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THE INFLUENCE OF WASTE CONSTRUCTION MATERIALS USAGE ON HIGHWAYS SUBGRADE LAYER

تأثير استخدام المخلفات الصناعية علي طبقة تأسيس الطرق

BY

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ABSTRACT

Now-a-days disposal of different wastes materials produced from different industries is a great problem. These materials pose environmental pollution in the nearby locality. Their potential for use in the construction of highways suggests that valuable benefits in terms of economic and environmental gains are possible. Two types of wastes materials, rice husk and sawdust were used to improve the properties of the clayey subgrade soil. A procedure was adopted to quantify the beneficial effect of subgrade soils stabilization benefits which base on the extension of pavement service life and reduction in the base course thickness. Results show that both types of wastes materials helps in great improvement of soil properties as California bearing ratio and unconfined compressive strength to use in the construction of highways.

الملخص العربي

يحتوي هذا البحث علي دراسة معملية لاستخدام نوعين مختلفين من المخلفات الصناعية لبحث مدى الاستفادة منها في تثبيت طبقة التأسيس لنظام الرصف مع دراسة كل نوع من المثبتات علي حدة لاستخدامها في تحسين خواص التربة الطينية الضعيفة المستخدمة في هذه الدراسة.وقد تم اختيار مجموعتين من المثبتات منها قشر الأرز ونشارة الخشب بنسب مختلفة. وتمت دراسة المحتوي الأمثل الذي يؤدي إلي الوصول إلي أعلي معاملات المتانة للتربة المثبتة. وقد تم إبتكار طريق للتقدير الكمي لفوائد التثبيت بدلالة الزيادة في عمر الرصف أو النقص في السمك التصميمي. ويمكن إستخدامها أثناء التصميم لتعطي المصمم بدائل مختلفة للتصميم وكذلك كيفية تقييمها وتحديد أولويات التصميم. وكذلك إشتمل البحث علي مثال تطبيقي لتوضيح وشرح خطوات طريقة التقدير الكمي لفوائد التثبيت. حيث أشارت النتائج أن كلا من نوعي المخلفات المستخدم لهما الأثر الكبير في تحسين خواص اللدونة ومقاومة التحمل ويمكن استخدامها في أعمال الطرق.

Keywords: Stabilization, Subgrade Soil, Rice Husk, Sawdust, Beneficial Benefits and KENPAVE.

1. INTRODUCTION

In order to increase the life and the quality of the pavement, improving the strength and the characteristics of highways subgrade soil should be occurred by using of soil-stabilization. Soil stabilization process is mainly practiced in road construction to improve certain undesirable properties of soils, such as excessive swelling or shrinkage, high plasticity and difficulty in compacting [1]. Soil-stabilization is carried out by physically mixing additives with the surface layers. Additives include natural soils, industrial by-products or waste materials, cementations and other chemicals, which react with each and/or the ground [2]. Since in flexible pavement, the bituminous concrete and it's under courses cannot rely on the bending resistance of a slab for load transport, but they must distribute load downward through the pavement to the subgrade soil. Additional strength in the subgrade soil can lead to a prolonged pavement life [3]. Stabilization works are being for the improvement of sub-base and base materials in order to reduce the required overall pavement thickness [4].

The have been many techniques for the safe disposal of the waste materials but we still need to take advantages of them and re-use as environmental friendly through the use with the soil as stabilizers. Information about the use of recycled waste materials (rice husk, rice straw and sawdust) which derive from rice cultivation and timber industry, in ground improvement is limited over the world. The have been few previous studies which investigated the use of these wastes in ground improvement. Rice hush and fly ash were used as a stabilizer to upgrade expensive soil as a construction material. When the rice husk content was increased from 0 to 12%, the unconfined compressive stress increased by 97% and the value of California Bearing Ratio improved by 47%. This conclusion was found when the fly ash content equal to 25% [5]. In the other side, the rice husk and lime sludge were used in road construction, can be are liable solution for solid waste pollution problem. The effect of use of rice husk and lime sludge on consistency limit is to increase the liquid limit, plastic limit and decrease the plasticity index of the soil. The value of plasticity index of the soil decreased from 12.28 to 8.84 and the compressive strength increased by 146% when 10% rice husk and 16% lime sludge were added [6]. Three different types of waste materials; rice straw, rice husk and sawdust were used to stabilize the subgrade soil. The results indicated that the subgrade soil stabilization with rice husk found an increase in the unconfined compressive strength as well as the modulus of elasticity. Also, it was found that stabilization with rice straw indicated lower values of the unconfined compressive strength or the modulus of elasticity if compared with other investigated stabilizers. Also, the results of the laboratory investigation have been used to adopt as approach to quantify the beneficial effect of different stabilizers [7].

