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Application of the Nchrp-1-28 Resilient Modulus Model for Characterizing Granular Material in Sudan

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Abstract: *This paper displays an attempt to examine the suitability of the NCHRP-1-28 prediction model for estimating the Resilient Modulus (M_R) of blended unbound granular materials from M_R test data. The blending process was mechanically done using two natural coarse Wadi sand and pure crushed basaltic stones. An experimental testing program was performed on these typical blends involving the basic tests as well as the dynamic triaxial tests for resilient modulus (M_R). The predicted M_R values showed good agreement with the measured ones. The predicted M_R values are about 8 % to 10% lower than the measured ones indicating conservative estimates for M_R using the NCHRP-1-28 model for the blended unbound aggregates of Khartoum.*
Keywords: *Unbound gravel, gradation, gradation correction, prediction, resilient modulus*

I. Introduction

The resilient modulus is the elastic modulus under dynamic loading. The resilient modulus (M_R) can be numerically quantified as the ratio of the applied deviator stress (σ_d) to the recoverable vertical strain “resilient strain” (ϵ_r). The measured laboratory MR under the optimum compaction condition could reflect the actual resilient behavior of granular material in a flexible pavement [1]. The resilient modulus (M_R) testing provides a mean of characterizing pavement construction materials, including subgrade under variety conditions [2]. According to AASHTO 307-TP 46-1999; the resilient modulus test procedure for base/subbase material comprises 15 sequences each sequence has 100 cycles (repeated load application) with variable deviator stress values (σ_d) at 5 different values of confining pressure (σ_3). The obtained resilient material properties are important input parameters for the mechanistic procedures for designing pavement structures.

Numerous researchers suggested and developed various regression equations for predicting resilient modulus values for unbound granular materials. Several attempts were carried out for developing models correlating the resilient modulus and the cyclic test parameters such as stress states. The recent and the most validated one is the generalized constitutive model that was earlier suggested by Uzan [3] and developed under NCHRP 1-28 [4] and used within the context of the 2002 Mechanistic-Empirical Pavement Design Guide.

This paper focuses on reviewing NCHRP-1-28 model used to estimate resilient modulus for unbound granular base material and verifying its application on mechanically blended unbound gravelly materials. This paper focuses on reviewing different developed prediction models used to estimate resilient modulus for unbound granular base material and verifying the validation of the recent adopted model NCHRP-1-28 on mechanically blended unbound gravelly materials.

II. Review Of The Resilient Modulus (Mr) Prediction Models

Several attempts were carried out for developing models correlating the resilient modulus and the cyclic test parameters such as stress states [5]. The advantage of the application of the regression equation or model that is used for determining the resilient modulus of any material (NCHRP project 1-37 A) is to provide a way of documenting the resilient modulus of the materials tested; all final values of the resilient modulus data will be represented by the materials respective regression constants. The material dependent regression constants can then be used to determine the resilient modulus for each material at any stress condition [6]. For clarification certain models will be illustrated hereunder:

Uzan can be considered as the focal developer of the NCHRP model. At the beginning he studied the bulk stress model (K- θ) which was expressed as

M_R= k1 (θ_b) K2 ……………………. (1)

Where: M_R = Resilient modulus
θ_b = Bulk stress
k1& k2 = Regression analysis constants

Further, Uzan made a major modification by considering both bulk stress and deviator stress (**σ**d) to account for the effect of shear stress. The Uzan model is defined by the following relationship:

M_R= k1 (θ_b) k2 (𝝈d) k3 …….. (2)
Where: M_R = Resilient modulus
θ_b = Bulk stress
k1, k2 & k3 = Regression analysis constants
𝝈d = Deviator stress

Further improvement to the Uzan model (2) was made by replacing the deviator stress term with a more fundamental parameter, the octahedral shear stress [7]. The produced new model has been accepted as a universal material model:

M_R ……. (3)
Where: M_R = Resilient modulus
θ_b = Bulk stress = First stress invariant
(𝝈1+ 2 𝝈3) or (𝝈d+ 3 𝝈3)
P_o=Atmospharic pressure
τ_oct= Octahedral shear stress =1/3((𝝈1- 𝝈2)2+ (𝝈1- 𝝈3)2+ (𝝈2- 𝝈3)2)1/2
k1, k2 & k3 = Regression analysis constants

