Performance of Natural Unbound Material Blended with Wadi Sand under Dynamic Loading

Omer Gurham Omer[1]; Ahmed M. Elsharief[2]; Awad Elkarim M. Mohammed[3];

Abstract

This paper investigates the effects of adding natural wadi sand to a typical unbound subbase material from Alsilait area in Khartoum. Four trials blends were prepared.Only two of the blends satisfied the (TRL, GB3) gradation and strength requirements of the unbound base course material. The strength, the stiffness and deformations characteristics were evaluated for the blends, using the CBR, resilient modulus (M_R) and permanent deformation (PD) tests. Pavement physical models were constructed using the studied samples in the resilient modulus mould. The physical model comprises subgrade, sub-base, base course, and asphalt layer. The only variable in the physical model testing was the type of base course material. The model was subjected to dynamic loading typical to PD test conditions. The tests results have shown that the blends satisfying the GB3 base requirements measured the smallest values of permanent deformations. Minor differences were found for the PD values this also applies to the physical model tests. The study has shown that the large differences in CBR values did not result in large differences in permanent deformation and stiffness (M_R) values.

Key words: Natural unbound Material, Blending, Relaxation, physical section, , Permanent deformation.

مستخلص:

هذه الورقه تعنى بداسة تأثير إضافة الرمل الطبيعى الخشن إلى الخرسانة الترابية الطبيعية المستعمله فى الأساس المساعد والتى تم توريدها من منطقة السليت بولاية الخرطوم. تم تحضير أربعة خلطات اثنان من الخلطات طابقت المواصفات البريطانيه- (TRL-GB3) الخاصه بمواد طبقة الاساس الغير مربوطه.

تم تقييم خواص المقاومة والصلادة والهبوط لكل الخلطات بالإضافه إلى خرسانة السليت لوحدها بدون إضافه باستخدام اختبارات قوة تحمل كاليفورنيا (CBR) ومعامل الرجوعResilientModulus والهبوط الدائم Permanent Deformation على التوالى. وتم تجهيز خمسة مجسمات صغيره كنمازج رصف باستعمال القالب الأسطوانى الخاص بتجربة معامل الرجوع مستخدمين خرسانة السليت والخلطات الأربعة. المتغير الوحيد فى هذه النماذج هو مادة طبقة الأساس والتى تتغير حسب نسب الخلطات أعلاه و تم تعريض النماذج للحمل الديناميكى شبيه لظروف اختبار الهبوط الدائم .

---

1. Senior Civil Engineer – Sudan Civil Aviation Authority
2. Associate Professor, Building and Road Research Institute, U of K
3. Assistant Professor, Building and Road Research Institute, U of K

اوضحت نتائج الإختبارات لخرسانة السليت الطبيعية لوحدها والخلطات ان العينتان اللتان طابقتا المواصفه البريطانيه GB3 أعطيتا أقل هبوط دائم وان هناك فوارق قليله وجدت فى قيم الهبوط الدائم التى قيست لكل خلطة ولخرسانة السليت وهذا ينطبق على اختبارات النماذج.
أظهرت النتائج ان الفوارق الكبيره فى قيم قوة تحمل كاليفونيا (CBR) لم تنتج عنها فوارق كبيره فى قيم الصلاده (M_R) والهبوط الدائم.

1. Introduction

Natural gravelly unbound materials are the most common and available road materials in Sudan. They can easily be mined, stockpiled and therefore used with less and cheap mechanical effort. They have been used as natural sub-base and base materials provided that they satisfy the required specifications. Their use is restricted by their inherent properties and they seldom satisfy the gradation and strength requirements for road base and subbase course materials.

The scarcity of road base materials has been tackled by mixing the natural materials with crushed stone for important projects [1] and/or relaxing the strength and grading requirements by accepting materials with quality lower than the standard specifications for low level projects. As denoted in Road Note 31 [2] that for low traffic categories (T1,T2) the maximum allowable plasticity index (PI) can be increased to 12% (from 6%)and the maximum soaked California Bearing Ratio (CBR) could be reduced to 60% (from 80%) at the expected field densities.