The goal of this study is centered on the improvement of the properties of clay soil with low plasticity and having very poor properties which covers large area of Egypt. This weak soil is creating many problems for construction of roads; therefore, it should be stabilized before establishing new construction of roads. Soil stabilization was carried out by using both rice husk and sawdust to act as a good subgrade soil for all highway subgrades. Moreover, both rice husk and sawdust are available in large quantities in Egypt. The selected soil samples were taken from different parts of Kafr El-Sheikh city. Some samples were mixed with rice husk and others with sawdust in different percentages ranging from 4% to 20% by weight. Tests were performed on each sample to determine the properties and strength of the stabilized and unstabilzed subgrade soil. The beneficial benefits of subgrade soil stabilization in pavement systems should be quantified. This is should be investigated either in terms of extension of service life of pavement or in terms of reduction in the thickness of pavement layers. Comparisons were held and a set of conclusions and recommendations are listed to enable engineers in design and supervising highway construction to reach as safe, convenient and economic construction.

2. USED MATERIALS AND TESTING PROGRAM

Soils sample were taken in a distributed condition from a depth of one meter below the ground surface with shovels. The soil samples were placed in plastic bags and transported to the laboratory of "Higher Institute of Engineering and Technology- Kafr El-Sheikh" for testing. The physical properties of the selected soil are shown in Table (1). The table shows that the soil is A-6 according to (AASHTO M 145-91) [8] and it is (CL) according to the Unified Soil Classification System (USCS).

Two stabilizing materials, rice husk and sawdust were used to stabilize the selected soil. Rice husk is an outer shell of a grain of barely and rice produce large quantities each year received a great burden upon being discharged in addition to being poor in nutritional value and represents 20% of the weight of grain and thus the quantity produced annually is estimated their estimated hundreds of thousands of tons. A large quantity of husk is available as waste from rice milling industries. This can be used as an industrial raw material, for example, as an insulating material. Another group was considered for stabilization of investigated soil with different percentages of rice husk. Exhaustive studies were carried out on various aspects of rice husk whereas only very limited information on its physical and thermal properties are available these information were collected from Botany Department-Faculty of Science-Mansoura University [7]. The composition of rice husk on dry basis is shown in Table (2). Sawdust and wood shavings are waste products resulting from wood processing. Very promising is the use of waste products as stabilization of soil directly in the place where the waste has been produced. Another group was considered for stabilization of investigated soil with different percentages of sawdust [7].

The selected soil samples were mixed with rice husk and others with sawdust with percentage of 4%, 8%, 12%, 16% and 20% by weight for the two types of the different groups of stabilizers. The following tests were performed:

• Liquid Limit, Plastic Limit and Plasticity Index were determined as per ASTM D-4318 [9];

• Standard Compaction Test to determine the maximum dry density and optimum moisture content according to the ASTM D 1557 [10];

• California Bearing Ratio (CBR) Test according to the AASHTO test T193 [11]; and

• The Unconfined Compressive Strength according to the ASTM D 2166 [12].

3. ANALYSIS AND DISCUSSION OF RESULTS

3.1 Plasticity Properties

Summary of test results are given in Figure (1) and Figure (2). It can be seen that for an amount equals 20% of either rice husk or sawdust was required to increase plastic limit and reduce both the liquid limit and plasticity index.

3.2 Maximum Dry Density and the Optimum Moisture Content

The effect of both rice husk and sawdust on the maximum dry density and optimum moisture content are shown in Figures (3, 4, 5 and 6). Results shown in these Figures indicate the following:

(1) The Effect of Rice Husk

The addition of greater amounts of rice husk decreased slowly the dry density. It was decreased by about 1.5% by adding 4% of rice husk. By adding 20% of rice husk, the maximum dry density was decreased by about 10%, as shown in Figure (3). The above results mean that the maximum dry density was decreased by adding greater amounts of rice husk. The reason for the decrease in the maximum dry density is attributed to the lower value of specific gravity of rice husk in comparison to that of the soil. The optimum moisture content of the soil was increased with the increase in proportions of rice husk in the soil, as shown in Figure (4).

(2) The Effect of Sawdust

The addition of greater amounts of rice husk decreased slowly the dry density. It was decreased by about 9% by adding 4% of rice husk as shown in Figure (5). Also, it was conclude that, by adding 20% of rice husk, the maximum dry density was decreased by about 21.3%. The above results mean that the maximum dry density was decreased by adding greater amounts of rice husk. The reason for the decrease in the maximum dry density is attributed to the lower value of specific gravity of rice husk in comparison to that of the soil. The optimum moisture content of the soil was increased with the increase in proportions of rice husk in the soil, as shown in Figure (6).

3.3 California Bearing Ratio (CBR)

The California Bearing Ratio is one of the most convenient and widely methods used to evaluate soil strength. A summary of obtained CBR values for different samples were shown in Figure (7) and Figure (8). From Figure (7), it could be seen that, the CBR value was increased by 275% when 4% of rice husk was added. In the other side, by adding 20% of rice husk, the CBR value was increased by about 450%. In the case of using the sawdust as an additive, the CBR value was increased by 120% when 4% of sawdust was added, as shown in Figure (8). On the other hand, by adding 20% of sawdust, the CBR value was increased by about 210%. Generally, rice husk give a greater CBR value as compared value than using sawdust.