The NCHRP model model was suggested for predicting MR values by NCHRP Project 1-37 [8], and was recently validated in NCHRP project 1-37 A [9]. The model is the same as the octahedral shear stress model in equation (3) but it was further modified by adding a "+1" term to avoid the absurd calculation of modulus when the tends to zero (the modulus tends to zero when tends to zero).

$$M_R = k_1 P_0 \left(\frac{\theta_b}{P_o}\right)^{k_2} \left(\frac{\tau_{oct}}{P_o} + 1\right)^{k_3} \quad \ldots (4)$$

Where: M_R = Resilient modulus
θ_b = Bulk stress
P_o = Atmospharic pressure
τ_{oct}= Octahedral shear stress
k_1, k_2 & k_3 = Regression analysis constants

All final values of the resilient modulus data will be represented by the materials respective regression constants (k1, k2, k3). The three material dependent regression constants can then be used with the given equation to determine the resilient modulus for each material at any stress condition [10].

The new Mechanistic-Empirical Design Guide Method (M-EPDG) is utilizing the resilient modulus constitutive abovementioned equation and it is referred to K1-K3 or universal model and its main advantage being the consideration of the stress state (i.e., change of normal and shear stress) of the material during testing [11]. Buchanan [11] explained that "k" coefficients for the given model are determined through regression analysis. The k1 is proportional to the elastic modulus of the material and will be positive; k2 is the exponent of the bulk stress term and will be positive since an increasing bulk stress results in a higher modulus; k3 is the exponent for the shear stress term and will typically be slightly negative since an increasing shear stress will likely weaken the material resulting in a lower modulus.

III. The Materials And Testing Program

The materials used in this investigation are blended natural unbound materials from Khartoum state. The gradation correction was done using wadi sand and crushed stone. The natural materials are colluvial deposits originally conglomerates belonging to Nubian Sandstone Formation. The formations were deposited by braided streams under semi-dry tropical climate. These natural gravels often satisfy subbase requirements but seldom satisfy base ones.

For this investigation, three different natural unbound gravels were used; Umm Ketti (C1), Al-Silait (M2) and Huttab (F3) to represent the three ranges of gradation, coarse (C1), medium (M2) and fine (F3), respectively. Figure 1 shows the three gradations plotted with the Transport Research Laboratory (TRL) standard envelope for GB3 base material. The coarse aggregates (gravels) are about rounded or elongated for F3 and M2 materials whereas they are rounded to angular for C1 material.

The Wadi sand was obtained from the seasonal water sources locally known as Wadis. Its gradation is shown in Figure1. Fresh crushed basaltic stone with three different sizes (19-12 mm, 12-5 mm, and 5-0 mm) was provided from a crushing plant in south- west Khartoum for the gradation correction process.

Trial mixes were made for the three natural unbound gravels in an attempt to produce materials that satisfy TRL GB3 base course material requirements [12]. The grain size distribution results from the trial mixes are given in Figures 2 and 3 for Wadi sand and crushed stone mixes, respectively. The results of the routine laboratory tests: sieve analysis, Atterberg Limits and Linear Shrinkage of the fines particles, Modified Proctor, California Bearing Ratio (CBR) and Los Angeles Abrasion for the six blends are presented in Table (1). The CBR values greater than 100 % are presented for research purpose.

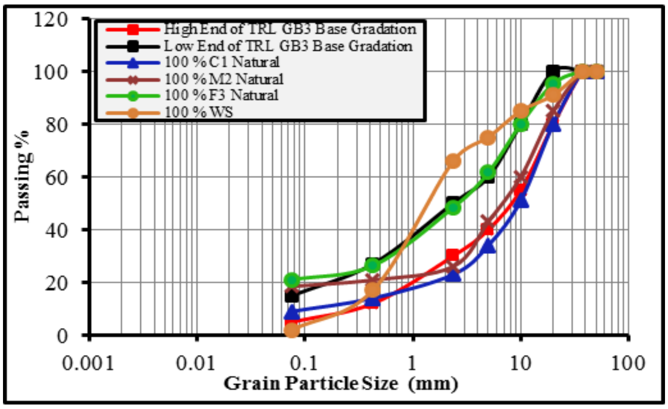

Fig - 1: Grain Size Distribution of the Three Natural Unbound Gravels, and Wadi Sand Compared to TRL GB3

