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REDUCTION OF PAVEMENT THICKNESS USING A SUBGRADE LAYER TREATED BY DIFFERENT TECHNIQUES

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Abstract. A range of stabilisers for poor quality subgrade soils have been developed to promote road constructions. Many of them are becoming more popular depending on their effectiveness. The purpose behind this research is to identify the relative efficacy of many physical and chemical stabilisation techniques for enhancing the properties of three types of local Iraqi subgrade soils. The comparison of the samples is based on the CBR tests. The AASHTO (1993) flexible pavement design was used to compute the pavement thickness requirements. The soil samples A, B and C have a natural CBR values of 3.8, 3.9 and 4, respectively, on which the physical stabilisers of Powdered rock (PR), grained recycled concrete (GRC), and recycled crumb rubber grains (CR) were employed, while Quicklime (QL) and activated fly ash (AFA) were both utilised as chemical stabilisers. The stabilisation with 15 % of AFA proved to be the most applicable method for soil types A and B for reducing the pavement thickness requirements by 51 % and 32 %, respectively, with a reasonable financial feasibility for both. The same feasibility is proven when stabilising soil type C with 15 % of GRC, which reduces the pavement thickness by 25.7 %.

Keywords: Flexible pavement, AASHTO flexible design method, CBR, physical stabilizers, chemical stabilizers.

1. Introduction

There are several highway pavement distresses, some of which can be attributed to subgrade soils' inadequate support. Such cases often result from the sensitivity to a high-water content, low specific gravity, and low shear strength, along with many undesirable characteristics of highway pavement subgrade soils. Subgrade strength is often assessed by many kinds of tests conducted either in the field or in the lab, tests like the field density and the California Bearing ratio (CBR) value [1].

To achieve an optimal performance of a flexible pavement, the design method must depend on cost effective, proper, and readily existing subgrade layer components. Soft soil in a subgrade layer, for example, needs very special improvements to ensure the suitability for constructing a supporting layer for flexible pavement layers. The process of stabilising subgrade soil is both efficient and cost effective in most cases, because road paving materials are generally less expensive than replacing the existing subgrade with stronger materials [2].

The process of stabilisation could be mechanical, chemical, or a combination of both. The mechanical stabilisation is usually performed by guaranteeing the proper arrangement of soil particles either by compacting the soil layer by vibrations to rearrange the soil particles, or by adopting some advanced methods such as soil nailing with the use of barriers. The chemical methods are usually achieved through the use of a stabilising agent such as cementation substances causing a chemical reaction with soil particles.

In the case of soft natural soil, such as clayey peat, silt or organic soil, the majority of stabilising mechanisms may be used [3]. Fine-grained granular soils are the best for stabilisation. This is due to the huge ratio of the surface area to the diameter of the particles. During such a stabilisation process for soils that has the potential of swelling danger, the physio-synthetic within and around the clay particles . As a result, the treated CL soil showed an increase in the CBR value, which may signify the enhancement of the quality of the subgrade and, consequently, an increase in the carrying capacity of the pavement [4].

Over the last few decades, non-traditional soil stabilising additives have been introduced at a rapid rate. Due to their affordability, quick treatment times, and ease of use, these stabilisers are becoming more popular [5–7].

The aim of this research is to study the effect of soil stabilisation for road subsoil whose resistance strength was measured by a CBR experiment, and to study the effect of this resistance index on the design of pavement thickness by the AASHTO method. Five physical and chemical additives were used – quicklime, activated fly ash, powdered rock, grinded recycled concrete, and crumb rubber.