3.4 The Unconfined Compressive Strength

A summary of the obtained unconfined compressive strength values for different samples were shown in Figure (9) and Figure (10). From Figure (9), it could be seen that, the value of unconfined compression strength was increased by 3% when 4% of rice husk was added. Also, it was found that, by adding 20% of rice husk, the value of unconfined compression strength was increased by about 20%. In the case of using the sawdust as an additive, the value of unconfined compression strength was increased by 2% when 4% of sawdust was added, as shown in Figure (10). In the other side, by adding 20% of sawdust, the value of unconfined compression strength was increased by about 13%. Generally, rice husk give a slightly greater strength as compared value than using sawdust.

3.5 The Modulus of Elasticity

The results of unconfined compression tests were plotted in the form of stress-strain curves for soils under use of different percentages of stabilizers. These curves were used to determine the unconfined compressive strength (failure stress) and also the modulus of elasticity of soil under different specific conditions. It should be noted that the modulus of elasticity is usually calculated from the straight portion of the stress-strain curve. For most cases, however, the stress-strain curve of the soil will not be straight for any appreciable distance but rather will be curved. So, the modulus of elasticity was calculated corresponding to initial tangent of the stress-strain curve [7]. A summary of the obtained modulus of elasticity values for different samples were shown in Figure (11) and Figure (12). It could be seen that, the value of the modulus of elasticity was increased by 2% when 4% of rice husk was added, as shown in Figure (11). In the other side, by adding 20% of rice husk, the value of the modulus of elasticity was increased by about 75%. In the case of using the sawdust as an additive, the value of the modulus of elasticity was increased by 1% when 4% of sawdust was added, as shown in Figure (12). Also, it was found that, by adding 20% of sawdust, the value of the modulus of elasticity was increased by about 70%. Generally, rice husk give a slightly greater the modulus of elasticity as compared value than using sawdust.

4. QUANTIFICATION OF SUBGRADE SOILS STABILIZATION BENEFITS

Computation of stresses, deflections and strains in a flexible pavement due to traffic loading is an important aspect of mechanistic approach. After the advent of high-speed computer, several computer programs have been developed for computing the stresses and strains in the pavement system. Layered elastic theory is the simplest and most widely used in pavement analysis [13]. In this part of study, KENPAVE software was used to adopt the stress-strain analysis for a typical cross-section of a pavement where, the subgrade was stabilized with different stabilizers categorized in the present study. A procedure was adopted in order to quantify the beneficial benefits of subgrade soil stabilizations. A solved example was taken to illustrate the procedure based on actual case on Kafr El-Sheikh city subgrade soil.

4.1 Pavements Failure Criteria

Structural failures in flexible pavement are of two types, surface cracking and rutting. Cracking is due to fatigue, which occurs due to the repeated applications in bound layers generated by traffic. Rutting develops due to accumulation of pavement deformation in various layers along the wheel path [7]. The horizontal tensile strain at the bottom of the bituminous layer and the vertical compressive strain on the subgrade are considered as indices of fatigue and rutting of the pavement structure, respectively [1]. Most of the empirical damage models relate both the horizontal tensile strain and the subgrade vertical strain to long-term pavement performance [7].

4.2 Evaluation of Stabilization Benefits

The benefits of pavement layers stabilization or reinforcement are applicable for situations where pavement life is governed by excessive pavement surface deformation due to the development of permanent strain in the unbound aggregate and subgrade layers [1]. Previous experimental work has demonstrated that the values of benefits are strongly dependent on pavement design parameters such as thickness of the structural section, its properties and type of the use stabilizing materials [14]. Many studies [15, 16] quantified benefits of stabilization or reinforcement in terms of traffic benefit ratio (TBR). The TBR may be defined in different terms to represent the gained benefit in specified design element like service life and surface rutting of stabilized pavement as compared to an equivalent unstabilized pavement. So, the TBR is expressed as an extension in service life of the pavement section. It can be determined for both fatigue and rutting criteria.

4.3 Worked Example

This section demonstrates a solved example to illustrate the proposed procedure for quantification of stabilization of subgrade soil in flexible pavements. The solved example concerns Kafr El-Sheikh city subgrade soil where a typical designed pavement section is selected for the analysis which is actually applied in the practice. KENPAVE software was used for the stress-strain analysis of the section. Through this software, loading conditions were assumed as a single axel load with 40 KN wheel load (single tire) and contact radius of 15 cm were used in this analysis of all stabilized and unstabilized sections. The input data (the material properties of different pavement layers) were assumed as shown in Table (3). A typical section for pavements in Kafr El-Sheikh city in Egypt subgrade soil is shown in Figure (13). The following steps summarize the adopted procedure for optimization of the stabilized subgrade pavement section.

