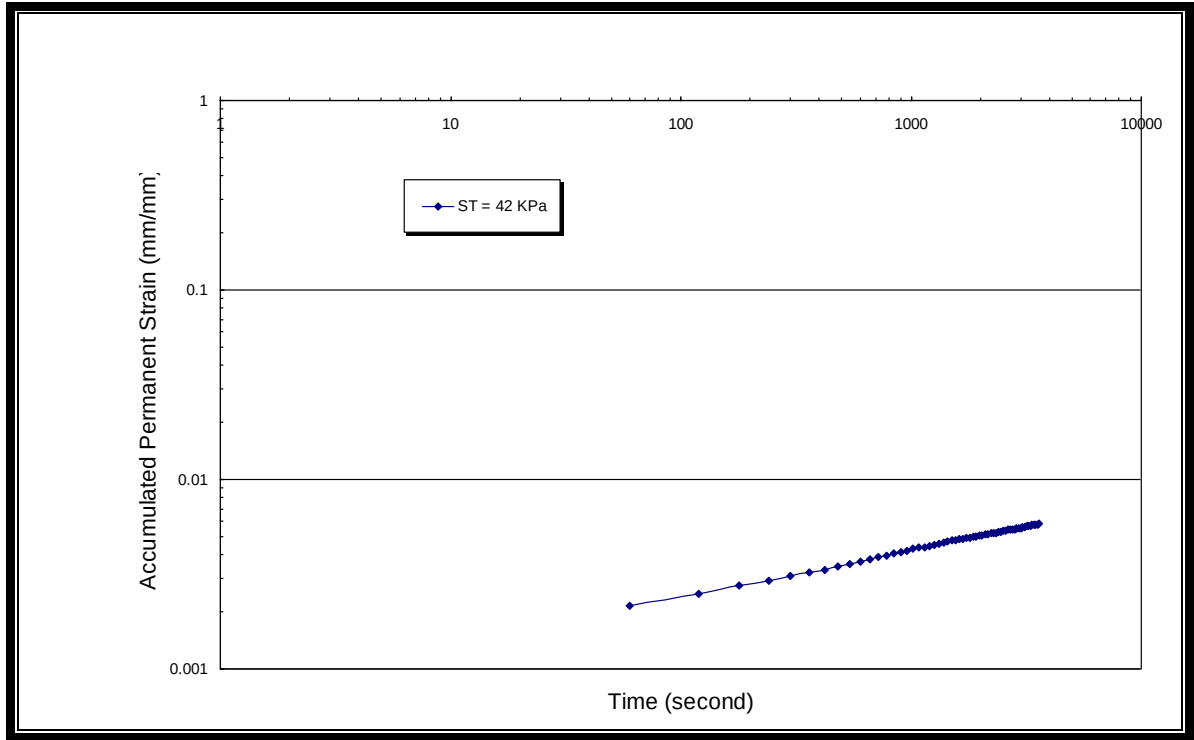


Figure (4-23) the Relationship Between Log of Permanent Strain and Log of Time (Soil A4, MC=105% of OMC, ST= 42 KPa, DD= 95% of MDD)

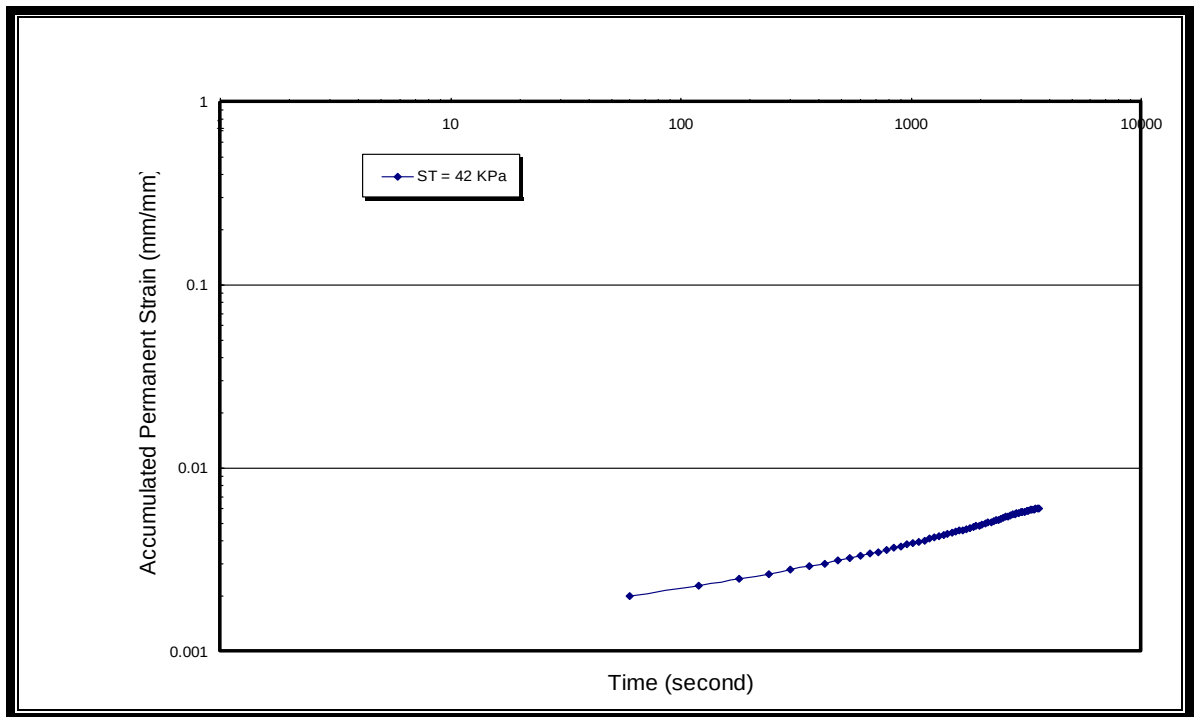


Figure (4-24) the Relationship Between Log of Permanent Strain and Log of Time (Soil A6, MC=105% of OMC, ST= 42 KPa, DD= 95% of MDD)

4.6: Model Development

The ultimate goal of every research or scientific analysis is finding relations between variables. Thus, in this section the variables that related to the permanent strain will be combined in statistical models.

By using **STATISTICA** software, these variables will be obtained and determined simultaneously under each moisture content using nonlinear regression analysis on the obtained tests results.

4.6.1: Statistical Analysis

In a statistical modeling the overall objective is to develop a predictive equation relating a criterion variable to predictor variables. The criterion variable is the permanent strain while the predictor variables include the test conditions (stress level), and some of the soil properties (dry density, moisture content) and soil types.

The **STATISTICA** software is a data management and analysis product. It can perform a variety of data analysis and presentation functions, including a statistical analysis and a graphical presentation of data. Among these features there are modules for the statistical data analysis, including descriptive statistics such as plots, frequencies, charts and lists.

4.6.2: Model Adequacy Assessment

There are two approaches generally used to assess the adequacy of the proposed regression models, the first one is based on the examining goodness of fit measures, where the second approach is based on the graphical analysis of the residuals, (also called diagnostic plots) **[Albayati, 2006]**.

The measures of goodness of fit are aimed to quantify how well the proposed regression model obtained fit the data. The coefficient of multiple determinations (R^2) is bounded between (0) and (1), the higher the value of (R^2), the more successful is the regression model. If the coefficient of multiple determinations (R^2) is small, an analyst will usually want to search for alternative models.

Another effective approach to the assessment of model adequacy is to compute the predicted criterion values and the residuals. Residuals are the difference between an observed value of the criterion variable and the value predicted by the model, and then to plot various functions of these computed quantities, and then examine the plots either to confirm our choice of model or for indications that the model is not appropriate [Albayati, 2006].

4.6.3: Prediction Models for Permanent Strain

The adopted models structure and the terms included in these models are shown in Table (4-5), while in Table (4-6), (4-8) and (4-10) the statistical summary of these models are presented. Also Tables (4-7), (4-9) and (4-11) shows the nonlinear analysis for the soils.

The models that attempt to describe the relationship between the permanent strain and the predictor variables are shown in Table (4-5).

Table (4-6) includes a statistical summary for the permanent strain models for soil A4, the analysis produced the coefficient of determination values ranging from (0.027) to (0.936) for all soil specimens tests results for soil A4.

Based on the data presented in Table (4-6) it can be seen that the predictive equations are explained from (2.7) to (93.68) percent of the scatter in the data. Model no.1 yields low (R^2) values while model no. (4) has the coefficient of multiple determinations (R^2) values of (0.936), which indicate that the measured permanent strain can be explained with a high degree of accuracy in terms of test conditions and soil properties. The calculated (R^2) is 0.936 which has the implication that only (6.4)% of the observed variation between the permanent strain and the selected predictor variables is unexplained by the developed model.

Figures (4-25), (4-26), (4-27) and (4-28) provide the diagnostic plots for permanent strain results from A4 soil tests.

Also it can be seen from Figure (4-28) that the residuals in the first plot are normally distributed, and the second plot yields points close to the (45)^o line, then the proposed regression function gives an accurate prediction of the values that are actually observed.

Table (4-5) General Models Structure for the Permanent Strain

Model No.	Model Structure	Criterion Variable
1	$C_o [(T \text{ DD MC ST})^{C1}]$	ϵ_p
2	$C_o + (T^{C1}) + (ST^{C2}) + (MC^{C3}) + (DD^{C4})$	ϵ_p
3	$C_o + C_1T + C_2ST + C_3MC + C_4DD$	ϵ_p
4	$C_o [(T^{C1}) (ST^{C2}) (MC^{C3}) (DD^{C4})]$	ϵ_p

Where:

ϵ_p = accumulated permanent strain (mm/mm)

T= time of loading (second)

DD= dry density (gm/cm³) as a percentage of maximum dry density

ST= applied stress (KPa)

MC= moisture content (%) as a percentage of optimum moisture content

Table (4-6) Statistical Summary for Permanent Strain Models for Soil A4

Model No.	Variance Explained (R ²)	R	Final Loss	Loss Function
1	2.7589%	0.16610	0.024990903	(OBS-PRED)**2
2	63.280%	0.79549	0.009437004	(OBS-PRED)**2
3	66.474%	0.81532	0.008616109	(OBS-PRED)**2
4	93.687%	0.96792	0.001622474	(OBS-PRED)**2

Table (4- 7) Nonlinear Analysis for Soil A4

Sta. Nonlin. Estimation	Model: $\varepsilon_p = C_0 * ((T^{**}C_1) * (ST^{**}C_2) * (MC^{**}C_3) * (DD^{**}C_4))$ Final loss = 0. 001622474				
N = 1020	C_0	C_1	C_2	C_3	C_4
Estimate	0.000250	0.145878	0.817165	14.856185	-15.502487

Where:

N = numbers of valid cases

According to Tables (4-6) and (4-7), the final form of proposed model for soil A4 is:

$$\varepsilon_p = 2.5 * 10^{-4} (T^{0.145878}) (ST^{0.817165}) (MC^{14.856185}) (DD^{-15.502487}) \dots\dots\dots(4-1)$$

In this model the numbers of valid cases (N) are (1020) which represent a large number of data in order to give the model high accuracy.

