UNIVERSITY OF GAZIANTEP
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COMPACTION AND CBR PROPERTIES OF SAND MIXED WITH MODIFIED WASTE EPS

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Compaction and CBR Properties of Sand Mixed with Modified Waste EPS

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Supervisor
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by
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Didar Yasin Najmaddin

ABSTRACT

COMPACTION AND CBR PROPERTIES OF SAND MIXED WITH MODIFIED WASTE EPS

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M.Sc. in Civil Engineering

Supervisor: Assoc. Prof. Dr. Hanifi ÇANAKÇI

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53 Pages

This research presents the results of the study which influence the use of recycled waste expanded polystyrene foams (EPS), as a lightweight fill material when mixed with river sand. In this study, thermally modified waste EPS have been used. The waste EPS were put in to an oven at 130°C through 15 minutes to obtain modified expanded polystyrene (MEPS). Compaction properties and California Bearing Ratio (CBR) values of sand mixed with MEPS were investigated. For this purpose, five series of compaction tests were prepared that have 0%, 5%, 10%, 15%, and 20% MEPS by weight. Two types of compaction tests were carried out. These are standard and modified proctor tests. From each test results, effect of MEPS on optimum moisture content and maximum dry density was investigated. CBR are tests were also carried out after standard and modified proctor compaction. Tests were performed for unsoaked condition. The results showed that addition of MEPS to river sand decreases maximum dry density with increasing percentage of MEPS for both standard and modified proctor compaction. Optimum moisture content of the mixture was not affected for both tests. CBR values of the mixture were reduced when the percentage of the MEPS increased in the mixture. However, lowest CBR value at 20% MEPS are still within the acceptance limits for sub-base.

Keywords: River Sand, Lightweight fill, Geofoam (EPS), Unit weight, Recycling waste, Standard Proctor test, Modified Proctor test, California Bearing Ratio (CBR).

ÖZ

GELİŞTİRİLMİŞ STRAFORLA KUM KARIŞIMININ KOMPAKSİYON ÖZELLİKLERİ

Najmaddin, Didar
Yüksek Lisans Tezi, İnşaat Mühendisliği
Danışman: Doç. Dr. Hanifi ÇANAKÇI
06 September 2012
53 Sayfa

Bu çalışma hafif dolgu malzemesi olarak kullanılan atık straforun dere kumu ile karıştırıldığında geri dönüşüm kullanımına etkisini sunmuştur . Yapılan çalışmada termal yöntemlerle ısıtılarak özelliği değiştirilmiş atık strafor kullanılmıştır. Özelliği değiştirilmiş straforu elde etmek için, atık strafor bir fırında 130 ^{0}C ‘de 15 dakika boyunca bekletilmiştir. Kumla karıştırılmış straforun CBR ve kompaksiyon özellikleri bu çalışmada incelenmiştir. Bu sebepten çalışma boyunca ağırlıkça %0, %5, %10, %15 ve % 20 oranlarında atık straforla hazırlanmış numuneler üzerinde 5 adet kompaksiyon deneyleri yapılmıştır. Standart proktor ve modifiye proktor deneyleri olmak üzere 2 çeşit kompaksiyon deneyi yapılmıştır. Bütün deney sonuçlarından, geliştirilmiş straforun optimum su muhtevasına ve maksimum kuru birim hacim ağırlığına etkisi açıkça gözlemlenmiştir. CBR deneyleri için standart ve modifiye proktor deneyleriyle numuneler hazırlanmıştır. Bu numuneler islatilmamis durumda hazırlanmıştır. Deney sonuçları göstermiştir ki; gerek standart proktor gerekse modifiye proctor deneylerinde ağırlıkça yüzde olarak geliştirilmiş straforun dere kumu içerisinde ki artışı maksimum kuru yoğunluğunu azaltmıştır. Optimum su muhtevası özelliği her iki deney tipi içinde değişmemiştir. Karışımdaki geliştirilmiş strafor oranının ağırlıkça artması CBR değerlerini düşürmüştür. En düşük CBR değerinin elde edildigi %20 lik karisim orani temel ve altı temel için istenen degerleri sagladigi goruldu.

Anahtar kelime: dere kumu, hafif dolgu malzemesi, strafor, birim ağırlık, geri dönüşümsel atık, standart proktor deneyi, modifiye proktor deneyi, CBR

This study is dedicated to:

All those who taught me throughout the learning.

My Parents.

My kindness wife, Rezhna.

My Lovely Daughter, Dima.

My Lovely Son, Danyar.

My dear brothers and sisters.

Didar

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My sincere appreciation also extends to all my friends. My honest respect to my mother, my sisters, my brothers, and all my relatives.

My final special thank will go to my wife (Rezhna), without her support, I could have never completed this work.

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LIST OF SYMBOLS

ASTM	American society for Testing and Material
Gs	Specific Gravity
IP	Plasticity Index
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
EPS	Expanded polystyrene
MEPS	Modified Expanded polystyrene
E	Compaction Effort
CBR	California Bearing Ratio
W	Weight of the compacted soil in the mold
$V_{(m)}$	Volume of the mold ($944cm^3$)
γ_d	Dry density
LWA	Light Weight Aggregate
HDPE	High Density polyethylene
PLR	Piston Load Ratio

CHAPTER 1

INTRODUCTION

For years, human have been attempting to save the environment immaculate. Researches supply us with notion on how we can keep the natural equilibrium of life, and recycling has a base role in these researches. Large amounts of waste materials are created because of natural scourge or growing population and urbanization. These wastes contain iron, wood, glass, ceramics, rubber and EPS (i.e.; expanded polystyrene). To turn out the recycling of these different materials productive, we should first differentiate them with respect to their types (Abdulkadir Kan, Ramazan Demirbogˇa, 2009). Unmodified EPS foam has a cellular microstructure with closed cell membranes made of expanded polystyrene and its density is typically less than 50kg/m3. Nowadays, EPS is actually used as an involution or insulating material in different industrial areas in the world. A big quantity of EPS is consumed, and is organized as a waste. Furthermore, it is recognized that the waste EPS has caused many environmental issues, particularly water and land pollution, because it cannot be decayed in nature. Thermal curing is applied to convert behaviors of materials in addition to softening and hardening. These operations change the property of the EPS in a beneficial form to maximize service life, e.g., density, strength properties, or some other desirable properties, e.g., water absorption and thermal conductivity. Heat treatments are used in many industries to make efficient the physical attribute of wastes. In recent years using geofoam (EPS), which are measured as lightweight materials, in geotechnical applications have increased.

These uses contain: lightweight fill (Humphrey D.N. and Maion, W.P., 1992; Frascoia R.I. and Cauley, R.F., 1995), insulation under roads, and lightweight backfill for retaining walls (Humphrey D.N. and Sandford, T.C., 1993; Humphrey D.N. et al, 1998). Using modified expanded polystyrene with river sand as retaining wall backfill has sundry prospect advantages. One of the most substantial properties of EPS is that they are a lightweight material. In fields where the underlying soil is soft, the lower density of foam-sand mixture would stratify minimal vertical stress than, traditional backfill, leading to smaller settlement and increased overall stability. The horizontal stress on a retaining wall would be lower than with traditional backfill, resulting in cheaper retaining wall design. In many countries, due to the rising price of raw materials and the continuous reduction of natural resources, the utilize of waste materials is a potential alternative in the construction industry. Waste materials, when properly processed, have shown to be functional as construction materials and easily meet the design specifications (Abdulkadir Kan, Ramazan Demirbogˇa, 2009).The insulation qualities of EPS would decrease frost penetration. Moreover, their elevated permeability would supply kindly drainage. Table (1-1) (Sungmin Yoon et al, 2006) shows the density and sacrificial cost of Geofoam (EPS), with the corresponding values of other vastly utilized lightweight materials.

1.1 Principal Object

During this study an effort has been made to explain the potential and effect of MEPS on the soil (river sand) when mixed in a certain percentages. The paper characterizes a series of CBR tests executed with changing percentages of MEPS jumbled uniformly with the soil. The results gained from the tests were presented and discussed. It is also significant to mention that the selection of the California Bearing Ratio (CBR) test apparatus as the testing platform brings some inherent problems into the experimental study. The changed material may have safely various strength characteristics than the original material. Despite these restrictions, a large experience base has been advanced using the CBR test and some favorable design methods are in utilize setup on the test results (A.K. Choudhary et al, 2010).

The objective of this research is to find the effect of using waste material (i.e., geofoam) on compaction characteristics and California Bearing Ratio (CBR).

Table 1.1 density and price of different lightweight fill material

Lightweight material	Unit weight(KN/m3)	Approximate cost ($/m3)
Geofoam (EPS)	0.1-1	35-65
Shredded tires	5.5-6.4	20-30
Wood fiber/sawdust	8-10	12-20
Expanded shale and clay	3-10	40-55
Fly ash	10-14	15-21

1.2 Layout of Thesis

The contents of each chapter can be explained as follows:

Chapter 1 Introduction: Introducing a brief history of (waste material, i.e., EPS) and its necessity to human being as well as explaining the principal objectives and layout of the thesis.

Chapter 2 Literature review of using waste material in geotechnical engineering.

Chapter 3 Compaction of Soil: Define of compaction and the factors affecting it, influence of soil type, proctor test, and California bearing ratio.

Chapter 4 Experimental Study: Materials, methods, and test procedure explained in this chapter.

Chapter 5 Test results and discussion: Explaining the results with drawing the charts and their discussion.

Chapter 6 Conclusion: Includes comments and evaluation of the work and results of the thesis as well as presenting ideas for future work in this field.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Sungmin Yoon et al (2006) have performed series of tests on sand–tire shred mixture as fill material for construction of the test embankment. They have discussed and evaluated the feasibility of utilizing of tire-shred-sand mixtures as a fill material in embankment prosperity. The test constructed using a 50/50 mixture, by volume of tire shreds, and sand was instrumented and monitored to: (a) Determination total and differential settlements; (b) the environment effect of the embankment construction was evaluated on the ground water quality due to leaching of fill material; (c) the temperature variation study inside the embankment. They have also showed the maximum unit weight and minimum void ratio of sand-tire shred mixture as in shown in figure2-1.

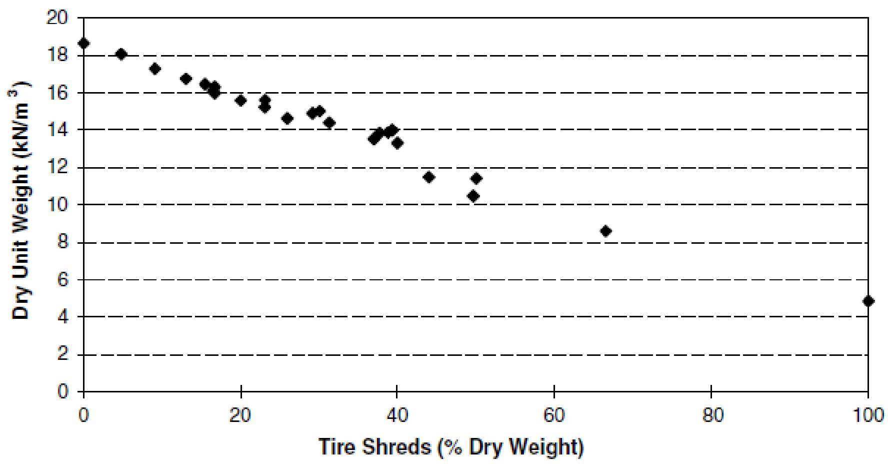


Figure 2-1(a). Maximum density of mixtures of 25-mm tire shreds and sand provided with various tire shred percentages (adapted from Ahmed, 1993).