Step 1: Extension in Service Life

By running the KENPAVE software with the previous indicated inputs, vertical compressive strains, horizontal tensile strain and critical strain for the unstabilized and the stabilized subgrade soil were calculated. The value of TBR (extension in service life) was determined based on both rutting and fatigue criteria. The values of TBR for the two types of stabilizers are shown in Table (4). The results indicated that the pavement life will increase by 1.67 times with stabilization of subgrade soil with 20 % rice husk. In the case of using 20% sawdust as an additive to the subgrade soil, the pavement life will increase by 1.65 times. These reflect the benefits of stabilization in terms of increase the service life.

Step 2: The Same Service Life and Reduction in Thickness

Assuming that the service life of stabilized section is equal to the service life of unstabilized section in the second design strategy, this will lead to a reduction in thickness of the base course. The stabilized and unstabilized sections were analyzed for various thickness of base course and the same asphalt thickness. Figure (14) shows the plot relating the base thickness to the vertical compression strain for different cases of stabilizers as well as the unstabilized sections which can be considered as a design chart to find out the corresponding base thickness. To use this chart for design of stabilized sections, the vertical compressive strain at the top of subgrade for unstabilized section, which equal to 1.09×10-2, will be considered as a key value. By keeping same value for stabilized sections also, different design alternatives may be evaluated and analyzed separately.

For example, consider the first case when the subgrade soil was stabilized with 20% rice husk, the thickness of the base layer was reduced. Figure (14) may be used to deal with this case. For a vertical compressive strain of 1.09×10-2, the required base layer thickness will be almost 36.6 cm. Also, when the subgrade soil was stabilized with 20% sawdust, the thickness of the base layer was reduced to 36.9 cm by using Figure (14). This means that the stabilized section can perform with lesser thickness to extend the same service life as the unstabilized section. It is found that the subgrade soil was stabilized with 20 % rice husk can save 8.5% of the thickness required in the base layer if the same service life is assumed. In the other side, when the subgrade soil was stabilized with 20 % sawdust can save 7.75% of the thickness of the base layer if the same service life is assumed.

5. CONCLUSIONS

Two different types of waste materials, rice husk and sawdust, were used to stabilize the selected subgrade soil in order to improve the workability of clayey subgrades The laboratory results investigations have been used to adopt an approach to quantify the beneficial effect of different stabilizers. The important findings of this study are summarized below.

1. For using of either rice husk or sawdust in improvements of subgrade soil properties, california bearing ratio and the unconfined compressive strength were enhanced with the increase of it's content. Generally, rice husk give a greater value of california bearing ratio as compared value than using sawdust. In the other side, rice husk give a slightly greater strength as compared value than using sawdust.
2. The modulus of elasticity was increased with the increase of rice husk and sawdust contents. Generally, rice husk give a slightly greater the modulus of elasticity as compared value than using sawdust.
3. The mechanistic design approach and subsequently, the available software provide many alternative to the designer to quantify stabilization benefits in terms of traffic benefit ratio or layer thickness reduction.
4. The possibility of safe disposal of wastes harmful to the environment through their use as stabilization of soil.

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Table (1): Physical Properties of the Subgrade Clayey-Soil

Test type	Properties
Atterberge Limits: Liquid Limit %, Plastic Limit %, Plasticity Index %	 38 26 12
Classification: AASHTO, Unified	 A-6 CL
Compaction Properties: Maximum Dry Density, t/m^3, Optimum Moisture Content %.	 1.55 18
Specific Gravity	2.198
Unconfined Compression Strength (kg/cm^2) Modulus of Elasticity (MPa)	1.51 3.1

Table (2): Composition of Rice Husk on Dry Basis (Botany Department-Faculty of Science-Mansoura University) [1]

Element	Mass Fraction %
Carbon	41.44
Hydrogen	4.94
Oxygen	37.32
Nitrogen	0.57
Silicon	14.66
Potassium	0.59
Sodium	0.035
Sulfur	0.3
Phosphorous	0.07
Calcium	0.06
Iron	0.006
Magnesium	0.003

Table (3): Properties of the Materials of the Pavement Layers Used in the Worked Problem

Layer	E-value (MPa)		
	Unstabilized	Stabilized Subgrade With 20% Rice Husk	Stabilized Subgrade With 20% Sawdust
Kafr El-Sheikh subgrade soil	3.1	5.45	5.24
Base Course	6.5	6.5	6.5
Bituminous	26	26	26

Table (4): The TRB Values for the Subgrade Soil Based on Rutting and Fatigue

Alternative	Critical Strains		TBR	
	Rutting	Fatigue	Rutting	Fatigue
Subgrade Soil Without Stabilization	1.09×10^{-2}	1.39×10^{-2}	1.0	1.0
Stabilization of Subgrade with 20% Rice Husk	0.97×10^{-2}	1.40×10^{-2}	1.67	0.97
Stabilization of Subgrade with 20% Sawdust	0.98×10^{-2}	1.41×10^{-2}	1.55	0.97