2. Literature review

The subgrade's quality has a significant impact on the design of the pavement as well as its life time and performance. The highway pavements, which are constructed on problematic soil usually demonstrate poor performance and unpredictable behaviour due to the influence of the subgrade soil type [8]. Shrinkage-driven fissures may be in-filled with sediment over a geological time scale, resulting in subgrade irregularities. It is worth noting that in the field of geotechnical soil stabilisation, the substructure of the paved highway is subject to all the usual soil stabilisation laws. According to Asad et al. [9], who studied the stabilisation of subgrade consisting of low plastic clayey soil (CL), when lime additive is used in a percentage ranging from 0 % to 6 %, then the unconfined compressive strength (UCS) of the stabilised soil increases from 46.08 psi to 103.27 psi. Increasing the percentage of the additive above 6 % decreases the UCS [9]. The explanation of the UCS increase of soil is due to the increased flocculation induced by lime in the treated clayey soil. Many properties of the lime-treated soil were observed to be improved, such as the plasticity index of soil decreasing and the soil type transforming from clay with a low plasticity to silty soil. The swelling of the treated soil is omitted and the soil becomes un-expanded soil. The CBR of the lime-treated soil is increased. This increase in CBR value has the potential to reduce both the cost and total thickness of the multi-layer pavement.

According to Karim et al. [10], who studied the effect of fly ash addition on the geotechnical properties of the soil, which is soft clay. The addition of fly ash lowers the specific gravity of the treated soil because the specific gravity of fly ash is lower than the specific gravity of the soil. The plasticity of the treated soil is reduced. The maximum dry density (MDD) of the soil is reduced while the optimum water content (OWC) of the treated soil is increased, which solves many of the issues with the untreated soil [10]. The UCS of the soil increased with increasing fly ash percentages. The CBR of soil increased from 90.1 % at 5 % fly ash to 538.3 % at 20 % fly ash and after the 20 % fly ash increase, the CBR decreases. Also, the compressibility of the soil decreases. In this study, it was found that 20 % of fly ash is the optimum percentage. Many other studies concluded similar results by the addition of approximate percentages of fly ash [11–13].

Kumar & Biradar utilised the quarry-dust as a physical additive, which has been collected from a quarry at Srikakulam in India. The samples were blended with waste materials at different percentages of which the SG is 2.68, the OMG is 9.3 % and the MDD is 17.02 kN/m^3. It was found that the plasticity of the soil treated by this substance was reduced because the quarry dust is a non-plastic material. The MDD of the modified soil was increased by 5.88 % when adding 40 % of quarry dust. But beyond the 40 % the MDD of soil began to decrease. The CBR of the soil also increased, and after the 40%, it also started to decrease. It was found by this study that the 40 % of quarry dust is the optimum percentage [14].

The use of grained recycled concrete (GRC) as an additive has been proven to enhance the properties of soft soils [15, 16]. Saeed and Rashed assessed experimentally the ability to use demolished waste concrete (DWC) as a mechanical (physical) stabiliser that is added for treating expansive soil geotechnically. The plasticity of the treated soil was reduced as the (DWC) is a non-cohesive material. The swelling potential (which includes both the swelling percentage and the swelling pressure) decreased with the increase in DWC up to 12 %, but above this percentage, no significant decrease in swelling potential was noticed. According to their opinion, both the MDD and the OMC of the soil were reduced because of the presence of fine sand in the substance. The strength of the soil represented by UCS increased up to 12 % of DWC cured for 28 days and the behaviour of the soil changed from flexible to brittle with the increment of this substance. The CBR of the soil treated by 12 % of DWC increased from 4.27 % to 24.14 %. It was concluded by this study that grained recycled concrete (GRC) is economical, environment-friendly, and effective for treating adverse properties of expansive soils [17].

Many researches dealt with the addition of crumb rubber to improve the properties of soft soils in terms of CBR and MR. values and to enhance their support of flexible pavements [5, 18]. Ravichandran et.al. tested the use of crumb rubber grains of waste tires in the stabilisation process of weak soils. It was found that the CBR value of the treated soil increased up to 10 % of tire rubber grains, and above this percentage, the CBR decreased. Increased CBR value of stabilised soil can greatly lower the overall pavement thickness and, as a result, the entire cost of road construction. The permeability of the treated soil denoted by the coefficient of permeability was increased. It was concluded at the end of this study that the use of rubber grains as a stabiliser presents a low-cost stabilisation technology that considerably decreases the current waste tire disposal problem [19].