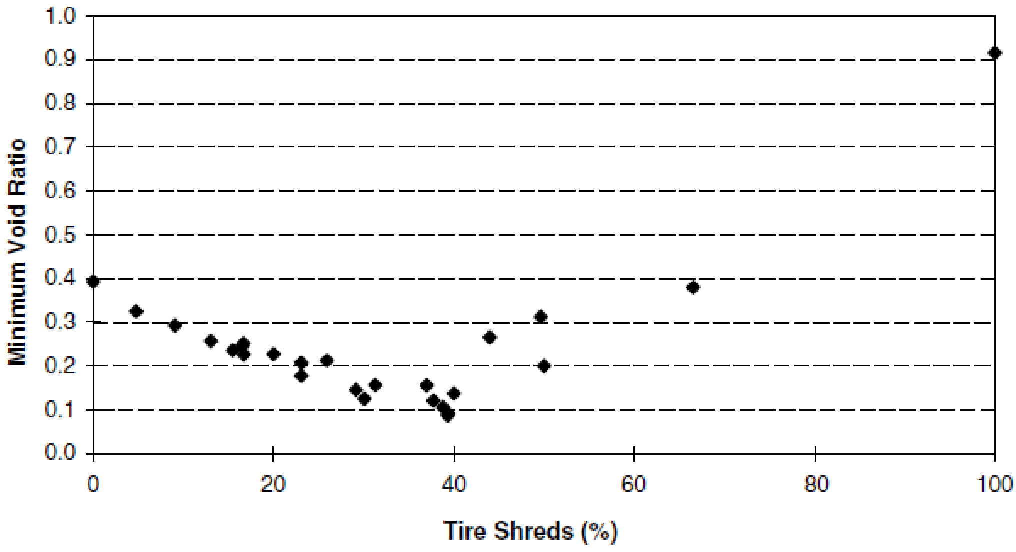


Figure 2-1(b) Minimum void ratio of mixtures of 25-mm tire shreds and sand as a function of the tire shred percentages of the mixtures by weight (adapted from Ahmed, 1993).

Dana N. Humphrey and Jeffery J. Tweedie (2002) performed Full-scale trails to demonstrate the viability of utilizing tire shreds (waste material) as retaining wall backfill. The applied Surcharges were up to 35.9Kpa. Horizontal stress with tire shreds was about 45% lower than predictable for gravel backfill at-rest condition. However, for active earth pressure case, the horizontal stress with tire shreds was 35% lower than predictable for gravel. They also used a 4.3m thick tire shred layer as backfill beyond a bridge abutment.

Abdulkadir Kan and Ramazan Demirbogˇa (2009) were developed a kind of aggregate with up to 8 MPa design strength by heat treatment, which was a operation by which the heat is stratified to waste (EPS) in order to destroy exterminate it or decrease its volume, prior to reutilize. According to their work, heat treatment converted the waste EPS to a firm and applicable output and reduced the quantity that demands last disposal in landfills. The best exposed temperature and duration in their study were demonstrated to be 130°C and 15 minutes respectively. They have obtained a touch EPS aggregate after modifying EPS by heat treatment for materials such as lightweight concrete (LWC) and other application. The major purposes of their study were to achieve an extra source for LWA and decrease the environmental pollution. Table 2-1 shows the average specification of waste EPS foam before and after heat treatment respectively.

Table 2-1 average specification of waste EPS

	Before heating	After heating
Density (kg/m^3)	10	217
Compressive strength (MPa)	0.12	8.29
Thermal conductivity (W/mK)	0.0369	0.055
Maximum absorption % by volume	< 3	-
Glass temperature (°C)	95	-
Increasing ratio of density (%)	-	2070
Increasing ratio of comp. strength	-	6900
Loss of weight after 10 cycles freezing And thaw (%)	-	0.31
Absorption by weight (Sa) (%)	-	4.1
Absorption by volume (Sh) (%)	-	0.58

Y.T. Kim et al (2008) have investigated the strength properties and stress-strain characteristic of reinforced with waste fishing net and unreinforced lightweight soils (LS) was cement-treated and consisted of dredged clayey soil, cement, and air-foam. According to their work, the effective factor on that property was the content of waste fishing net as shown in figure (2-2). However, the results indicated that the bulk unit weight of lightweight soil was substantially attached on the air-foam percentage of the soil mixture as in figure (2-3).

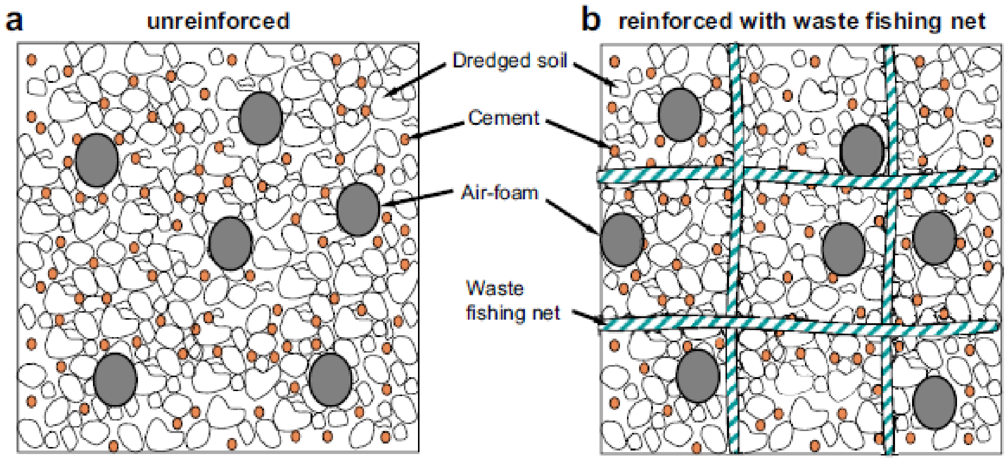


Figure 2.2 Schematic diagram of (a) unreinforced and (b) reinforced lightweight soils.

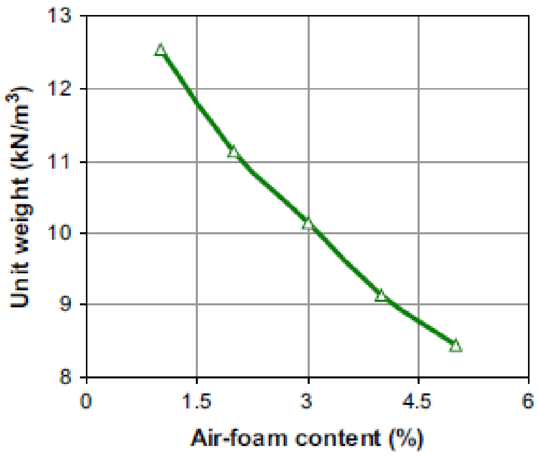


Figure 2-3 Bulk unit weight as a function of air-foam percentages.

Shaukat Ali Khan (2007) has performed the feasibility of the improvement properties of unsuitable highway sub grade soil which the stabilization required. Stabilization was performed by using steel industry waste produced from the molds during forging process. The addition of waste concluding (comprising) of sand particles and skinny metal pieces changes the gradation of soil, resulting in improvement in the density and strength of the stabilized material. However, there are situations (status) in which two materials by themselves do not have the desired engineering properties, but when mixed together, produce a satisfactory material. In his research, the new stabilized material has demonstrate that it will be more resistant to load and seasonal effects. He was obtained from results, that the maximum dry density increased rapidly with the increasing percentage of the steel industry waste, and the optimum moisture content decreased with increasing percentage of steel industry waste, as in figure2-4 and figure 2-5.

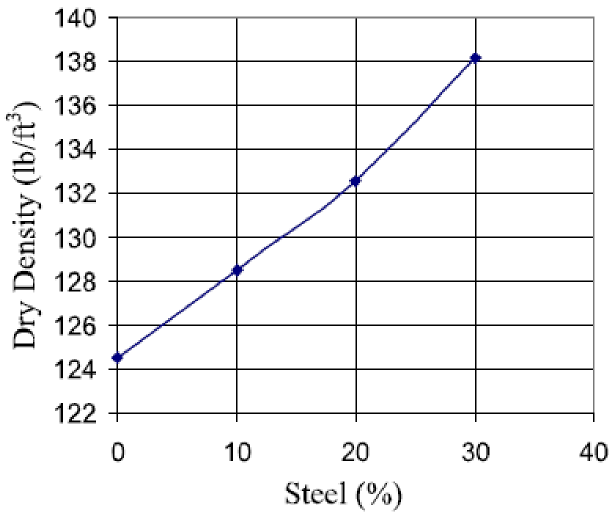


Figure 2-4 Variation in the maximum dry density of the soil mixed with varing percentage of steel industry waste.

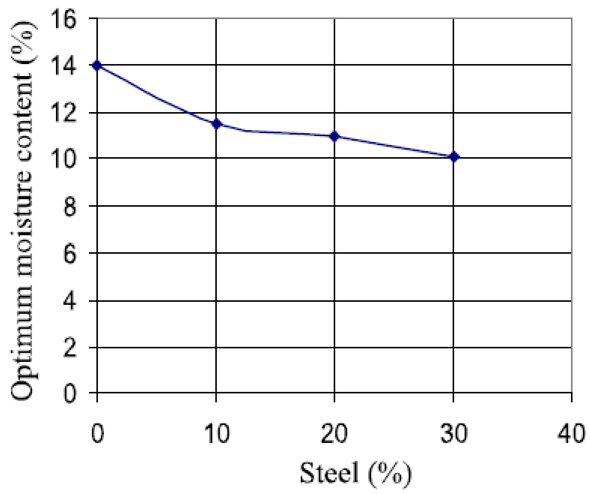


Figure 2-5 Variation in optimum moisture content of the soil mixed with varing percentage of steel industry waste.

Roald Aabøe and Even Øiseth (2005) lead a research project for investigation the possible use of granulated foamed glass (cellular glass) as lightweight material for road construction application (figure2-6). The production has performed by using an environmentally amiable recycling technology for polluted and toxic material. The normal grain size was in the range (10-60) mm. When the granulated foamed glass put and compacted in a drained fill, the unit density of the lightest drawing out would be (300-350) kg/m^3 relying on the compaction. The material might be used as lightweight fill material and frost protection layer/thermal insulation in roads or other civil engineering implementations. However, their research within the Norwegian Public Road Administration (NPRA) has sponsored a program in order to enhance the utilize of recycled material in road structures where an observing program was one of sundry activities. According to NPRA, in Europe the average yearly glass exhaustion was about (30-40) kg/per habitant. Figure 2-7 gave information about yearly utilize of lightweight fill in Norway.

Figure 2-6 typcial foamglass particle

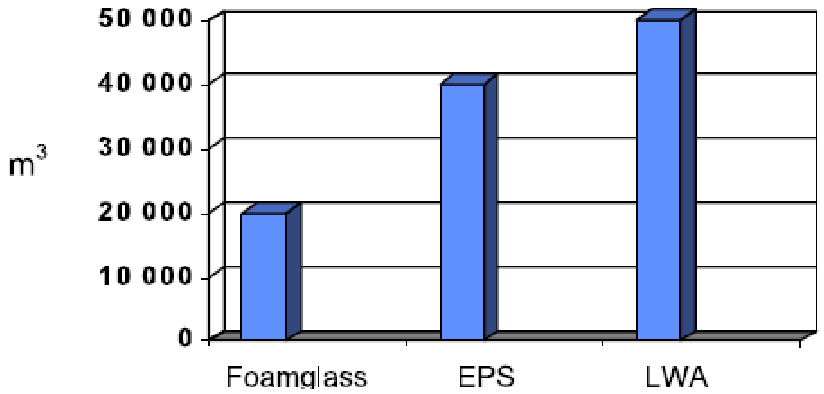


Figure 2-7 (Yearly utilize of lightweight fill material of road in Norway)

Imtiaz Ahmed and C.W.Lovell (1993) have performed a solution to promote the stability and reduce the settlement of highway structures on slope and highly compressible soils was to replace the existing material with a material of lower unit weight or use lighter weight fills. On the basis of their analysis of limited data on rubber soils, it was concluded that the use of shredded tires in highway construction offered technical, environmental, and economic benefits under certain conditions. The main function of using tire chips were reduced weight of fill, which helps increasing stability, reduce settlements, and correct or prevent slides on slopes, and reduced backfill pressure on retaining structures. Potentially large settlements could be reduced by providing a thicker soil cap and using a rubber-soil mix instead of chips alone. It was found that about 40% chips by weight of soil was an optimum account for the amount of chips in a rubber-soil mix, where large settlements were a concern. The chip/ soil ratio would yield a compacted dry density of rubber-soil mix that was about two-third that of soil alone.