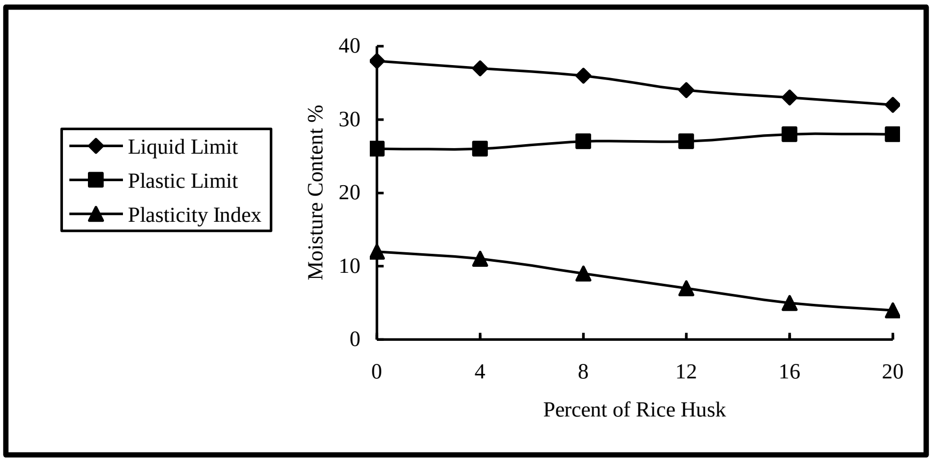

Figure 1: The Effect of Rice Husk Content on Atterberge Limits

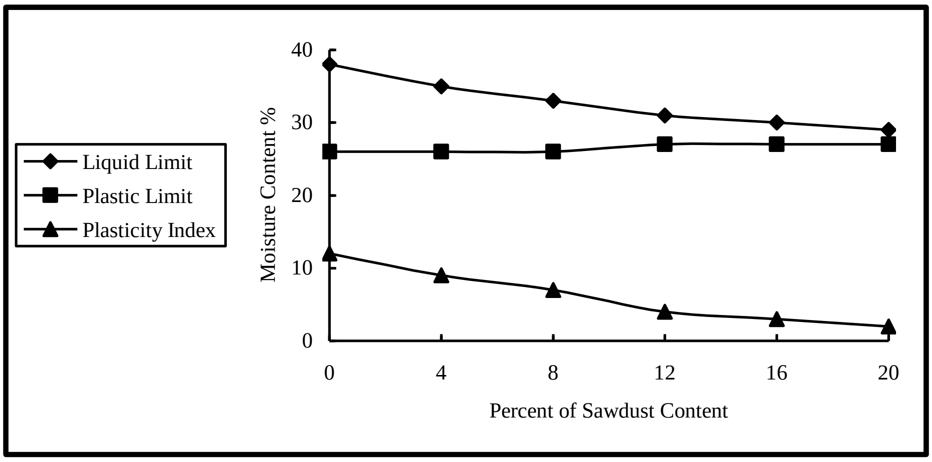

Figure 2: The Effect of Sawdust Content on Atterberge Limits

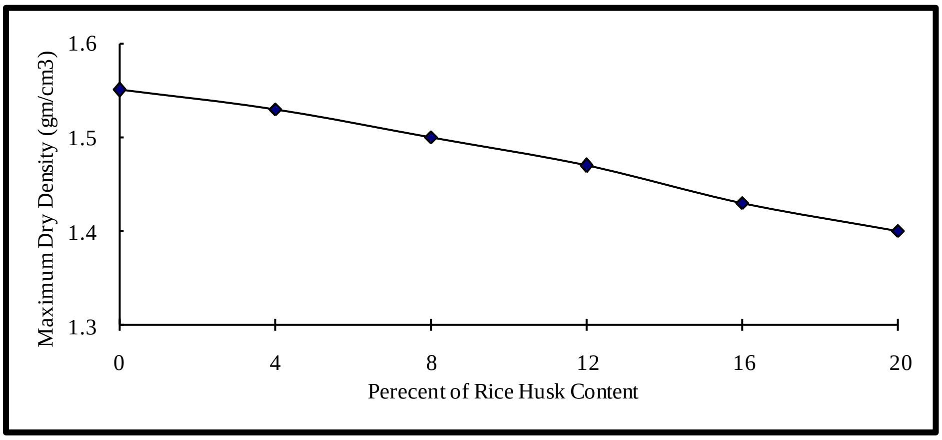

Figure 3: The Effect of Rice Husk Content on the Maximum Dry Density

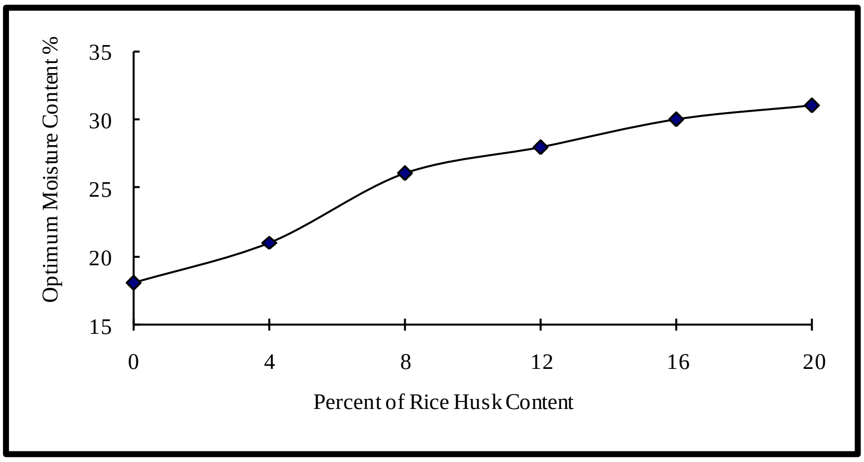