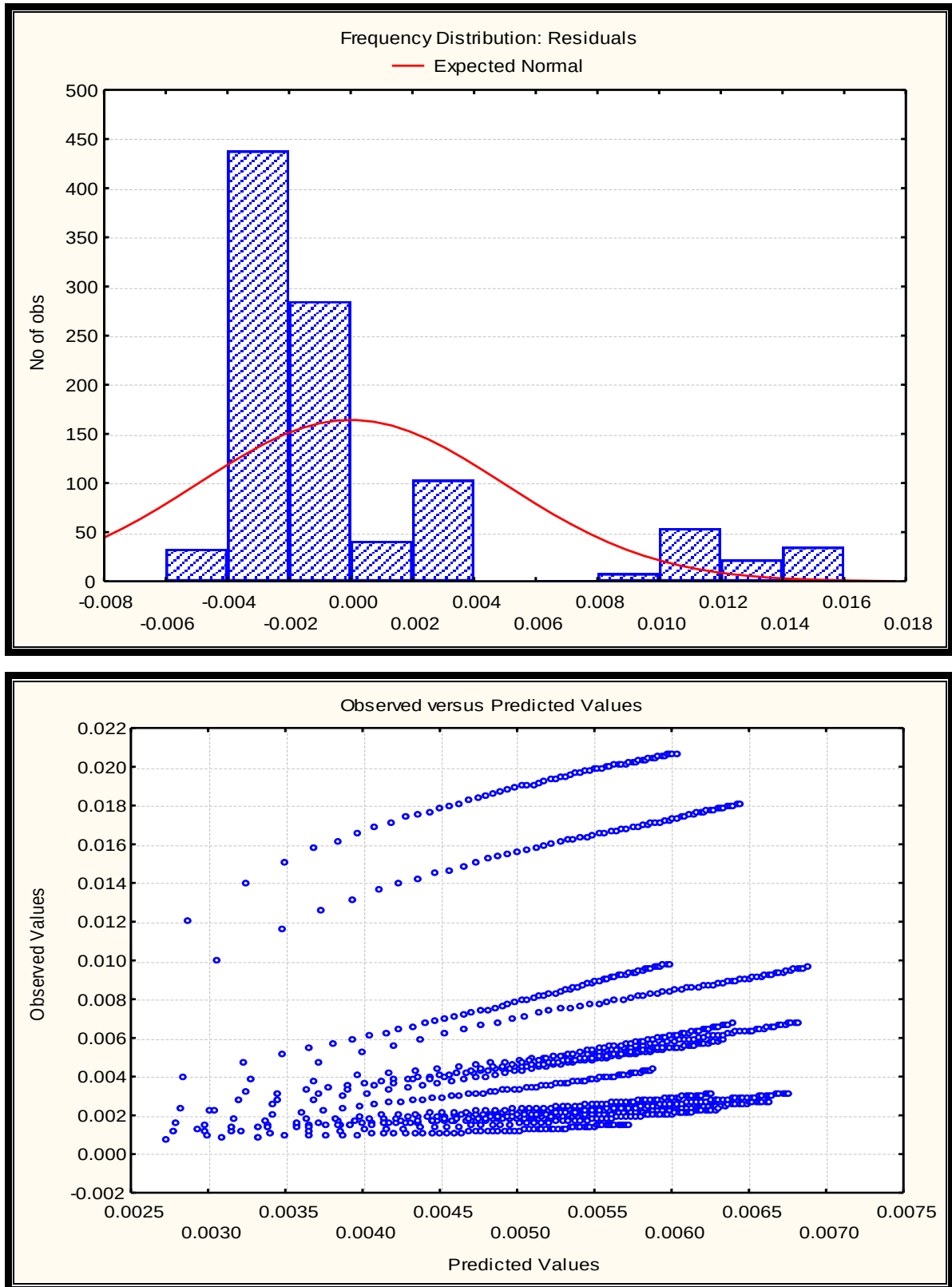


Figure (4-25) Diagnostic Plot for Permanent Strain (Model No.1) Soil A4

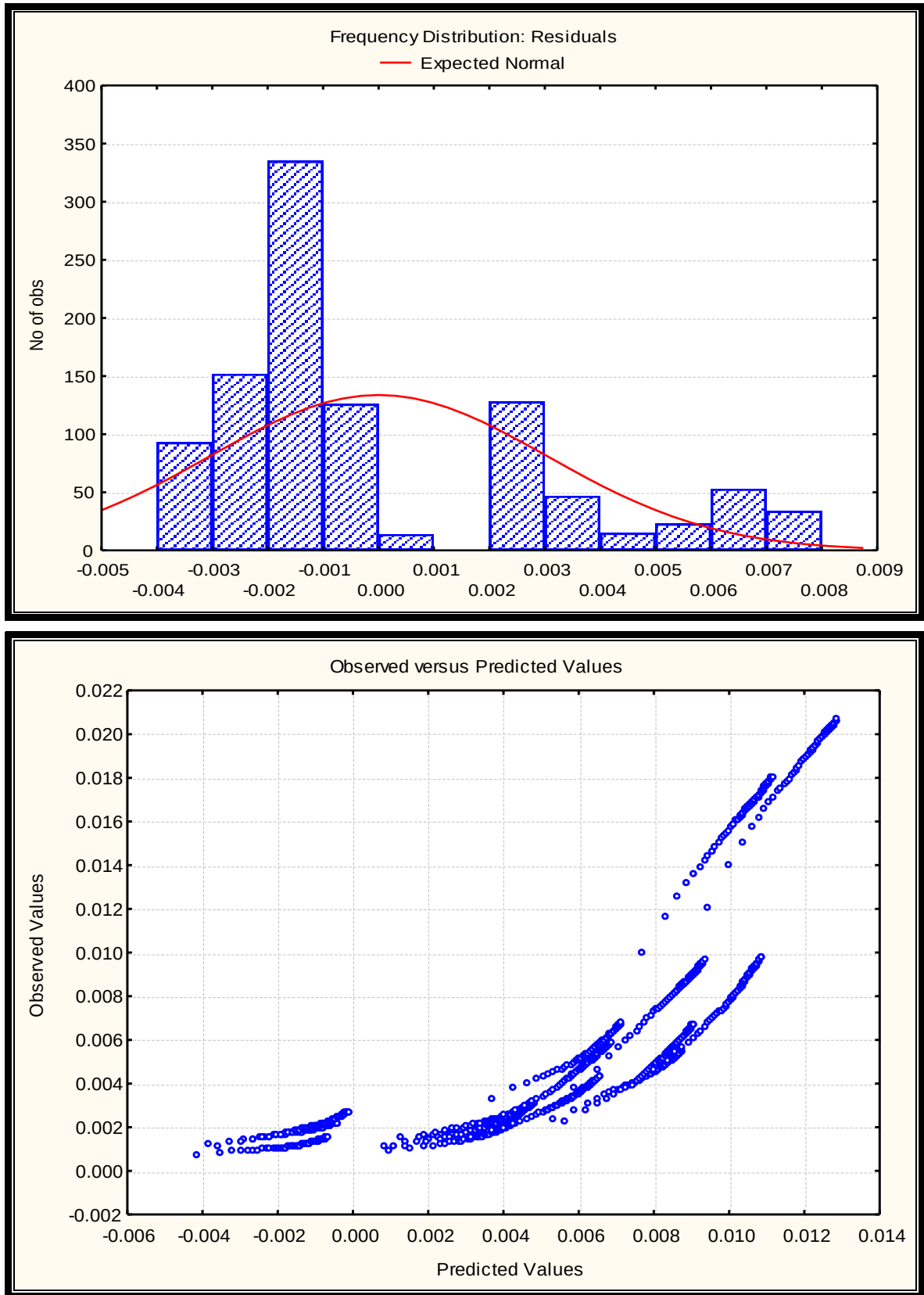


Figure (4-26) Diagnostic Plot for Permanent Strain (Model No.2) Soil A4

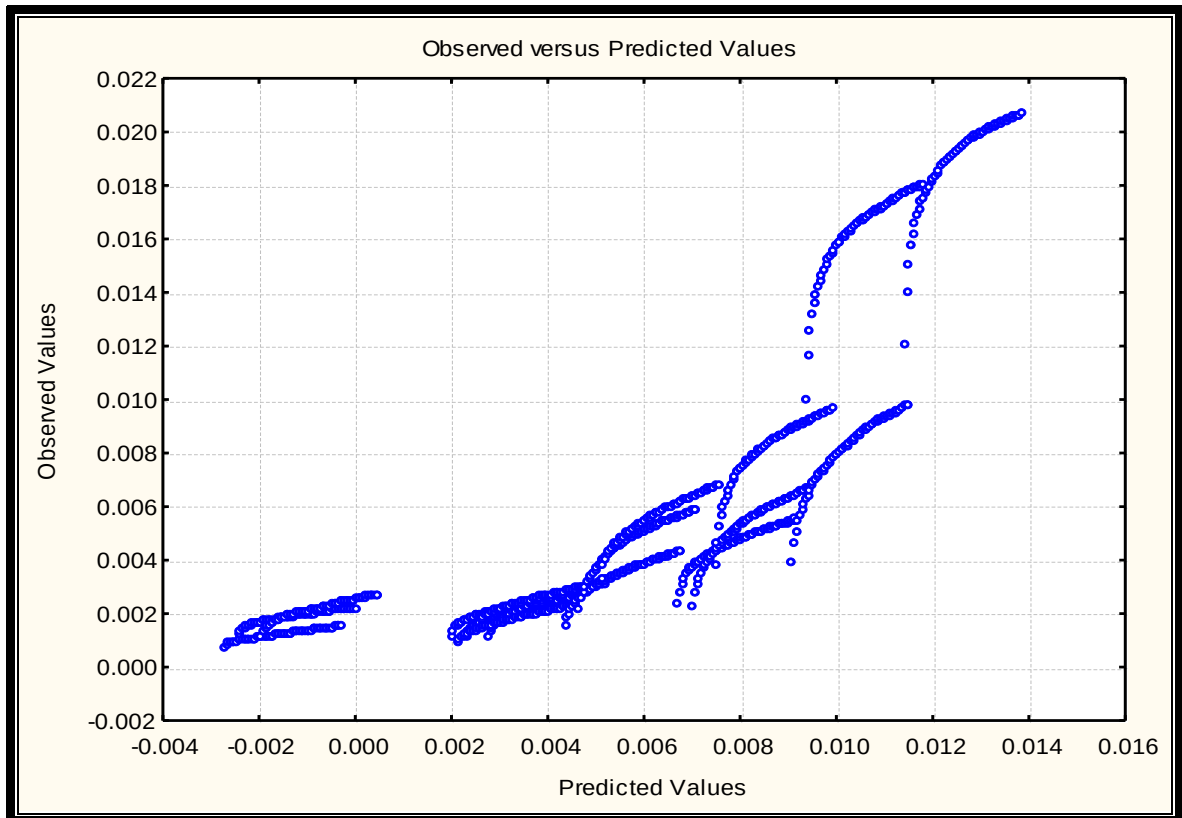
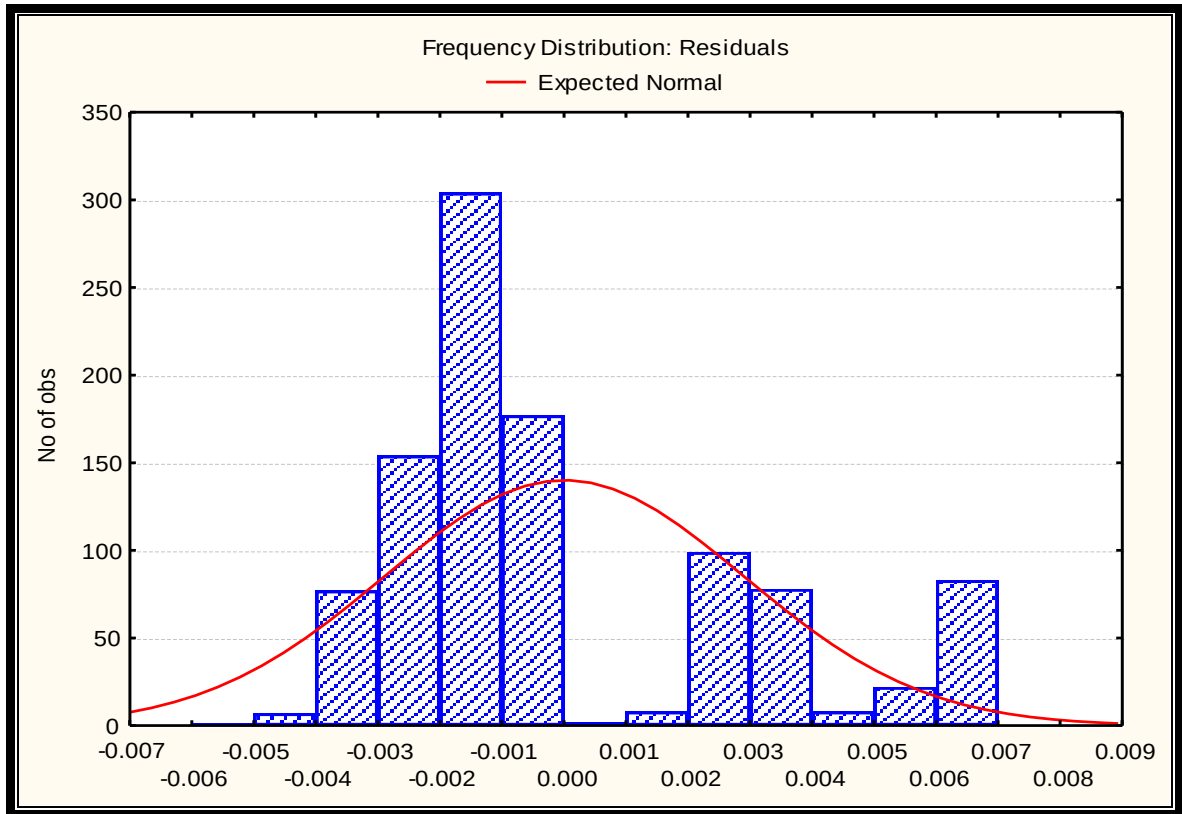


Figure (4- 27) Diagnostic Plot for Permanent Strain (Model No.3) Soil A4

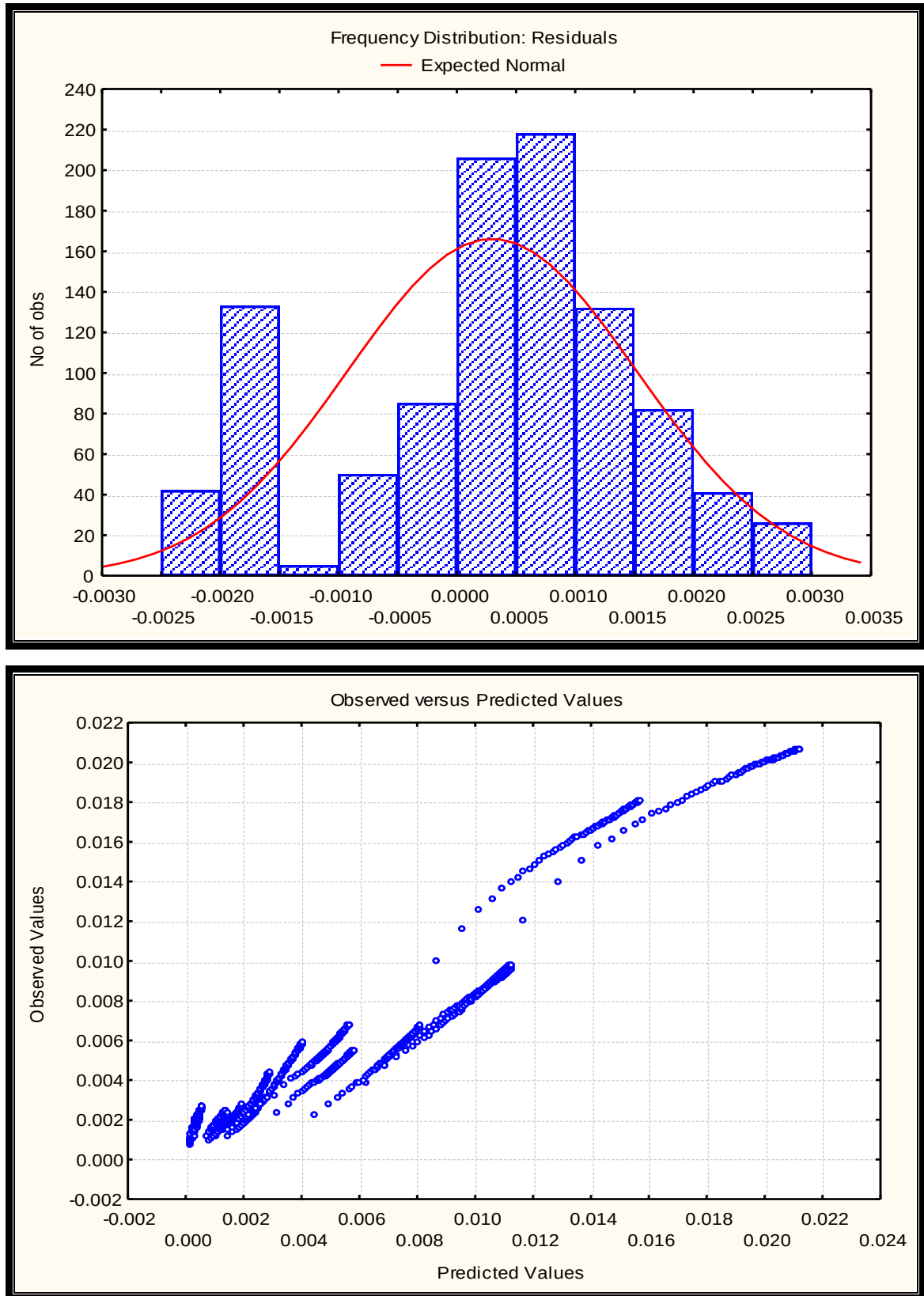


Figure (4-28) Diagnostic Plot for Permanent Strain (Model No.4) Soil A4

Table (4-8) includes a statistical summary for the permanent strain models for soil A6, the analysis produced the coefficient of determination values ranging from (0.131) to (0.939) for all soil specimens tests results for soil A6.

The calculated (R^2) is 0.939 which has the implication that only (6.1)% of the observed variation between the permanent strain and the selected predictor variables is unexplained by the developed model.

Equation (4-2) has (R^2) values of (0.939), which indicates that a good correlation exists between measured and predicted values and indicates that the present formulation has adequately represented the plastic strain response of the soils tested..

Figures (4-29), (4-30), (4-31) and (4-32) provide the diagnostic plots for permanent strain results from A6 soil tests.

Figure (4-32) provides the comparisons between predicted versus measured plastic strain, shows that good correlations are obtained, which indicate that the present formulation has adequately represented the plastic strain response of soil tested under the cyclic loading test.

Table (4-8) Statistical Summary for Permanent Strain Models for Soil A6

Model No.	Variance Explained (R^2)	R	Final Loss	Loss Function
1	13.118%	0.362	0.0157	(OBS-PRED)**2
2	76.124%	0.872	0.0043	(OBS-PRED)**2
3	78.663%	0.886	0.0038	(OBS-PRED)**2
4	93.986%	0.969	0.00109	(OBS-PRED)**2

Table (4- 9) Nonlinear Analysis for Soil A6

Sta. Nonlin. Estimation	Model: $\varepsilon_p = C_0 * (T^{**C1}) * (ST^{**C2}) * (MC^{**C3}) * (DD^{**C4})$ Final loss: 0.001092820				
N = 1020	C0	C1	C2	C3	C4
Estimate	0.000475	0.21570	0.676856	8.615739	-9.14337

According to tables (4-8) and (4-9), the final form of proposed model for A6 soil is:

$$\varepsilon_p = 4.75 * 10^{-4} (T^{0.21570}) (ST^{0.676856}) (MC^{8.615739}) (DD^{-9.14337}) \dots\dots(4-2)$$

As in equation (4-1), In this model the numbers of valid cases (N) are (1020) which represent a large number of data in order to give the model high accuracy.

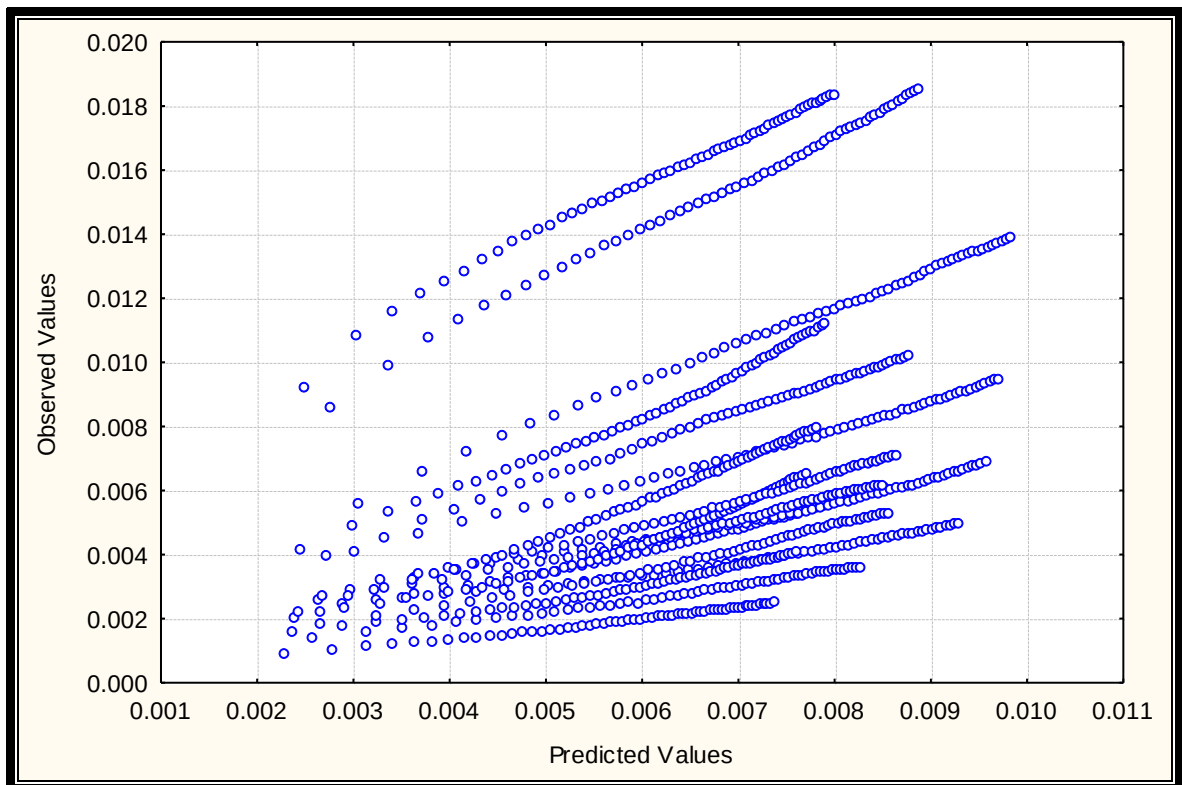
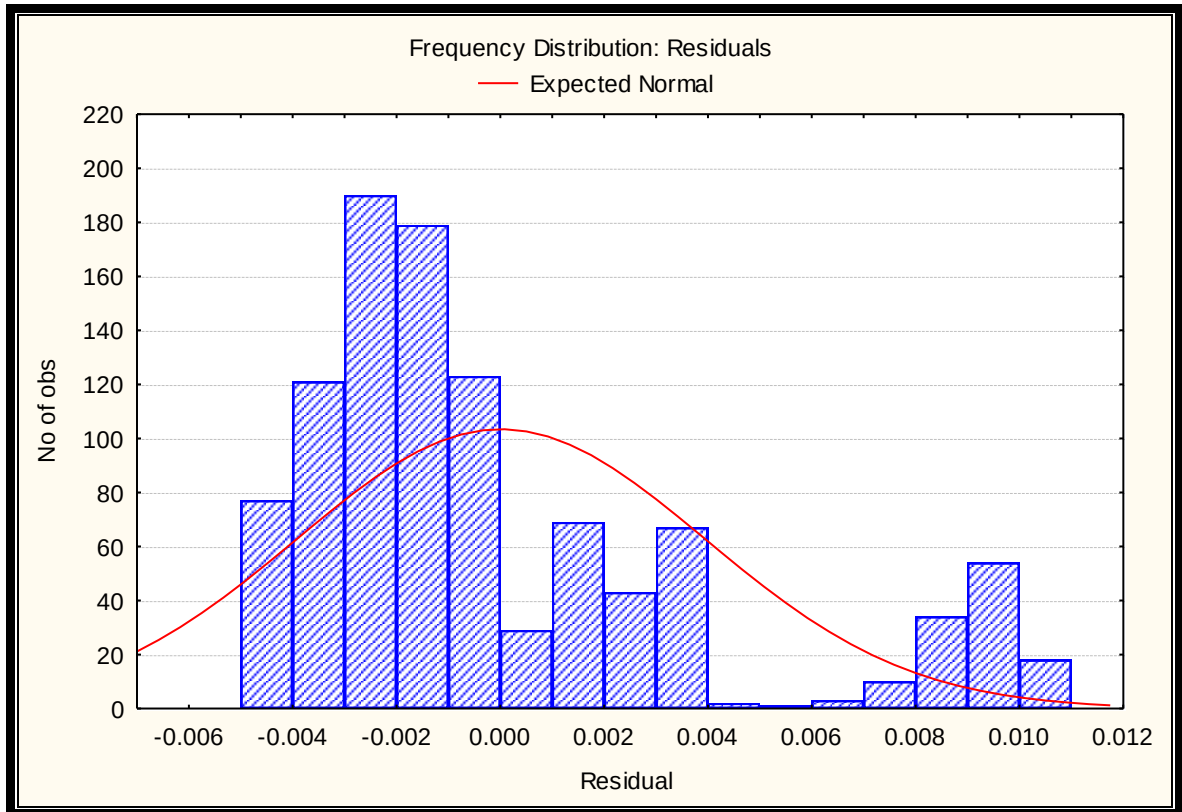