Krishna R. Reddy (1999) has investigated a potential application of glass cullet as a substitutional backfill material for retaining structures. It was shown that glass cullet is viable alternative to conventional granular soil backfill with both economic and environmental benefits. However, there was presented different uses and engineering properties of glass cullet. His research has shown that using recovered glass as a construction aggregate has several advantages over reusing it in the container industry. Color sorting, a tedious and costly undertaking was not required. Depending on the type of application, up to 10% debris level (by weight) was permitted in the mix. A comparison has made between glass cullet with other granular materials such as sands. The size distribution of glass cullet was regarded for civil engineering applications generally consisted of (67-84) % greater than 4.75mm, (16-32)% between (0.075-4.75)mm, and (0.4-1.4)% less than 0.075mm in size. In general, the particle shape of cullet was angular in nature. Some engineering properties have compared between cullet and sand as shown in table 2-2.

Table2-2 Comparison of Properties of Cullet and Sand

Property	Test Method	Cullet	Sand
Specific gravity	ASTM D 854	1.96-2.52	2.6-2.8
Unit Weight (pcf)	ASTM 4254	76-109	80-130
Hydraulic conductivity (cm/s)	ASTM D 2434	10^{-1}-1	10^{-3}-10^{-2}
Durability	ASTM C 131	30-42	NA
Compactability	ASTM D 698		
Optimum Moisture Content (%)		5	8-10
Maximum Dry Density (pcf)		105-124	116-133
Shear strength:	ASTM D 3080		
Cohesion (c´)		0	0
Friction angle (φ)		49-53	32-38
Thermal conductivity (W/mK)	ASTM C 518	0.26-0.64	2.9-7.7
Chemical Resistance (%)	ASTM C 3042	99.8	70.1

Andreas NATAATMADJA and Hema Kumar ILLURI (2009) have described in their research how expansive clays with plasticity indices (PI) ranging from 22% to 53% were artificially made and mixed with granulated waste expanded polystyrene (EPS) in the laboratory. They have conducted a series of free swell and swell pressure tests on those soils. Their test results have showed that the inclusion of EPS granules importantly reduced the potential volume change of the soils when subjected to one dimensional free swell condition. In addition, three-dimensional volumetric shrinkage test results also showed that the recycled EPS granules could reduce the volumetric shrinkage potential of the expansive soils.

Petry and Armstrong (1989) have performed a suggestion to avoid failure of retaining walls located in expansive soil regions, they suggested that the expansive clay behind the retaining wall should be cut back to at least 45˚ from the horizontal and should be filled with non-active, free drainage material such as clean granular sand or gravel so that as the clay swells, it will not impose loads on the wall. Recently, there has been a considerable interest on the potential benefit of placing geoinclusions (i.e. EPS). See figure 2-8.

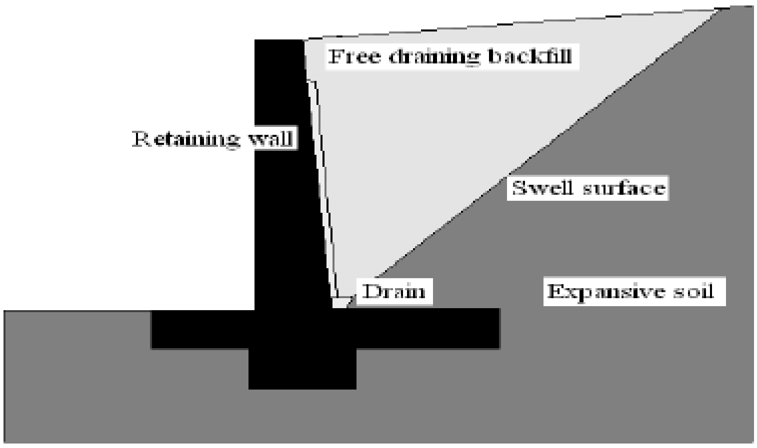


Figure 2-8 Retaining wall backfill treatments (Petry and Armstrong, 1989)

Sotirios Psomas (2001) has conducted an experimental work on foam/sand mixture. His study was executed so as to estimate the essential soil characteristics of foamed sand, especially its compressibility, permeability and shear strength. Two types of sand (fine, coarse) and four types of foam were used during tests. In some cases, sodium bentonite was utilized sole or in composition with foam and polymer. He has noted that for fine sand even at peak pressure the final voids ratio of foam/sand mixture after the compression kept higher than the maximum void ratio of dry sand. Results are showed as plots of shear strength versus horizontal deformation, very weak values of shear strength for foamed sand tests are observed.

Ghazavi et al (2012) have performed laboratory California Bearing Ratio (CBR) tests on sand-tire chips mixture reinforced with geogrid. For this purpose, various percentages of tire chips and sand were mixed and reinforced with geogrid in CBR tests. Tire chips grain size was vary between (2-7) mm. Tire chips contents of 15%, 25%, 30%, and 35% by volume were taken and mixed with sand at a sand matrix unit weight of 14KN/m^3. Reinforcing the mixtures with geogrid were conducted at different depths in the CBR mold, however, in some tests a surcharge was applied that in fact reduced the CBR values but it has been compensated by using geogrid. Test results gave CBR values for a given content of tire chips-sand mixture and reinforced with geogrid more than of unreinforced sand. Due to their research, as the tire chips contents increase to a specific amount, the CBR values increased (see figure 2-9).

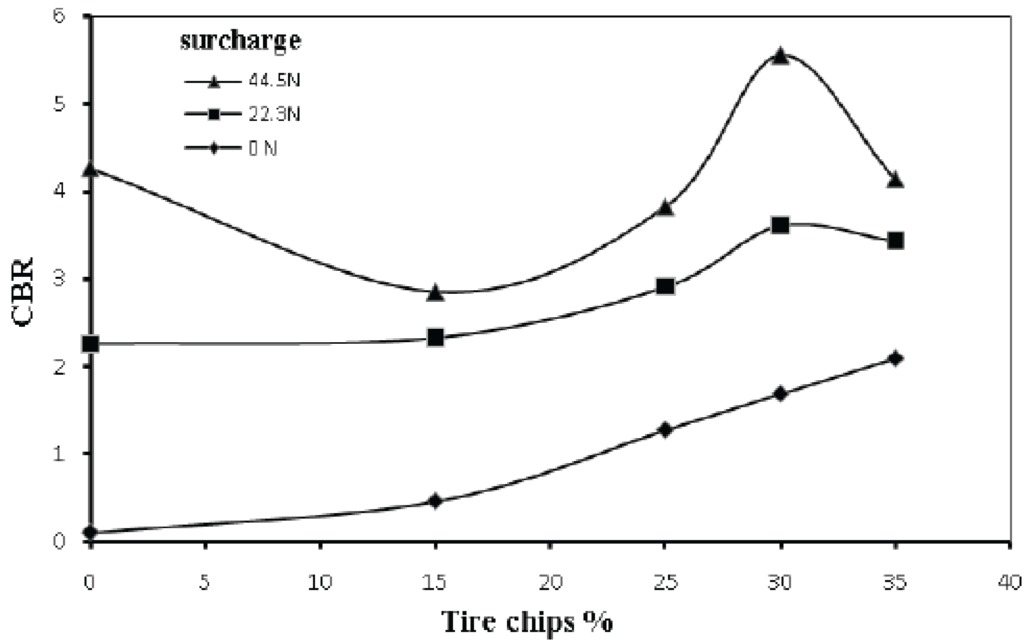


Figure 2-9 CBR values versus tire chip contents for sand-tire chip mixture for various surcharges.

In addition, the CBR values could be enhanced by displaying geogrid location in the mold (see figure 2-10).

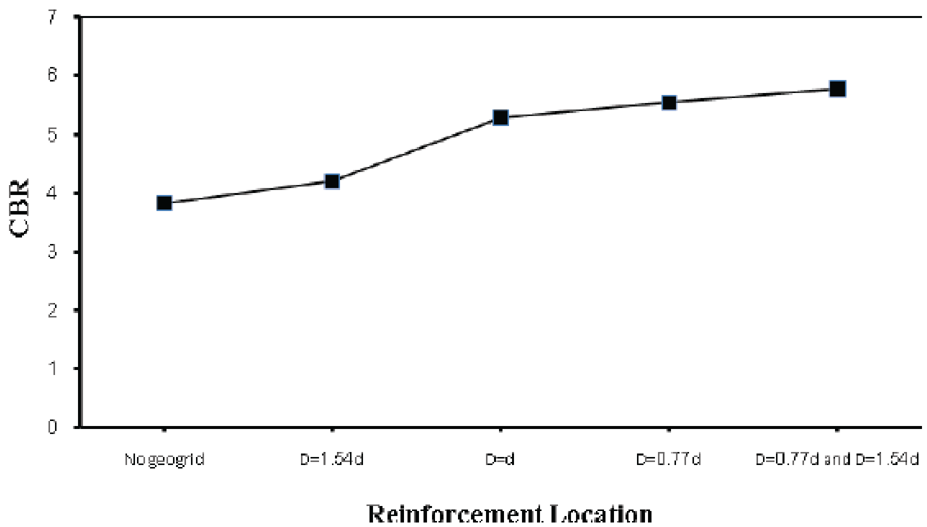


Figure 2-10 CBR values versus geogrid location for sand mixed 25% tire chips tested under 44.5N surcharges.

A.K.Choundhary et al (2010) have tried to explain the potential of reclaimed high density (HDPE) as soil reinforcement for progressing engineering execution of sub-grade soil. The soils were mixed randomly with HDPE strips obtained from waste plastic. They have conducted a series of California Bearing Ratio (CBR) tests on at random reinforced soil by varying content of HDPE strips (0%, 0.25%, 0.5%, 1%, 2%, and 4%) with different lengths and proportions (see figure 2-11). The outcome CBR values explained that inclusion of waste HDPE strips in soil with convenient quantity amended strength (i.e., increased CBR values) and has affected on deformation behavior of sub grade soils substantially (see figure 2-12). They have suggested that using the proposed technique has an advantage in embankment/road construction.

