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A study on Mechanical Stabilization to Improve Marginal Base Materials in Khartoum

Magdi Zumrawi

[1]University of Khartoum, Department of Civil Engineering, Khartoum, Sudan

Abstract: ***This study is aimed to improve the engineering properties of marginal base materials by mechanical stabilization. Currently used techniques for stabilization of marginal base materials are reviewed. This research studied the suitability and mechanical stabilization requirements of some selected granular materials as base construction materials. Six samples A to F collected from three sources of base materials in Khartoum state were subjected to preliminary tests (sieve analysis and Atterberg's limits) and strength tests (compaction, California bearing ratio (CBR) and Abrasion). Results of these tests classified the samples as marginal base materials. These samples were stabilized mechanically by the addition of gravels with sand or crushed stones with sand. The addition of sand from 10% to 15% to the samples caused a reduction in their plasticity indices. The CBR was improved by the addition of gravel from 15% to 20% or crushed stones from 12% to 15% to the samples. General conclusions are drawn with regard to success of recommended stabilization method.***

Keywords: Marginal, base materials, mechanical stabilization, suitability, granular materials

1. Introduction

The base course is the main load spreading layer in pavement structure. A wide range of materials can be used including crushed rock and naturally occurring gravels and sand that provided the necessary strength and durability. Alternatively, available local materials can be stabilized mechanically or chemically to achieve comparable performance at a competitive price. To perform well, base aggregates must be strong and durable, and must meet very specific gradation, plasticity and strength requirements. Material survey showed that increasing shortage of quarried base materials in Khartoum state due to their continued use in construction. As a result, high quality materials have to be hauled in long distances, sometimes from other States. This act would significantly increase the costs associated with the construction of roads. Marginal or substandard local materials are normally available. If through appropriate modifications of the materials by adjusting the gradation or/and chemical treatment or structural design (specifying thicker layers of base) the use of the local materials can be permitted, the construction can be accelerated and significant benefits can be realized, [1]. In this study upgrading of marginal base materials by mechanical treatment is investigated.

2. Literature Review

Base materials are often divided into two general categories: unbound aggregate materials and stabilized base materials. The limiting criteria such as strength, plasticity and grading set out in most conventional specifications for base materials are based on universal standards applied to all traffic levels. Where the materials fail to meet these criteria they are termed marginal or substandard, [2]. They reported that marginal base gravels in terms of their grading can fall into three groups depending on whether the material is too coarse, too fine or gap graded. The too coarse materials generally tend to reduce stability, increase risk of shear and settlement, low in situ density and difficult to compact. The too many fines materials are known to have low compacted strength and increased risk of deformation and high potential for capillary rise and moisture susceptibility. The gap-graded materials are difficult to compact, increased risk of deformation under traffic, increased moisture susceptibility and pumping of fines. The aggregate bases with high fines content are susceptible to loss of strength and load supporting capability upon wetting, [3]. However, marginal base materials often lead to distress and can lead to premature failure in the form of severe shrinkage cracking followed by accelerated fatigue cracking and a general loss of stability, [4].

Base aggregate may be considered marginal in terms of shape if it is not only too flaky or elongated but also if its particles are over-rounded with no angular faces. Rounded with smooth surface texture have poor inter-particle friction and loss of stability, compaction difficulty, low density and high air voids content and low stability, (Cook, J.R. et al., 2001). High flakiness or elongation aggregates cause particle breakdown or crushing and compaction problems and high air voids. Base aggregates may be considered marginal in terms of particle strength if individual particles fail to meet crushing strength criteria. Low particle strength is normally due to inherent fabric defects, incomplete or weak induration and weathering, [2].

The use of marginal or substandard base materials for pavement construction will affect design, pavement performance, and construction, [5]. He reported that these materials may cause poorer performance of the pavement and often result in rutting, cracking, shoving, raveling, aggregate abrasion, low skid resistance, low strength, shortened service life, or some combination of these problems. Moreover, Rollings [5] showed that marginal materials may also greatly affect the workability of pavement materials, and adjustments in construction procedures may be required.