Figure (4- 29) Diagnostic Plot for Permanent Strain (Model No.1) Soil A6

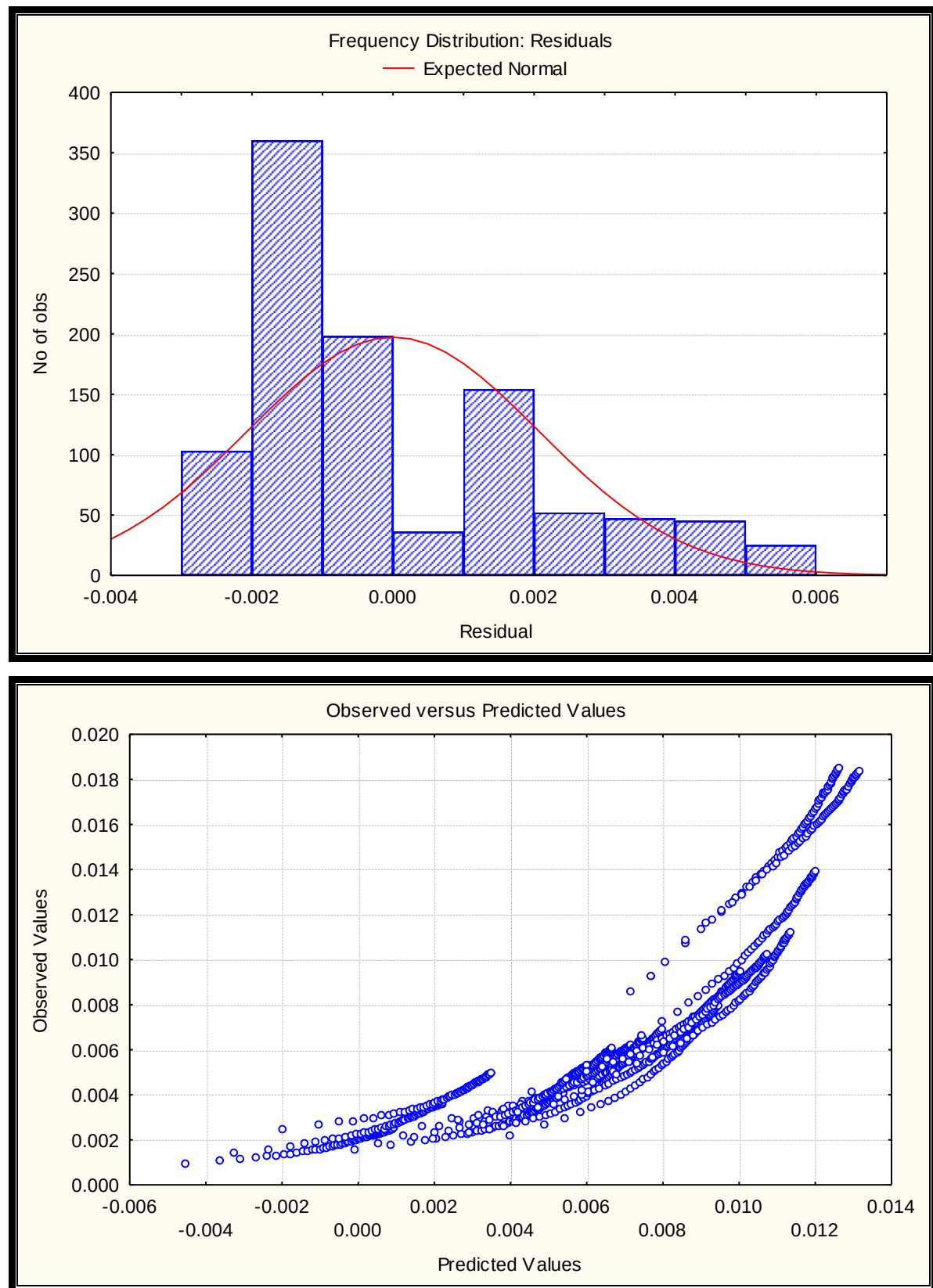


Figure (4- 30) Diagnostic Plot for Permanent Strain (Model No.2) Soil A

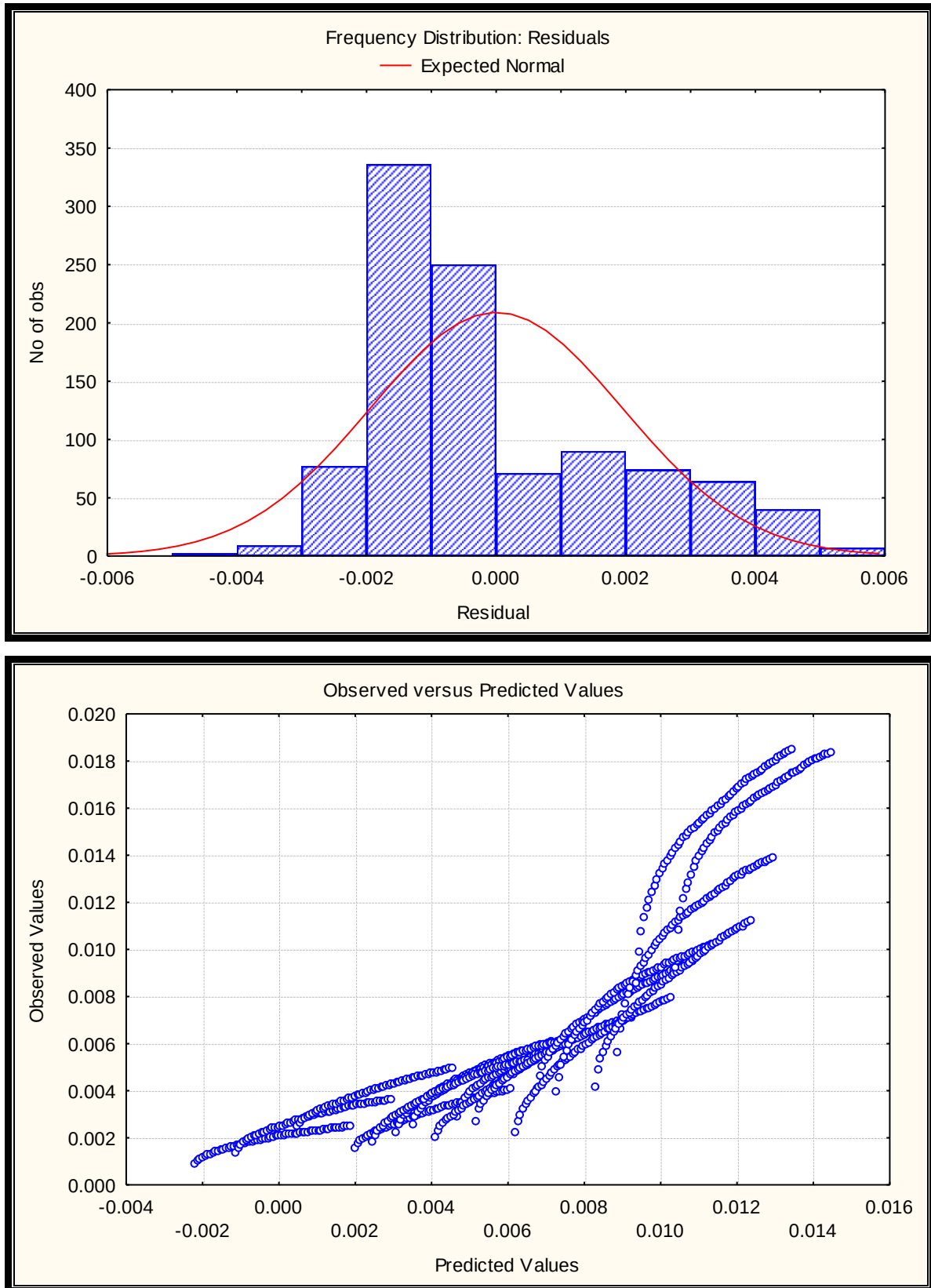


Figure (4-31) Diagnostic Plot for Permanent Strain (Model No.3) Soil A6

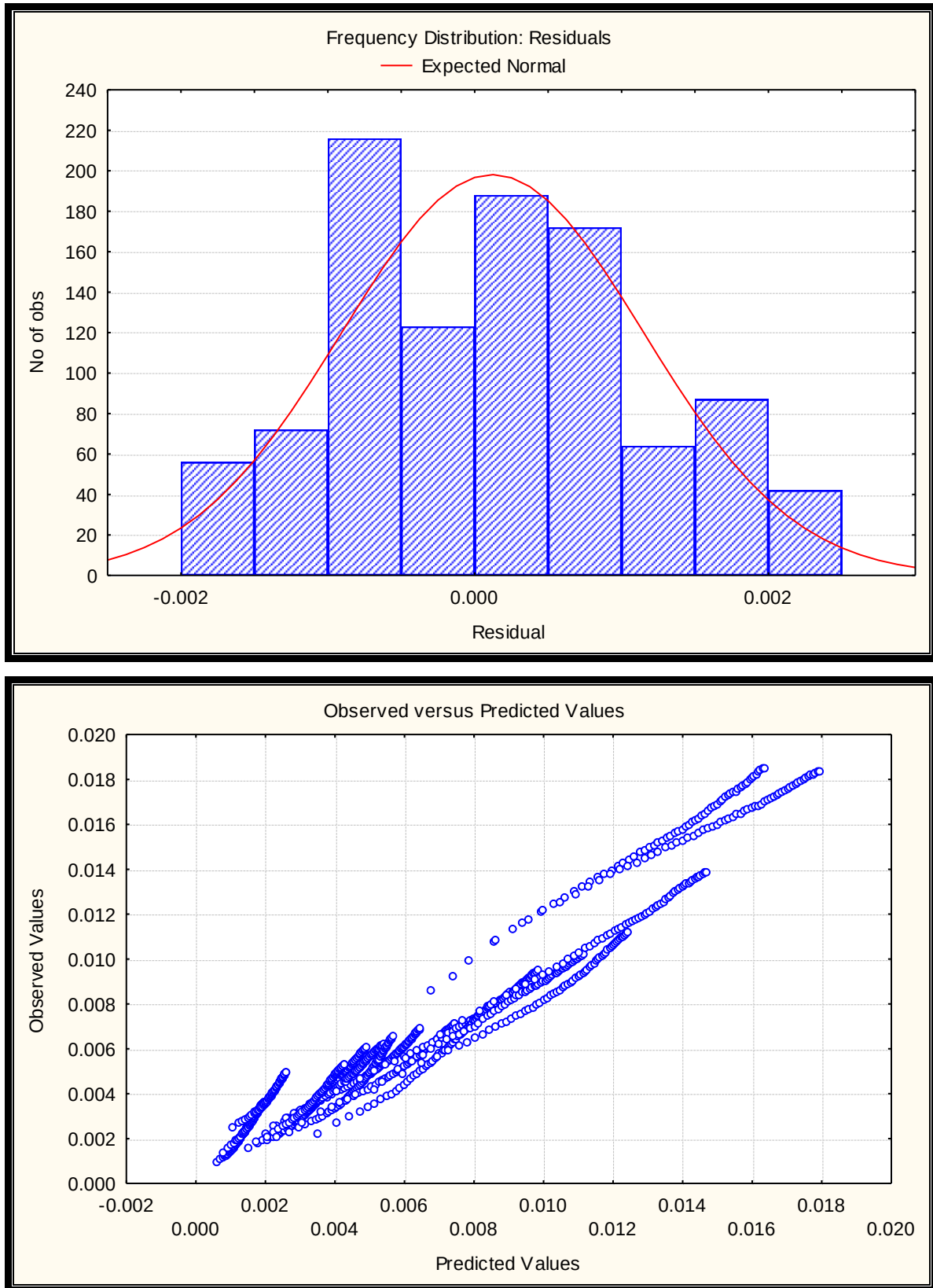


Figure (4-32) Diagnostic Plot for Permanent Strain (Model No.4) Soil A

Equation (4-3) represents a model for both soils (A4 and A6) where the results of both soils were collected and dealing in the statistica software with

(2040) number of valid cases which represent a large number of data in order to represent the two soils in one model.

Table (4-10) includes a statistical summary for the permanent strain models for both soils A4 and A6, the analysis produced coefficient of determination values ranging from (0.063) to (0.887) for all soil specimens tests results for soils A4 and A6.

Model no.1 yields low (R^2) values while model no. (4) has the coefficient of multiple determinations (R^2) values of (0.887), which indicate that the measured permanent strain can be explained with a good degree of accuracy in terms of test conditions and soil properties. The calculated (R^2) is 0.887 which has the implication that only (11.3)% of the observed variation between the permanent strain and the selected predictor variables is unexplained by the developed model. Figures (4-33), (4-34), (4-35) and (4-36) provide the diagnostic plots for permanent strain results from A4 and A6 soils tests.

Also it can be seen from Figure (4-36) that the residuals in the first plot are normally distributed, and the second plot yields points close to the (45) $^\circ$ line, then the proposed regression function gives an accurate prediction of the values that are actually observed.

Table (4-10) Statistical Summary for Permanent Strain Models for Soil A6 and A4

Model No.	Variance Explained (R^2)	R	Final Loss	Loss Function
1	6.3200%	0.25140	0.041975841	(OBS-PRED)**2
2	65.892%	0.81174	0.015282834	(OBS-PRED)**2
3	68.721%	0.82898	0.014015237	(OBS-PRED)**2
4	88.796%	0.94232	0.005020326	(OBS-PRED)**2

Table (4- 11) Nonlinear Analysis for Soil A6 and A4

Sta. Nonlin. Estimation	Model: $\varepsilon_p = C_0 * (T^{**C_1}) * (ST^{**C_2}) * (MC^{**C_3}) * (DD^{**C_4})$ Final loss: 0.005020326				
N = 2040	C0	C1	C2	C3	C4
Estimate	$7*10^{-10}$	0.181595	0.701858	11.19941	-8.83546

According to tables (4-10) and (4-11), the final form of proposed model for both A4 and A6 soils IS:

$$\varepsilon_p = 7*10^{-10} (T^{0.181595}) (ST^{0.701858}) (MC^{11.19941}) (DD^{-8.83546}) \dots\dots\dots(4-3)$$

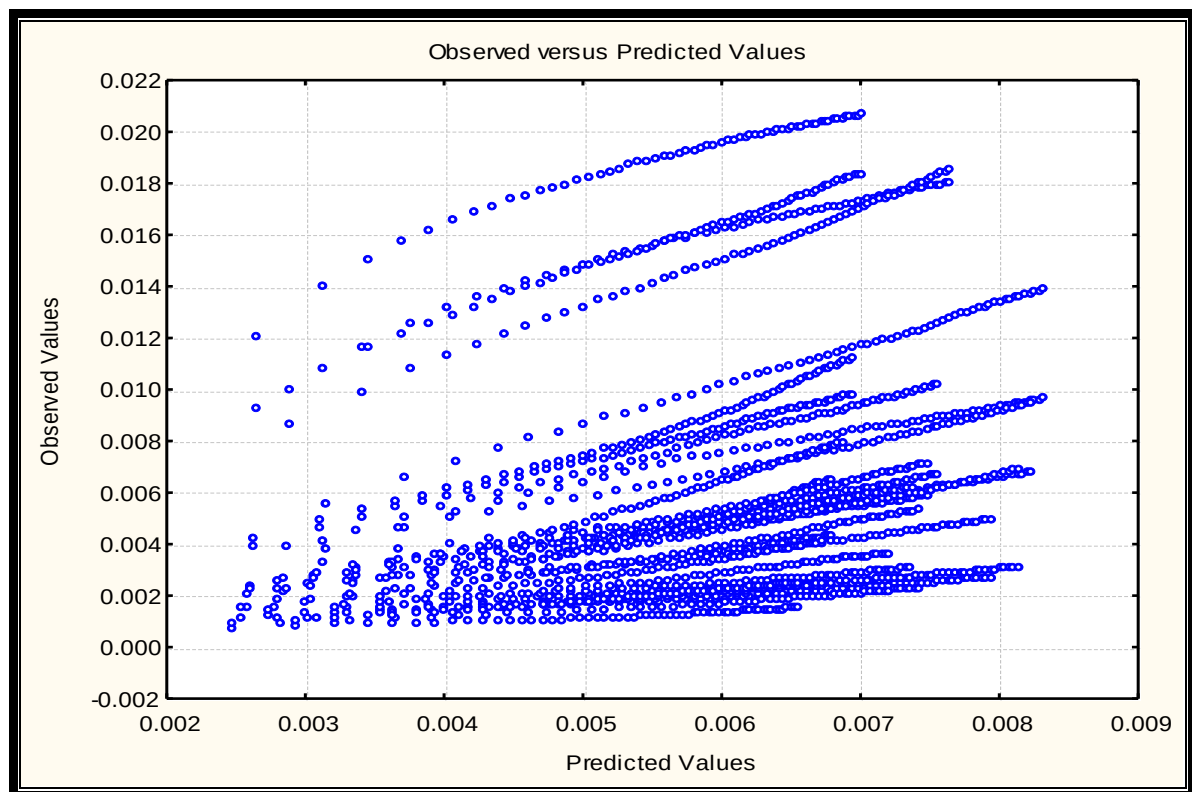
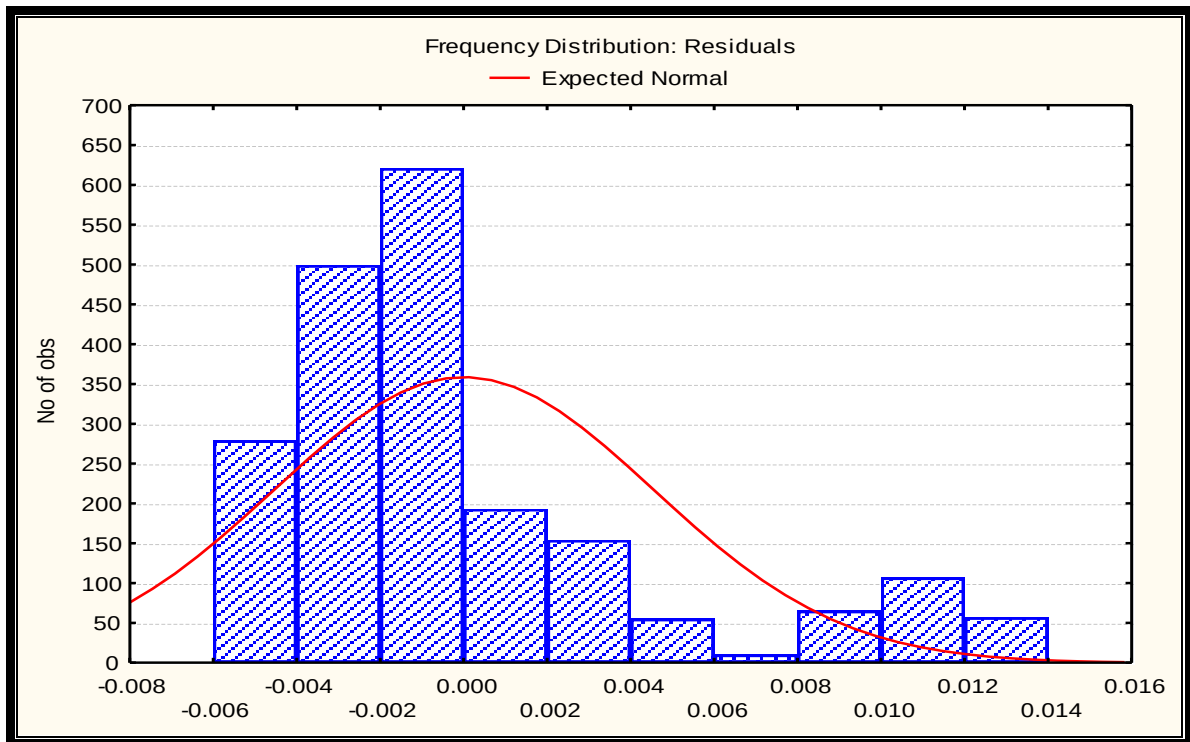


Figure (4-33) Diagnostic Plot for Permanent Strain (Model No.1) Soil A6 and A4

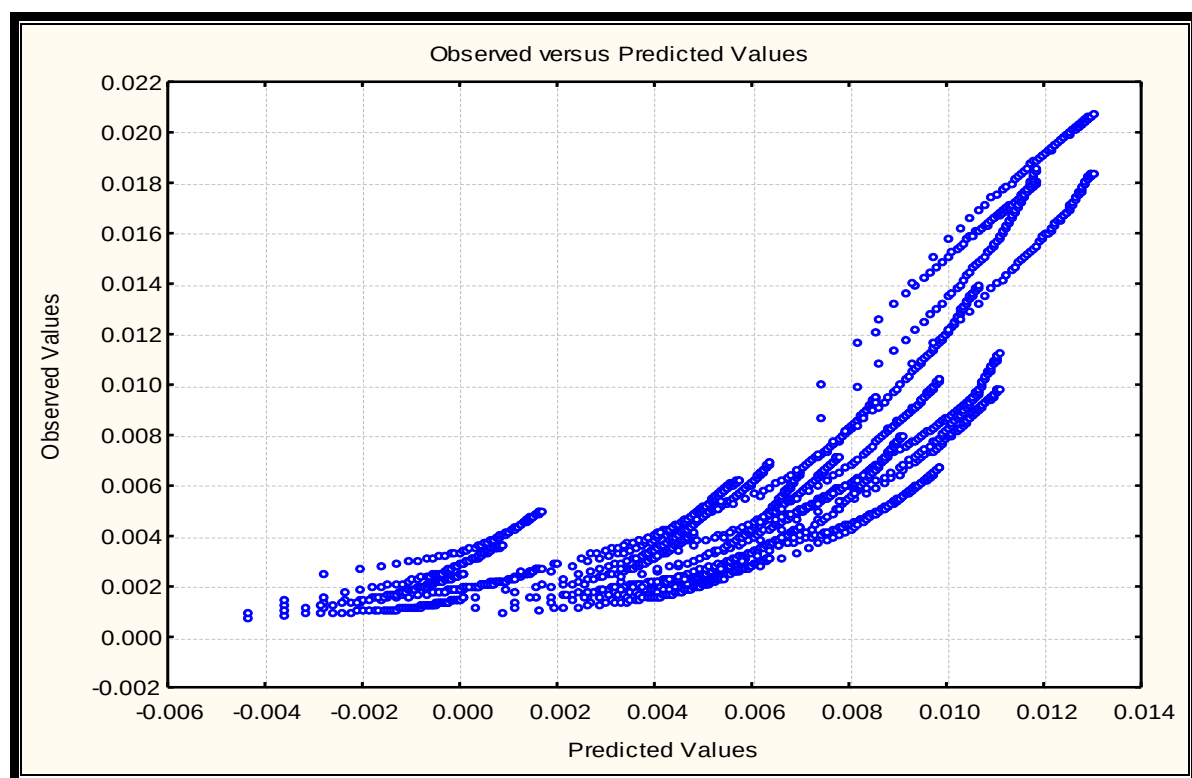
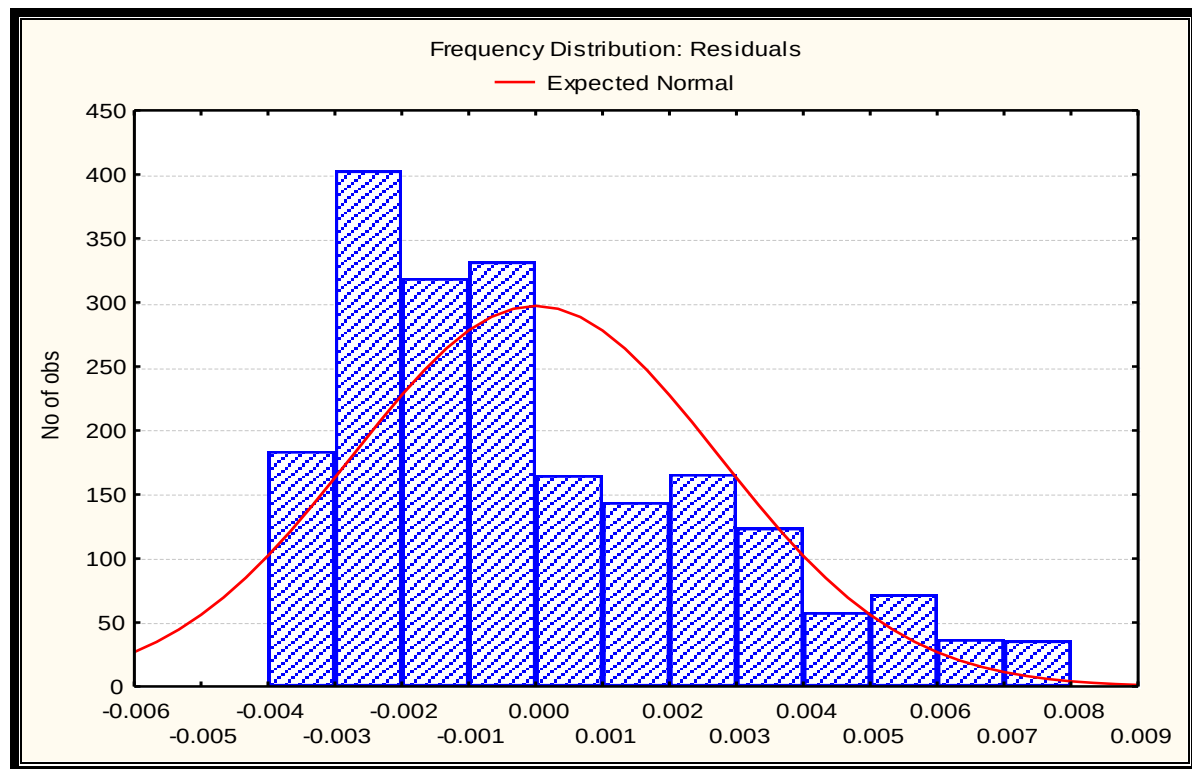