This research paper studies the strength, stiffness and deformation characteristics of blends of natural granular material and wadi sand aiming at exploring the effect of deviations from the Transport Research Laboratory (TRL) GB3 gradation and strength requirements for pavement unbound base course materials on their deformation response.

2. Literature review

The unbound natural gravels are the common available cheap and easy mined road materials in Khartoum State. They are usually satisfying sub-base requirements but scarcely the base ones. These natural gravels are basically colluvial deposits originally conglomerates belonging to Nubian Sandstone Formation. The formation has been deposited by braided streams under semi-dry tropical climate, Whiteman [3]. According to Popic [4] the term bound materials is used for materials with linear or nearly linear stress- strain relationship whereas unbound concerns with those with stress- dependent trend on non-linear stress- strain behaviour.Transport Research Laboratory (TRL) associated the code GB3, with limited specifications to naturally occurring gravels or blends satisfying road- base requirements [2].

As locally recognized; stabilizing natural gravels with natural coarse wadi sand is the cheapest agent for improving their engineering properties, but obviously, it can be noticed that no previous intensive local documented investigations were introduced on the natural unbound gravels in Khartoum State; the only one that recently made was conducted by Ismail [5] on typical five natural gravels provided from different open quarries in North Kordofan State (west of Khartoum State). The study showed that the five samples failed to satisfy the base requirements [British Standards, and AASHTO], then mechanical stabilization trials were made to improve them by adding different percentages of clean natural coarse sand (10%, 15%, and 17%). The test results indicated that 17% added sand satisfied the base course requirements. Khanna et al. [6] practiced the soil mechanical stabilization with sand and he found that the basic principles for this method are (i) proportioning and (ii) compaction. Further he stabilized the granular materials with sand which showed a remarkable improvement in their measured engineering properties.

Frank et al. [7] reported that it is practical to produce base course with a dense grading by blending normal quarry product with crusher dust or sand. He reported that; blending aggregate with sand is simple and relatively cheap way to manufacture a denser graded aggregate. Later he assessed two pavements found that rut had developed soon after being traffickedand attributed the distress to improper densification of the base and sub-base pavement layers. Dawson et al. [8] expressed that; the necessity of using a minimally treated materials means that it is impossible to engineer it to meet all requirements equally well. Dawson [9] specified the base layer as the chief structural element of a pavement.The success or failure of the pavement’s role depends, above all, on the base’s performance. Get the base right and the essence of a successful pavement is assured. Kornel [10] and Dawson et al. [8] clarified that the main function of the base course is to reduce the vertical compressive stress induced by traffic, in the sub-base and the subgrade to a level at which no un acceptable deformation will occur in these layers.

Pink et al. [11] explained the resilient modulus (M_R) as an elastic modulus under dynamic loading and he added that the measured laboratory M_R under the optimum compaction condition could reflect the actual resilient behavior of granular material in the flexible pavements. Tao et al. [12] reported that the CBR value is used to characterize shear strength of pavement base, sub-base, and subgrade soils, the resilient modulus is a parameter to characterize stiffness of pavement materials under repeated loading whereas the permanent deformation is a parameter reflecting rutting potential and structural stability of individual pavement layers. He added that gradation of unbound aggregate is one of the key factors directly affecting grain-to-grain contacts, which in turn have significant influence on properties of unbound aggregates, such as strength, stiffness and permanent deformation.

Arnold et al. [13] assessed and commented that 30% to 70% of the surface rutting is attributed to the unbound granular materials layers. They added that the available natural materials can, however, be assessed for their suitability for use in a pavement by considering performance criteria such as resistance to permanent deformation and degradation instead of relying on compliance with inflexible specification. Lekarp et al. [14] found that the crushed stone, angular materials undergo smaller permanent deformation compared to materials such as gravel with rounded grain.