2.1 Soil Stabilization

The stabilization of pavement materials is a widely used practice in road construction. Thagesen [6] defined stabilization as any process by which a soil material is improved and made more stable. Garber and Hoel [7] described soil stabilization as the treatment of natural soil to improve its engineering properties. In general, soil stabilization is the process of creating or improving certain desired properties in a soil material so as to render it stable and useful for a specific purpose. Since the inception of this process of stabilization, most soil materials which have been thought not useful have found application in many areas of engineering, [8]. McNally [9] stated that the improvements in engineering properties caused by stabilization can include the following: increases in soil strength (shearing resistance), stiffness (resistance to deformation) and durability (wear resistance), reductions in swelling potential of wet clay soils and other desirable characteristics, such as dust proofing and water proofing unsealed roads.

Stabilization of soil is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that fully complies with the requirements of specification for the soil, [10]. It has been regarded as a best option for upgrading marginal materials where no economic alternative is available.

There are many techniques for soil stabilization, including compaction, dewatering and by adding material to the soil. Mechanical or granular stabilization is accomplished by mixing or blending soils to obtain a material meeting the required specifications, [11]. The soil blending may take place at construction site, or a borrow area. The blended material is then spread and compacted to required density by conventional means. This is the simplest method of stabilization. In general, if a soil is coarse grained (i.e. sandy gravel) requisite quantity of fine grained soil (i.e. cohesive soils) is added to adjust the proportion. Similarly, if the soil is fine grained then coarse grained is added, [11]. Chemical stabilization has traditionally relied on Portland cement, lime and bitumen, [6]. He reported that cement and bitumen are best suited for granular and non-plastic soils, while lime performs better in cohesive soils.

2.2 Base Material Characteristics

Base materials are expected to have a particle size distribution and particle shape strength that will provide a high mechanical stability. The grading should contain sufficient low plasticity fines (amount of material passing the 0.425 mm sieve) to produce a dense material. The plasticity is primarily associated with the presence of clay in the fine fraction of the aggregate. In general increasing plasticity characteristics (i.e. liquid limit and plasticity index) may be accompanied by increasing proportion of the fine content (i.e. clay/silt percent). The adverse effects associated with of the presence of clay minerals in a base material relate primarily to the property of clay minerals to attract moisture, which may soften the fine fraction and cause swelling, [11].

The grading requirements for granular base materials are specified by standard methods such as AASHTO [12]. The natural base materials form of coarse and fine aggregates. The coarse aggregates that retained on 4.75 mm sieve consist of hard, durable particles or fragments of stones, gravel or slag. The coarse aggregates shall show a loss on abrasion of not more than 50 percent using AASHTO T96. When tested with magnesium sulfate solution for soundness using AASHTO T104, coarse aggregate shall not have a loss of more than 15 percent at the end of five cycles. The fine aggregates which pass 4.75 mm sieve form of natural or crushed sand and fine mineral particles passing 0.075mm sieve. The soil fraction passing 0.075mm sieve should be more than two third the fraction passing 0.425mm sieve. The soil fraction passing 0.425mm sieve shall not have liquid limit more than 25 percent using AASHTO T89 and plasticity index not more than 6 percent using AASHTO T90. Materials meeting these requirements will normally meet the minimum CBR strength criterion of 80 percent after 4 days soaking using AASHTO T193.

Crushed stones or angular rock is produce by mining a suitable rock deposit and breaking to the desired sizes using crushers. Angular crushed stones, for its strength as base material depends on the interlocking of the individual stones of angular faces. After crushing, the coarse fraction should be angular in shape with flakiness and elongation indices less than 35 percent using ASTM [13]. In most of the standard specifications, crushed stones require to have high strength, CBR=100% and crushing value less than 40%. Crushed stones make both coarse and fine aggregate suitable for base material. One benefit of crushed stones is that it keeps high quality natural aggregates in use. In addition, crushed stones can be produced on site, which reduce project costs by eliminating the transportation costs. Normally considered a hard aggregate and rock chips have also been used in base construction, usually mixed with natural aggregate materials. The major driver for using rock chips is that they provide good drainage while reducing the weight of the aggregate layer. At the same time, the performance of these materials is better than natural materials.

3. Materials and Methods

The experimental work program was carried out to determine the physical and mechanical characteristics of the samples studied. Their suitability as base materials were checked and if fail to comply with standard specifications they will be subjected to mechanical stabilization.