Figure (4-34) Diagnostic Plot for Permanent Strain (Model No.2) Soil A6 and A4

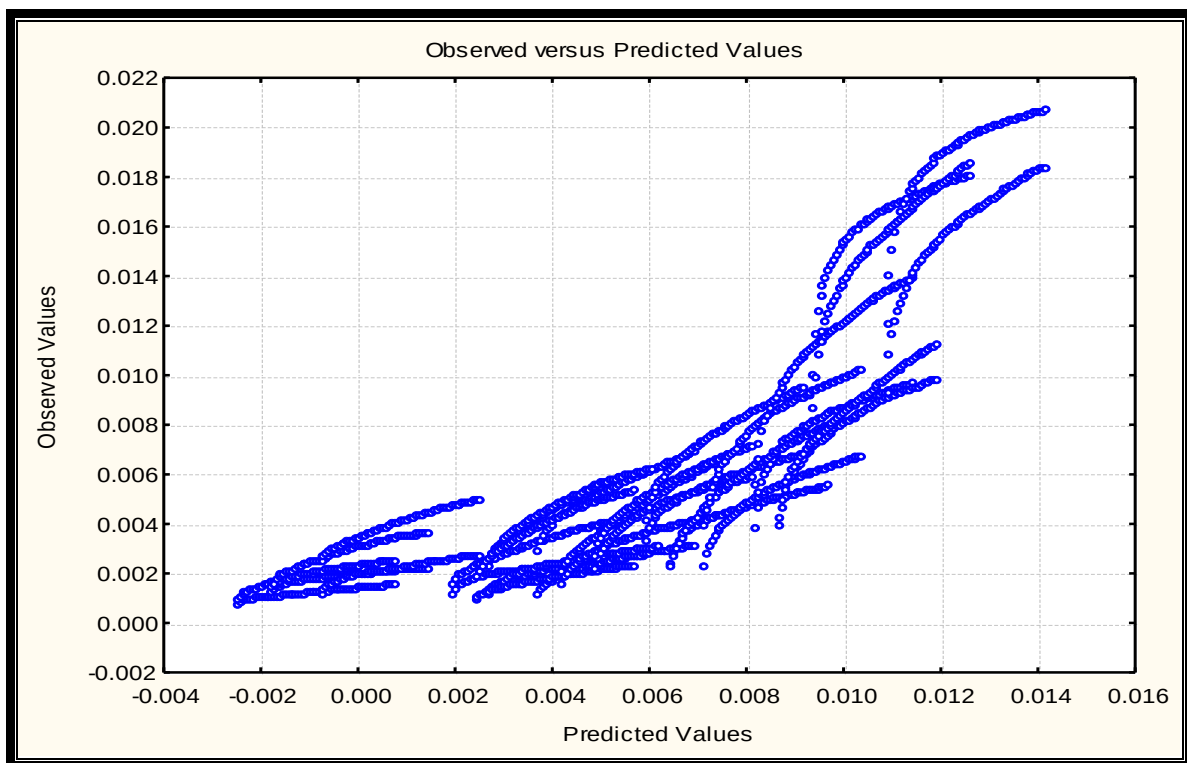
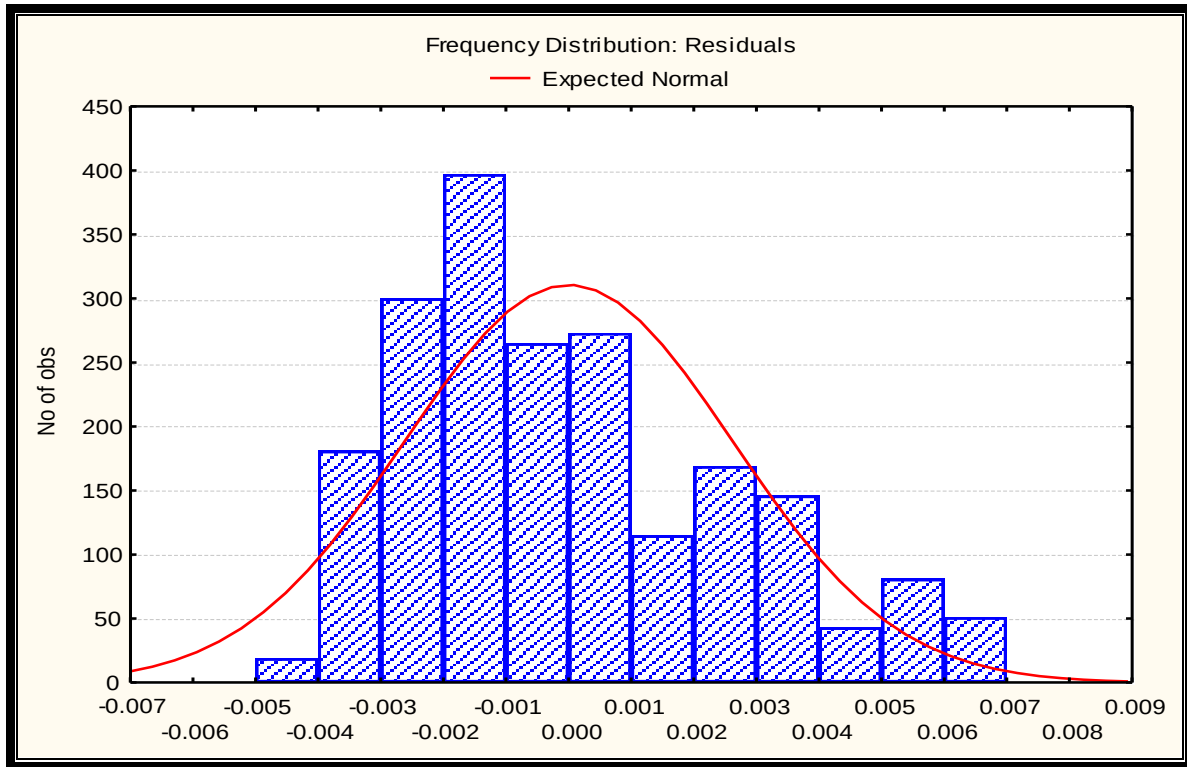


Figure (4-35) Diagnostic Plot for Permanent Strain (Model No.3) Soil A6 and A4

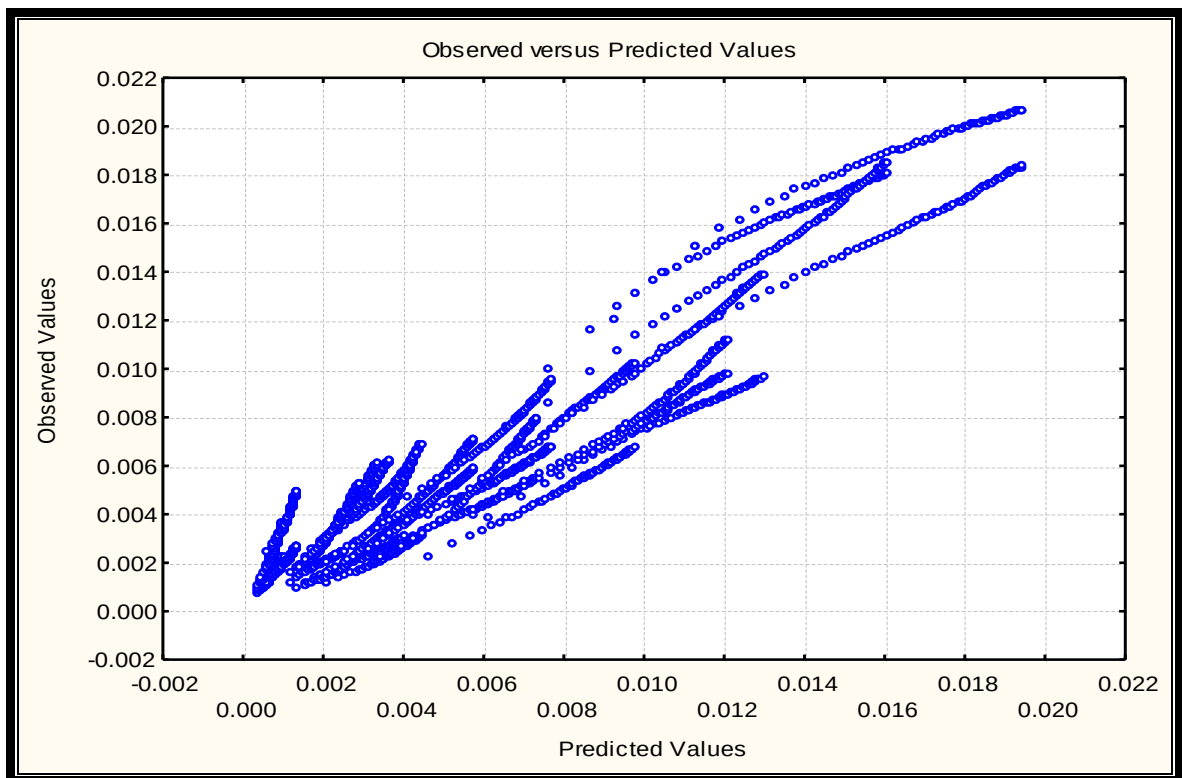
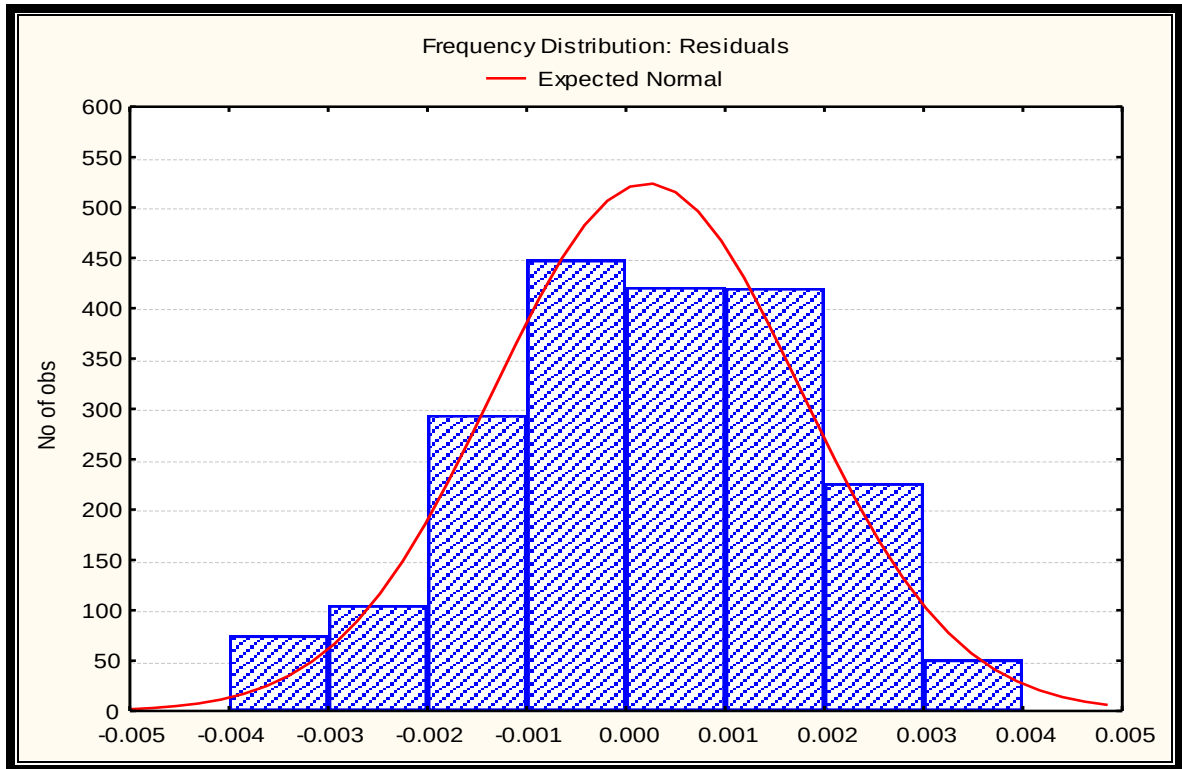


Figure (4-36) Diagnostic Plot for Permanent Strain (Model No.4) Soil A6 and A4

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1: Introduction

This chapter presents the main conclusions, which are evolved from the present research, together with recommendations for future works.

5.2: Conclusions

Within the limitations of materials and testing program adopted in this work, the followings are concluded:

- 1) The moisture content has a significant effect on the permanent strain for A4 and A6 soils. The increase of the moisture content from 90% to 110%, has increased the permanent strain by 270% for A4 soil and by 220% for A6 soil. Therefore, with the increase of the moisture content a considerable increase in the permanent strain is highly expected.
- 2) The applied stress showed a considerable influence on the permanent strain values, specially on the first cycle of loading, where the increase of stresses from 28 KPa to 63 KPa, has increased the permanent strain by (81%) for A4 soil and by (100%) for A6 soil. Therefore, High permanent strain was recorded when soils were subjected to high stresses.
- 3) The permanent strain results for soils A4 and A6 compacted at wet of optimum moisture content condition was higher than those compacted at dry of optimum moisture content.
- 4) The permanent strain results showed that A4 soil at the optimum moisture content exhibited lower plastic deformation (about 105%) compared with A6 soil for all degrees of stresses.

- 5) At the optimum moisture content, the permanent strain has been increased by 25% for soil A4 and by 69.7% for soil A6 for an increase in the applied stresses from 28 KPa to 63 KPa.
- 6) The effect of limited variation in dry density on deformation behavior produces a slight increase in the permanent strain for both soils.
- 7) The log of the axial permanent strain versus the log of time of loading demonstrates linear relationship.
- 8) A regression models have been obtained to predict the permanent strain of some Iraqi subgrade soils as related to the moisture content, applied stress, time of loading and dry density, depending on a large number of valid cases. These developed models will add to the local knowledge a suitable aid for controlling the design and construction of asphalt pavement.

i) Model for A4 soil :

$$\epsilon_p = 2.5 \cdot 10^{-4} (T^{0.145878}) (ST^{0.817165}) (MC^{14.856185}) (DD^{-15.502487})$$

ii) Model for A6 soil:

$$\epsilon_p = 4.75 \cdot 10^{-4} (T^{0.21570}) (ST^{0.676856}) (MC^{8.615739}) (DD^{-9.14337})$$

iii) Model for both A4 and A6 soils:

$$\epsilon_p = 7 \cdot 10^{-10} (T^{0.181595}) (ST^{0.701858}) (MC^{11.19941}) (DD^{-8.83546})$$

Where: ϵ_p is the permanent strain (mm/mm), T is the time of loading (sec.), ST is the applied stress (KPa), MC is the moisture content (%) as a percentage of optimum moisture content and DD is the dry density (gm/cm³) as a percentage of maximum dry density.

5.3: RECOMMENDATIONS

For further research about the permanent deformation of subgrade soils, the following investigations are suggested:

- 1) Due to the short coming of data or not available, it is recommended to carry out tests at the field and the laboratory for the same soils to investigate the validity of the laboratory models and there relations with the results obtained.
- 2) The use of triaxial repeated load test apparatus for predicting permanent deformation of subgrade soils with high number of repetitions.
- 3) investigate the effect of confine pressure on the accumulation of permanent deformation.

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APPENDIX A

CYCLIC LOADING TEST DATA

Legend

DUR = applied stress duration (sec.)