3. Experimental study

3.1 Objective and test methods

This experimental exercise attempts to investigate, through a series of tests, the effect of deviations from the specification requirements of unbound natural gravelly base coarse materials on their strength, stiffness and deformation responses. The following investigation program was performed:

- Natural coarse wadi sand was added in different percentages to natural sub-base material to prepare four blends trials of varying quality. These materials are then tested for their stiffness and deformation responses

- Five pavement physical models were constructed in split test moulds; each comprising subgrade layer, sub-base and base coarse layers and an asphaltic concrete layer. The variable will be the types of base coarse materials. The models were tested for their strength, stiffness and deformation responses under dynamic loading.The fact that the M_R, and PD tests are highly expensive and time consuming restricted the interest of testing different subbase gravels.

3.2 Tests procedures and results

The gravelly unbound material used in this study was collected and batched from an open quarry situated north-east Khartoum in Al-Silait area. The material is geologically described as weathered conglomerate belonging to Nubian Sandstone Formation [3]. The coarse wadi sand was collected from seasonal streams in north Khartoum and was used as a natural blending agent. Figure 1 presents the gradation of the unbound material and the wadi sand used in this study.

The TRL GB3 Base specifications (Table 1) were used as reference for the base course material. The base course specification requires gradation within the TRL jacket, PI less than 6% and CBR greater than or equals to 80%. The selected unbound material was mixed with natural wadi sand to prepare a material that satisfies the technical requirements of a base course material and materials with properties short of the ideal material (i.e. in terms of gradation, strength and other requirements).

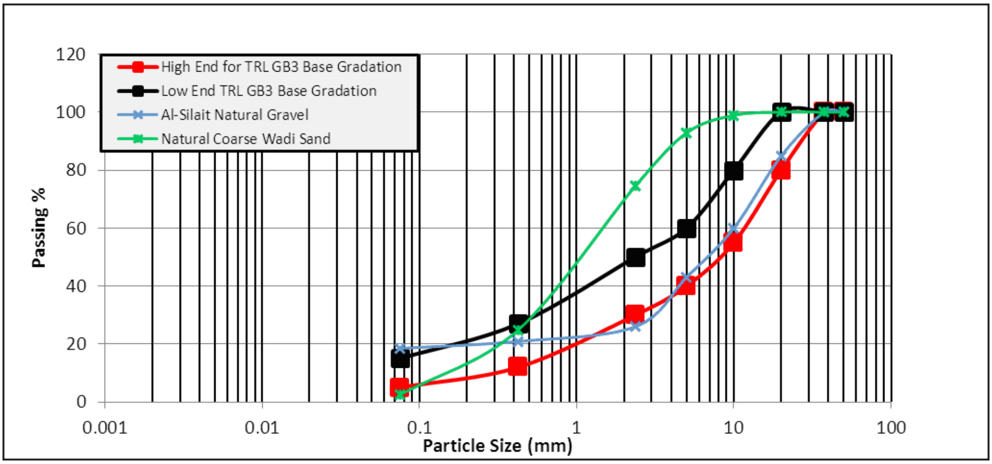

Fig. 1 Grain size distribution for Al-Silait natural gravel and the natural coarse Wadi sand.

Table 1: Typical TRL GB3 Base Specifications

GB3 Gradation for 20 mm Nominal Size	B.S. Test Sieve Size (mm)	37.5	20	10	5	2.36	0.425	0.075
	% Passing by Weight	100	80-100	55-80	40-60	30-50	12-27	5-15
Eng. Index	California Bearing Capacity (CBR)			Plasticity Index (PI)				
Specifications	CBR ≥ 80%			PI ≤6%				