3.1 Materials Used

The materials used in this study are natural base materials, gravels, crushed stones and natural sand. The natural base materials were collected from three different sources in Khartoum state, Wad Assad and Hattab quarries in Khartoum north and Om Katti in Omdurman. Unfortunately, in the capital Khartoum there is no any source of base materials. The gravels, crushed stones and natural sand were obtained from a crusher plant at Toria hill in west Omdurman. Six samples of natural base materials were collected from different locations and the samples were labeled A-F. The aggregates include gravels, crushed stones and natural sand used as stabilizers were screened to remove the impurities and large particles.

3.2 The tests procedures

Each of the six base materials were subjected to preliminary tests which are particle size analysis and Atterberg limits (i.e. Liquid and plastic limits) tests. The following strength tests were performed: compaction test to obtain the maximum dry density and the optimum moisture content of the soil, California bearing ratio (CBR) test for soaked conditions and los angles abrasion test. The testing procedures followed were in general conformance with those recommended in the AASHTO standard.

Initially, the soils were tested to find out their conformability to the standard specifications. The results obtained from these tests, as shown in Table 1 and Fig. 1 were compared with the standard specifications of AASHTO. For the soils not comply with specifications, mechanical stabilization was carried out to improve their failed properties. Experimental trails were carried out by adding percentage of gravels or crushed stones and natural sand to the marginal base materials. The natural sand is mainly added to reduce the plasticity while the gravels or crushed stones are used to increase the strength (CBR) of the marginal base materials. The mixture specimens were prepared using crushed stones or gravels as strength stabilizer varying from 10% to 15% or 20% by weight respectively and for plasticity reduction, natural sand added from 10% to 15%. The trails started with the minimum value of the stabilizer, 10% by weight and then gradually increased by 2% till attained the target specified characteristics of base material.

4. Results and Discussion

The results of the preliminary tests (grain size analysis and Atterberg's limits test) as well as the strength tests (compaction, California bearing ratio and Los Angles abration tests) are hereby discussed.

The summary of the tests results is presented in Table 1. The particle size analysis for the soils tested were graphically drawn with the standard envelop as shown in Figure 1. It can be observed that the gradation curves for the six soils A-F were located outside the standard envelope which indicate disconfirm with the specifications. In Table 1, it is shown that the liquid limit, LL of the soils B to F are varying from 27% to 35% and also the plasticity index, PI from 8% to 17%. For soil A, the liquid limit and plasticity index are 20% and 6% respectively which implies that all the soils (except soil A) failed to comply with the standard specifications.

The fine contents that pass No. 200 sieve as shown in Table 1 for all the soils except soil A exceed the required amount, 15% and that may adversely affect the soil strength. The CBR values for soils B to F are ranged from 56% to 70% which is less than the standard (Minimum CBR 80%). The CBR of Soil A confirms with the specifications. Moreover, The abrasion loss of samples A-F values fall within the range from 23% to 36% which confirmed with the specifications. According to AASHTO specifications, the samples A-F are classified as marginal base materials.

Table 1: The tests results for the samples A-F pre-treatment

Property	*Wad Assad*		*Hatab*		*Om Katti*	
	A	*B*	*C*	*D*	*E*	*F*
Gravel, %	70	41	40	37	38	47
Sand, %	25	41	41	44	48	30
Clay/Silt, %	5	18	19	19	14	23
Liquid Limit, %	20	35	29	35	27	31
Plasticity Index, %	6	17	12	19	8	16
Max. dry density, g/cm^3	2.32	2.26	2.25	2.24	2.25	2.27
Optimum water content,%	4.5	6.6	6.2	6.8	5.8	6.2
CBR, %	82	68	62	56	60	70
Abrasion loss, %	27	30	34	36	23	24