STR = applied stress (KPa)

DD = dry density (gm/cm^3) as a percentage of maximum dry density

MDD = maximum dry density (gm/cm^3)

MC = moisture content (%) as a percentage of optimum moisture content

OMC = optimum moisture content (%)

Results of Cyclic Load Test No (1) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	90	0.000718504
2	10	28	95	90	0.000807087
3	10	28	95	90	0.000846457
4	10	28	95	90	0.000875984
5	10	28	95	90	0.000905512
6	10	28	95	90	0.000905512
7	10	28	95	90	0.000935039
8	10	28	95	90	0.000944882
9	10	28	95	90	0.000964567
10	10	28	95	90	0.000984252
11	10	28	95	90	0.000984252
12	10	28	95	90	0.000994094
13	10	28	95	90	0.001003937
14	10	28	95	90	0.001003937
15	10	28	95	90	0.001023622
16	10	28	95	90	0.001023622
17	10	28	95	90	0.001033465
18	10	28	95	90	0.00105315
19	10	28	95	90	0.001062992
20	10	28	95	90	0.001072835
21	10	28	95	90	0.00109252
22	10	28	95	90	0.00109252
23	10	28	95	90	0.001102362
24	10	28	95	90	0.001122047
25	10	28	95	90	0.00113189
26	10	28	95	90	0.001141732
27	10	28	95	90	0.001161417
28	10	28	95	90	0.001161417
29	10	28	95	90	0.00117126
30	10	28	95	90	0.001181102
31	10	28	95	90	0.001190945
32	10	28	95	90	0.001200787
33	10	28	95	90	0.00121063
34	10	28	95	90	0.001230315
35	10	28	95	90	0.001240157
36	10	28	95	90	0.00125
37	10	28	95	90	0.00125
38	10	28	95	90	0.001259843
39	10	28	95	90	0.001269685
40	10	28	95	90	0.001279528
41	10	28	95	90	0.001299213
42	10	28	95	90	0.001309055
43	10	28	95	90	0.00132874
44	10	28	95	90	0.001338583
45	10	28	95	90	0.001348425
46	10	28	95	90	0.001358268
47	10	28	95	90	0.00136811
48	10	28	95	90	0.001387795
49	10	28	95	90	0.001397638
50	10	28	95	90	0.001397638
51	10	28	95	90	0.00140748
52	10	28	95	90	0.001427165
53	10	28	95	90	0.001427165
54	10	28	95	90	0.001437008
55	10	28	95	90	0.00144685
56	10	28	95	90	0.00144685
57	10	28	95	90	0.001456693
58	10	28	95	90	0.001466535
59	10	28	95	90	0.001476378
60	10	28	95	90	0.001476378

Results of Cyclic Load Test No (2) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	90	0.00121063
2	10	42	95	90	0.001338583
3	10	42	95	90	0.001417323
4	10	42	95	90	0.00144685
5	10	42	95	90	0.001476378
6	10	42	95	90	0.001515748
7	10	42	95	90	0.001545276
8	10	42	95	90	0.001574803
9	10	42	95	90	0.001574803
10	10	42	95	90	0.001614173
11	10	42	95	90	0.001633858
12	10	42	95	90	0.001643701
13	10	42	95	90	0.001673228
14	10	42	95	90	0.001663386
15	10	42	95	90	0.001692913
16	10	42	95	90	0.001722441
17	10	42	95	90	0.001732283
18	10	42	95	90	0.001742126
19	10	42	95	90	0.001761811
20	10	42	95	90	0.001761811
21	10	42	95	90	0.001771654
22	10	42	95	90	0.001791339
23	10	42	95	90	0.001801181
24	10	42	95	90	0.001801181
25	10	42	95	90	0.001820866
26	10	42	95	90	0.001840551
27	10	42	95	90	0.001840551
28	10	42	95	90	0.001850394
29	10	42	95	90	0.001870079
30	10	42	95	90	0.001889764
31	10	42	95	90	0.001889764
32	10	42	95	90	0.001889764
33	10	42	95	90	0.001909449
34	10	42	95	90	0.001919291
35	10	42	95	90	0.001948819
36	10	42	95	90	0.001948819
37	10	42	95	90	0.001958661
38	10	42	95	90	0.001958661
39	10	42	95	90	0.001968504
40	10	42	95	90	0.001978346
41	10	42	95	90	0.001998031
42	10	42	95	90	0.002007874
43	10	42	95	90	0.002027559
44	10	42	95	90	0.002037402
45	10	42	95	90	0.002037402
46	10	42	95	90	0.002047244
47	10	42	95	90	0.002057087
48	10	42	95	90	0.002076772
49	10	42	95	90	0.002086614
50	10	42	95	90	0.002086614
51	10	42	95	90	0.002096457
52	10	42	95	90	0.002116142
53	10	42	95	90	0.002116142
54	10	42	95	90	0.002125984
55	10	42	95	90	0.002135827
56	10	42	95	90	0.002135827
57	10	42	95	90	0.002145669
58	10	42	95	90	0.002155512
59	10	42	95	90	0.002155512
60	10	42	95	90	0.002155512

Results of Cyclic Load Test No (3) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	63	95	90	0.001112205
2	10	63	95	90	0.00132874
3	10	63	95	90	0.001437008
4	10	63	95	90	0.001496063
5	10	63	95	90	0.001525591
6	10	63	95	90	0.001584646
7	10	63	95	90	0.001643701
8	10	63	95	90	0.001673228
9	10	63	95	90	0.001712598
10	10	63	95	90	0.001742126
11	10	63	95	90	0.001781496
12	10	63	95	90	0.001811024
13	10	63	95	90	0.001840551
14	10	63	95	90	0.001870079
15	10	63	95	90	0.001899606
16	10	63	95	90	0.001929134
17	10	63	95	90	0.001948819
18	10	63	95	90	0.001958661
19	10	63	95	90	0.001978346
20	10	63	95	90	0.001988189
21	10	63	95	90	0.001998031
22	10	63	95	90	0.002017717
23	10	63	95	90	0.002027559
24	10	63	95	90	0.002027559
25	10	63	95	90	0.002057087
26	10	63	95	90	0.002076772
27	10	63	95	90	0.002096457
28	10	63	95	90	0.002106299
29	10	63	95	90	0.002125984
30	10	63	95	90	0.002145669
31	10	63	95	90	0.002155512
32	10	63	95	90	0.002185039
33	10	63	95	90	0.002204724
34	10	63	95	90	0.002214567
35	10	63	95	90	0.002253937
36	10	63	95	90	0.00226378
37	10	63	95	90	0.002293307
38	10	63	95	90	0.002312992
39	10	63	95	90	0.002322835
40	10	63	95	90	0.002352362
41	10	63	95	90	0.00238189
42	10	63	95	90	0.002391732
43	10	63	95	90	0.002411417
44	10	63	95	90	0.00242126
45	10	63	95	90	0.002431102
46	10	63	95	90	0.002450787
47	10	63	95	90	0.00246063
48	10	63	95	90	0.002480315
49	10	63	95	90	0.002490157
50	10	63	95	90	0.002509843
51	10	63	95	90	0.002519685
52	10	63	95	90	0.00253937
53	10	63	95	90	0.002568898
54	10	63	95	90	0.002588583
55	10	63	95	90	0.002598425
56	10	63	95	90	0.00261811
57	10	63	95	90	0.002627953
58	10	63	95	90	0.002647638
59	10	63	95	90	0.00265748
60	10	63	95	90	0.002677165

Results of Cyclic Load Test No (4) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	100	0.001141732
2	10	28	95	100	0.001348425
3	10	28	95	100	0.001476378
4	10	28	95	100	0.001525591
5	10	28	95	100	0.001594488
6	10	28	95	100	0.001643701
7	10	28	95	100	0.001673228
8	10	28	95	100	0.001722441
9	10	28	95	100	0.001751969
10	10	28	95	100	0.001781496
11	10	28	95	100	0.001830709
12	10	28	95	100	0.001840551
13	10	28	95	100	0.001870079
14	10	28	95	100	0.001879921
15	10	28	95	100	0.001919291
16	10	28	95	100	0.001948819
17	10	28	95	100	0.001958661
18	10	28	95	100	0.001978346
19	10	28	95	100	0.001978346
20	10	28	95	100	0.002007874
21	10	28	95	100	0.002027559
22	10	28	95	100	0.002047244
23	10	28	95	100	0.002047244
24	10	28	95	100	0.002057087
25	10	28	95	100	0.002066929
26	10	28	95	100	0.002096457
27	10	28	95	100	0.002096457
28	10	28	95	100	0.002106299
29	10	28	95	100	0.002125984
30	10	28	95	100	0.002145669
31	10	28	95	100	0.002155512
32	10	28	95	100	0.002155512
33	10	28	95	100	0.002155512
34	10	28	95	100	0.002175197
35	10	28	95	100	0.002185039
36	10	28	95	100	0.002214567
37	10	28	95	100	0.002234252
38	10	28	95	100	0.002244094
39	10	28	95	100	0.002244094
40	10	28	95	100	0.002253937
41	10	28	95	100	0.002253937
42	10	28	95	100	0.002253937
43	10	28	95	100	0.00226378
44	10	28	95	100	0.002283465
45	10	28	95	100	0.002283465
46	10	28	95	100	0.002283465
47	10	28	95	100	0.00230315
48	10	28	95	100	0.002312992
49	10	28	95	100	0.002322835
50	10	28	95	100	0.00234252
51	10	28	95	100	0.002362205
52	10	28	95	100	0.002362205
53	10	28	95	100	0.002362205
54	10	28	95	100	0.002362205
55	10	28	95	100	0.00238189
56	10	28	95	100	0.002391732
57	10	28	95	100	0.002411417
58	10	28	95	100	0.002411417
59	10	28	95	100	0.00242126
60	10	28	95	100	0.002440945

Results of Cyclic Load Test No (5) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	100	0.00113189
2	10	42	95	100	0.001299213
3	10	42	95	100	0.001397638
4	10	42	95	100	0.001476378
5	10	42	95	100	0.001535433
6	10	42	95	100	0.001574803
7	10	42	95	100	0.001624016
8	10	42	95	100	0.001653543
9	10	42	95	100	0.001692913
10	10	42	95	100	0.001722441
11	10	42	95	100	0.001761811
12	10	42	95	100	0.001781496
13	10	42	95	100	0.001801181
14	10	42	95	100	0.001830709
15	10	42	95	100	0.001850394
16	10	42	95	100	0.001889764
17	10	42	95	100	0.001938976
18	10	42	95	100	0.001968504
19	10	42	95	100	0.001988189
20	10	42	95	100	0.002007874
21	10	42	95	100	0.002037402
22	10	42	95	100	0.002057087
23	10	42	95	100	0.002076772
24	10	42	95	100	0.002106299
25	10	42	95	100	0.002125984
26	10	42	95	100	0.002145669
27	10	42	95	100	0.002155512
28	10	42	95	100	0.002165354
29	10	42	95	100	0.002185039
30	10	42	95	100	0.002204724
31	10	42	95	100	0.002224409
32	10	42	95	100	0.002244094
33	10	42	95	100	0.00226378
34	10	42	95	100	0.002283465
35	10	42	95	100	0.002293307
36	10	42	95	100	0.00230315
37	10	42	95	100	0.002322835
38	10	42	95	100	0.002332677
39	10	42	95	100	0.002352362
40	10	42	95	100	0.002362205
41	10	42	95	100	0.00238189
42	10	42	95	100	0.002391732
43	10	42	95	100	0.002411417
44	10	42	95	100	0.002431102
45	10	42	95	100	0.002440945
46	10	42	95	100	0.00246063
47	10	42	95	100	0.002480315
48	10	42	95	100	0.0025
49	10	42	95	100	0.002519685
50	10	42	95	100	0.002529528
51	10	42	95	100	0.002549213
52	10	42	95	100	0.002568898
53	10	42	95	100	0.00257874
54	10	42	95	100	0.002588583
55	10	42	95	100	0.002608268
56	10	42	95	100	0.002627953
57	10	42	95	100	0.002637795
58	10	42	95	100	0.00265748
59	10	42	95	100	0.002677165
60	10	42	95	100	0.00269685

Results of Cyclic Load Test No (6) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	63	95	100	0.001122047
2	10	63	95	100	0.001318898
3	10	63	95	100	0.001437008
4	10	63	95	100	0.001525591
5	10	63	95	100	0.001594488
6	10	63	95	100	0.001653543
7	10	63	95	100	0.001702756
8	10	63	95	100	0.001771654
9	10	63	95	100	0.001811024
10	10	63	95	100	0.001870079
11	10	63	95	100	0.001909449
12	10	63	95	100	0.001948819
13	10	63	95	100	0.001988189
14	10	63	95	100	0.002027559
15	10	63	95	100	0.002066929
16	10	63	95	100	0.002096457
17	10	63	95	100	0.002135827
18	10	63	95	100	0.002165354
19	10	63	95	100	0.002204724
20	10	63	95	100	0.002234252
21	10	63	95	100	0.00226378
22	10	63	95	100	0.00230315
23	10	63	95	100	0.002322835
24	10	63	95	100	0.00234252
25	10	63	95	100	0.002362205
26	10	63	95	100	0.002401575
27	10	63	95	100	0.00242126
28	10	63	95	100	0.00246063
29	10	63	95	100	0.002490157
30	10	63	95	100	0.002509843
31	10	63	95	100	0.002529528
32	10	63	95	100	0.002559055
33	10	63	95	100	0.002568898
34	10	63	95	100	0.002598425
35	10	63	95	100	0.00261811
36	10	63	95	100	0.002637795
37	10	63	95	100	0.00265748
38	10	63	95	100	0.002667323
39	10	63	95	100	0.002687008
40	10	63	95	100	0.002706693
41	10	63	95	100	0.00273622
42	10	63	95	100	0.002755906
43	10	63	95	100	0.002775591
44	10	63	95	100	0.002795276
45	10	63	95	100	0.002805118
46	10	63	95	100	0.002824803
47	10	63	95	100	0.002844488
48	10	63	95	100	0.002864173
49	10	63	95	100	0.002874016
50	10	63	95	100	0.002893701
51	10	63	95	100	0.002913386
52	10	63	95	100	0.002933071
53	10	63	95	100	0.002952756
54	10	63	95	100	0.002972441
55	10	63	95	100	0.002992126
56	10	63	95	100	0.003011811
57	10	63	95	100	0.003021654
58	10	63	95	100	0.003031496
59	10	63	95	100	0.003041339
60	10	63	95	100	0.003061024

Results of Cyclic Load Test No (7) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	93	100	0.001476378
2	10	42	93	100	0.001633858
3	10	42	93	100	0.001751969
4	10	42	93	100	0.001811024
5	10	42	93	100	0.001879921
6	10	42	93	100	0.001938976
7	10	42	93	100	0.001968504
8	10	42	93	100	0.002007874
9	10	42	93	100	0.002047244
10	10	42	93	100	0.002086614
11	10	42	93	100	0.002106299
12	10	42	93	100	0.002135827
13	10	42	93	100	0.002165354
14	10	42	93	100	0.002185039
15	10	42	93	100	0.002204724
16	10	42	93	100	0.002224409
17	10	42	93	100	0.00226378
18	10	42	93	100	0.002283465
19	10	42	93	100	0.002293307
20	10	42	93	100	0.00230315
21	10	42	93	100	0.002322835
22	10	42	93	100	0.00234252
23	10	42	93	100	0.002372047
24	10	42	93	100	0.002401575
25	10	42	93	100	0.00242126
26	10	42	93	100	0.002431102
27	10	42	93	100	0.002450787
28	10	42	93	100	0.002470472
29	10	42	93	100	0.0025
30	10	42	93	100	0.002519685
31	10	42	93	100	0.002549213
32	10	42	93	100	0.002568898
33	10	42	93	100	0.002598425
34	10	42	93	100	0.002598425
35	10	42	93	100	0.002627953
36	10	42	93	100	0.002647638
37	10	42	93	100	0.00265748
38	10	42	93	100	0.002677165
39	10	42	93	100	0.002687008
40	10	42	93	100	0.002706693
41	10	42	93	100	0.002726378
42	10	42	93	100	0.00273622
43	10	42	93	100	0.002755906
44	10	42	93	100	0.002775591
45	10	42	93	100	0.002785433
46	10	42	93	100	0.002814961
47	10	42	93	100	0.002834646
48	10	42	93	100	0.002844488
49	10	42	93	100	0.002864173
50	10	42	93	100	0.002883858
51	10	42	93	100	0.002903543
52	10	42	93	100	0.002923228
53	10	42	93	100	0.002933071
54	10	42	93	100	0.002952756
55	10	42	93	100	0.002962598
56	10	42	93	100	0.002982283
57	10	42	93	100	0.002992126
58	10	42	93	100	0.003011811
59	10	42	93	100	0.003021654
60	10	42	93	100	0.003031496

Results of Cyclic Load Test No (8) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	96.6	100	0.000866142
2	10	42	96.6	100	0.001003937
3	10	42	96.6	100	0.001082677
4	10	42	96.6	100	0.001141732
5	10	42	96.6	100	0.001190945
6	10	42	96.6	100	0.001230315
7	10	42	96.6	100	0.001259843
8	10	42	96.6	100	0.00128937
9	10	42	96.6	100	0.001318898
10	10	42	96.6	100	0.001338583
11	10	42	96.6	100	0.001377953
12	10	42	96.6	100	0.001397638
13	10	42	96.6	100	0.001427165
14	10	42	96.6	100	0.001456693
15	10	42	96.6	100	0.001476378
16	10	42	96.6	100	0.001496063
17	10	42	96.6	100	0.001525591
18	10	42	96.6	100	0.001545276
19	10	42	96.6	100	0.001555118
20	10	42	96.6	100	0.001574803
21	10	42	96.6	100	0.001594488
22	10	42	96.6	100	0.001614173
23	10	42	96.6	100	0.001633858
24	10	42	96.6	100	0.001653543
25	10	42	96.6	100	0.001673228
26	10	42	96.6	100	0.001692913
27	10	42	96.6	100	0.001712598
28	10	42	96.6	100	0.001732283
29	10	42	96.6	100	0.001751969
30	10	42	96.6	100	0.001771654
31	10	42	96.6	100	0.001781496
32	10	42	96.6	100	0.001811024
33	10	42	96.6	100	0.001830709
34	10	42	96.6	100	0.001850394
35	10	42	96.6	100	0.001870079
36	10	42	96.6	100	0.001889764
37	10	42	96.6	100	0.001899606
38	10	42	96.6	100	0.001919291
39	10	42	96.6	100	0.001938976
40	10	42	96.6	100	0.001948819
41	10	42	96.6	100	0.001968504
42	10	42	96.6	100	0.001988189
43	10	42	96.6	100	0.002007874
44	10	42	96.6	100	0.002017717
45	10	42	96.6	100	0.002027559
46	10	42	96.6	100	0.002037402
47	10	42	96.6	100	0.002057087
48	10	42	96.6	100	0.002076772
49	10	42	96.6	100	0.002096457
50	10	42	96.6	100	0.002116142
51	10	42	96.6	100	0.002135827
52	10	42	96.6	100	0.002145669
53	10	42	96.6	100	0.002165354
54	10	42	96.6	100	0.002185039
55	10	42	96.6	100	0.002204724
56	10	42	96.6	100	0.002224409
57	10	42	96.6	100	0.002234252
58	10	42	96.6	100	0.002244094
59	10	42	96.6	100	0.002253937
60	10	42	96.6	100	0.00226378

Results of Cyclic Load Test No (9) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	105	0.001545276
2	10	28	95	105	0.001820866
3	10	28	95	105	0.001968504
4	10	28	95	105	0.002106299
5	10	28	95	105	0.002244094
6	10	28	95	105	0.002352362
7	10	28	95	105	0.002450787
8	10	28	95	105	0.00253937
9	10	28	95	105	0.002598425
10	10	28	95	105	0.00265748
11	10	28	95	105	0.002716535
12	10	28	95	105	0.002765748
13	10	28	95	105	0.002814961
14	10	28	95	105	0.002874016
15	10	28	95	105	0.002913386
16	10	28	95	105	0.002972441
17	10	28	95	105	0.003011811
18	10	28	95	105	0.003070866
19	10	28	95	105	0.003110236
20	10	28	95	105	0.003149606
21	10	28	95	105	0.003188976
22	10	28	95	105	0.003228346
23	10	28	95	105	0.003257874
24	10	28	95	105	0.003287402
25	10	28	95	105	0.003326772
26	10	28	95	105	0.003366142
27	10	28	95	105	0.003405512
28	10	28	95	105	0.003435039
29	10	28	95	105	0.003464567
30	10	28	95	105	0.003503937
31	10	28	95	105	0.003543307
32	10	28	95	105	0.003562992
33	10	28	95	105	0.003602362
34	10	28	95	105	0.003622047
35	10	28	95	105	0.003651575
36	10	28	95	105	0.003681102
37	10	28	95	105	0.003720472
38	10	28	95	105	0.003740157
39	10	28	95	105	0.003759843
40	10	28	95	105	0.00378937
41	10	28	95	105	0.003809055
42	10	28	95	105	0.003848425
43	10	28	95	105	0.003877953
44	10	28	95	105	0.003897638
45	10	28	95	105	0.003927165
46	10	28	95	105	0.00394685
47	10	28	95	105	0.003976378
48	10	28	95	105	0.004005906
49	10	28	95	105	0.004035433
50	10	28	95	105	0.004055118
51	10	28	95	105	0.004074803
52	10	28	95	105	0.004094488
53	10	28	95	105	0.004114173
54	10	28	95	105	0.004143701
55	10	28	95	105	0.004173228
56	10	28	95	105	0.004192913
57	10	28	95	105	0.004232283
58	10	28	95	105	0.004251969
59	10	28	95	105	0.004291339
60	10	28	95	105	0.004311024

Results of Cyclic Load Test No (10) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	105	0.002165354
2	10	42	95	105	0.0025
3	10	42	95	105	0.00273622
4	10	42	95	105	0.002933071
5	10	42	95	105	0.003110236
6	10	42	95	105	0.003248031
7	10	42	95	105	0.003346457
8	10	42	95	105	0.003484252
9	10	42	95	105	0.003602362
10	10	42	95	105	0.003700787
11	10	42	95	105	0.003779528
12	10	42	95	105	0.003877953
13	10	42	95	105	0.003956693
14	10	42	95	105	0.004055118
15	10	42	95	105	0.004133858
16	10	42	95	105	0.004212598
17	10	42	95	105	0.004291339
18	10	42	95	105	0.004370079
19	10	42	95	105	0.004409449
20	10	42	95	105	0.004468504
21	10	42	95	105	0.004527559
22	10	42	95	105	0.004586614
23	10	42	95	105	0.004625984
24	10	42	95	105	0.004685039
25	10	42	95	105	0.004744094
26	10	42	95	105	0.00476378
27	10	42	95	105	0.004822835
28	10	42	95	105	0.004862205
29	10	42	95	105	0.004901575
30	10	42	95	105	0.004901575
31	10	42	95	105	0.004980315
32	10	42	95	105	0.005019685
33	10	42	95	105	0.005059055
34	10	42	95	105	0.005098425
35	10	42	95	105	0.00511811
36	10	42	95	105	0.005137795
37	10	42	95	105	0.00519685
38	10	42	95	105	0.005226378
39	10	42	95	105	0.00523622
40	10	42	95	105	0.005295276
41	10	42	95	105	0.005314961
42	10	42	95	105	0.005374016
43	10	42	95	105	0.005393701
44	10	42	95	105	0.005413386
45	10	42	95	105	0.005433071
46	10	42	95	105	0.005452756
47	10	42	95	105	0.005472441
48	10	42	95	105	0.005501969
49	10	42	95	105	0.005541339
50	10	42	95	105	0.005561024
51	10	42	95	105	0.005580709
52	10	42	95	105	0.005620079
53	10	42	95	105	0.005649606
54	10	42	95	105	0.005669291
55	10	42	95	105	0.005688976
56	10	42	95	105	0.005728346
57	10	42	95	105	0.005748031
58	10	42	95	105	0.005787402
59	10	42	95	105	0.005807087
60	10	42	95	105	0.005826772