The material from Al-Silait fits well with the high end of TRL base gradation; therefore any addition of fine material will shift the produced curve towards the middle range of the TRL gradation for base coarse material. Different amounts of wadi sand were added to the unbound material from Al-silait to produce four samples of varying quality as follows: {S1} 90% Al-Silait and 10% wadi sand, {S2}85% Al-Silait and 15% wadi sand, {S3} 80% Al-Silait and 20% wadi sand, and {S4} 75% Al-Silait and 25% wadi sand. The produced gradations are given in Figure 2 and Table 2, whereas their physical and engineering properties are given in Figure 3. It is observed that:

- All samples in the investigation fall within the specified limits (High & Low Ends).
- All blends within the limits for sieve No. 50 (0.425 mm)
- Only blends {S3} and {S4} are within limits for sieve No. 200 (0.075 mm).
- For sieve 2.36 mm all blends are within the limits, but Al-Silait natural gravel is out of the limits.
- Only two materials {S3} and {S4}) completely satisfied the reference specifications for base coarse material (Fig. 3 & Table 2) whereas the other two samples and the natural sample ({S0}100% Alsilait) were short of satisfying all the specification limits.

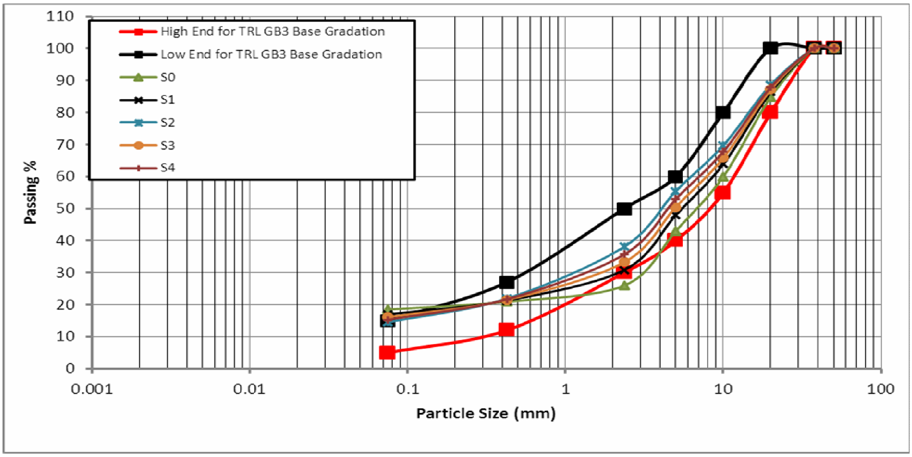

Fig. 2 Grain size distribution for the blends compared with TRL gradation limits

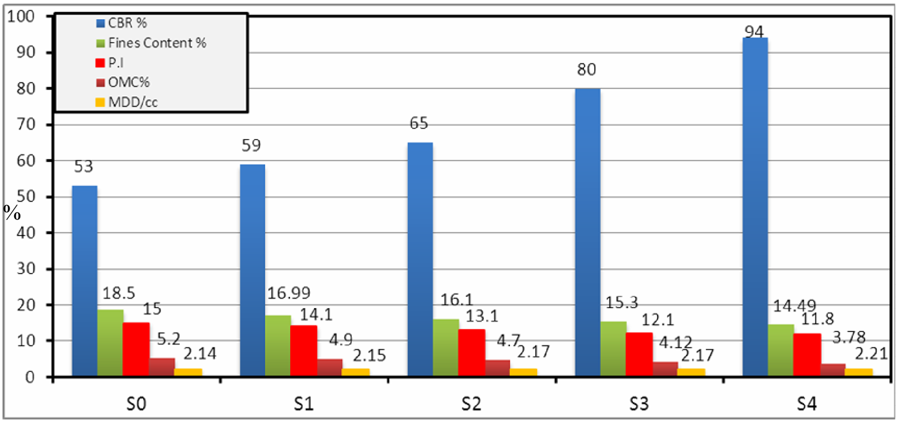