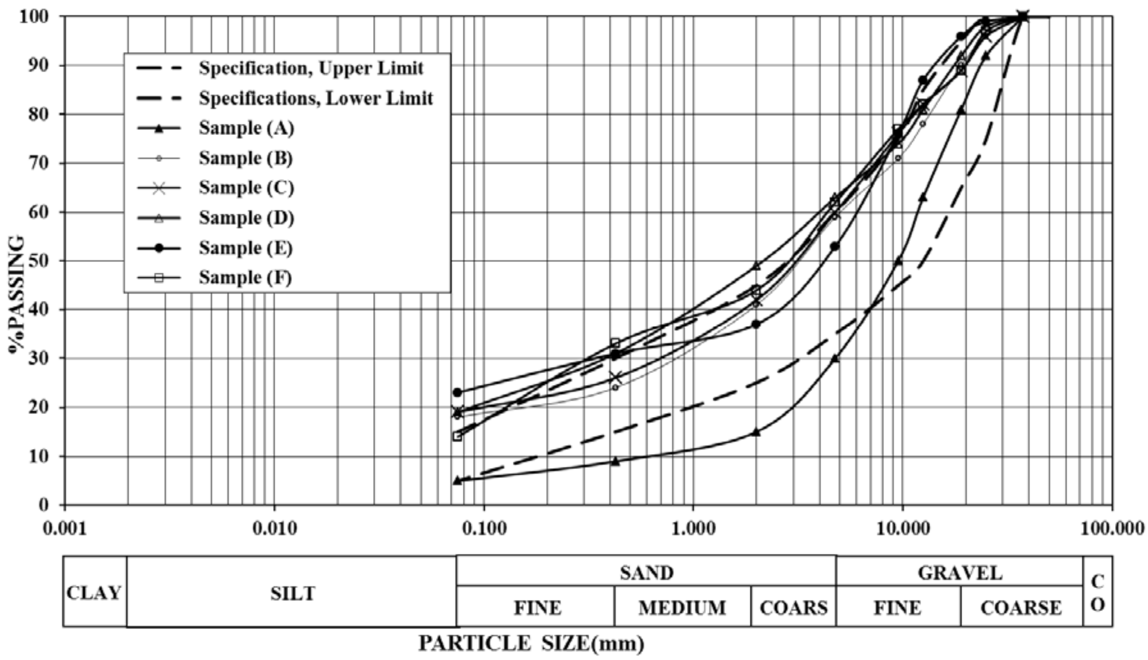

Figure 1: The gradation curves for samples pre-treatment compared by AASHTO grading envelope

The summary of results for samples stabilized with natural gravels and sand given in Table 2. It can be observed that the addition of gravels, 15% to 20% with natural sand, 10% to 15% to samples A to F produced corresponding improve in the gradation curves and decrease in the liquid limit causing a high decrease in the plasticity index. As clearly shown in Fig. 2, the gradation curves for the samples treated were plotted within the standard envelop which implies conformity with the specifications. From Table 2 it can be observed that, the soaked CBR values for all the samples increased with the addition of gravels and sand. For all samples, the increase of The CBR value was as a result of the increase in maximum dry density and the decrease in optimum moisture content.

Table 2: The tests results for the samples stabilized with natural gravels and sand

Property	*Wad Assad*		*Hatab*		*Om Katti*	
	A	*B*	*C*	*D*	*E*	*F*
Marginal Base Material,%	90	83	83	65	83	83
Natural Gravel, %	0	15	17	20	17	15
Natural Sand, %	10	12	10	15	10	12
Gravel, %	62	47	57	54	48	56
Sand, %	31	43	37	35	48	30
Clay/Silt, %	7	10	6	11	7	13
Liquid Limit, %	NP	NP	25	20	21	25
Plasticity Index, %			6	5	5	6
Max. dry density, g/cm^3	2.30	2.32	2.35	2.27	2.30	2.31
Optimum water content,%	5.0	5.7	5.7	5.9	5.2	5.0
CBR, %	87	85	82	81	83	84