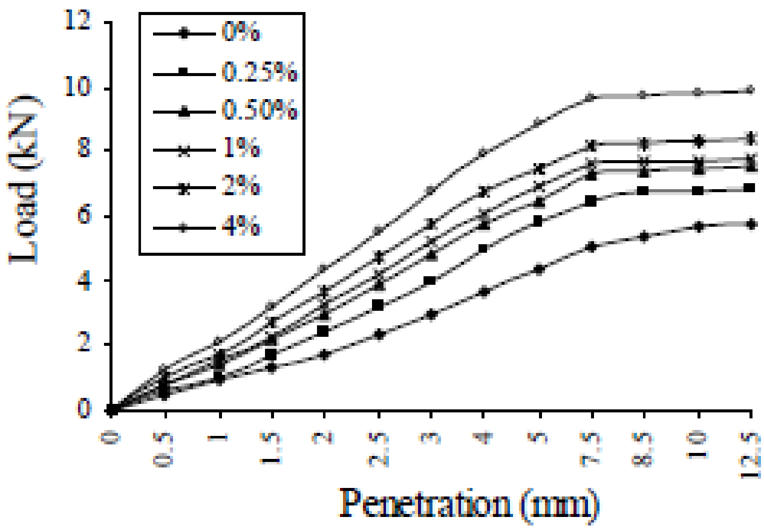


Figure 2-11 Load penetration curve for varying strip

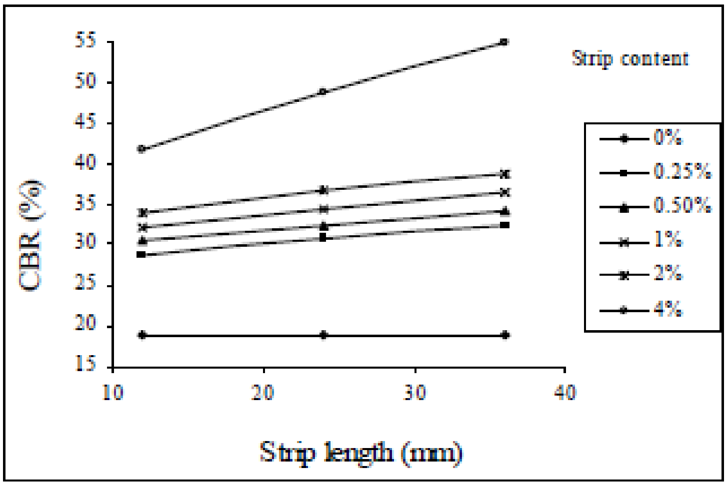


Figure 2-12 Change of California Bearing Ratio (CBR) with strip length at different strip percentage.

Saman Zarnani et al (2005) have investigated that the potential reduces seismic-induced dynamic earth pressures versus rigid wall structures during an experimental program by utilizing a vertical inclusion of expanded polystyrene (EPS) geofoam buffer material. Various EPS included in their study with a range of modulus values were located between the rigid wall and a uniformly graded sand material. A stepped amplitude base excitation was applied on the entire table payload with peak acceleration as high as 0.9g. The outcomes of the study presented clearly that dynamic lateral earth forces were mitigated with lowering geofoam modulus. For the optimum condition, the total earth force acting versus the rigid wall during seismic vibration was decreased to 60% of the value for the symbolically corresponding structure without a geofoam buffer inclusion.

V. Cecich et al (1996) reported laboratory tests on shredded tires. In their study, first performance was finding the engineering characteristics of shredded tires. Due to sieve analysis, the shredded tires were uniformly graded. Its unit weight was obtained to range from 35 to 38 Ibs ft^{-3} and the hydraulic conductivity was 0.03cm s

[1]. The shear strength parameters were 147 Ibs ft^{-2} and 27 degree for cohesion and angle of internal friction respectively. Retaining walls were designed to backfill material using (shredded tires, conventional sand, and shredded tires with sand). They have demonstrated that when the shredded tires were used with sand as backfill material, the cost of detained is wall lowered (see figure 2-13). The factor of safety increases by using shredded tires alone in backfilling.

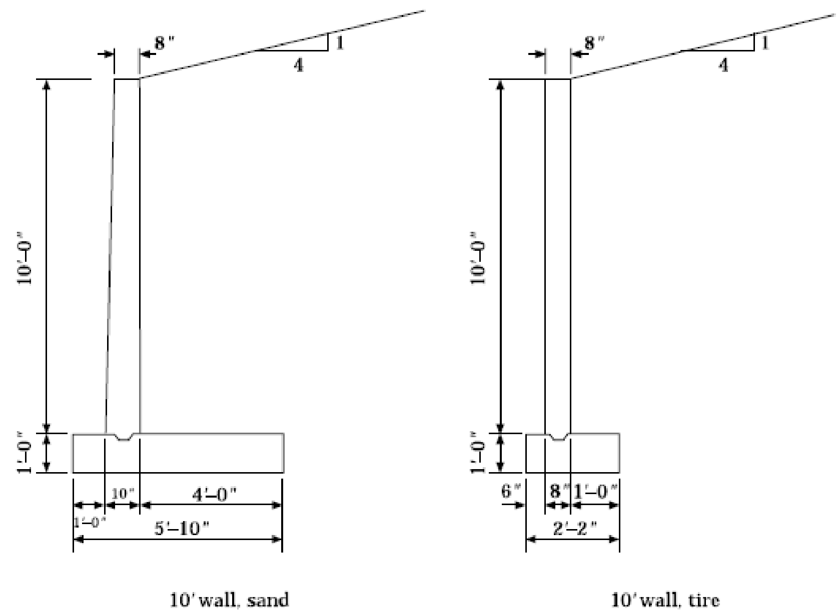


Figure 2-13a Design of 10-ft high retaining wall with sand and shredded tires as backfill materials

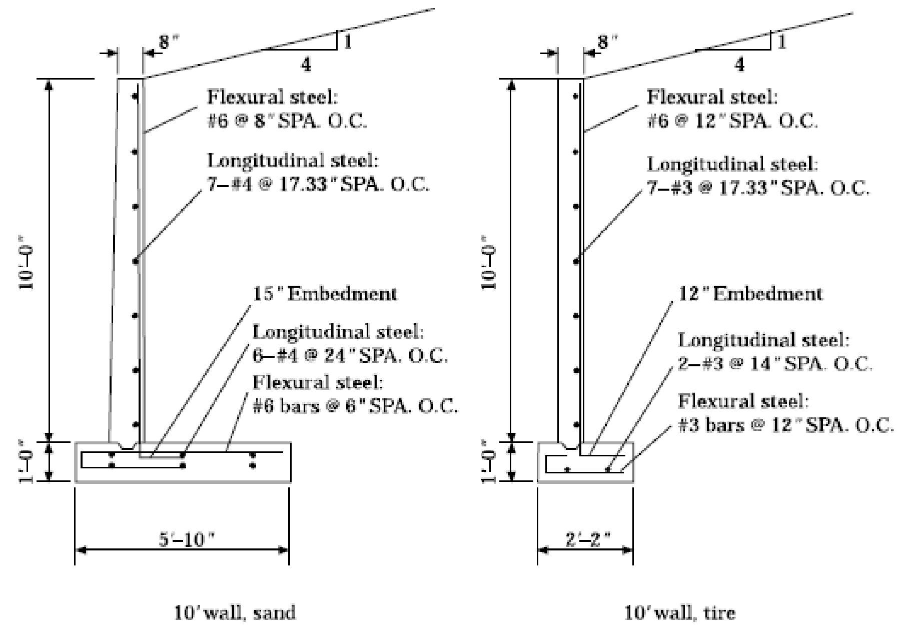


Figure 2-13b Design of 10-ft high retaining wall with sand and shredded tires as backfill materials.

D.Arellano and T.D.Stark (2009) have presented a deformation-based load bearing analysis steps that benefits the elastic limits stress, i.e. the compressive stress at 1% strain, for designing expanded-polystyrene (EPS)-block geofoam for roadway embankments (Figure 2-14). They made a procedure to determine the maximum vertical stress from dead and traffic loads at different levels within the EPS fill mass and choosing an EPS type that exhibits an elastic limit stress vertical stress at a certain depth. The greater block requirement density when it needed a higher elastic limit stress. Therefore, one of the merits of the recommended deformation-based design procedure was that the calculation of stresses and strains within the EPS mass permits the choosing of the kind of EPS blocks to be succeeded by selecting blocks with a lower density for the lower portions of the embankment and the higher density blocks for the upper of part of the embankment.

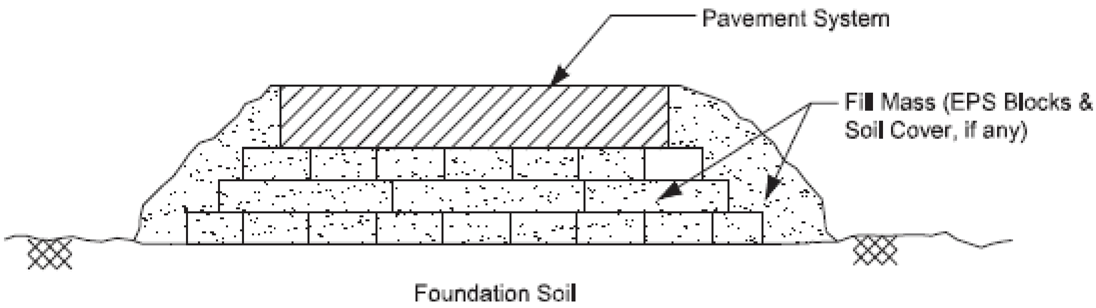


Figure 2-14 Major components of an EPS-block gefoam embankment

CHAPTER 3

COMPACTION OF SOIL

Compaction shall be done to increase the unit weight of loose soils in the construction of earth dams, highway embankments, and many other engineering structures. Compaction raises the strength properties of soils, which increase the bearing capacity of foundation built above them. It also increases the stability of slopes of embankments and decreases the amount of undesirable settlement of structure. (Das, 2006)

3.1 General Principles of Compaction

Compaction, in general, is the densification of soil by elimination of air, which demands mechanical energy. The grade of compaction of a soil is measured in terms of its dry density. When water is attached to the soil during compaction, it works as a softening employee on the soil particles. The soil particles skid over each other and shift into a violently packed position. The dry density rearward compaction first raises as the moisture content increases. (see figure 3.1) Note that at a moisture content w=0, the moist unit weight (γ) is equal to the dry density (γ_d) or

$$\gamma = \gamma_{d_{w=0}} = \gamma_1$$

when the moisture content is gradually increased and the same compactive effort is used for compaction, the weight of the soil solids in a unit volume progressively increases. For example, $w=w_1$

$$\gamma = \gamma_2$$

However, the dry hnit weight at this moisture content is given by

$$\gamma_{d(w=w1)} = \gamma_{d(w=0)} + \Delta\gamma_d$$

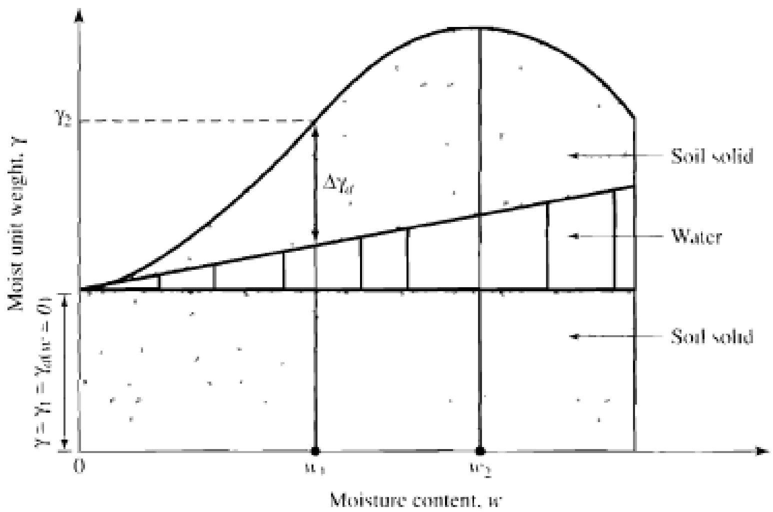


Figure 3.1 principles of compaction **(**Das, 2006)

After a certain moisture content $w=w_2$ (figure 3.1), any increase in the moisture content heads for to decrease the dry density. This happening takes place because the water raises the spaces that would have been taken by the solid particles. The moisture content at which the maximum dry density is achieved is generally indicated to as the optimum moisture content. Figure 3.2 shows three phase diagrams showing the changes in soil as it moves from its naturel location to a compacted fill.