Fig. 3 Typical engineering properties for Al-silait Material and its blends

Table 2: The gradation of the Alsilait sample and its blends

BS test sieve (mm)	% Passing by Weight						
	High End	Low End	{SO}	{S1}	{S2}	{S3}	{S4}
50	100	100	100	100	100	100	100
37.5	100	100	100	100	100	100	100
20	80	100	84.9	86.4	87.2	87.9	88.7
10	55	80	60	63.9	65.8	67.8	69.7
5	40	60	43	48.0	50.5	53.0	55.5
2.36	30	50	26	30.9	33.3	35.7	38.1
0.425	12	27	20.9	21.3	21.5	21.7	21.9
0.075	5	15	18.5	17.0	16.1	15.0	14.0

Two identical specimens were prepared from each of the five samples. They were moistened to optimum water content and compacted to the maximum dry density in the standard resilient modulus mould using vibratory compactor. The compacted specimens were subjected to the resilient modulus (M_R) test following AASHTO T 307-99 test method and permanent deformation (PD) test by subjecting the compacted material to 10000 load cycles under 230 kPa deviator stress and 20.7 kPa confinement (AASHTO Non Standard Test). The test results are presented in Figures 4 and 5 for the M_R and Table 3 for PD tests.

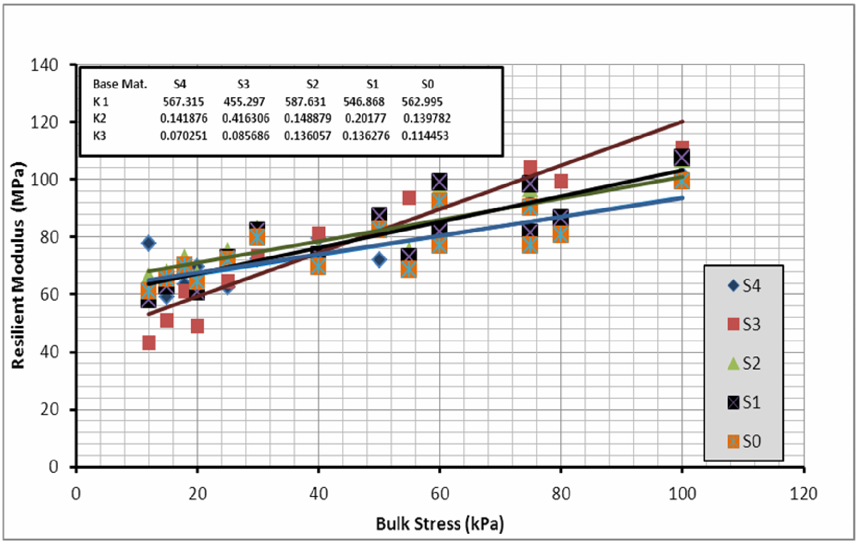

Fig. 4 Resilient modulus versus bulk stress for Al-silait and its blends

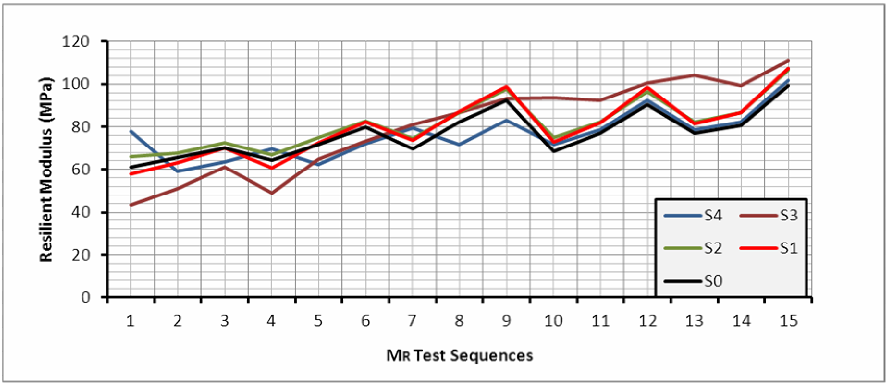

Fig. 5 Resilient modulus versus test sequences for Alsilait and its blends

Table 3: Permanent deformation (PD) values for the Alsilait Material and its blends