In this research, five additives are used; quicklime, activated fly ash, powdered rock, grained recycled concrete, and crumb rubber. All these additives are mixed with three soil samples representing the subgrades of three main highways connecting Baquba city. The experimental work is conducted on these mixtures to determine the effect of these additives on increasing the strength of soils in terms of CBR values and, consequently, the expected reduction in highway pavements.

3. Materials used

3.1. Soil

Three samples of soil were used in this study and all of them were extracted from flexible pavement road soil subgrades. They were brought from three different locations at Diyala governorate in the middle of Iraq. The first soil sample (denoted soil A) was brought from the subgrade of Baquba-Khalis highway (Latitude 33° 48′ 27.43″ N and Longitude 44° 35′ 0.32″ E).

Property	Soil A	Soil B	Soil C
Natural water content [%]	40	32	28
Liquid Limit [%]	48	35	34
Plastic Limit [%]	15	15	20
Plasticity Index [%]	33	20	14
Gravel [%]	0	0	0
Sand [%]	0.7	5	15
Silt [%]	38.3	36	40
Clay [%]	61	59	45
Specific Gravity (GS)	2.67	2.71	2.75
USCS Soil Classification	CL	CL	CL
AASHTO Soil Classification	A-7-6 (35)	A-6 (29)	A-6 (11)
Maximum Dry Density [kN/m^3]	17.5	18.6	19.1
Optimum Moisture Content [%]	17.7	16.5	16

Table 1. Properties of the collected soil samples.

The second soil sample (soil B) was brought from the subgrade of Baquba-Al Sabtiya highway (Latitude 33° 47′ 7.59″ N and Longitude 44° 37′ 22.36″ E) . The third soil sample (soil C) was brought from the University of Diyala-Khan Bani Saad highway (Latitude 33° 40′ 29.32″ N and Longitude 44° 35′ 7.66″ E). Table 1 shows some index properties of the collected soil samples.

3.2. Additives

3.2.1. Quicklime (QL)

The type of lime employed in this study was the un-slaked lime, often known as quicklime, which is obtained from limestone. This material was manufactured by the Azerbaijan Lime Chemical Company in Iran. Its particles , determined by a sieve analysis, is 850 microns (sieve No. 20).

3.2.2. Activated fly ash (AFA)

Type F fly ash employed in this study is a soil stabiliser, but it lacks cementation and pozzolanic qualities, which were compensated by adding the Sulfate-Resistant Portland Cement, which is manufactured by Al-Geser manufacturing company in the governorate of Kerbela in southern Iraq. The fly ash used in this investigation was produced in India.

3.2.3. Powdered rock (PR)

This material was obtained from a local quarry in Diyala province by grinding the local sand stone according to the Iraqi specification (2715) [20]. Its particle size, determined by a sieve analysis, is 0.075 mm.

3.2.4. Grained recycled concrete (GRC)

This material was made from the leftovers of concrete cubes that were used for research engineering purposes in the University of Diyala's College of Engineering's Structural Testing Laboratory, where it was crushed in a specific local mill for this purpose. Its particle size, determined by a sieve test, is 0.45 mm. The tested specific gravity of the material was found to be 2.7.

3.2.5. Crumb rubber grains (CR)

For obtaining this material, worn tires were cut into small pieces with a grain size of one to two millimeters in diameter maximum. The specific gravity is 0.91, the compacted void ratio ranges between (0.9–1.3) while the uncompacted void ratio ranges between (1.2–2.4) and Poisson's ratio is 0.5.