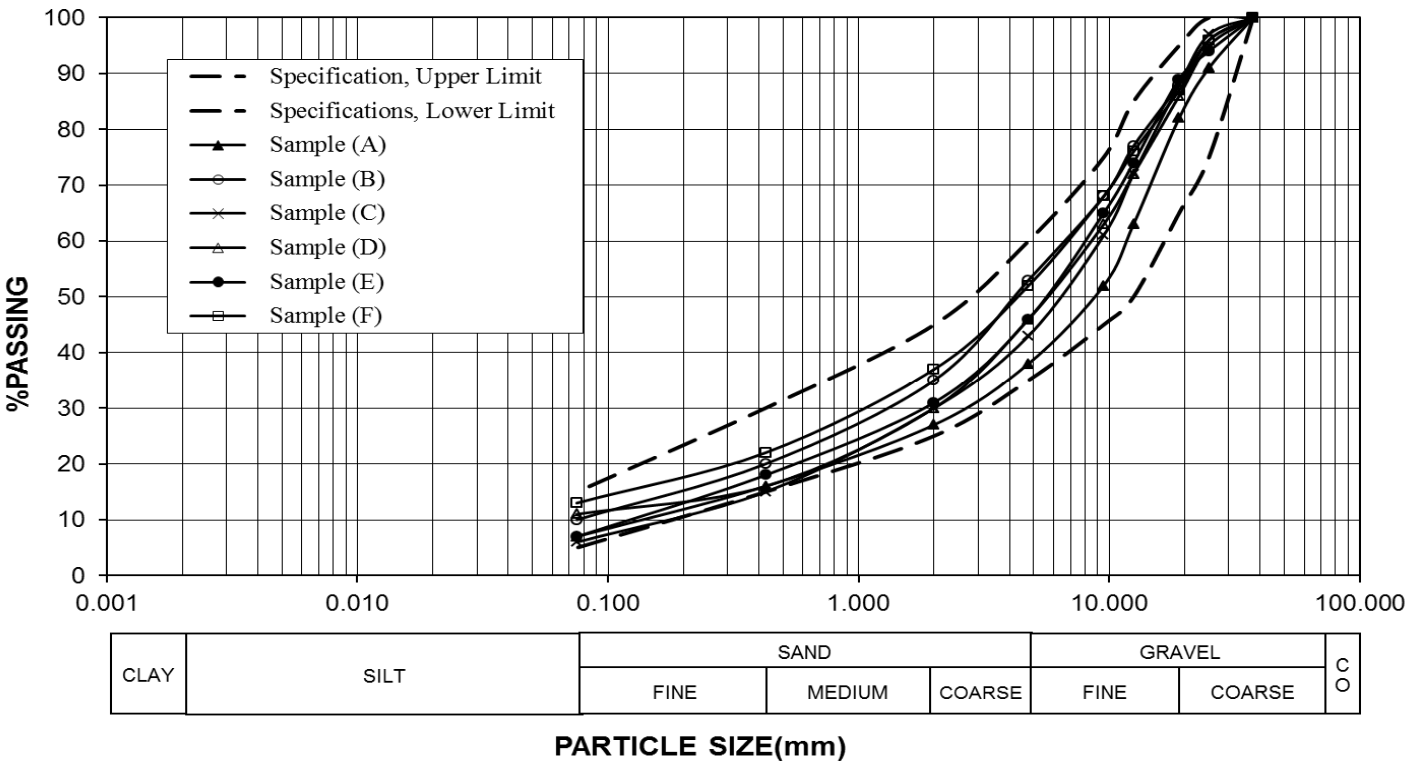

Figure 2: The gradation curves for the samples stabilized with gravels and sand compared by AASHTO grading envelope

Table 3 shows a summary of the results obtained from samples stabilized with crushed stones and natural sand. From the table it can be observed that the target characteristics for base materials such as strength, gradation and plasticity were achieved by adding 12% to 15% by weight crushed stones and 10% to 12% by weight natural sand to the samples studied.

The gradation curves as shown in Fig. 3 were corrected and located within the standard envelop which confirm with specifications. It is clear from Table 3 that there is a considerable reduction in plasticity index when crushed stones added to the samples. It can also be observed that, as the maximum dry density increased and the optimum moisture content decreased, there was a corresponding increase in the CBR for all the samples. The CBR values of all the samples are quite high values which show that the strength of the soils is greatly improved by crushed stone stabilization. The CBR values of the crushed stabilized samples, when compared with those of the gravel stabilized samples, shows that the samples gained high strength.

Table 3: The tests results for the samples stabilized with crushed stones and sand

Property	*Wad Assad*	*Hatab*		*Om Katti*	
	B	*C*	*D*	*E*	*F*
Marginal Base Material,%	83	83	65	83	83
Natural Gravel, %	12	12	15	15	12
Natural Sand, %	10	10	12	10	10
Gravel, %	55	56	54	52	51
Sand, %	31	37	35	36	34
Clay/Silt, %	14	7	9	10	12
Liquid Limit, %	NP	25	23	25	NP
Plasticity Index, %		4	5	4	
Max. dry density, g/cm^3	2.30	2.30	2.29	2.31	2.33
Optimum water content,%	6.1	6.1	5.8	6.0	5.4
CBR, %	89	91	87	86	90