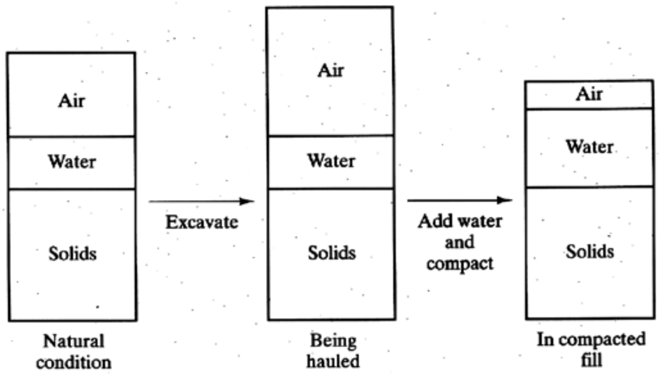


Figure 3.2 three phase diagrams showing the changes in soil as it moves from its naturel location to a compacted fill (Das, 2006).

The laboratory test mostly utilized to gain the maximum dry density of compaction and the optimum moisture content is called the Proctor compaction test (Proctor, 1933).

3.2 Standard Proctor Test

In the Proctor test, compactions of the soil have performed in a mold that has a volume of 944cm^3. The diameter of the mold is 101.6 mm. In the laboratory during the test, the mold is fixed to a base plate at the bottom and to an extension at the top (figure 3.2a). The soil is mixed with changing amounts of water and then compacted in three equal layers by a hammer (figure3.3b) that delivers 25 blows to each layer. The hammer has a mass of 2.5 kg and has a drop of 30.5 mm.

For each test, the moist density of compaction, γ, can be evaluated as

$$\gamma = \frac{W}{V_m} \quad (1)$$

Where W= weight of the compacted soil in the mold

$V_{(m)}$ = volume of the mold (944cm^3)

For each test, the moisture content of the compacted soil is calculated in the laboratory. With knowing moisture content, the dry density can be evaluated as

$$\gamma_d = \gamma/(1 + (\frac{w(\%)}{100}) \quad (2)$$

Where w (100%) = percentage of moisture content.

The values of γ_d determined from Eq. (3-2) can be schemed versus the corresponding moisture contents to gain the maximum dry density and the optimum moisture content for the soil.

The procedure for the standard Proctor test is elaborated in ASTM Test Designation D-698 (ASTM, 1999).

3.3 Factors Affecting Compaction

It is clear that moisture content has a storage effect on the degree of compaction accomplished by a given soil. Besides moisture content, other significant factors that involve compaction are soil type and compaction effort (energy per unit volume).

3.3.1 Influence of Soil Type

The soil type – that is, grain-size distribution, shape of the soil grains, specific gravity of soil solids, quantity and kind of clay minerals present– has a great effect on the maximum dry density and optimum moisture content. Figure 3.3 shows typical compaction curves obtained from four soils. The laboratory tests were carried out according to ASTM Test Designation D-698.

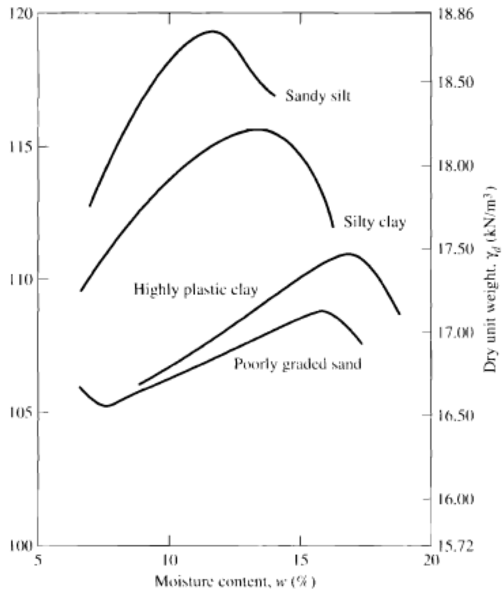


Figure 3.3 Typical compaction curves for four soils ASTM D-698 (Das, 2006)

Figure 3.3 shows that for sands, the dry density has a general inclination first to reduce as moisture content increases, and then to increase to a maximum value with further increase of moisture. The initial reduce of dry density with increase of moisture content can be attributed to the capillary tension influence. At less moisture contents, the capillary tension in the pore water prevents the inclination of the soil particles to shift concerning and be densely compacted.

Lee and Suedkamp (1972) studied compaction curves for 35 soil samples. They observed that four types of compaction curves can be found. These curves are shown in figure 3.4.

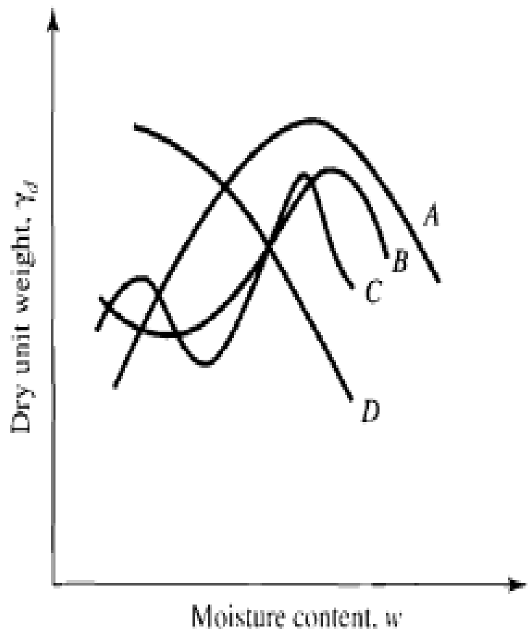


Figure 3.4 Types of compaction curve (Das, 2006)

3.3.2 Effect of Compaction Effort

The compaction energy per unit volume used for the standard Proctor test characterized in section 3.2 can be given as

$$E = \frac{\begin{pmatrix}\text{Number}\\ \text{of blows}\\ \text{per layer}\end{pmatrix} \times \begin{pmatrix}\text{Number}\\ \text{of}\\ \text{layers}\end{pmatrix} \times \begin{pmatrix}\text{Weight}\\ \text{of}\\ \text{hammer}\end{pmatrix} \times \begin{pmatrix}\text{Height of}\\ \text{drop of}\\ \text{hammer}\end{pmatrix}}{\text{Volume of mold}} \qquad (3)$$

If the compaction effort per unit volume of soil is changed, the moisture-unit weight curve also changes. This fact can be demonstrated with the aid of figure 3.5, which shows four compaction curves for sandy clay. The standard Proctor mold and hammer were used to obtain these compaction curves. The number of layers of soil used for compaction was three for all cases. However, the number of hammer blows per each layer varied from 20 to 50, which varied the energy per unit volume.

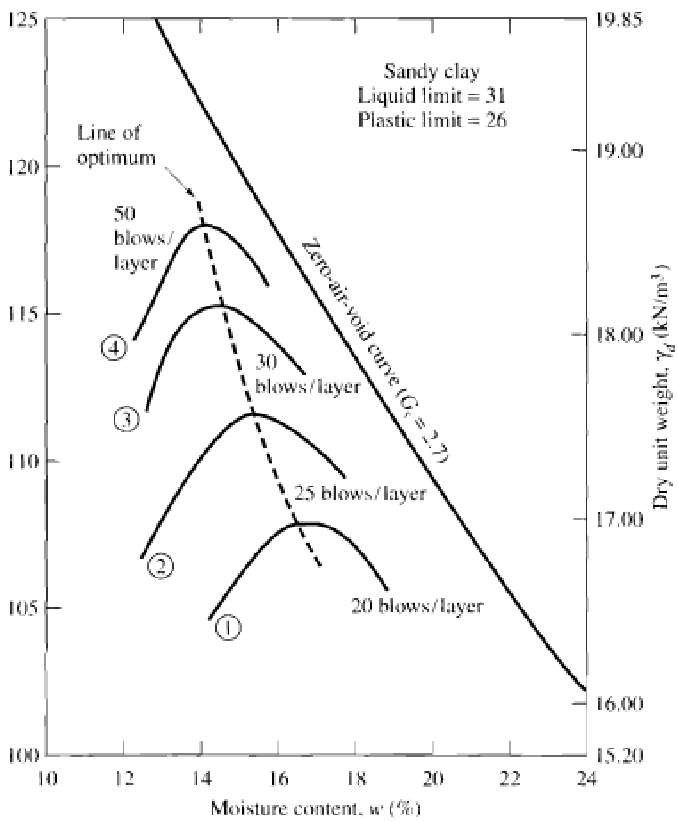


Figure 3.5 Influence of compaction energy on the compaction of sandy clay (Das, 2006)

From the previous observation and figure 3.5, we can look that

1. As the compaction potential is increased, the maximum dry density of compaction is also increased.
2. As the compaction potential is increased, the optimum moisture content is reduced to some extent.

The previous statements are true for all soils. Note, however, that the degree of compaction is not directly proportional to the compaction effort.

3.4 Modified Proctor test

The standard Proctor test was modified to better represent field conditions with the development of heavy rollers and their use in field compaction. This revised version is sometimes referred to as the modified Proctor test (ASTM Test Designation D-

1557). To performing the modified Proctor test, the same mold is used with a volume of 944cm^3 as in the case of the standard Proctor test. However, the soil is compacted in five layers by a hammer that has a mass of 4.54 kg. The drop of the hammer is 457 mm. The number of hammer blows for each layer is kept at 25 as in the case of the standard Proctor test. A summary of the test methods is given in table 3.1.

Table 3.1 Summary of Standard and Modified Proctor Compaction
Test specifications (ASTM D-698 and D-1557)

	Description	Method A	Method B	Method C
Physical Data for the test	Material	Passing No.4 sieve	Passing 9.5mm sieve	Passing 19mm sieve
	Use	Used if 20% or less by weight of material is retained on No.4(4.75mm) sieve	Used if more than 20% by weight of material is retained on No.4 (4.75mm)sieve and 20% or less by weight of material is retained on 9.5mm sieve	Used if more than 20% by weight of material is retained on 9.5mmsieve and less than 30% by weight of material is retained on 19mm sieve
	Mold Vol.	944 cm^3	944 cm^3	944 cm^3
	Mold dia.	101.6mm	101.6mm	101.6mm
	Mold height	116.4mm	116.4mm	116.4mm
Standard Proctor test	Hammer Wt	24.4 N	24.4 N	24.4 N
	Height of drop	305mm	305mm	305mm
	No. of layers	3	3	3
	No. of blows/layer	25	25	25
Modified proctor test	Hammer Wt	44.5 N	44.5 N	44.5 N
	Height of drop	457mm	457mm	457mm
	No. of layers	5	5	5
	No. of blows/layer	25	25	56

3.5 California Bearing Ratio Test

The California Bearing Ratio (CBR) test is a comparatively easy test that is usually utilized to obtain an indication of the strength of a sub grade soil, sub base, and base course material for use in road and airfield pavements. CBR tests are normally conducted on compacted (remolded) specimens, although they may be performed on undisturbed soils or on soil in situ. Remolded specimens may be compacted to their maximum density at their optimum moisture content. Soil specimens may be tested unsoaked or soaked; the latter by immersing them in water for a certain period of time in order that demonstrate very poor soil conditions. The CBR for a soil is the ratio (expressed as a percentage) gained by dividing the penetration stress required to cause a 3-in^2 area piston to penetrate 0.10 in. into the soil by a standard penetration stress of 1000 psi. The CBR may be thought of, therefore, as an indication of the strength of the soil relative to that of crushed rock. The CBR may be expressed in equation as

For 2.5 mm penetration:

$$\%CBR = \frac{\{penetration\ load\ (KN) required\ to\ penetrate 2.5mm\}}{13.5} \times 100 \tag{4}$$

For 5 mm penetration:

$$\%CBR = \frac{\{penetration\ load\ (KN) required\ to\ penetrate\ 5mm\}}{20} \times 100 \tag{5}$$