Type of Material	S0	S1	S2	S3	S4
PD (mm)	0.110	0.110	0.125	0.159	0.093

Physical models were prepared in the M_R split mould to simulate typical flexible pavement sections for light traffic. Local practice adopts flexible pavement structural layers for light traffic having about 300 mm natural sub base, 150 mm natural base course and 50 mm asphaltic surfacing (HMA). To satisfy the total height of M_R test mould (30 cm), each layer in the flexible pavement was represented by half of the actual thickness. A 50 mm layer of natural clayey subgrade soil was placed in the bottom of the mould. A 150 mm sub-base layer, 75 mm base layer and 25 mm HMA layer were then placed on the subgrade (Plate I-a, & b). The natural subgrade, sub-base and base materials were separately compacted at their optimum moisture to their maximum dry density using the vibratory compactor. Table 4 gives the engineering properties for the materials used in the physical sections.Since the experimental variable was the type of base material, the physical sections were prepared for each base coarse type (S0, S1,S2,S3 and S4). The prepared sections were placed in the cyclic tri-axial device then 10000 dynamic load applications were applied on the HMA layer and the test proceeded following the same testing procedure for a permanent deformation test. The test results are given in Table 5.

Plate I-a Photo of the five physical models

Plate I-b One of physical Model after PD test

Table 4: Typical engineering properties for the subgrade and the sub-base used in the Model

The Type of Material	CBR%	M_R at Sequence$_6$ (MPa)	Permanent Deform.(mm)	Plasticity Index %	Linear Shrinkage%
Al-Silait Natural (S0)	53	79.8	0.563	15	14
Model Sub-base Material	32	124.3	2.53	19	14.3
Clayey Subgrade	1	22.1	0.12	27	17

Table 5: Permanent deformation (PD) values for the physical model tests

Type of Base Material	S0	S1	S2	S3	S4
PD (mm)	0.63	0.35	0.39	1.10	0.29

4. Analysis and discussion

The objective of this experimental investigation is to study the effects of deviations from the gradation, strength and stiffness specifications of TRL GB3 unbound natural base course material on the deformation characteristics of the deviated samples compared to the standard material. The exercise was carried out through gradual process of blending typical unbound subbase material from Alsilait with natural coarse wadi sand to obtain blends of natural gravelly materials of base course quality and blends short of, or not, satisfying the base course requirements.

Five materials were investigated, a natural subbase material from Alsilait and four blends, two of the blends satisfied the GB3 base course gradation requirements (Table 1, Table 2 and Figure 4) whereas the other two did not satisfy the mentioned specification requirements. It is observed that the incremental blending process reported unequal gradation changes in the three areas (gravel, sand and fines), e.g. the added 15% wadi sand shifted the corresponding blend curve to the middle range of TRL base gradation (in the sand zone) whereas the changes in the other areas (gravel and fines) were minor.

The engineering properties for Alsilait sample and the produced blends are given in Figure 4. It is observed that as the wadi sand percentage in the blend increases, plasticity index, optimum moisture content OMC and fines content decrease, consequently their corresponding dry density and strength (CBR) values increase.