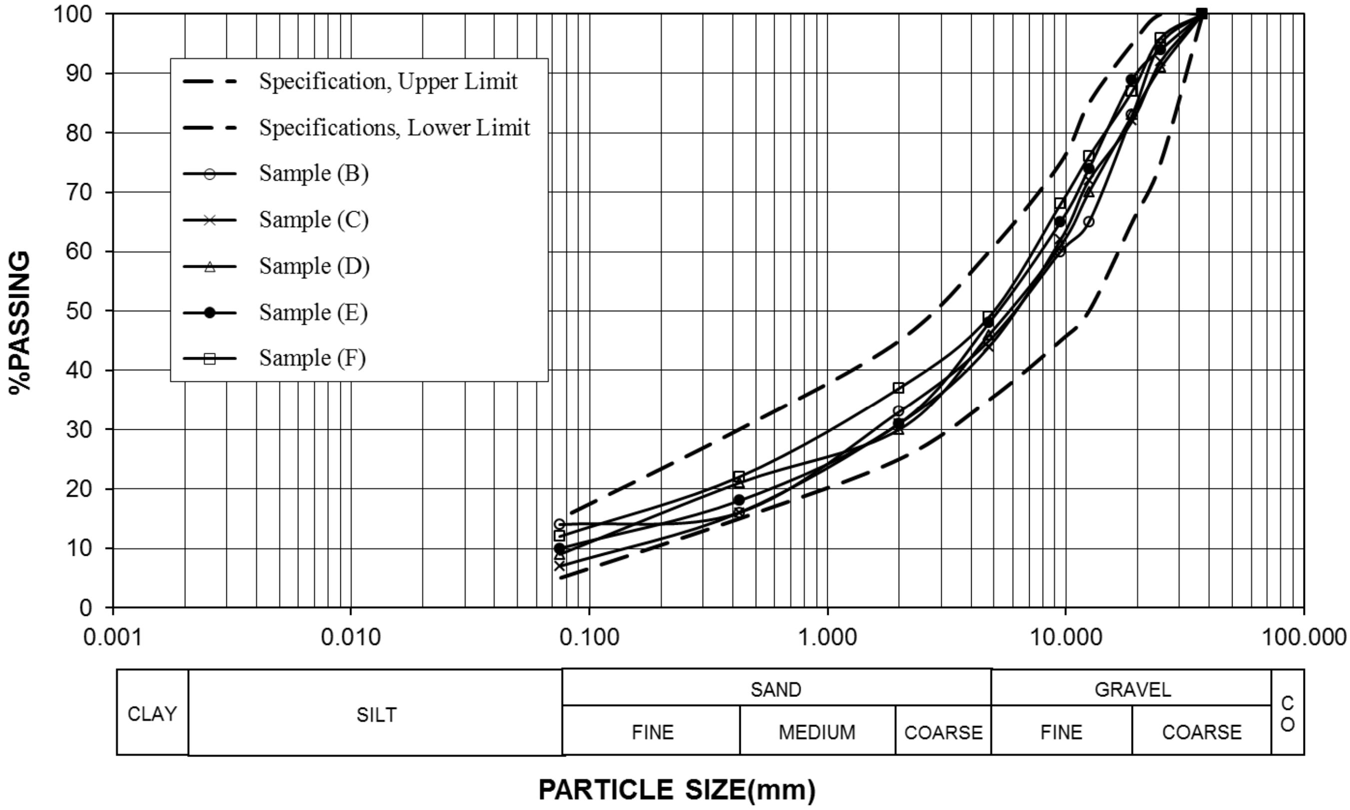

Figure 3: The gradation curves for the samples stabilized with crushed stones and sand compared by AASHTO grading envelope

When comparing the strength and plasticity of all the samples stabilized. The CBR and the plasticity indices for all the samples are shown in plots of Figure 4 and 5. It can be notice from figures 4 and 5 that crushed stabilized samples have quite higher CBR values and almost lower plasticity indices compared with those of the gravel stabilized samples. Moreover, in stabilization of marginal base materials, the percent added of gravels and sand compared to that of crushed stones is quite more. These results indicate the fact that crushed stones is more efficient and may be economical than natural gravels as a mechanical stabilizer. It is suggested to use crushed stones and sand to stabilize marginal base materials.