Results of Cyclic Load Test No (11) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	63	95	105	0.003208661
2	10	63	95	105	0.003740157
3	10	63	95	105	0.003996063
4	10	63	95	105	0.004153543
5	10	63	95	105	0.004291339
6	10	63	95	105	0.004389764
7	10	63	95	105	0.004488189
8	10	63	95	105	0.004566929
9	10	63	95	105	0.004645669
10	10	63	95	105	0.004704724
11	10	63	95	105	0.004783465
12	10	63	95	105	0.00484252
13	10	63	95	105	0.004901575
14	10	63	95	105	0.00496063
15	10	63	95	105	0.005019685
16	10	63	95	105	0.00507874
17	10	63	95	105	0.005137795
18	10	63	95	105	0.00519685
19	10	63	95	105	0.00523622
20	10	63	95	105	0.005295276
21	10	63	95	105	0.005334646
22	10	63	95	105	0.005393701
23	10	63	95	105	0.005452756
24	10	63	95	105	0.005511811
25	10	63	95	105	0.005570866
26	10	63	95	105	0.005610236
27	10	63	95	105	0.005649606
28	10	63	95	105	0.005688976
29	10	63	95	105	0.005728346
30	10	63	95	105	0.005767717
31	10	63	95	105	0.005807087
32	10	63	95	105	0.005846457
33	10	63	95	105	0.005885827
34	10	63	95	105	0.005905512
35	10	63	95	105	0.005944882
36	10	63	95	105	0.005984252
37	10	63	95	105	0.006023622
38	10	63	95	105	0.006062992
39	10	63	95	105	0.006082677
40	10	63	95	105	0.006122047
41	10	63	95	105	0.006161417
42	10	63	95	105	0.006200787
43	10	63	95	105	0.006240157
44	10	63	95	105	0.006259843
45	10	63	95	105	0.006279528
46	10	63	95	105	0.006318898
47	10	63	95	105	0.006338583
48	10	63	95	105	0.00636811
49	10	63	95	105	0.00640748
50	10	63	95	105	0.00644685
51	10	63	95	105	0.00648622
52	10	63	95	105	0.006525591
53	10	63	95	105	0.006555118
54	10	63	95	105	0.006574803
55	10	63	95	105	0.006614173
56	10	63	95	105	0.006653543
57	10	63	95	105	0.006673228
58	10	63	95	105	0.006692913
59	10	63	95	105	0.006732283
60	10	63	95	105	0.006751969

Results of Cyclic Load Test No (12) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	110	0.002362205
2	10	28	95	110	0.002765748
3	10	28	95	110	0.003021654
4	10	28	95	110	0.003277559
5	10	28	95	110	0.003415354
6	10	28	95	110	0.003523622
7	10	28	95	110	0.003622047
8	10	28	95	110	0.00371063
9	10	28	95	110	0.003769685
10	10	28	95	110	0.00382874
11	10	28	95	110	0.003887795
12	10	28	95	110	0.003937008
13	10	28	95	110	0.00398622
14	10	28	95	110	0.004045276
15	10	28	95	110	0.004084646
16	10	28	95	110	0.004143701
17	10	28	95	110	0.004183071
18	10	28	95	110	0.004242126
19	10	28	95	110	0.004281496
20	10	28	95	110	0.004320866
21	10	28	95	110	0.004360236
22	10	28	95	110	0.004399606
23	10	28	95	110	0.004429134
24	10	28	95	110	0.004458661
25	10	28	95	110	0.004498031
26	10	28	95	110	0.004537402
27	10	28	95	110	0.004576772
28	10	28	95	110	0.004606299
29	10	28	95	110	0.004635827
30	10	28	95	110	0.004675197
31	10	28	95	110	0.004714567
32	10	28	95	110	0.004734252
33	10	28	95	110	0.004773622
34	10	28	95	110	0.004793307
35	10	28	95	110	0.004822835
36	10	28	95	110	0.004852362
37	10	28	95	110	0.004891732
38	10	28	95	110	0.004911417
39	10	28	95	110	0.004931102
40	10	28	95	110	0.00496063
41	10	28	95	110	0.004980315
42	10	28	95	110	0.005019685
43	10	28	95	110	0.005049213
44	10	28	95	110	0.005068898
45	10	28	95	110	0.005098425
46	10	28	95	110	0.00511811
47	10	28	95	110	0.005147638
48	10	28	95	110	0.005177165
49	10	28	95	110	0.005206693
50	10	28	95	110	0.005226378
51	10	28	95	110	0.005246063
52	10	28	95	110	0.005265748
53	10	28	95	110	0.005285433
54	10	28	95	110	0.005314961
55	10	28	95	110	0.005344488
56	10	28	95	110	0.005364173
57	10	28	95	110	0.005403543
58	10	28	95	110	0.005423228
59	10	28	95	110	0.005462598
60	10	28	95	110	0.005482283

Results of Cyclic Load Test No (13) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	110	0.002185039
2	10	42	95	110	0.002716535
3	10	42	95	110	0.003031496
4	10	42	95	110	0.003287402
5	10	42	95	110	0.003464567
6	10	42	95	110	0.003641732
7	10	42	95	110	0.003779528
8	10	42	95	110	0.00386811
9	10	42	95	110	0.003976378
10	10	42	95	110	0.004114173
11	10	42	95	110	0.004212598
12	10	42	95	110	0.004311024
13	10	42	95	110	0.004429134
14	10	42	95	110	0.004507874
15	10	42	95	110	0.004606299
16	10	42	95	110	0.004685039
17	10	42	95	110	0.00476378
18	10	42	95	110	0.004812992
19	10	42	95	110	0.004901575
20	10	42	95	110	0.00496063
21	10	42	95	110	0.005019685
22	10	42	95	110	0.005098425
23	10	42	95	110	0.00515748
24	10	42	95	110	0.005216535
25	10	42	95	110	0.005275591
26	10	42	95	110	0.005334646
27	10	42	95	110	0.005393701
28	10	42	95	110	0.005452756
29	10	42	95	110	0.005492126
30	10	42	95	110	0.005551181
31	10	42	95	110	0.005590551
32	10	42	95	110	0.005610236
33	10	42	95	110	0.005649606
34	10	42	95	110	0.005708661
35	10	42	95	110	0.005748031
36	10	42	95	110	0.005787402
37	10	42	95	110	0.005826772
38	10	42	95	110	0.005885827
39	10	42	95	110	0.005925197
40	10	42	95	110	0.005964567
41	10	42	95	110	0.006003937
42	10	42	95	110	0.006043307
43	10	42	95	110	0.006062992
44	10	42	95	110	0.006102362
45	10	42	95	110	0.006141732
46	10	42	95	110	0.006181102
47	10	42	95	110	0.006220472
48	10	42	95	110	0.006240157
49	10	42	95	110	0.006279528
50	10	42	95	110	0.006318898
51	10	42	95	110	0.006377953
52	10	42	95	110	0.006397638
53	10	42	95	110	0.006437008
54	10	42	95	110	0.006476378
55	10	42	95	110	0.006515748
56	10	42	95	110	0.006555118
57	10	42	95	110	0.006594488
58	10	42	95	110	0.006614173
59	10	42	95	110	0.006653543
60	10	42	95	110	0.006692913

Results of Cyclic Load Test No (14) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	63	95	110	0.003818898
2	10	63	95	110	0.004645669
3	10	63	95	110	0.005216535
4	10	63	95	110	0.005590551
5	10	63	95	110	0.005905512
6	10	63	95	110	0.006161417
7	10	63	95	110	0.006377953
8	10	63	95	110	0.006594488
9	10	63	95	110	0.006771654
10	10	63	95	110	0.006948819
11	10	63	95	110	0.007086614
12	10	63	95	110	0.007224409
13	10	63	95	110	0.00734252
14	10	63	95	110	0.00742126
15	10	63	95	110	0.007519685
16	10	63	95	110	0.007598425
17	10	63	95	110	0.007677165
18	10	63	95	110	0.007726378
19	10	63	95	110	0.007814961
20	10	63	95	110	0.007874016
21	10	63	95	110	0.007933071
22	10	63	95	110	0.008011811
23	10	63	95	110	0.008070866
24	10	63	95	110	0.008129921
25	10	63	95	110	0.008188976
26	10	63	95	110	0.008248031
27	10	63	95	110	0.008307087
28	10	63	95	110	0.008366142
29	10	63	95	110	0.008405512
30	10	63	95	110	0.008464567
31	10	63	95	110	0.008503937
32	10	63	95	110	0.008523622
33	10	63	95	110	0.008562992
34	10	63	95	110	0.008622047
35	10	63	95	110	0.008661417
36	10	63	95	110	0.008700787
37	10	63	95	110	0.008740157
38	10	63	95	110	0.008799213
39	10	63	95	110	0.008838583
40	10	63	95	110	0.008877953
41	10	63	95	110	0.008917323
42	10	63	95	110	0.008956693
43	10	63	95	110	0.008976378
44	10	63	95	110	0.009015748
45	10	63	95	110	0.009055118
46	10	63	95	110	0.009094488
47	10	63	95	110	0.009133858
48	10	63	95	110	0.009153543
49	10	63	95	110	0.009192913
50	10	63	95	110	0.009232283
51	10	63	95	110	0.009291339
52	10	63	95	110	0.009311024
53	10	63	95	110	0.009350394
54	10	63	95	110	0.009389764
55	10	63	95	110	0.009429134
56	10	63	95	110	0.009468504
57	10	63	95	110	0.009507874
58	10	63	95	110	0.009527559
59	10	63	95	110	0.009566929
60	10	63	95	110	0.009606299

Results of Cyclic Load Test No (15) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	115	0.003917323
2	10	28	95	115	0.004625984
3	10	28	95	115	0.005059055
4	10	28	95	115	0.005393701
5	10	28	95	115	0.005629921
6	10	28	95	115	0.005856299
7	10	28	95	115	0.006043307
8	10	28	95	115	0.006220472
9	10	28	95	115	0.006397638
10	10	28	95	115	0.006555118
11	10	28	95	115	0.006712598
12	10	28	95	115	0.006850394
13	10	28	95	115	0.006938976
14	10	28	95	115	0.007047244
15	10	28	95	115	0.007145669
16	10	28	95	115	0.007224409
17	10	28	95	115	0.007322835
18	10	28	95	115	0.007401575
19	10	28	95	115	0.007519685
20	10	28	95	115	0.007598425
21	10	28	95	115	0.00769685
22	10	28	95	115	0.007775591
23	10	28	95	115	0.007874016
24	10	28	95	115	0.007913386
25	10	28	95	115	0.008011811
26	10	28	95	115	0.008070866
27	10	28	95	115	0.008129921
28	10	28	95	115	0.008208661
29	10	28	95	115	0.008248031
30	10	28	95	115	0.008326772
31	10	28	95	115	0.008405512
32	10	28	95	115	0.008454724
33	10	28	95	115	0.008523622
34	10	28	95	115	0.008582677
35	10	28	95	115	0.008661417
36	10	28	95	115	0.008720472
37	10	28	95	115	0.008779528
38	10	28	95	115	0.008858268
39	10	28	95	115	0.008897638
40	10	28	95	115	0.008956693
41	10	28	95	115	0.008996063
42	10	28	95	115	0.009055118
43	10	28	95	115	0.009094488
44	10	28	95	115	0.009143701
45	10	28	95	115	0.009192913
46	10	28	95	115	0.009232283
47	10	28	95	115	0.009271654
48	10	28	95	115	0.009311024
49	10	28	95	115	0.009350394
50	10	28	95	115	0.009370079
51	10	28	95	115	0.009429134
52	10	28	95	115	0.009468504
53	10	28	95	115	0.009488189
54	10	28	95	115	0.009547244
55	10	28	95	115	0.009586614
56	10	28	95	115	0.009625984
57	10	28	95	115	0.009665354
58	10	28	95	115	0.009704724
59	10	28	95	115	0.009724409
60	10	28	95	115	0.00976378

Results of Cyclic Load Test No (16) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	115	0.009940945
2	10	42	95	115	0.011614173
3	10	42	95	115	0.012519685
4	10	42	95	115	0.013110236
5	10	42	95	115	0.013582677
6	10	42	95	115	0.013917323
7	10	42	95	115	0.014192913
8	10	42	95	115	0.014429134
9	10	42	95	115	0.014625984
10	10	42	95	115	0.014822835
11	10	42	95	115	0.015019685
12	10	42	95	115	0.015177165
13	10	42	95	115	0.015295276
14	10	42	95	115	0.015433071
15	10	42	95	115	0.015551181
16	10	42	95	115	0.015669291
17	10	42	95	115	0.015787402
18	10	42	95	115	0.015866142
19	10	42	95	115	0.015984252
20	10	42	95	115	0.016062992
21	10	42	95	115	0.016161417
22	10	42	95	115	0.016200787
23	10	42	95	115	0.016259843
24	10	42	95	115	0.016338583
25	10	42	95	115	0.016417323
26	10	42	95	115	0.016496063
27	10	42	95	115	0.016555118
28	10	42	95	115	0.016614173
29	10	42	95	115	0.016673228
30	10	42	95	115	0.016712598
31	10	42	95	115	0.016751969
32	10	42	95	115	0.016811024
33	10	42	95	115	0.016870079
34	10	42	95	115	0.016929134
35	10	42	95	115	0.016968504
36	10	42	95	115	0.017007874
37	10	42	95	115	0.017066929
38	10	42	95	115	0.017106299
39	10	42	95	115	0.017145669
40	10	42	95	115	0.017204724
41	10	42	95	115	0.017244094
42	10	42	95	115	0.017293307
43	10	42	95	115	0.017332677
44	10	42	95	115	0.017391732
45	10	42	95	115	0.017431102
46	10	42	95	115	0.017490157
47	10	42	95	115	0.01753937
48	10	42	95	115	0.017568898
49	10	42	95	115	0.017627953
50	10	42	95	115	0.017667323
51	10	42	95	115	0.017706693
52	10	42	95	115	0.017746063
53	10	42	95	115	0.017775591
54	10	42	95	115	0.017814961
55	10	42	95	115	0.017834646
56	10	42	95	115	0.017874016
57	10	42	95	115	0.017893701
58	10	42	95	115	0.017933071
59	10	42	95	115	0.017972441
60	10	42	95	115	0.017992126

Results of Cyclic Load Test No (17) - Soil (A4)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	120	0.012007874
2	10	28	95	120	0.013956693
3	10	28	95	120	0.015
4	10	28	95	120	0.015708661
5	10	28	95	120	0.016082677
6	10	28	95	120	0.016515748
7	10	28	95	120	0.016830709
8	10	28	95	120	0.017106299
9	10	28	95	120	0.017322835
10	10	28	95	120	0.017440945
11	10	28	95	120	0.017637795
12	10	28	95	120	0.017795276
13	10	28	95	120	0.017933071
14	10	28	95	120	0.018051181
15	10	28	95	120	0.018188976
16	10	28	95	120	0.018326772
17	10	28	95	120	0.018425197
18	10	28	95	120	0.018543307
19	10	28	95	120	0.018681102
20	10	28	95	120	0.018759843
21	10	28	95	120	0.018838583
22	10	28	95	120	0.018937008
23	10	28	95	120	0.018976378
24	10	28	95	120	0.019015748
25	10	28	95	120	0.019133858
26	10	28	95	120	0.019192913
27	10	28	95	120	0.019271654
28	10	28	95	120	0.019330709
29	10	28	95	120	0.019389764
30	10	28	95	120	0.019468504
31	10	28	95	120	0.019527559
32	10	28	95	120	0.019606299
33	10	28	95	120	0.019665354
34	10	28	95	120	0.019704724
35	10	28	95	120	0.019704724
36	10	28	95	120	0.019822835
37	10	28	95	120	0.01984252
38	10	28	95	120	0.01988189
39	10	28	95	120	0.01992126
40	10	28	95	120	0.019980315
41	10	28	95	120	0.020019685
42	10	28	95	120	0.02003937
43	10	28	95	120	0.02007874
44	10	28	95	120	0.020098425
45	10	28	95	120	0.020137795
46	10	28	95	120	0.020177165
47	10	28	95	120	0.020216535
48	10	28	95	120	0.02023622
49	10	28	95	120	0.020275591
50	10	28	95	120	0.020314961
51	10	28	95	120	0.020354331
52	10	28	95	120	0.020374016
53	10	28	95	120	0.020413386
54	10	28	95	120	0.020452756
55	10	28	95	120	0.020472441
56	10	28	95	120	0.020511811
57	10	28	95	120	0.020551181
58	10	28	95	120	0.020570866
59	10	28	95	120	0.020610236
60	10	28	95	120	0.020649606

Results of Cyclic Load Test No (1) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	90	0.000885827
2	10	28	95	90	0.001023622
3	10	28	95	90	0.001102362
4	10	28	95	90	0.001161417
5	10	28	95	90	0.001220472
6	10	28	95	90	0.001259843
7	10	28	95	90	0.001299213
8	10	28	95	90	0.001348425
9	10	28	95	90	0.001397638
10	10	28	95	90	0.001427165
11	10	28	95	90	0.001456693
12	10	28	95	90	0.001496063
13	10	28	95	90	0.001545276
14	10	28	95	90	0.001564961
15	10	28	95	90	0.001594488
16	10	28	95	90	0.001614173
17	10	28	95	90	0.001653543
18	10	28	95	90	0.001683071
19	10	28	95	90	0.001712598
20	10	28	95	90	0.001732283
21	10	28	95	90	0.001771654
22	10	28	95	90	0.001791339
23	10	28	95	90	0.001830709
24	10	28	95	90	0.001850394
25	10	28	95	90	0.001879921
26	10	28	95	90	0.001899606
27	10	28	95	90	0.001919291
28	10	28	95	90	0.001938976
29	10	28	95	90	0.001958661
30	10	28	95	90	0.001988189
31	10	28	95	90	0.002007874
32	10	28	95	90	0.002037402
33	10	28	95	90	0.002057087
34	10	28	95	90	0.002076772
35	10	28	95	90	0.002086614
36	10	28	95	90	0.002106299
37	10	28	95	90	0.002125984
38	10	28	95	90	0.002135827
39	10	28	95	90	0.002145669
40	10	28	95	90	0.002165354
41	10	28	95	90	0.002185039
42	10	28	95	90	0.002204724
43	10	28	95	90	0.002224409
44	10	28	95	90	0.002234252
45	10	28	95	90	0.002244094
46	10	28	95	90	0.00226378
47	10	28	95	90	0.002273622
48	10	28	95	90	0.002283465
49	10	28	95	90	0.00230315
50	10	28	95	90	0.002322835
51	10	28	95	90	0.00234252
52	10	28	95	90	0.002352362
53	10	28	95	90	0.002372047
54	10	28	95	90	0.00238189
55	10	28	95	90	0.002401575
56	10	28	95	90	0.00242126
57	10	28	95	90	0.002431102
58	10	28	95	90	0.002450787
59	10	28	95	90	0.00246063
60	10	28	95	90	0.002470472