Figure 4: The Effect of Rice Husk Content on the Optimum Moisture Content

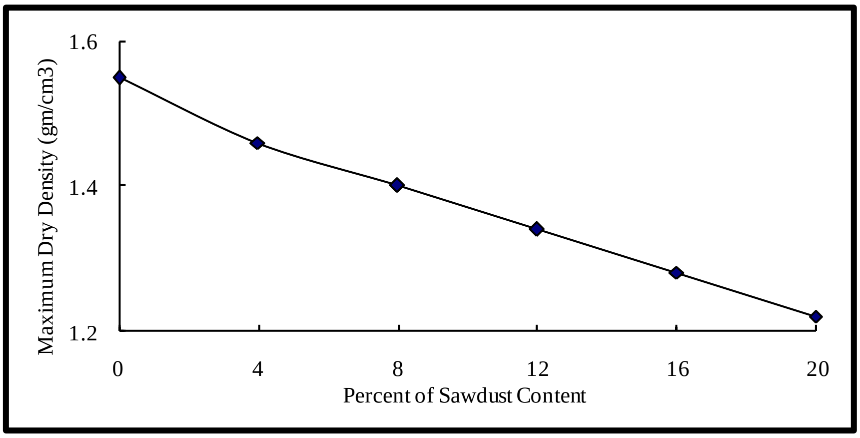

Figure 5: The Effect of Sawdust Content on the Maximum Dry Density

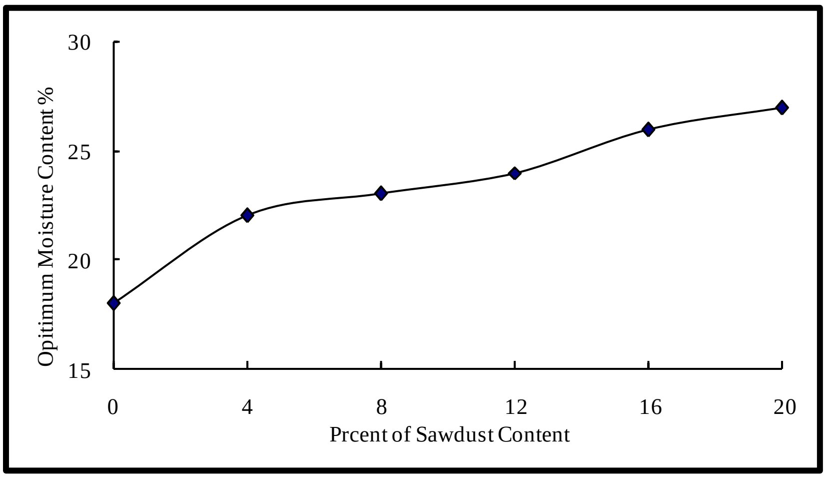

Figure 6: The Effect of Sawdust Content on the Optimum Moisture Content

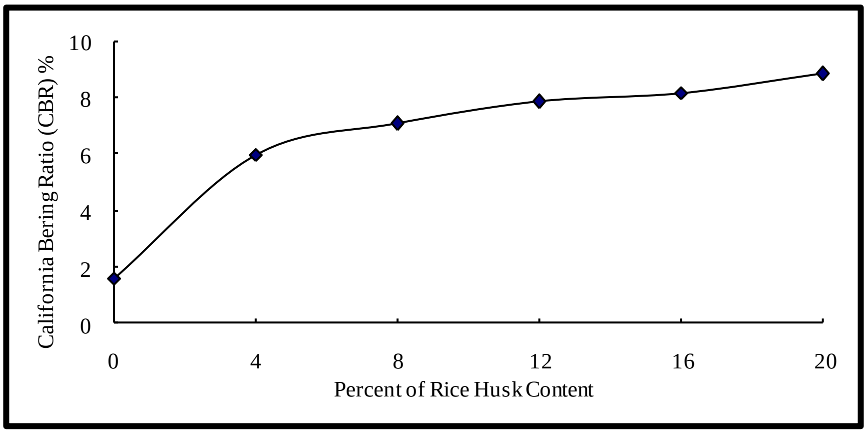

Figure 7: The Effect of Rice Husk Content on California Bearing Ratio (CBR)