The blends containing high percentages of sand ({S3} & {S4}) satisfied the recommended TRL GB3 base requirements (Table 2 and Figure 4).
The M_R is a measure of material stiffness and is known to be stress dependent and is affected by different factors such as the applied stress, moisture content, dry density, gradation, compaction, particle mineralogy, shape and texture,...etc [15]. The tests were performed at optimum water content and maximum dry density. Figures 4 and 5 present the results of resilient modulus (M_R) for the five samples versus bulk stress and test sequences, respectively. All samples gave almost close M_R values through the test sequences as shown in Figure 5. The blend {S3} resulted in a high M_R whereas the {SO} 100% natural sample measured the smallest M_R value.
Table 3 gives the permanent deformation test results for the five blends. It is observed that the {S4} results in the lowest permanent deformation value followed by {S1}. However, very minor differences between the permanent deformation values were observed for all the five tested samples. There is neither a direct correlation between M_R and PD values nor such a correlation between CBR and PD values. The apparent reason could be that, as mentioned above, the conditions under which the M_R and CBR tests were carried are very different. The relatively uniform graded wadi sand exhibited remarkable influence on blending sand zone and less on gravel and fines areas; consequently this non-homogeneity of the blend resulted in steady strength improvement but to some extent in fluctuating stiffness values and permanent deformation values as clarified here-under. Another reason is that, the CBR is a penetration test that indirectly assesses the shear resistance and is function of the factors which influence shear strength such as gradation, angularity of the grains, dry density and plasticity. The test is performed under soaked conditions therefore is sensitive to moisture changes.
The physical model results are used to compare the performance of the blended samples in a typical pavement. The permanent deformation test results (Table 5) are used as basis for comparison. It is important to notice that all the materials were compacted at their OMC and MDD. The only variable was the type of blended base course material. It is observed that the physical section with {S4} blend base (already satisfied TRL base requirements) measured the lowest PD value compared to the other physical sections followed by {S1} then {S2}. The performance of the models coincided well with the PD test results (Table 3).
Given the relatively large difference in the CBR values of the blends, it is interesting to note that only minor differences are observed for the PD values of

the tested specimens and of the tested physical models. This could indicate that the idea of relaxing strength and grading specifications of natural unbound base course materials could be technically justifiable for some unbound materialsprovided that moisture conditions will not change towards wetting side of optimum. The large difference or drop in CBR does not necessarily result in large difference in permanent deformation and stiffness (M_R values).

Aiming at studying the influence of the large number of load repetitions on the pavement rutting, the PD test for the physical section of {S0} base was allowed to continue for 50000 load cycles (test duration was 15 hours). It is observed that the measured PD value for cycle 10000 was 0.63 mm, whereas for cycle 50000 was 0.82 mm. Minor or very small (0.19 mm) increase is reported.

5. Conclusion

In this paper an unbound granular material of subbasecourse (from Alsilait) was blended with natural wadi sand to produce natural material of GB3 base course quality and materials short of, or not satisfying, the GB3 specifications. The strength, stiffness and deformation characteristics of Alsilait material and the four blends were measured using the CBR, M_R and permanent deformation tests. Five physical pavement models were made for which the major variable was the base course layer. The model was constructed in the M_R mould using a typical subgrade soil layer at the bottom, typical sub-base soil, base layer of Alsilait material or its blends and on the top of them was the asphaltic concrete material. Thicknesses of layers were adjusted to suit actual conditions for a light traffic pavement. The major variable for the physical models was the type of base layer. The models were tested for permanent deformation using dynamic loading.

The result of the two test programs have shown that:

- The wadi sand is uniformly graded and the addition of sand improved the gradation of the natural material mainly in the sand zone.
- The CBR increased with sand content up to 25% of sand.
- The blends satisfying the GB3 base requirements ({S3} & {S4} (Alsilait + 20% and Alsilait + 25%) measured the smallest values of permanent deformations. However, very minor differences between the permanent deformation values were observed for all the tested samples.
- There is neither a direct correlation between M_R and PD values nor such a correlation between CBR and PD values. The apparent reason is that the conditions under which the M_R and CBR tests were carried are very

different. Another reason is that, the CBR is a penetration test that indirectly assesses the shear resistance and is function of the factors which influence shear strength such as gradation, angularity of the grains, dry density and plasticity. The test is performed under soaked conditions therefore is sensitive to moisture changes.