Results of Cyclic Load Test No (2) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	90	0.001358268
2	10	42	95	90	0.001555118
3	10	42	95	90	0.001692913
4	10	42	95	90	0.001781496
5	10	42	95	90	0.001879921
6	10	42	95	90	0.001929134
7	10	42	95	90	0.001988189
8	10	42	95	90	0.002047244
9	10	42	95	90	0.002066929
10	10	42	95	90	0.002145669
11	10	42	95	90	0.002204724
12	10	42	95	90	0.002224409
13	10	42	95	90	0.002283465
14	10	42	95	90	0.002322835
15	10	42	95	90	0.002372047
16	10	42	95	90	0.002401575
17	10	42	95	90	0.002431102
18	10	42	95	90	0.002480315
19	10	42	95	90	0.00246063
20	10	42	95	90	0.002559055
21	10	42	95	90	0.00257874
22	10	42	95	90	0.002637795
23	10	42	95	90	0.00265748
24	10	42	95	90	0.002706693
25	10	42	95	90	0.00273622
26	10	42	95	90	0.002765748
27	10	42	95	90	0.002814961
28	10	42	95	90	0.002854331
29	10	42	95	90	0.002874016
30	10	42	95	90	0.002913386
31	10	42	95	90	0.002913386
32	10	42	95	90	0.002972441
33	10	42	95	90	0.003001969
34	10	42	95	90	0.003021654
35	10	42	95	90	0.003051181
36	10	42	95	90	0.003070866
37	10	42	95	90	0.003100394
38	10	42	95	90	0.003120079
39	10	42	95	90	0.003149606
40	10	42	95	90	0.003179134
41	10	42	95	90	0.003218504
42	10	42	95	90	0.003257874
43	10	42	95	90	0.003277559
44	10	42	95	90	0.003307087
45	10	42	95	90	0.003326772
46	10	42	95	90	0.003346457
47	10	42	95	90	0.003375984
48	10	42	95	90	0.003395669
49	10	42	95	90	0.003415354
50	10	42	95	90	0.003435039
51	10	42	95	90	0.003454724
52	10	42	95	90	0.003464567
53	10	42	95	90	0.003484252
54	10	42	95	90	0.003494094
55	10	42	95	90	0.00351378
56	10	42	95	90	0.003533465
57	10	42	95	90	0.003543307
58	10	42	95	90	0.003562992
59	10	42	95	90	0.003572835
60	10	42	95	90	0.00359252

Results of Cyclic Load Test No (3) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	63	95	90	0.002440945
2	10	63	95	90	0.002637795
3	10	63	95	90	0.002755906
4	10	63	95	90	0.002814961
5	10	63	95	90	0.002903543
6	10	63	95	90	0.002952756
7	10	63	95	90	0.003031496
8	10	63	95	90	0.003090551
9	10	63	95	90	0.003139764
10	10	63	95	90	0.003179134
11	10	63	95	90	0.003228346
12	10	63	95	90	0.003267717
13	10	63	95	90	0.003307087
14	10	63	95	90	0.003346457
15	10	63	95	90	0.003395669
16	10	63	95	90	0.003435039
17	10	63	95	90	0.003484252
18	10	63	95	90	0.003523622
19	10	63	95	90	0.003562992
20	10	63	95	90	0.003602362
21	10	63	95	90	0.003661417
22	10	63	95	90	0.003700787
23	10	63	95	90	0.003740157
24	10	63	95	90	0.003779528
25	10	63	95	90	0.003809055
26	10	63	95	90	0.003858268
27	10	63	95	90	0.003897638
28	10	63	95	90	0.003937008
29	10	63	95	90	0.003976378
30	10	63	95	90	0.004015748
31	10	63	95	90	0.004055118
32	10	63	95	90	0.004094488
33	10	63	95	90	0.004114173
34	10	63	95	90	0.004143701
35	10	63	95	90	0.004192913
36	10	63	95	90	0.004222441
37	10	63	95	90	0.004251969
38	10	63	95	90	0.004281496
39	10	63	95	90	0.004320866
40	10	63	95	90	0.004350394
41	10	63	95	90	0.004389764
42	10	63	95	90	0.004429134
43	10	63	95	90	0.004448819
44	10	63	95	90	0.004488189
45	10	63	95	90	0.004517717
46	10	63	95	90	0.004547244
47	10	63	95	90	0.004576772
48	10	63	95	90	0.004606299
49	10	63	95	90	0.004625984
50	10	63	95	90	0.004655512
51	10	63	95	90	0.004675197
52	10	63	95	90	0.004704724
53	10	63	95	90	0.004724409
54	10	63	95	90	0.004753937
55	10	63	95	90	0.004793307
56	10	63	95	90	0.004832677
57	10	63	95	90	0.004852362
58	10	63	95	90	0.00488189
59	10	63	95	90	0.004911417
60	10	63	95	90	0.004940945

Results of Cyclic Load Test No (4) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	100	0.001555118
2	10	28	95	100	0.001751969
3	10	28	95	100	0.001870079
4	10	28	95	100	0.001929134
5	10	28	95	100	0.002017717
6	10	28	95	100	0.002066929
7	10	28	95	100	0.002145669
8	10	28	95	100	0.002204724
9	10	28	95	100	0.002253937
10	10	28	95	100	0.002293307
11	10	28	95	100	0.00234252
12	10	28	95	100	0.00238189
13	10	28	95	100	0.00242126
14	10	28	95	100	0.00246063
15	10	28	95	100	0.002509843
16	10	28	95	100	0.002549213
17	10	28	95	100	0.002598425
18	10	28	95	100	0.002637795
19	10	28	95	100	0.002677165
20	10	28	95	100	0.002716535
21	10	28	95	100	0.002775591
22	10	28	95	100	0.002814961
23	10	28	95	100	0.002854331
24	10	28	95	100	0.002893701
25	10	28	95	100	0.002923228
26	10	28	95	100	0.002972441
27	10	28	95	100	0.003011811
28	10	28	95	100	0.003051181
29	10	28	95	100	0.003090551
30	10	28	95	100	0.003129921
31	10	28	95	100	0.003169291
32	10	28	95	100	0.003208661
33	10	28	95	100	0.003228346
34	10	28	95	100	0.003257874
35	10	28	95	100	0.003307087
36	10	28	95	100	0.003336614
37	10	28	95	100	0.003366142
38	10	28	95	100	0.003395669
39	10	28	95	100	0.003435039
40	10	28	95	100	0.003464567
41	10	28	95	100	0.003503937
42	10	28	95	100	0.003543307
43	10	28	95	100	0.003562992
44	10	28	95	100	0.003602362
45	10	28	95	100	0.00363189
46	10	28	95	100	0.003661417
47	10	28	95	100	0.003690945
48	10	28	95	100	0.003720472
49	10	28	95	100	0.003740157
50	10	28	95	100	0.003769685
51	10	28	95	100	0.00378937
52	10	28	95	100	0.003818898
53	10	28	95	100	0.003838583
54	10	28	95	100	0.00386811
55	10	28	95	100	0.00390748
56	10	28	95	100	0.00394685
57	10	28	95	100	0.003966535
58	10	28	95	100	0.003996063
59	10	28	95	100	0.004025591
60	10	28	95	100	0.004055118

Results of Cyclic Load Test No (5) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	100	0.002185039
2	10	42	95	100	0.00253937
3	10	42	95	100	0.002755906
4	10	42	95	100	0.002913386
5	10	42	95	100	0.003011811
6	10	42	95	100	0.003129921
7	10	42	95	100	0.003248031
8	10	42	95	100	0.003307087
9	10	42	95	100	0.003405512
10	10	42	95	100	0.003464567
11	10	42	95	100	0.003562992
12	10	42	95	100	0.003622047
13	10	42	95	100	0.003681102
14	10	42	95	100	0.003779528
15	10	42	95	100	0.003838583
16	10	42	95	100	0.003956693
17	10	42	95	100	0.004015748
18	10	42	95	100	0.004094488
19	10	42	95	100	0.004133858
20	10	42	95	100	0.004192913
21	10	42	95	100	0.004261811
22	10	42	95	100	0.004301181
23	10	42	95	100	0.004389764
24	10	42	95	100	0.004448819
25	10	42	95	100	0.004488189
26	10	42	95	100	0.004566929
27	10	42	95	100	0.004606299
28	10	42	95	100	0.004665354
29	10	42	95	100	0.004744094
30	10	42	95	100	0.00476378
31	10	42	95	100	0.004812992
32	10	42	95	100	0.004901575
33	10	42	95	100	0.004940945
34	10	42	95	100	0.004980315
35	10	42	95	100	0.00503937
36	10	42	95	100	0.00507874
37	10	42	95	100	0.00511811
38	10	42	95	100	0.00515748
39	10	42	95	100	0.005216535
40	10	42	95	100	0.005275591
41	10	42	95	100	0.005314961
42	10	42	95	100	0.005354331
43	10	42	95	100	0.005413386
44	10	42	95	100	0.005452756
45	10	42	95	100	0.005492126
46	10	42	95	100	0.005531496
47	10	42	95	100	0.005570866
48	10	42	95	100	0.005610236
49	10	42	95	100	0.005649606
50	10	42	95	100	0.005688976
51	10	42	95	100	0.005728346
52	10	42	95	100	0.005767717
53	10	42	95	100	0.005807087
54	10	42	95	100	0.005826772
55	10	42	95	100	0.005866142
56	10	42	95	100	0.005905512
57	10	42	95	100	0.005925197
58	10	42	95	100	0.005964567
59	10	42	95	100	0.006003937
60	10	42	95	100	0.006043307

Results of Cyclic Load Test No (6) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	63	95	100	0.002893701
2	10	63	95	100	0.003267717
3	10	63	95	100	0.003503937
4	10	63	95	100	0.003661417
5	10	63	95	100	0.003799213
6	10	63	95	100	0.003917323
7	10	63	95	100	0.004055118
8	10	63	95	100	0.004133858
9	10	63	95	100	0.004222441
10	10	63	95	100	0.004291339
11	10	63	95	100	0.004370079
12	10	63	95	100	0.004438976
13	10	63	95	100	0.004507874
14	10	63	95	100	0.004566929
15	10	63	95	100	0.004625984
16	10	63	95	100	0.004694882
17	10	63	95	100	0.004744094
18	10	63	95	100	0.004793307
19	10	63	95	100	0.004862205
20	10	63	95	100	0.00492126
21	10	63	95	100	0.00496063
22	10	63	95	100	0.00503937
23	10	63	95	100	0.005068898
24	10	63	95	100	0.00511811
25	10	63	95	100	0.00519685
26	10	63	95	100	0.00523622
27	10	63	95	100	0.005275591
28	10	63	95	100	0.005334646
29	10	63	95	100	0.005383858
30	10	63	95	100	0.005442913
31	10	63	95	100	0.005511811
32	10	63	95	100	0.005551181
33	10	63	95	100	0.005600394
34	10	63	95	100	0.005649606
35	10	63	95	100	0.005688976
36	10	63	95	100	0.005748031
37	10	63	95	100	0.005787402
38	10	63	95	100	0.005856299
39	10	63	95	100	0.005905512
40	10	63	95	100	0.005944882
41	10	63	95	100	0.005984252
42	10	63	95	100	0.006043307
43	10	63	95	100	0.006072835
44	10	63	95	100	0.006112205
45	10	63	95	100	0.006151575
46	10	63	95	100	0.00621063
47	10	63	95	100	0.006269685
48	10	63	95	100	0.006318898
49	10	63	95	100	0.006358268
50	10	63	95	100	0.00640748
51	10	63	95	100	0.00644685
52	10	63	95	100	0.006496063
53	10	63	95	100	0.006545276
54	10	63	95	100	0.006584646
55	10	63	95	100	0.006643701
56	10	63	95	100	0.006683071
57	10	63	95	100	0.006742126
58	10	63	95	100	0.006781496
59	10	63	95	100	0.006830709
60	10	63	95	100	0.006879921

Results of Cyclic Load Test No (7) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	94	100	0.00253937
2	10	42	94	100	0.002854331
3	10	42	94	100	0.003070866
4	10	42	94	100	0.003208661
5	10	42	94	100	0.003326772
6	10	42	94	100	0.003484252
7	10	42	94	100	0.003562992
8	10	42	94	100	0.003661417
9	10	42	94	100	0.003740157
10	10	42	94	100	0.003818898
11	10	42	94	100	0.003877953
12	10	42	94	100	0.003956693
13	10	42	94	100	0.004015748
14	10	42	94	100	0.004074803
15	10	42	94	100	0.004153543
16	10	42	94	100	0.004232283
17	10	42	94	100	0.004291339
18	10	42	94	100	0.004370079
19	10	42	94	100	0.004429134
20	10	42	94	100	0.004488189
21	10	42	94	100	0.004527559
22	10	42	94	100	0.004625984
23	10	42	94	100	0.004645669
24	10	42	94	100	0.004724409
25	10	42	94	100	0.004783465
26	10	42	94	100	0.004822835
27	10	42	94	100	0.004862205
28	10	42	94	100	0.00492126
29	10	42	94	100	0.00496063
30	10	42	94	100	0.005019685
31	10	42	94	100	0.00507874
32	10	42	94	100	0.00511811
33	10	42	94	100	0.00515748
34	10	42	94	100	0.005216535
35	10	42	94	100	0.005275591
36	10	42	94	100	0.005314961
37	10	42	94	100	0.005374016
38	10	42	94	100	0.005433071
39	10	42	94	100	0.005472441
40	10	42	94	100	0.005531496
41	10	42	94	100	0.005580709
42	10	42	94	100	0.005620079
43	10	42	94	100	0.005639764
44	10	42	94	100	0.005679134
45	10	42	94	100	0.005718504
46	10	42	94	100	0.005757874
47	10	42	94	100	0.005797244
48	10	42	94	100	0.005836614
49	10	42	94	100	0.005866142
50	10	42	94	100	0.005885827
51	10	42	94	100	0.005915354
52	10	42	94	100	0.005935039
53	10	42	94	100	0.005974409
54	10	42	94	100	0.006003937
55	10	42	94	100	0.006033465
56	10	42	94	100	0.006062992
57	10	42	94	100	0.006082677
58	10	42	94	100	0.006112205
59	10	42	94	100	0.00613189
60	10	42	94	100	0.006151575

Results of Cyclic Load Test No (8) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	96.4	100	0.001811024
2	10	42	96.4	100	0.002066929
3	10	42	96.4	100	0.00226378
4	10	42	96.4	100	0.00238189
5	10	42	96.4	100	0.0025
6	10	42	96.4	100	0.00261811
7	10	42	96.4	100	0.00269685
8	10	42	96.4	100	0.002795276
9	10	42	96.4	100	0.002883858
10	10	42	96.4	100	0.002962598
11	10	42	96.4	100	0.003021654
12	10	42	96.4	100	0.003090551
13	10	42	96.4	100	0.003149606
14	10	42	96.4	100	0.003208661
15	10	42	96.4	100	0.003277559
16	10	42	96.4	100	0.003346457
17	10	42	96.4	100	0.003405512
18	10	42	96.4	100	0.003474409
19	10	42	96.4	100	0.003533465
20	10	42	96.4	100	0.00359252
21	10	42	96.4	100	0.00363189
22	10	42	96.4	100	0.003730315
23	10	42	96.4	100	0.003769685
24	10	42	96.4	100	0.003848425
25	10	42	96.4	100	0.00390748
26	10	42	96.4	100	0.00394685
27	10	42	96.4	100	0.00398622
28	10	42	96.4	100	0.004035433
29	10	42	96.4	100	0.004074803
30	10	42	96.4	100	0.004133858
31	10	42	96.4	100	0.004192913
32	10	42	96.4	100	0.004232283
33	10	42	96.4	100	0.004271654
34	10	42	96.4	100	0.004330709
35	10	42	96.4	100	0.004389764
36	10	42	96.4	100	0.004429134
37	10	42	96.4	100	0.004488189
38	10	42	96.4	100	0.004547244
39	10	42	96.4	100	0.004586614
40	10	42	96.4	100	0.004645669
41	10	42	96.4	100	0.004694882
42	10	42	96.4	100	0.004734252
43	10	42	96.4	100	0.004753937
44	10	42	96.4	100	0.004793307
45	10	42	96.4	100	0.004832677
46	10	42	96.4	100	0.004872047
47	10	42	96.4	100	0.004911417
48	10	42	96.4	100	0.004950787
49	10	42	96.4	100	0.004980315
50	10	42	96.4	100	0.005
51	10	42	96.4	100	0.005029528
52	10	42	96.4	100	0.005049213
53	10	42	96.4	100	0.005088583
54	10	42	96.4	100	0.00511811
55	10	42	96.4	100	0.005147638
56	10	42	96.4	100	0.005177165
57	10	42	96.4	100	0.00519685
58	10	42	96.4	100	0.005226378
59	10	42	96.4	100	0.005246063
60	10	42	96.4	100	0.005265748

Results of Cyclic Load Test No (9) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	105	0.002007874
2	10	28	95	105	0.002283465
3	10	28	95	105	0.00246063
4	10	28	95	105	0.002598425
5	10	28	95	105	0.002716535
6	10	28	95	105	0.002814961
7	10	28	95	105	0.002893701
8	10	28	95	105	0.002962598
9	10	28	95	105	0.003090551
10	10	28	95	105	0.003149606
11	10	28	95	105	0.003228346
12	10	28	95	105	0.003326772
13	10	28	95	105	0.003385827
14	10	28	95	105	0.003464567
15	10	28	95	105	0.003543307
16	10	28	95	105	0.003622047
17	10	28	95	105	0.003681102
18	10	28	95	105	0.003759843
19	10	28	95	105	0.003838583
20	10	28	95	105	0.003917323
21	10	28	95	105	0.004005906
22	10	28	95	105	0.004094488
23	10	28	95	105	0.004173228
24	10	28	95	105	0.004232283
25	10	28	95	105	0.004271654
26	10	28	95	105	0.004370079
27	10	28	95	105	0.004448819
28	10	28	95	105	0.004507874
29	10	28	95	105	0.004586614
30	10	28	95	105	0.004655512
31	10	28	95	105	0.004694882
32	10	28	95	105	0.00480315
33	10	28	95	105	0.00488189
34	10	28	95	105	0.004940945
35	10	28	95	105	0.005
36	10	28	95	105	0.00507874
37	10	28	95	105	0.00511811
38	10	28	95	105	0.00519685
39	10	28	95	105	0.005255906
40	10	28	95	105	0.005324803
41	10	28	95	105	0.005383858
42	10	28	95	105	0.005452756
43	10	28	95	105	0.005511811
44	10	28	95	105	0.005590551
45	10	28	95	105	0.005649606
46	10	28	95	105	0.005718504
47	10	28	95	105	0.005777559
48	10	28	95	105	0.005836614
49	10	28	95	105	0.005875984
50	10	28	95	105	0.005954724
51	10	28	95	105	0.00601378
52	10	28	95	105	0.006072835
53	10	28	95	105	0.006122047
54	10	28	95	105	0.006190945
55	10	28	95	105	0.006259843
56	10	28	95	105	0.006299213
57	10	28	95	105	0.006358268
58	10	28	95	105	0.006397638
59	10	28	95	105	0.006456693
60	10	28	95	105	0.006496063

Results of Cyclic Load Test No (10) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	105	0.002677165
2	10	42	95	105	0.003188976
3	10	42	95	105	0.003395669
4	10	42	95	105	0.003562992
5	10	42	95	105	0.003720472
6	10	42	95	105	0.003858268
7	10	42	95	105	0.003976378
8	10	42	95	105	0.004074803
9	10	42	95	105	0.004173228
10	10	42	95	105	0.004271654
11	10	42	95	105	0.004370079
12	10	42	95	105	0.004468504
13	10	42	95	105	0.004566929
14	10	42	95	105	0.004635827
15	10	42	95	105	0.004724409
16	10	42	95	105	0.004793307
17	10	42	95	105	0.004862205
18	10	42	95	105	0.004940945
19	10	42	95	105	0.005009843
20	10	42	95	105	0.00507874
21	10	42	95	105	0.005147638
22	10	42	95	105	0.005206693
23	10	42	95	105	0.005275591
24	10	42	95	105	0.005334646
25	10	42	95	105	0.005413386
26	10	42	95	105	0.005452756
27	10	42	95	105	0.005531496
28	10	42	95	105	0.005570866
29	10	42	95	105	0.005629921
30	10	42	95	105	0.005688976
31	10	42	95	105	0.005748031
32	10	42	95	105	0.005797244
33	10	42	95	105	0.005856299
34	10	42	95	105	0.005905512
35	10	42	95	105	0.005944882
36	10	42	95	105	0.00601378
37	10	42	95	105	0.006062992
38	10	42	95	105	0.006112205
39	10	42	95	105	0.00617126
40	10	42	95	105	0.006220472
41	10	42	95	105	0.006279528
42	10	42	95	105	0.006318898
43	10	42	95	105	0.006387795
44	10	42	95	105	0.00644685
45	10	42	95	105	0.00648622
46	10	42	95	105	0.006555118
47	10	42	95	105	0.006594488
48	10	42	95	105	0.006633858
49	10	42	95	105	0.006683071
50	10	42	95	105	0.006722441
51	10	42	95	105	0.006761811
52	10	42	95	105	0.006801181
53	10	42	95	105	0.006840551
54	10	42	95	105	0.006870079
55	10	42	95	105	0.006909449
56	10	42	95	105	0.006948819
57	10	42	95	105	0.006978346
58	10	42	95	105	0.007017717
59	10	42	95	105	0.007057087
60	10	42	95	105	0.007076772