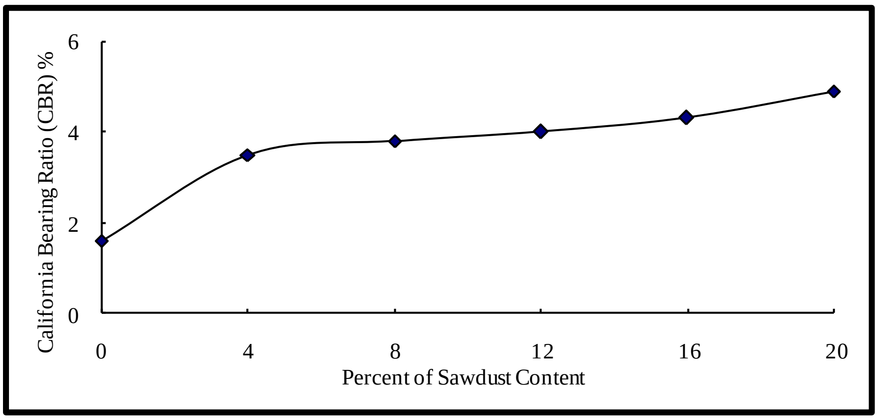

Figure 8: The Effect of Sawdust Content on California Bearing Ratio (CBR)