4. Experimental work

4.1. Preparation of treated soil samples

In this research, the five above-mentioned additives were added to soil samples (A, B, and C). An optimum ratio of each additive was selected depending on previous researches on similar types of soils in order to enhance their properties in terms of the CBR value [2, 5, 16]. The percentages of these stabilisers were; 9 % of quicklime, 15 % of activated fly ash, 25 % of powdered rock, 15 % of grained recycled concrete, and 4 % of crumb rubber grains [6, 10, 19]. These percentages were added to each soil sample and subjected to the CBR test before and after the addition.

4.2. CBR test

The CBR test is one of the important empirical tests for evaluating the strength of the subgrade soil and one of the input parameters in determining the flexible pavement thickness according to AASHTO design method. This test was conducted according to ASTM D1883-21. The test included the preparation and compaction of the test sample at the maximum dry density and then immersed in water path for 4 days as recommended in the specifications. Then, the samples were extracted from the water and allowed to drain, and then tested using CBR loading machine with a penetration rate of 1.25 mm/min [21].

5. Pavement design

In order to find out the optimal subgrade soil improvement strategy, a test with a unified set of parameters for the flexible pavement was used according to the AASHTO design method [22] and conducted on all soil types included in this study. The design parameters as adopted by the local directorate of highways and bridges Diyala governorate are detailed in Table 2. Table 3 shows the compositions and coefficients of each pavement layer according to its properties.

Parameter	Parameter's value
Pavement Lifetime	15 Years
Traffic ESAL (80 kN)	2×10^6
Reliability (R)	99 %
Standard deviation (So)	0.49
Initial Serviceability (Pi)	4.5
Terminal Serviceability (Pt)	2.5
State of Water Drainage	poor

Table 2. The adopted unified design parameters .

Parameter	Subbase	Base	Surface
Materials	Granular soil	Crushed stone	Asphalt concrete
Structural coefficient	a3 = 0.1	a2 = 0.14	a1 = 0.44
Drainage coefficient	m3 = 0.8	m2 = 0.8	–

Table 3. The compositions of pavement layers and coefficients.

The chosen flexible pavement is a three-layered system, which is composed of a wearing layer on the top, a base layer underneath it and a sub-base layer in the bottom. This three-layered system is supported by the subgrade soil. This system is assumed to be fixed, while the impacts of the soil improvements on the total thickness of the pavement is going to be investigated. The results of the calculation of each pavement layer thickness using the AASHTO method can be seen in Table 4 which shows the required thicknesses over each layer of the natural soils before the improvements.

Many relations that correlate the MR value to the CBR value were developed due to the importance of this topic [23, 24]. The following equation is used in this method for the calculation of the resilient modulus (MR) of the subgrade that uses the structural number (SN) of the pavement layer, according to the AASHTO method [25, 26]:

$$\mathrm{MR\ (psi)} = 1500 \times \mathrm{CBR}, \quad \text{for CBR} \leq 10\,\%. \tag{1}$$

The subgrade soil strength measured with the CBR value before and after treatment changes the bearing capacity values of the subgrade and a new flexible pavement thickness is calculated to investigate the impact of the five improvement techniques on the flexible pavement's total depth before and after the treatment and the percentage reduction for each treatment.

6. Results and discussion

The results indicated that all three low plasticity soil samples A, B, and C having the CBR values of 3.8, 3.9, and 4, respectively, have responded to the stabilisation process. Despite the difference between their CBR values being small, these samples have highly different characteristics for they were brought from different locations as stated earlier. These differences could be noticed in their responses to the stabilisation processes in terms of the increase in CBR values. This increment would result in reducing the road pavement's thickness requirements, and consequently make a financial profit due to the low cost of the stabilisation process as compared to the high cost of pavement construction.

The tests revealed that soil sample A responded very well to the stabilisation processes and the CBR value increased from 3.8 % to 30 % by adding the optimum percentages of AFA, QL, and PR, while the addition of GRC and CR increased the CBR value to 20 %.