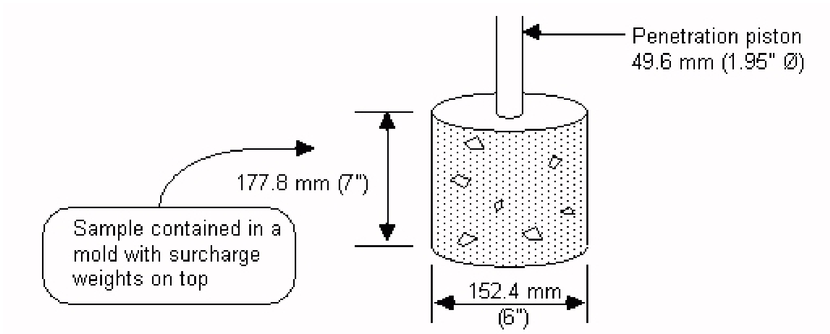


Figure 3.6 CBR sample

Table 3.2 Standard CBR limits

Type of Soil	CBR limit
Clay	1-3
Sandy clay	4-7
Well graded sand	15-40
Well graded sandy gravel	20-60

In calculation of CBR from load penetration curve, sometimes error occurring in the curve, one of the most common errors is that the initial portion of the curve may be concave upward; this upward concavity must be corrected by drawing a tangent to the upper curve at the point of contra flexure (see figure 3.6)

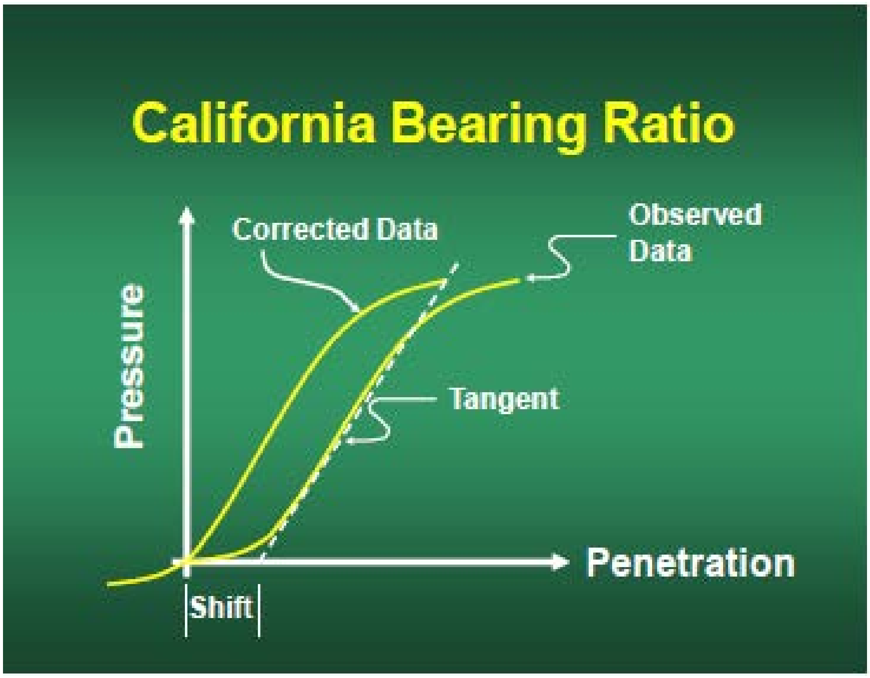


Figure 3.7 Load VS Penetration curve

CHAPTER 4

EXPERIMENTAL STUDY

General

The main goal of the effort in this study is to determine the effects of waste material (i.e., recycled waste expanded polystyrene foams (MEPS)) on compaction properties of soil used in backfilling retaining wall and abutment of bridge in highway construction. Laboratory tests were carried out to attest the decrease in dry unit weight by compaction proctor tests and California bearing ratio CBR test.

4.1 Materials

4.1.1 Soil

River sand: This soil was taken from river which known as river sand. The soil was putted in oven, after sieving its property were well grained sand, Cu=7.83 and Cc=1. The specific gravity of the soil was 2.65. The river sand were passed through #4 sieve (4.75mm) and the gradation shown in the figure 4.1.

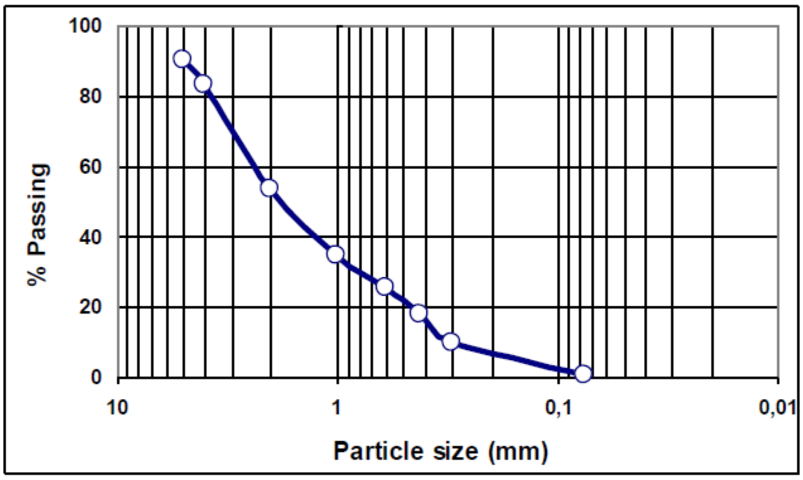


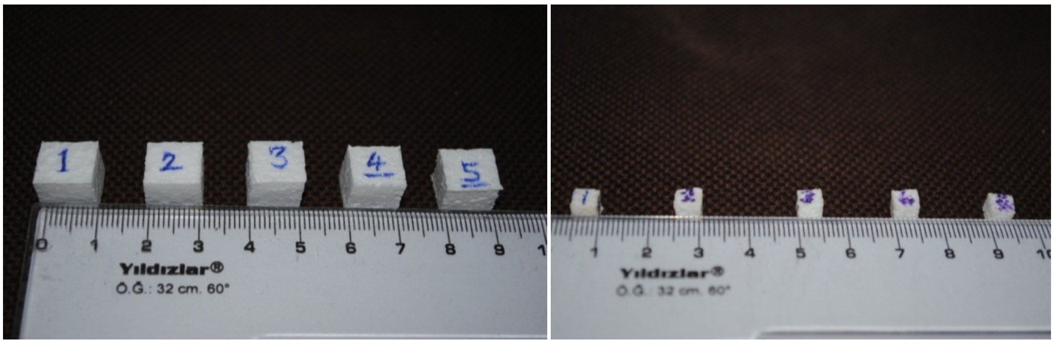
Figure 4.1 Sieve anlysis of river sand used in the tests

4.1.2 Geofoam

Modified expanded polystyrene foam (MEPS): EPS geofoam is a lightweight, solid foam plastic that has been used around the world as a fill for more than 30 years. EPS geofoam is approximately 100 times lighter than most soil and fully (20 – 30) times lighter than other lightweight fill substitutionals. This farthest distinction in density contrasted to other materials makes EPS geofoam an appealing fill material. Because it is a soil substitutional, EPS geofoam embankments can be coated to look like normal sloped embankments or finished to look like a wall. As mentioned before MEPS used in form of 0.5cm^3 and mixed with river sand at a certain percentages. The production of MEPS was prepared by heat treatment as shown in figure 4.2 [1]. The optimum time and temperature was 15 minutes and 130°C respectively.

Figure 4.2 characterization of the changing operation of waste MEPS foams

(Abdulkadir Kan, Ramazan Demirbog˘a, 2009).



a.EPS before heating 1cm^3 b. modified EPS after heating 0.5cm^3

Figure 4.3 Geoafoam (MEPS) sample size

4.1.3 Water

Tap water was used for all type of works.

4.2 Methods

4.2.1 Compaction Test

According to (ASTM methods D 698 and D 1557), both standard and modified compaction test were done on river sand-MEPS mixture during this study at percentages of 0%, 5%, 10%, 15%, and 20% MEPS.

Compaction Test procedure:

1. Relying on the kind of mold that is used to gain a adequate amount of air-dried soil in big mixing pan. For our test nearly about 4.5 kg was enough.
2. Finding the weight of the soil sample as well as weight of compaction mold with its base (without the collar) by utilizing the balance and book the weights.
3. Determine the quantity of initial water to affix by the following method:
   a. Assume water content equal to 8% for first trial.
   b. Calculate water to add from the below equation:

Water to add (in ml) = (soil mass in grams)*8 /100

Where "water to add" and the "soil mass" are in grams. Remember that a of water is equal to approximately one milliliter of water

4. Gauge out the water, add it to specimen, and then alloy it completely into the soil utilizing the trowel till the soil brings a uniform color (see photos B and C in figure 4.4)

Figure 4.4 Compaction instrument and its process (Engineering Properties of Soils Based on Laboratory Testing Prof. Krishna Reddy, UIC)

5. Collect the compaction mold to the base, put some soil in the mold and compact the soil in the number of equal layers appointed by the type of compaction method employed. The number of drops of the rammer per layer

is also dependent upon the type of mold utilized (see table 3.1). The drops should be stratified at a constant average not overriding around 1.5 seconds per drop, and the rammer should supply constant covering of the specimen surface. Attempt to avert rebound of the rammer from the top of the guide sleeve.

6. The soil must fully fill the cylinder and the last compacted layer must stretch a little above the collar joint. If the soil is below the collar joint at the compaction of the drops, the test point should be repeated.
7. Strip the collar and trim off the compacted soil so that it is fully even with the top of the mold utilizing the trowel. Substitute small bits of soil that may run out during the trimming procedure.
8. Weight the compacted soil while it's in the mold and to the base, and book the mass. Find the wet mass of the soil by deducting the weight of the mold and base.
9. Strip the soil from the mold utilizing a mechanical extruder and pick soil moisture content samples from the top and bottom of the specimen. Fill the moisture cans with soil and compute the water content.
10. Put the soil specimen in the big tray and fragment the soil until it seems visually as if it will pass through the #4 sieve, add 2% more water based on the original sample mass, and re-mix as in step4. Repeat steps 5 through 9 until, based on wet mass, a high value is hooked up followed by two somewhat lesser compacted soil masses.
11. For Sand-MEPS mixtures, percentages of 5%, 10%, 15%, and 20%MEPS added to sand for all steps above, to show influence of existing modified geofoam on the test characteristics.

Figure 4.5 Standard Proctor Compaction test for 5%MEPS

4.2.2 CBR Test

According to (Referenced Document: ASTM D 1883), California Bearing Ratio test were done for each of standard and modified proctor test. See figure 4.5

CBR tests are normally performed on remolded specimens, which may be compacted to their maximum density at their optimum moisture contents. The tests have conducted on unsoaked condition at various contents of 0%, 5%, 10%, 15%, and 20% that added to river sand.

CBR Mould and Accessories,

ASTM D1883

Figure 4.6 CBR test machine and CBR Mould

The CBR Test Procedure Adopted

The CBR test is designed to simulate conditions that will exist at the surface of the sub grade. A surcharge (weight) is placed on the surface of the compacted specimen to represent the weight of pavement above the sub grade. However, the sample in unsoaked, the force required to push a standard piston into the soil a specified amount is determined and is used to evaluate the CBR.

- The oven dried material (river sand) which passing through 4.75 mm sieve.
- About 4.5 kg of the soil in the mixing pan was taken.
- MEPS have prepared (see ch.4 material).
- River sand and MEPS mixed at percentages of 0%, 5%, 10%, 15%, and 20% MEPS by weight.
- Water was added such that the moisture content of the specimen was equal to the optimum moisture content of the specimen.
- The mixture have been done up uniformly.

- 56 blows were given for each of 5 layers of sample by 4.89 kg hammer dropping through 450mm evenly spread surface.
- After the 5 layers compaction, the extension collar was removed and the excess soil sample was trimmed. A little sample was taken for the determination of moisture content.
- Then the weight of the sample with the method without the collar was taken.
- The mould containing the compacted sample was then inverted and was clamped to the base plate.
- The surcharge weight was placed over the base plate centrally.
- The mould with the base plate was then placed under the plunger of loading machine and the penetration plunger was kept in contact with soil surface.
- Then the dial gauges were set into position to fix to zero then, the load was applied through the plunger at the uniform rate of 1.25 mm/min.
- Corresponding reading in dial gauge reading were recorded at 0, 0.5,1.0,2.0,2.5,3.0,4.0,5.0,1.5, and 7.5 mm reading of penetration reading dial gauge.
- Then the load was released and mould was removed from the loading machine.