- The relatively uniform graded wadi sand exhibited remarkable influence on sand zone and less on gravel and fines areas; consequently this non-homogeneity of the blend resulted in gradual strength improvement but to some extent in fluctuating stiffness values and permanent deformation values.
- The performance of the physical models coincided well with the PD test results
- The results from the model tests showed minor difference in PD values for the five tests. This could indicate that the idea of relaxing strength and grading specifications of natural unbound base course materials could be technically justifiable for some unbound materials provided that moisture conditions will not change towards wetting side of optimum. The large difference or drop in CBR does not necessarily result in large difference in permanent deformation and stiffness (M_R values).

6. Rederences

[32] Omer O.G. and Esharief A. M. (2011).“Improvement of Unbound Aggregates in Khartoum State”, Proceedings of the 15th African Regional Conference, Maputo 2011, pp. 415-421

[33] TRL Overseas Road Note 31 – A guide to the structural design of bitumen-surfaced roads in Tropical and Sub-Tropical countries pp. 1-31.

[34] Whiteman A. J. (1971). “The Geology of Sudan Republic” Clarendon Press, pp. 63-72.

[35] Popic, M., SusdnT.(2005). “The Effect of Seasonal Variation on the Resilient Modulus of Unbound Materials,” Annual Conference of Transportation Association of Canada. Calgary, Alberta, pp. 3-5.

[36] Ismail, M. D. (2013).”Evaluation and Characterization of Granular Soils as Pavement Materials in North Kordofan State,” M.Sc. Thesis, submitted to College of Graduate Studies and Scientific Research, July 2013, Kararay University, Sudan.

[37] Khanna, S. K. and Justo,C. E. G. (2001).”Highway engineering”, Text Book, 862 pages, Publisher: Nem Chand and Brothers 2001.
[38] Frank, G. Bartley Befipenz., “ Total Voids in Unbound Granular Pavement” LandTransport New Zealand Research Report 332, Bartley Consultants Ltd, Epsom, Auckland, New Zealand, pp. 1-50.
[39] Dawson, A., Kolisoja, P. &Vuorimies, N. [2005] ‘Permanent deformation behaviour of low volume roads in the northern periphery areas’.' Proceedings of 7th Int. Conf. on Bearing Capacity of Roads, Railways and Airfields, Trondheim.
[40] Dawson, A., R.(2003).“ The Unbound Aggregate Pavement Base” Paper.The University of Nottingham, England, Andro Dawson CARPAP2.DOC.
[41] Kornel ALMASSY, (2002),”Examination of Mechanical Properties Of Unbound Bases”. Periodica polytechnica Ser. Civ. Eng. Vol. 46, NO. 1, pp. 53-69
[42] W. Virgil Ping (2001). “Implementation of Resilient Modulus in the Florida Pavement Design Procedure” Summary of Final Report, WPI # 0510780 August, 2001, Florida A&M University- Florida State University College of Engineering.
[43] Tao, M., Abu-Farsakh, M., and Zhang, Z. (2008).” Characterization of Unbound Aggregates Revealed Through Laboratory Tests”, Technical note in International Journal of Pavement Research and Technology. Vol. 1 No. 2, Pp. 72-75.
[44] Arnold, G., K., Dawson, A. R., Hughes, D., and Robinson, D. (2004).”Serviceability Design of Granular Pavement Materials” Transportation Research Record 1819 Paper No.LVRB – 1057 pp. 194-200.
[45] Lekarp F. and Dawson, A.(1997) ” Analysis of Permanent Deformation Behaviour of Unbound Granular Materials” Paper presented at International Symposium on Thin Pavements, Surface Treatments, Unbound roads, Fredericton, New Brunswick, Canada..
[46] Lekarp F., Isacsson, U., and Dawson, A.(2000).State of the Art-I “Resilient Response of Unbound aggregates”, Journal of Transportation and Engineering, pp. 66-75