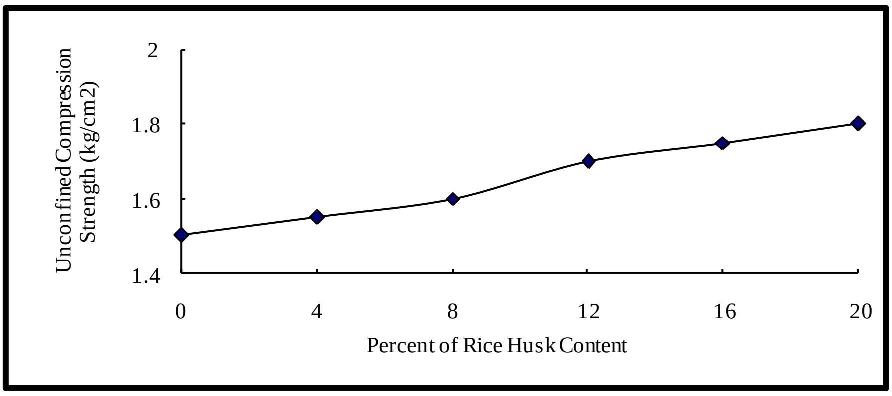

Figure 9: The Effect of Rice Husk Content on the Unconfined Compression Strength

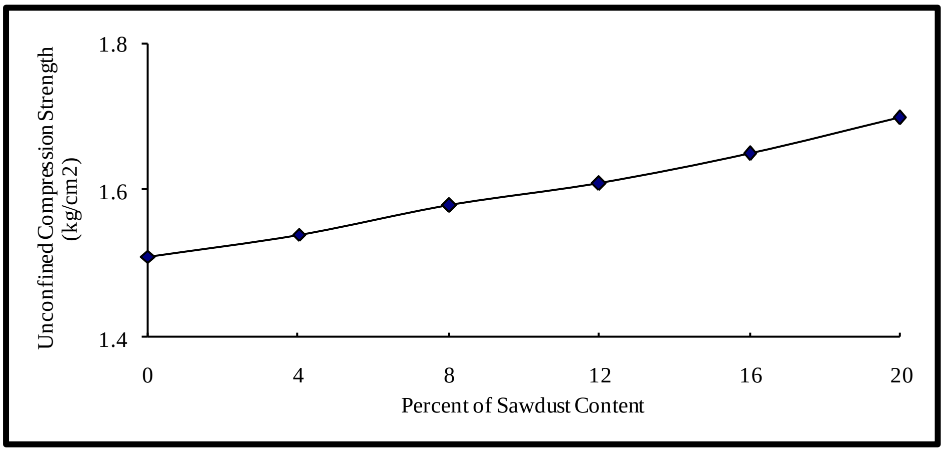

Figure 10: The Effect of Sawdust Content on the Unconfined Compression Strength

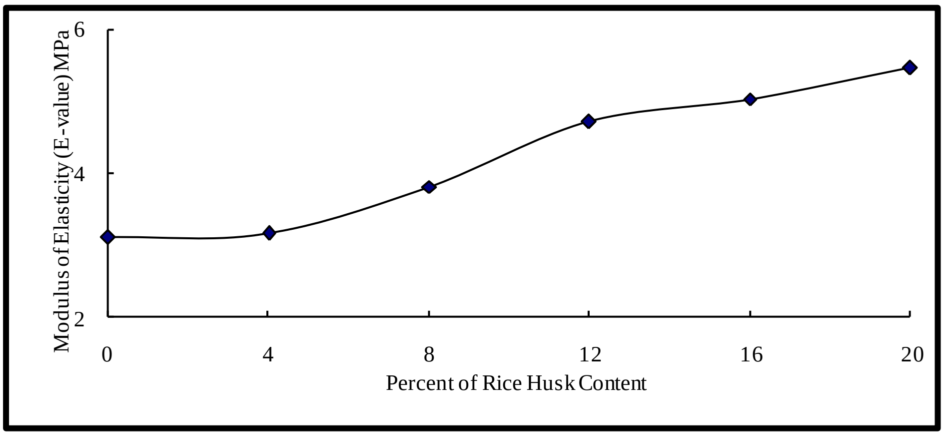

Figure 11: The Effect of Rice Husk Content on the Modulus of Elasticity

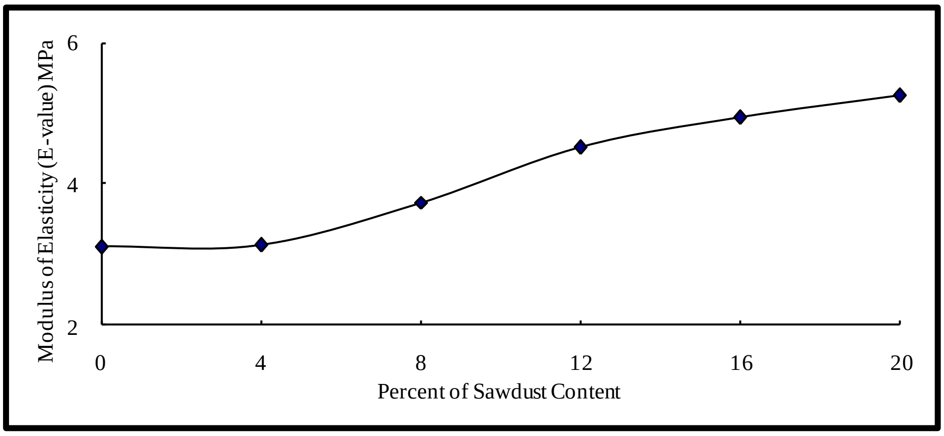

Figure 12: The Effect of Sawdust Content on the Modulus of Elasticity

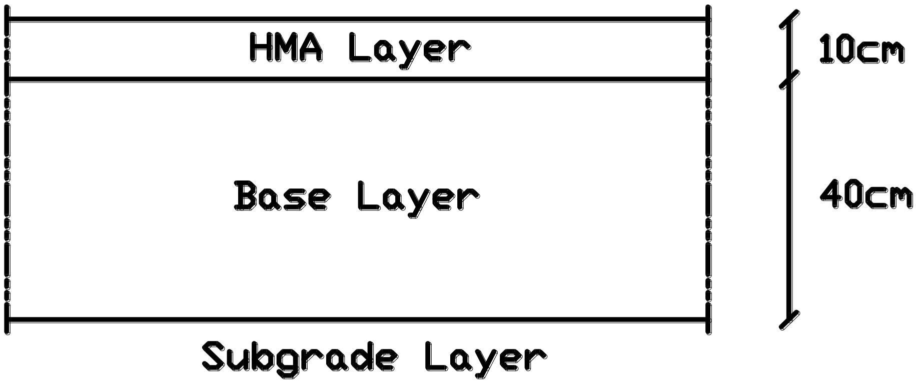

Figure 13: Typical Cross-Section for Pavement Used in Kafr El-Sheikh city

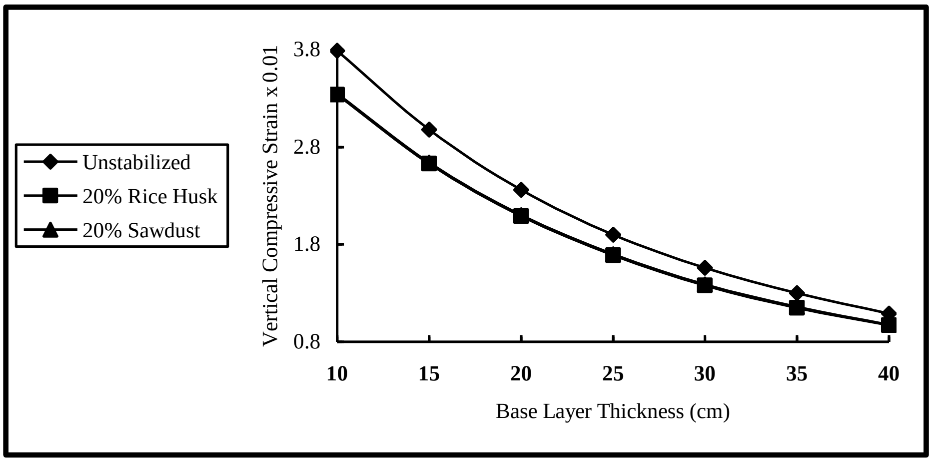

Figure 14: Variation of Vertical Compressive Strains with Base Thickness for Different Design Alternative