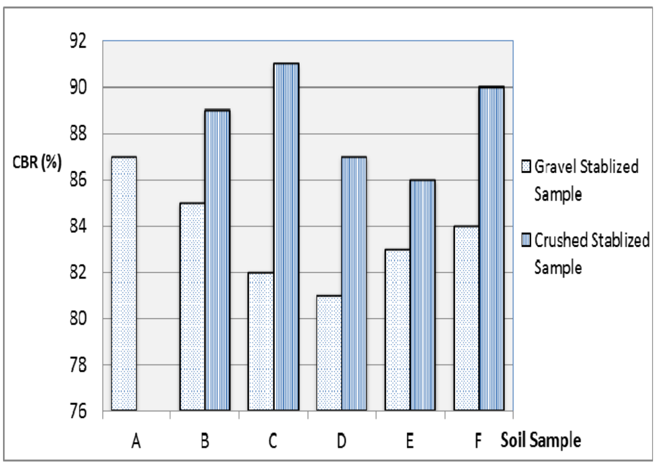

Figure 4: Variation of CBR with gravel stabilizer and crushed stones stabilizer for all the samples studied

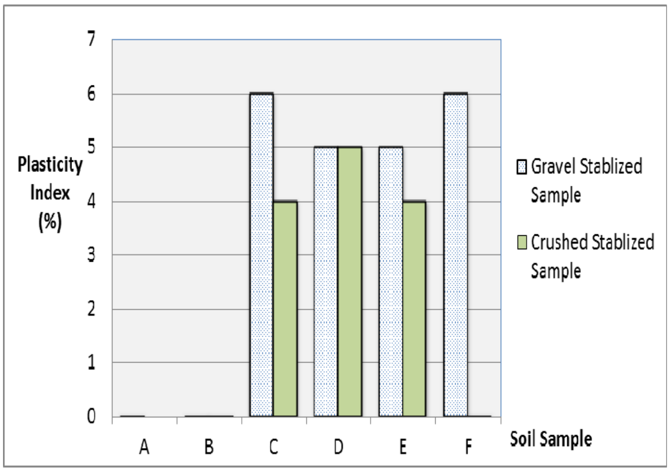

Figure 5: Variation of plasticity index with gravel stabilizer and crushed stones stabilizer for all the samples studied

5. Conclusions

This study has been undertaken to improve local marginal materials for use in construction of base course by means of mechanical stabilization. The results and the conclusions drawn as follows:

1. A material can be considered marginal (low-quality) for a variety of reasons such as inadequate gradation, inadequate plasticity and inadequate strength. In many cases, the local base materials miss the standard specifications by a small margin. Since the criteria set in most of the specifications are experienced-based, some of the parameters used to classify a base may be less significant than others.
2. Surveys of material sources in Khartoum showed that the

local base materials were being rapidly exhausted by their continued use in pavement construction. Thus cost saving could be made on choosing the option of mechanical stabilization of the available marginal base materials by aggregates, gravel or crushed stones and natural sand. This method is so simple, easy to apply and more economical compared to other stabilization methods such as chemical stabilization.

3. Based on experimental trails, marginal base materials were mechanically stabilized by using crushed stones between 12% and 15% by weight with natural sand, 10% and 12% by weight to achieve the target characteristics materials of base materials. Alternatively, using 15% to 20% natural gravels with 10% to 15% by weight natural sand will upgrade marginal base materials to confirm with to the specifications.
4. The future prospects of this study are that the only option to achieve comparable performance at a competitive price for base material in Khartoum will be crushed stones.

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Author Profile

Magdi Zumrawi was born in Omdurman, Sudan, 19 May 1963. He received the B.Sc. degree in Civil Engineering and M.Sc. degree in Road Technology from University of Khartoum in 1987 and 1991, respectively. He achieved Ph.D. in Highway and Railway Engineering, Chang'An University, Xi'an, in Sept. 2000. His present occupation is Head, Soil & Road Section, Civil Eng. Dept., Faculty of Eng., Khartoum University, since 2010. He is a highway expert working with local and international consultant firms. He has published many articles in local and international journals and attended national and international conferences. He is a member of International Society for Soil Mechanics and Geotechnical Engineering. He is a senior member of the APCBEES.