Results of Cyclic Load Test No (11) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	63	95	105	0.004094488
2	10	63	95	105	0.004625984
3	10	63	95	105	0.005
4	10	63	95	105	0.00523622
5	10	63	95	105	0.005433071
6	10	63	95	105	0.005590551
7	10	63	95	105	0.005748031
8	10	63	95	105	0.005875984
9	10	63	95	105	0.006023622
10	10	63	95	105	0.006141732
11	10	63	95	105	0.006259843
12	10	63	95	105	0.006377953
13	10	63	95	105	0.006476378
14	10	63	95	105	0.006574803
15	10	63	95	105	0.006673228
16	10	63	95	105	0.006771654
17	10	63	95	105	0.006870079
18	10	63	95	105	0.006948819
19	10	63	95	105	0.007027559
20	10	63	95	105	0.007086614
21	10	63	95	105	0.007165354
22	10	63	95	105	0.007244094
23	10	63	95	105	0.00730315
24	10	63	95	105	0.007401575
25	10	63	95	105	0.00746063
26	10	63	95	105	0.00753937
27	10	63	95	105	0.007598425
28	10	63	95	105	0.007647638
29	10	63	95	105	0.00773622
30	10	63	95	105	0.007795276
31	10	63	95	105	0.007854331
32	10	63	95	105	0.007913386
33	10	63	95	105	0.007972441
34	10	63	95	105	0.008051181
35	10	63	95	105	0.008110236
36	10	63	95	105	0.008169291
37	10	63	95	105	0.008228346
38	10	63	95	105	0.008287402
39	10	63	95	105	0.008346457
40	10	63	95	105	0.008405512
41	10	63	95	105	0.008484252
42	10	63	95	105	0.008523622
43	10	63	95	105	0.008562992
44	10	63	95	105	0.008622047
45	10	63	95	105	0.008681102
46	10	63	95	105	0.008740157
47	10	63	95	105	0.008799213
48	10	63	95	105	0.008838583
49	10	63	95	105	0.008897638
50	10	63	95	105	0.008937008
51	10	63	95	105	0.009015748
52	10	63	95	105	0.009055118
53	10	63	95	105	0.009094488
54	10	63	95	105	0.009153543
55	10	63	95	105	0.009212598
56	10	63	95	105	0.009271654
57	10	63	95	105	0.009330709
58	10	63	95	105	0.009370079
59	10	63	95	105	0.009429134
60	10	63	95	105	0.009468504

Results of Cyclic Load Test No (12) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	110	0.002185039
2	10	28	95	110	0.00265748
3	10	28	95	110	0.002933071
4	10	28	95	110	0.003188976
5	10	28	95	110	0.003385827
6	10	28	95	110	0.003523622
7	10	28	95	110	0.003690945
8	10	28	95	110	0.003838583
9	10	28	95	110	0.003956693
10	10	28	95	110	0.004104331
11	10	28	95	110	0.004232283
12	10	28	95	110	0.004350394
13	10	28	95	110	0.004488189
14	10	28	95	110	0.004625984
15	10	28	95	110	0.004744094
16	10	28	95	110	0.00484252
17	10	28	95	110	0.004980315
18	10	28	95	110	0.005059055
19	10	28	95	110	0.005177165
20	10	28	95	110	0.005295276
21	10	28	95	110	0.005354331
22	10	28	95	110	0.005433071
23	10	28	95	110	0.005531496
24	10	28	95	110	0.005610236
25	10	28	95	110	0.005728346
26	10	28	95	110	0.005748031
27	10	28	95	110	0.005866142
28	10	28	95	110	0.005925197
29	10	28	95	110	0.006023622
30	10	28	95	110	0.006122047
31	10	28	95	110	0.006181102
32	10	28	95	110	0.006240157
33	10	28	95	110	0.006358268
34	10	28	95	110	0.006417323
35	10	28	95	110	0.006496063
36	10	28	95	110	0.006574803
37	10	28	95	110	0.006594488
38	10	28	95	110	0.006692913
39	10	28	95	110	0.006751969
40	10	28	95	110	0.006811024
41	10	28	95	110	0.006870079
42	10	28	95	110	0.006948819
43	10	28	95	110	0.007007874
44	10	28	95	110	0.007086614
45	10	28	95	110	0.007125984
46	10	28	95	110	0.007204724
47	10	28	95	110	0.00726378
48	10	28	95	110	0.007322835
49	10	28	95	110	0.007362205
50	10	28	95	110	0.00742126
51	10	28	95	110	0.007480315
52	10	28	95	110	0.0075
53	10	28	95	110	0.007559055
54	10	28	95	110	0.007598425
55	10	28	95	110	0.007677165
56	10	28	95	110	0.00773622
57	10	28	95	110	0.007795276
58	10	28	95	110	0.007834646
59	10	28	95	110	0.007893701
60	10	28	95	110	0.007933071

Results of Cyclic Load Test No (13) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	110	0.003917323
2	10	42	95	110	0.004527559
3	10	42	95	110	0.00503937
4	10	42	95	110	0.005393701
5	10	42	95	110	0.005688976
6	10	42	95	110	0.005944882
7	10	42	95	110	0.006161417
8	10	42	95	110	0.006358268
9	10	42	95	110	0.006496063
10	10	42	95	110	0.006614173
11	10	42	95	110	0.006751969
12	10	42	95	110	0.006870079
13	10	42	95	110	0.006968504
14	10	42	95	110	0.007125984
15	10	42	95	110	0.007283465
16	10	42	95	110	0.00742126
17	10	42	95	110	0.007519685
18	10	42	95	110	0.00765748
19	10	42	95	110	0.007755906
20	10	42	95	110	0.007854331
21	10	42	95	110	0.007952756
22	10	42	95	110	0.008070866
23	10	42	95	110	0.008169291
24	10	42	95	110	0.008248031
25	10	42	95	110	0.008326772
26	10	42	95	110	0.008385827
27	10	42	95	110	0.008464567
28	10	42	95	110	0.008523622
29	10	42	95	110	0.008582677
30	10	42	95	110	0.008641732
31	10	42	95	110	0.008700787
32	10	42	95	110	0.008740157
33	10	42	95	110	0.008799213
34	10	42	95	110	0.008858268
35	10	42	95	110	0.008917323
36	10	42	95	110	0.008976378
37	10	42	95	110	0.009015748
38	10	42	95	110	0.009055118
39	10	42	95	110	0.009114173
40	10	42	95	110	0.009173228
41	10	42	95	110	0.009232283
42	10	42	95	110	0.009311024
43	10	42	95	110	0.009370079
44	10	42	95	110	0.009429134
45	10	42	95	110	0.009468504
46	10	42	95	110	0.009527559
47	10	42	95	110	0.009576772
48	10	42	95	110	0.009596457
49	10	42	95	110	0.009635827
50	10	42	95	110	0.009675197
51	10	42	95	110	0.009734252
52	10	42	95	110	0.009793307
53	10	42	95	110	0.00984252
54	10	42	95	110	0.00988189
55	10	42	95	110	0.009940945
56	10	42	95	110	0.01
57	10	42	95	110	0.01003937
58	10	42	95	110	0.01007874
59	10	42	95	110	0.010137795
60	10	42	95	110	0.010177165

Results of Cyclic Load Test No (14) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	63	95	110	0.005570866
2	10	63	95	110	0.006574803
3	10	63	95	110	0.007204724
4	10	63	95	110	0.007677165
5	10	63	95	110	0.008070866
6	10	63	95	110	0.008346457
7	10	63	95	110	0.008622047
8	10	63	95	110	0.008877953
9	10	63	95	110	0.009074803
10	10	63	95	110	0.009251969
11	10	63	95	110	0.009429134
12	10	63	95	110	0.009606299
13	10	63	95	110	0.00976378
14	10	63	95	110	0.009940945
15	10	63	95	110	0.010137795
16	10	63	95	110	0.010255906
17	10	63	95	110	0.010433071
18	10	63	95	110	0.010551181
19	10	63	95	110	0.010669291
20	10	63	95	110	0.010787402
21	10	63	95	110	0.010885827
22	10	63	95	110	0.011023622
23	10	63	95	110	0.011122047
24	10	63	95	110	0.011220472
25	10	63	95	110	0.011318898
26	10	63	95	110	0.011377953
27	10	63	95	110	0.011476378
28	10	63	95	110	0.011555118
29	10	63	95	110	0.011653543
30	10	63	95	110	0.011751969
31	10	63	95	110	0.011791339
32	10	63	95	110	0.011889764
33	10	63	95	110	0.011948819
34	10	63	95	110	0.012007874
35	10	63	95	110	0.012106299
36	10	63	95	110	0.012185039
37	10	63	95	110	0.01226378
38	10	63	95	110	0.012362205
39	10	63	95	110	0.012440945
40	10	63	95	110	0.012519685
41	10	63	95	110	0.01261811
42	10	63	95	110	0.01269685
43	10	63	95	110	0.012795276
44	10	63	95	110	0.012893701
45	10	63	95	110	0.012972441
46	10	63	95	110	0.013051181
47	10	63	95	110	0.013110236
48	10	63	95	110	0.013169291
49	10	63	95	110	0.013248031
50	10	63	95	110	0.013307087
51	10	63	95	110	0.013366142
52	10	63	95	110	0.013425197
53	10	63	95	110	0.013464567
54	10	63	95	110	0.013523622
55	10	63	95	110	0.013582677
56	10	63	95	110	0.013641732
57	10	63	95	110	0.013681102
58	10	63	95	110	0.013740157
59	10	63	95	110	0.013799213
60	10	63	95	110	0.013858268

Results of Cyclic Load Test No (15) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	115	0.004153543
2	10	28	95	115	0.00488189
3	10	28	95	115	0.005334646
4	10	28	95	115	0.005629921
5	10	28	95	115	0.005866142
6	10	28	95	115	0.006102362
7	10	28	95	115	0.006279528
8	10	28	95	115	0.006437008
9	10	28	95	115	0.006614173
10	10	28	95	115	0.006791339
11	10	28	95	115	0.006929134
12	10	28	95	115	0.007066929
13	10	28	95	115	0.007185039
14	10	28	95	115	0.00730315
15	10	28	95	115	0.00742126
16	10	28	95	115	0.007519685
17	10	28	95	115	0.007637795
18	10	28	95	115	0.007716535
19	10	28	95	115	0.007814961
20	10	28	95	115	0.007933071
21	10	28	95	115	0.008031496
22	10	28	95	115	0.008129921
23	10	28	95	115	0.008208661
24	10	28	95	115	0.008326772
25	10	28	95	115	0.008405512
26	10	28	95	115	0.008503937
27	10	28	95	115	0.008582677
28	10	28	95	115	0.008681102
29	10	28	95	115	0.008759843
30	10	28	95	115	0.008858268
31	10	28	95	115	0.008937008
32	10	28	95	115	0.009015748
33	10	28	95	115	0.009094488
34	10	28	95	115	0.009173228
35	10	28	95	115	0.009251969
36	10	28	95	115	0.009350394
37	10	28	95	115	0.009409449
38	10	28	95	115	0.009507874
39	10	28	95	115	0.009606299
40	10	28	95	115	0.009685039
41	10	28	95	115	0.009783465
42	10	28	95	115	0.009862205
43	10	28	95	115	0.009940945
44	10	28	95	115	0.01003937
45	10	28	95	115	0.01011811
46	10	28	95	115	0.010177165
47	10	28	95	115	0.010275591
48	10	28	95	115	0.010354331
49	10	28	95	115	0.010452756
50	10	28	95	115	0.010511811
51	10	28	95	115	0.010590551
52	10	28	95	115	0.010669291
53	10	28	95	115	0.010728346
54	10	28	95	115	0.010807087
55	10	28	95	115	0.010866142
56	10	28	95	115	0.010925197
57	10	28	95	115	0.010964567
58	10	28	95	115	0.011043307
59	10	28	95	115	0.011122047
60	10	28	95	115	0.011181102

Results of Cyclic Load Test No (16) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	42	95	115	0.008562992
2	10	42	95	115	0.00988189
3	10	42	95	115	0.010728346
4	10	42	95	115	0.011318898
5	10	42	95	115	0.011751969
6	10	42	95	115	0.012086614
7	10	42	95	115	0.012401575
8	10	42	95	115	0.01269685
9	10	42	95	115	0.012952756
10	10	42	95	115	0.013188976
11	10	42	95	115	0.013405512
12	10	42	95	115	0.013602362
13	10	42	95	115	0.013759843
14	10	42	95	115	0.013917323
15	10	42	95	115	0.014094488
16	10	42	95	115	0.014251969
17	10	42	95	115	0.014389764
18	10	42	95	115	0.014547244
19	10	42	95	115	0.014704724
20	10	42	95	115	0.014822835
21	10	42	95	115	0.014940945
22	10	42	95	115	0.01503937
23	10	42	95	115	0.01515748
24	10	42	95	115	0.015255906
25	10	42	95	115	0.015354331
26	10	42	95	115	0.015452756
27	10	42	95	115	0.015551181
28	10	42	95	115	0.015649606
29	10	42	95	115	0.015748031
30	10	42	95	115	0.015866142
31	10	42	95	115	0.015964567
32	10	42	95	115	0.016043307
33	10	42	95	115	0.016141732
34	10	42	95	115	0.016240157
35	10	42	95	115	0.016358268
36	10	42	95	115	0.016456693
37	10	42	95	115	0.016555118
38	10	42	95	115	0.016673228
39	10	42	95	115	0.016771654
40	10	42	95	115	0.016870079
41	10	42	95	115	0.016988189
42	10	42	95	115	0.017086614
43	10	42	95	115	0.017185039
44	10	42	95	115	0.01726378
45	10	42	95	115	0.01734252
46	10	42	95	115	0.017401575
47	10	42	95	115	0.017440945
48	10	42	95	115	0.017519685
49	10	42	95	115	0.01761811
50	10	42	95	115	0.017716535
51	10	42	95	115	0.017775591
52	10	42	95	115	0.017854331
53	10	42	95	115	0.017952756
54	10	42	95	115	0.018031496
55	10	42	95	115	0.018129921
56	10	42	95	115	0.018208661
57	10	42	95	115	0.018287402
58	10	42	95	115	0.018366142
59	10	42	95	115	0.018425197
60	10	42	95	115	0.018484252

Results of Cyclic Load Test No (17) - Soil (A6)

Cycles	DUR (sec)	STR (KPa)	DD (%) of MDD	MC (%) of OMC	Accumulation Permanent Strain (mm/mm)
1	10	28	95	120	0.009212598
2	10	28	95	120	0.010807087
3	10	28	95	120	0.011574803
4	10	28	95	120	0.012125984
5	10	28	95	120	0.012519685
6	10	28	95	120	0.012834646
7	10	28	95	120	0.013169291
8	10	28	95	120	0.013444882
9	10	28	95	120	0.013740157
10	10	28	95	120	0.013937008
11	10	28	95	120	0.014114173
12	10	28	95	120	0.014271654
13	10	28	95	120	0.014488189
14	10	28	95	120	0.014606299
15	10	28	95	120	0.01476378
16	10	28	95	120	0.01492126
17	10	28	95	120	0.015019685
18	10	28	95	120	0.015137795
19	10	28	95	120	0.01523622
20	10	28	95	120	0.015354331
21	10	28	95	120	0.015452756
22	10	28	95	120	0.015590551
23	10	28	95	120	0.015688976
24	10	28	95	120	0.015787402
25	10	28	95	120	0.015885827
26	10	28	95	120	0.015964567
27	10	28	95	120	0.016043307
28	10	28	95	120	0.016141732
29	10	28	95	120	0.016220472
30	10	28	95	120	0.016299213
31	10	28	95	120	0.016397638
32	10	28	95	120	0.016437008
33	10	28	95	120	0.016535433
34	10	28	95	120	0.016614173
35	10	28	95	120	0.016673228
36	10	28	95	120	0.016751969
37	10	28	95	120	0.016791339
38	10	28	95	120	0.016870079
39	10	28	95	120	0.016968504
40	10	28	95	120	0.017047244
41	10	28	95	120	0.017106299
42	10	28	95	120	0.017185039
43	10	28	95	120	0.017283465
44	10	28	95	120	0.017362205
45	10	28	95	120	0.017440945
46	10	28	95	120	0.0175
47	10	28	95	120	0.01753937
48	10	28	95	120	0.01761811
49	10	28	95	120	0.017677165
50	10	28	95	120	0.017775591
51	10	28	95	120	0.017854331
52	10	28	95	120	0.017933071
53	10	28	95	120	0.017992126
54	10	28	95	120	0.018051181
55	10	28	95	120	0.018090551
56	10	28	95	120	0.018149606
57	10	28	95	120	0.018208661
58	10	28	95	120	0.018248031
59	10	28	95	120	0.018287402
60	10	28	95	120	0.018346457

الخلاصة

التشوه الدائم للترب السطحية هو تراكم التشوه غير المرن في الترب بسبب الأحمال المتكررة المستمرة الناتجة من حركة المرور. إن التقدير الدقيق للتشوه الدائم في طبقات التبليط يُساعد في التصميم الأفضل لها ولسمكها في أنظمة تصميم طبقات التبليط. حيث إن التصميم الذي يهمل التشوه الدائم سيؤدي إلى تصدع طبقات التبليط وهذا يزيد كلف إعادة التأهيل سنوياً. ولا يزال التشوه الدائم للترب السطحية يشكل تحدياً كبيراً إلى مهندسي الطرق و السبب الأساسي يعود لان سلوك تشوه الترب السطحية لم تعطى له أهمية كافية في طرق التصميم الحالية.

إن الهدف الرئيسي لهذه الدراسة هو التحري حول بعض العوامل التي تسبب التشوه الدائم في الترب السطحية مثل أنواع التربة، محتوى الرطوبة، الإجهاد المسلط والكثافة الجافة. كذلك تم صياغة موديلات للتنبؤ بالتشوه الدائم في الترب السطحية تعتمد على محتوى الرطوبة، زمن تسليط الحمل، الكثافة الجافة والإجهاد المسلط باستخدام برنامج (STATISTICA).

كما إن هذا البحث قد وضع أسساً لإجراء اختبار باستخدام فحص الأحمال المتكررة لقياس التشوه الدائم في الترب السطحية. تم مراقبة التشوه الدائم خلال 60 دورة متكررة وتم حساب التشوهات الدائمة المتراكمة. إن إجراء الاختبار تم على نوعين من أنواع الترب اللذين يغطيان منطقة جغرافية مهمة من العراق وهما الترب نوع (A4) و (A6).

وتشير النتائج إلى إن محتوى الرطوبة والإجهاد المسلط يشكلان عاملان رئيسيان تحكم التشوه الدائم للترب السطحية، حيث إن زيادة محتوى الرطوبة من 90% إلى 110% من نسبة الماء المثلئ ستزيد التشوه الدائم بحدود 270%. بينما زيادة الإجهاد المسلط من 28 KPa إلى 63 KPa سيزيد التشوه الدائم بنسبة 81%.



جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية الهندسة
قسم الهندسة المدنية

خصائص التشوه الدائم للترب السطحية باستخدام فحص الأحمال المتكررة

رسالة مقدمة إلى
كلية الهندسة في جامعة بابل
كجزء من متطلبات نيل شهادة الماجستير في
علوم الهندسة المدنية

من قبل:

بكالوريوس هندسة مدنية

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