Soil sample B also showed an enhanced CBR value, which has increased from 3.9 % to about 19 % by the addition of PR and GRC. A lesser increment in CBR was observed for the addition of other additives, about 14 %.

As for soil sample C, for which the smallest increase was observed, the CBR value increased from 4% to 11% by adding GRC and CR while other additives didn't increase the CBR to more than 7.5 %.

In order to determine the effect of these enhancements in stabilised soils on the pavement thickness, the calculations according to the AASHTO flexible design method were repeated to find out the required total pavement thickness for all treatments for each soil type. The results are shown in Figure 1. At the same time, the financial impact has been determined in which the net profit is calculated by subtracting the cost of the additive's application process from the amount of costs saved due to the reduction of the pavement layer thickness. The financial details are shown in Table 5.

The results reveal that the biggest reductions found for soil A, in which the total pavement thickness requirement is reduced from 39 in to 19 in i.e. 51 %. Lesser reduction can be observed for treated soil sample B, in which the total pavement thickness is reduced

Parameter	Soil A	Soil B	Soil C	Subbase	Base	Asphalt
MR [Psi]	5760	5925	6000	13500	31800	450000
Structural Number SN	6.4	6.2	6	3.8	2.6	–
Total thickness [in]	39	37	35	18	6	–

Table 4. Design thicknesses above each layer on natural soils.

Additive	Soil	Stabilization cost [$/m^2]	Pavement reduction [cm]	Reduction cost [$/m^2]	Benefit [$/m^2]	B/C ratio
9% QL	A	3.64	50.8	15.24	11.6	3.19
9% QL	B	3.64	33.02	9.906	6.266	1.72
9% QL	C	3.64	12.7	3.81	0.17	0.05
15% AFA	A	2.26	50.8	15.24	12.98	5.74
15% AFA	B	2.26	30.48	9.144	6.884	3.05
15% AFA	C	2.26	15.24	4.572	2.312	1.02
25% PR	A	7.5	48.26	14.478	6.978	0.93
25% PR	B	7.5	38.1	11.43	3.93	0.52
25% PR	C	7.5	10.16	3.048	-4.452	–
15% GRC	A	2.72	45.72	13.716	10.996	4.04
15% GRC	B	2.72	35.56	10.668	7.948	2.92
15% GRC	C	2.72	22.86	6.858	4.138	1.52
4% CR	A	6.03	45.72	13.716	7.686	1.27
4% CR	B	6.03	33.02	9.906	3.876	0.64
4% CR	C	6.03	20.32	6.096	0.066	0.01

Table 5. Financial feasibility analyses.