A curve of penetration Load (KN) versus penetration (mm) should be prepared by plotting values of penetration load on the piston versus corresponding values of penetration, both on an arithmetic scale.

Figure 4.7 Reading Loads during CBR test

CHAPTER 5

TEST RESULTS AND DISCUSSION

5.1 Standard Proctor Test

5.1.1 Maximum Dry Unit Weight

Standard Proctor Test has performed on River Sand-MEPS mixture, its results shown in figure 5.1. After mixing MEPS with river sand at percentages of 0%, 5%, 10%, 15%, and 20%, as we expected, max.dry unit weight of the mixture was decreased from 1.9 g/cm^3 to 0.947 g/cm^3, there was a high difference of specific gravity between river sand and MEPS and under the effect of compaction this decrease was observed (see figure 5.2). Density of EPS before treatment was 0.06 $g/cm^{3,}$ however, after thermal process the density of MEPS was 0.48 g/cm^3 that increased four times. The density of river sand was 1.907g/cm^3.

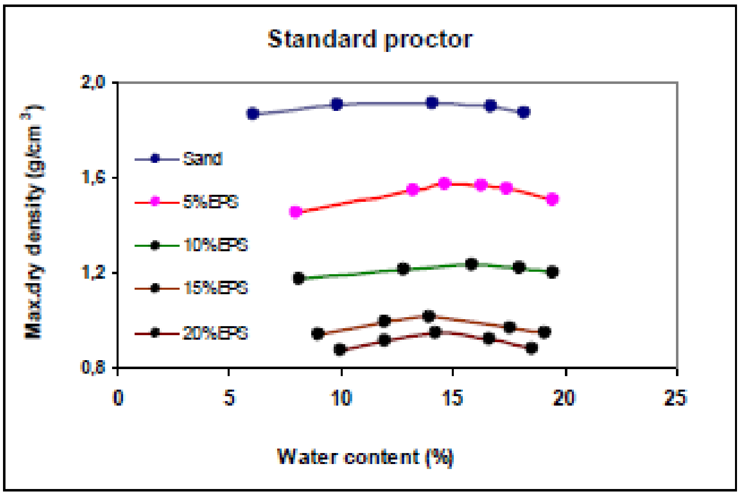


Figure 5.1 Standard Proctor Test

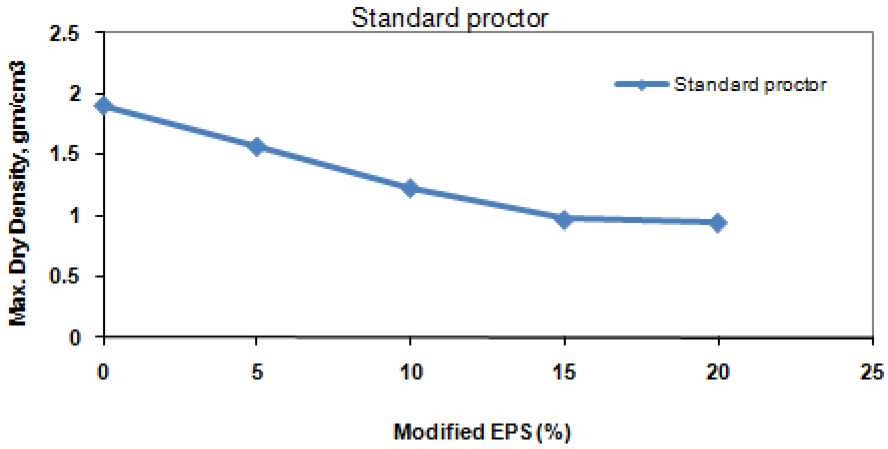


Figure 5.1 Maximum Dry Density and MEPS% relation

5.1.2 Water Content

When the MEPS% was increased, the optimum moisture content changes was not too much as we expected. However, the relationship between MEPS and optimum water content is not linear (figure 5.3) , because of the existency of more voids within the samples (i.e., MEPS were angular and equal shape(0.5cm^3)) that made the pearmeability to be randomly occured during compaction.

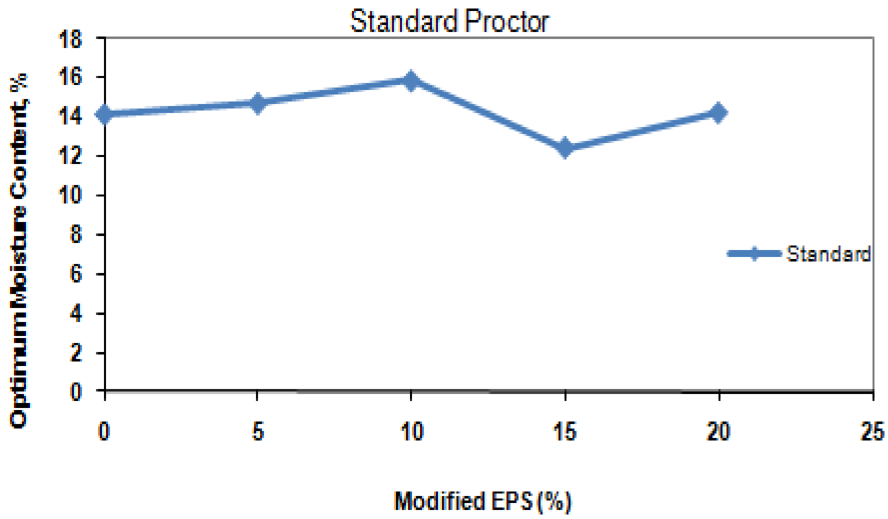


Figure 5.3 Optimum Moisture Content relations with MEPS%

5.2 Modified Proctor Test

5.2.1 Max. Dry Unit Weight

Modified Proctor Test which is heavy method was conducted on river sand-MEPS mixture for percentages of 0%, 5%, 10%, 15%, and 20% of MEPS and the results shown in figure 5.4. Maximum dry density decreased from 2.14 g/cm^3 to 1.014 g/cm^3 with increasing percentage of MESP (see figure 5.5), the reason was different between the soil and MEPS in weight that modified geofoam increased within the mold in each test, so the volume of mold was constant and maximum dry unit weight have been direct relation with weight of sample. The value of R^2 was 0.947 that a good indicator for their relation.

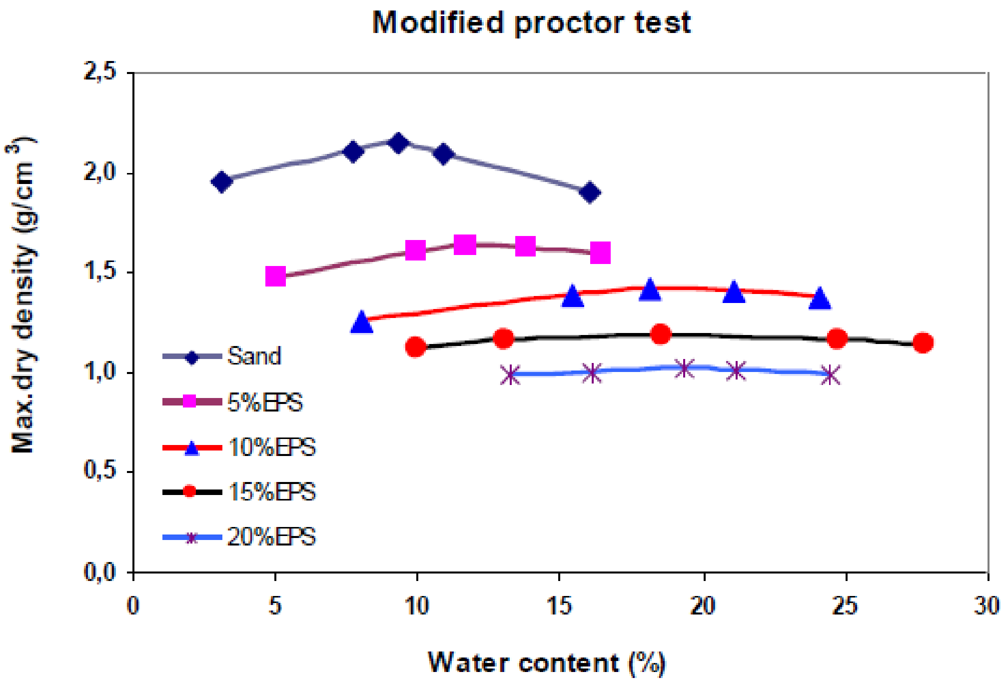


Figure 5.4 Modified Proctor Test

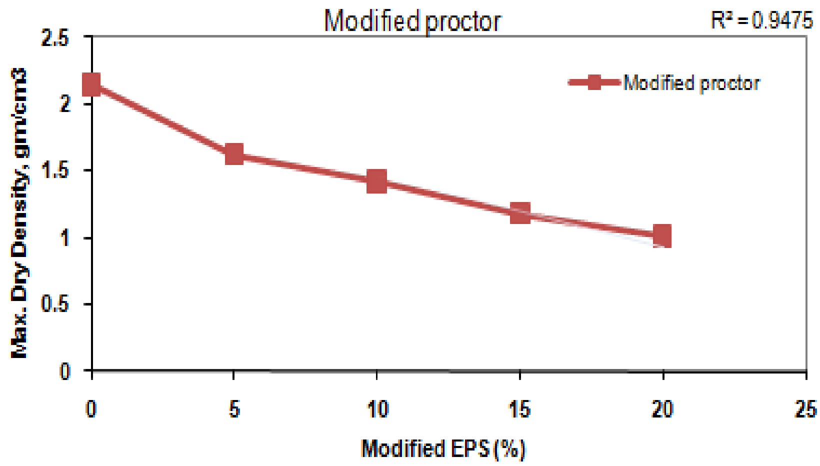


Figure 5.5 Max. Dry Unit Weight relationship with MEPS%

5.2.2 Water Content

The relation between optimum moisture content and MEPS% of modified proctor was not linear and more dogleg than of standard proctor test (see figure 5.6). The heavier hammer of test has affect on this relation because it was compact more amount of mixture within the mold. The MEPS% have great role on water content because of the size of modified geofoam pieces which were angular and same volume that made voids have been increased. Those voids might be a path of water discharging.

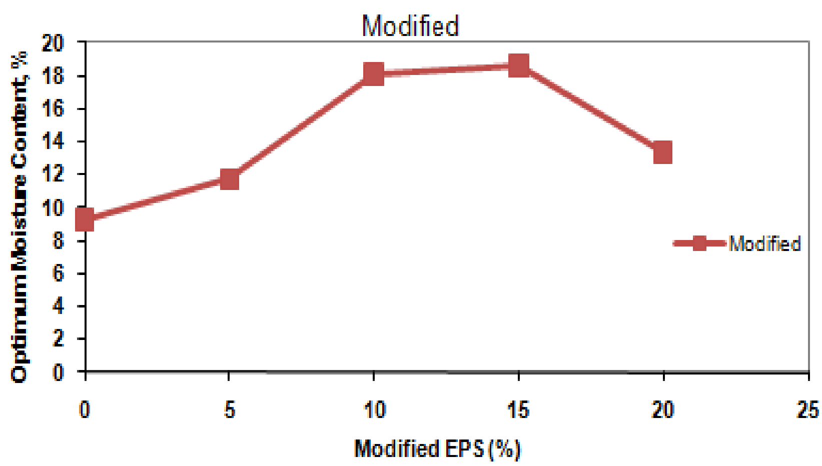


Figure 5.6 Optimum moisture content relations with MEPS%

5.3 California Bearing Ratio

The CBR values of the river sand without any addition of geofoam were found to be 39.9%and 48% for 2.5mm and 5mm penetration respectively for standard proctor; however for modified proctor the CBR values were 49% and 61% for 2.5mm and 5mm penetration respectively. It is visible that the piston load reduces with increase in MEPS percentage for same penetration (for example last reading in each test which was 7.5mm). It can be also noticed that the piston load of sample with 20% of MEPS system was almost three times as low as of sample without MEPS system (see figure 5.7).