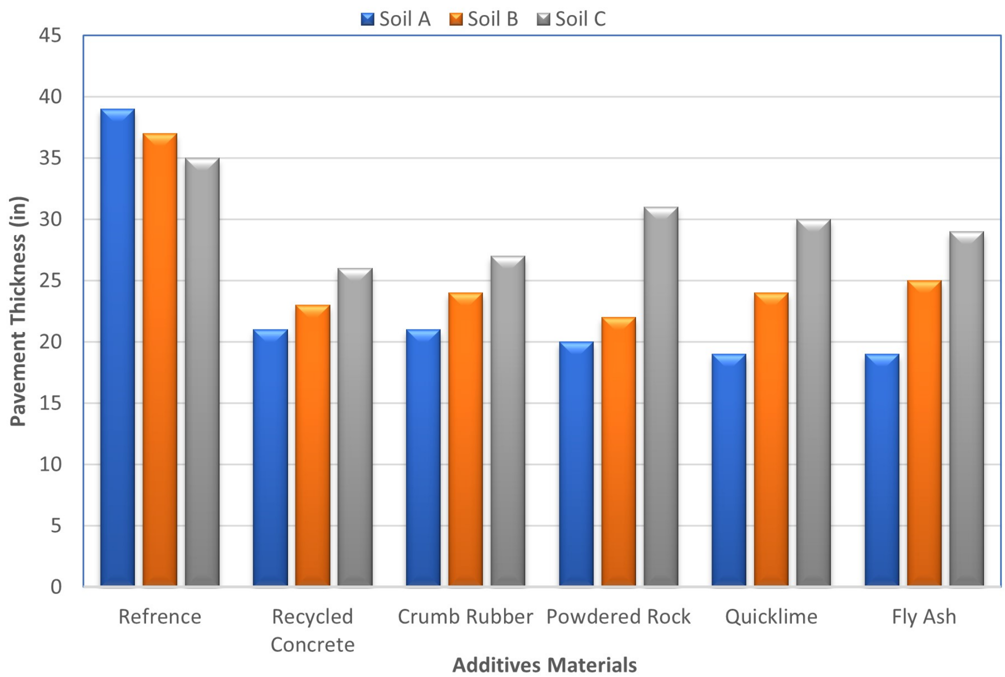

Figure 1. Effect of subgrade improvement on the pavement thickness.

by approximately 40 % from 37 in to 22 in. Soil sample type C has the worst results in this regard as the pavement thickness was reduced by no more than 25.7 % from 35 in to 26 in.

These results are very close , if not better, to the improvement achieved by Shubber & Saeed and Amakye et al. [27, 28], the variations in results are mostly due to the type of the treated soil.

The financial analyses showed another sequence of preferences among additives in terms of the benefit to cost ratio. For the soil type A, although; the addition of QL and AFA resulted in an identical pavement thickness reduction, they returned B/C ratios of 3.19 and 5.7, respectively, and, similarly, the addition of GRC and CR resulted in an identical reduction in pavement thickness, yet their B/C ratios were 4.4 and 1.27, respectively. Adding the PR resulted in a 0.93 B/C ratio, which is unacceptable despite its relatively high pavement reduction.

Likewise in soil type B, the highest reduction in pavement thickness was produced by the addition of PR , yet, financially, it is unacceptable due to the B/C ratio of 0.52. the same result was observed for CR, which returned a B/C ratio of 0.62. In this type of soil, the most financially efficient additives are AFA and GRC, yielding B/C ratios of 3.05 and 2.92, respectively.

For soil type C, most of these additives are not financially efficient producing B/C ratio lesser than 1, except for AFA and GRC for, yielding B/C ratios of 1.02 and 1.52, respectively.

7. Conclusions and recommendations

In this paper, three Iraqi local subgrade soil samples were stabilised using five different additives. these samples were tested for the CBR value both before and after the treatment in order to examine the extent to which these additives could enhance the soil support capability for the flexible pavement by utilising the AASHTO flexible pavement design guide. The most important conclusions drawn from the results of this research are as follows:

(1.) All three subgrade soil samples responded well to the stabilisation process, but to a varying extent.

(2.) The best reduction in the pavement thickness was about 51 %, achieved for soil (A) by a stabilisation with 15 % of AFA. At the same time, this process returns the highest financial feasibility.

(3.) The highest reduction in pavement thickness in soil B is approximately 47 %, achieved by a stabilisation with 25 % of PR, but it was found financially unacceptable for yielding a B/C ratio lesser than 1, while the most financial return in this soil is achieved by using 15 % of AFA that returns a 3.05 B/C ratio.

(4.) The smallest response to the stabilisation was observed for soil (C), in which the highest reduction in the pavement thickness is achieved by stabilisation with 15 % of GRC , resulting in a pavement thickness reduction of 26 % and it was proved to have the highest financial return with a 1.52 B/C ratio.

(5.) It is recommended to study the environmental impacts on the stabilised subgrade soils, especially water infiltration, and their effect on road pavements.

List of symbols

GS Specific gravity

CL Low plasticity clayey soil

MR Resilient modulus

UCS Unconfined compressive strength

MDD Maximum dry density

OWC Optimum water content

GRC Grained recycled concrete

DWC Demolished waste concrete

ASTM American society for testing and materials

SN Structural number

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