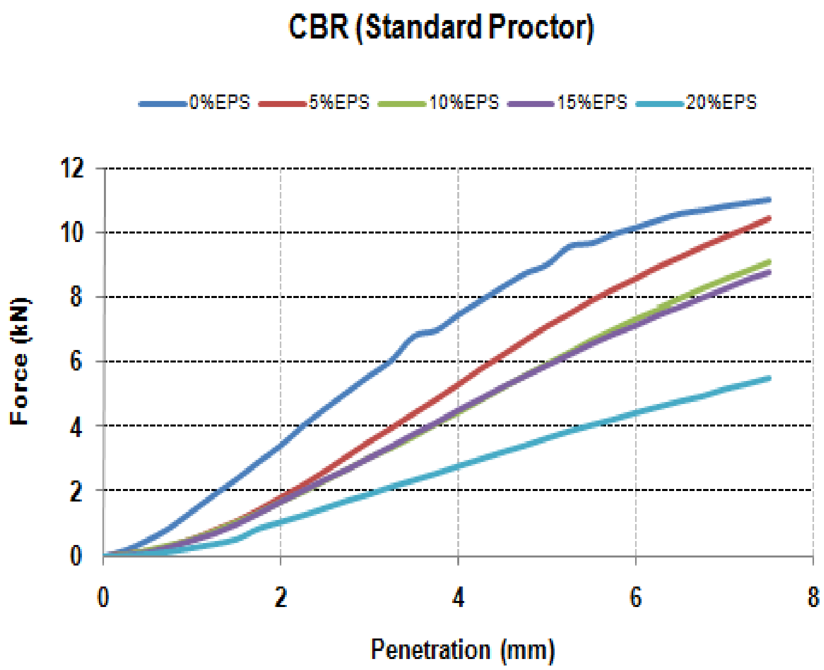


Figure (5.7a) Relationship between load and penetration for standard proctor compaction method in CBR test.

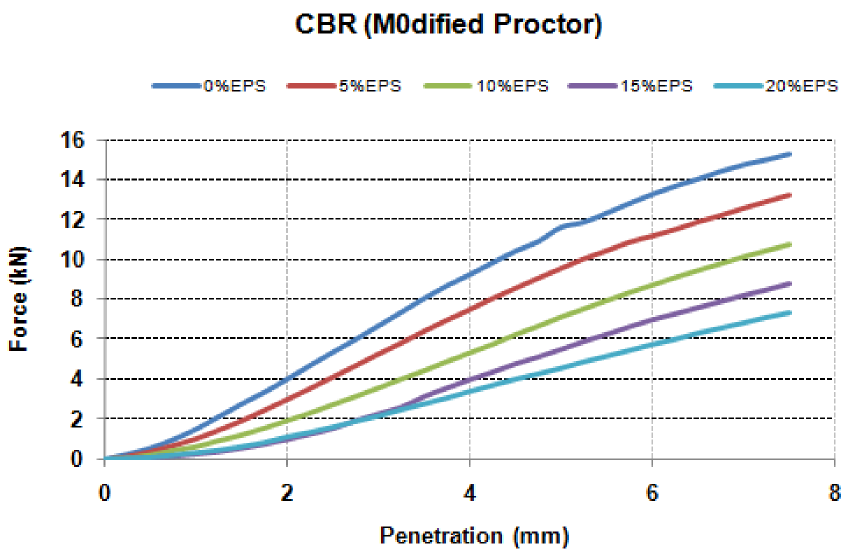


Figure (5.7b) Relationship between load and penetration for modified compaction method in CBR test.

Decrease in strength of soil due to inclusion of waste geofoam after treatment could also be expressed in terms of piston load. Decrease in piston load due to the presence of MEPS for all contents at the same reading (say 7.5mm penetration) has been presented by a dimensionless expressing known as piston load ratio (PLR), which is defined as ratio of maximum piston load at 7.5mm penetration for sand-MEPS mixture (L_{S+EPS}) to maximum piston load at same penetration for river sand only (L_S) see figure 5.8.

$$PLR = \frac{L_{S+EPS}}{L_S} \tag{5.1}$$

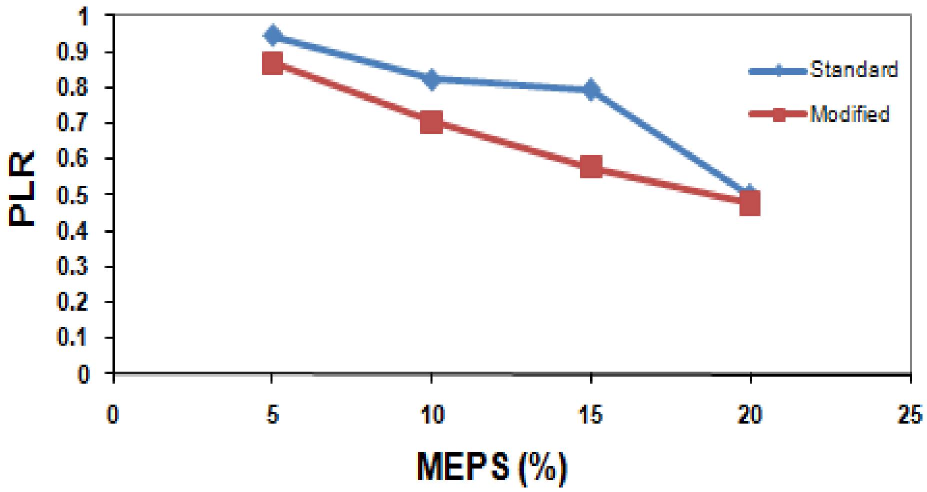


Figure 5.8 Relationship between PLR and MEPS% for standard and modified proctor.

The CBR values after correction were decreased by increasing MEPS% for both standard and modified compaction tests as shown in figure 5.9, because the MEPS has the property of re-actable, soft and absorbs the impact load during applying load which have made this decreasing of CBR values (i.e.; decrease in strength) see figure 5.10.

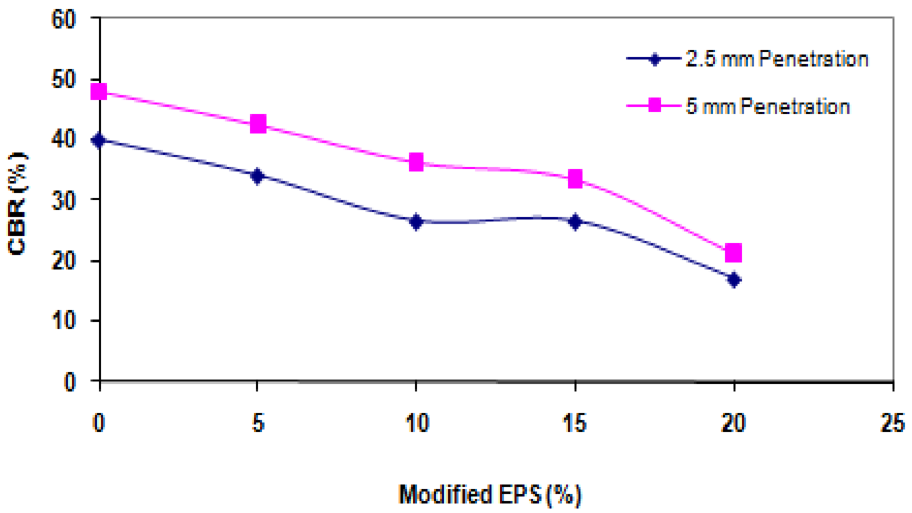


Figure (9-a) Decreasing CBR values by increasing MEPS% for standard compaction method.

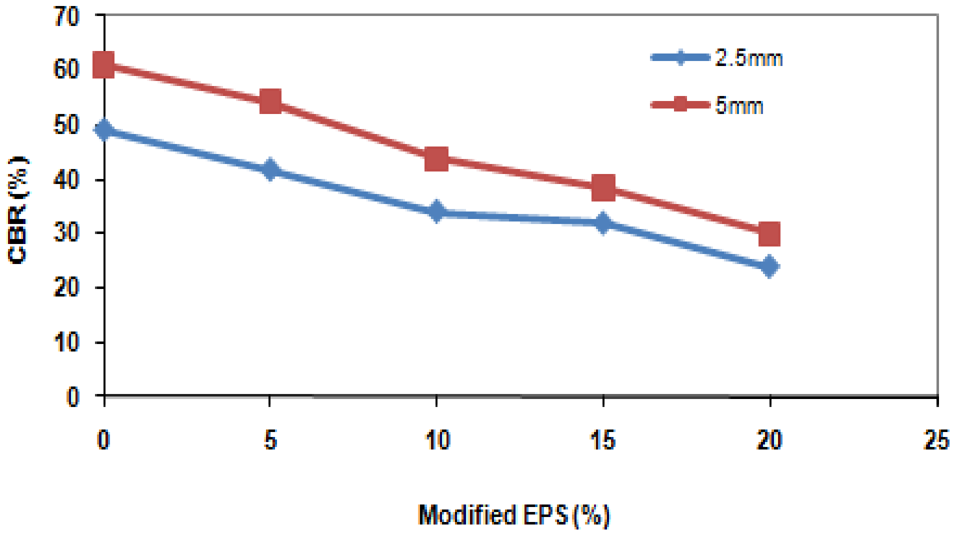


Figure (9-b) Decreasing CBR values by increasing MEPS% for modified compaction method.

CHAPTER 6

CONCLUSION

MEPS were mixed with river sand and tested to determine change in compaction properties such as optimum moisture content and maximum dry density. Also, CBR values of the same mixture were investigated. Based on the test results, the following conclusions were drawn:

1. For both standard and modified proctor tests, as the percentage of MEPS increased, the maximum dry densities were decreased. Reduction in the density for standard proctor was 96% when MEPS was 20%. This reduction for modified proctor test was higher and it was around 113% at 20% MEPS inclusion in sand because of the effect of weight of MEPS which was much lighter than sand.
2. The change of optimum moisture content with increasing percentages of MEPS was not too much for both standard and modified proctor. Although, this change for modified proctor was more than of standard proctor according to increasing MESP% because of the amount of compacted mixture (sand-MEPS) within the mold under effect of the hammer, the modified proctor hammer was heavier than standard proctor hammer. More amount of mixture has more voids due to angularity of MEPS that made water discharged easily.

3. For standard proctor, the CBR values were decreased from 41% to 17% for 2.5mm penetration and for 5mm penetration were decreased from 48% to 21%. However, for modified proctor the CBR values were decreased from 49% to 22% for 2.5mm penetration, while for 5mm penetration the CBR values were decreased from 60% to 29%. Furthermore, all CBR values within the acceptance limit.
4. The mixture of Sand-MEPS can be used as backfill material for retaining wall. When the backfill material weight of the retaining wall is decreased, the reinforcements and dimensions of the retaining wall decreased too. Leading to lower cost of design of it. However, The existence of MEPS within the backfill helps the discharge of water behind the retaining wall that influences the lowering effective pressure on the retaining wall
5. The mixture can be also used as fill material in abutment of bridges. However, according to unified classification system the mixture can be used as base and subbase material in roads and runways especially when soils were soft or compressible to reduce settlement.
6. For environmental status, waste material (i.e.; EPS) can be used. Most recyclable material obtained easily, sometimes they don’t have cost or very cheap.

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