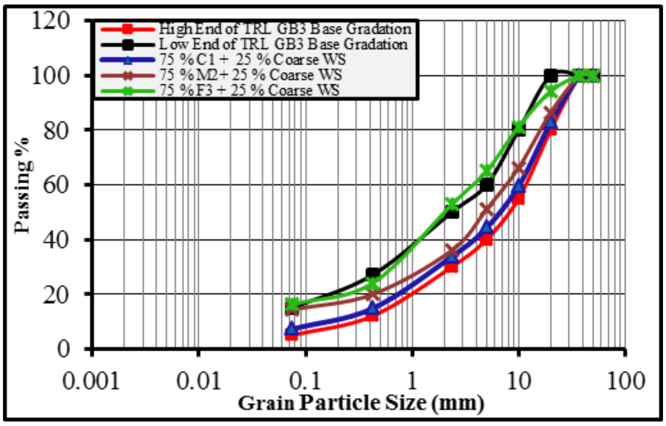

Fig - 2: Grain Size Distribution for the Three Gravels Blended with 25% Coarse Wadi Sand (TRL GB3)

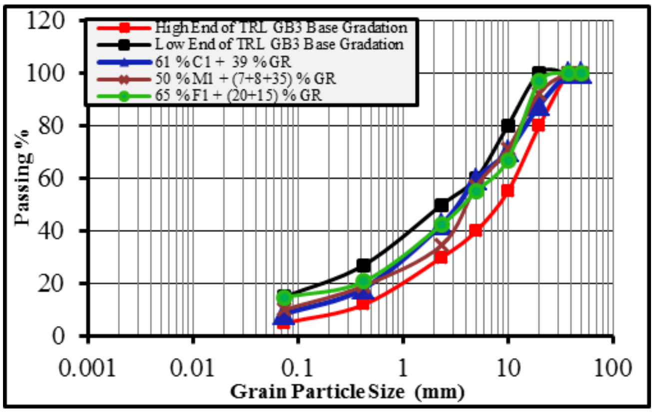

Fig - 3: Grain Size Distribution for the Three Natural Blends with Crushed Stone (TRL GB3)

Table - 1: Engineering Properties for the Natural and Blended Gravels that Nearly Satisfying or Satisfying TRL GB3 Base Requirements.

of ial	100% Natural Gravelly Unbound Material				75% Natural+25% WS			Natural+ CR Blend (TRL/GB3 Base)			
	CBR%	PI%	FC%	LA%	CBR%	PI%	FC%	CBR%	PI%	FC%	LA%
	68	11	9	32	79	7	7.25	168	9	7	32
	56	15	18.5	37.24	98	16	14.38	128	10	10.3	35.54
.	32	19	21	29.16	74	14.5	16.25	109	13	14.1	20.04

Note: PI % is plasticity Index, FC % is Fines Content% (% passing sieve No. 200) and LA% Los Angeles Abrasion Value

The blended materials were prepared at their optimum moisture contents (OMC), compacted in the resilient test mold (300 mm high & 150 mm diameter) to their corresponding maximum dry densities (MDD) using standard vibratory compactor, afterwards the resilient modulus (MR) test was performed on each of the samples in accordance to AASHTOT-307 TP 46 – 99. The MR test results compared to their corresponding predicted values are given in Fig. 4-9.

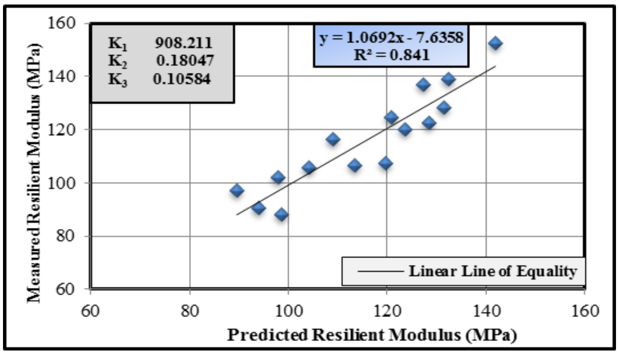

Fig - 4: Measured and Predicted Resilient Modulus for 75% Umm-Ketti+25% Wadi Sand Blend

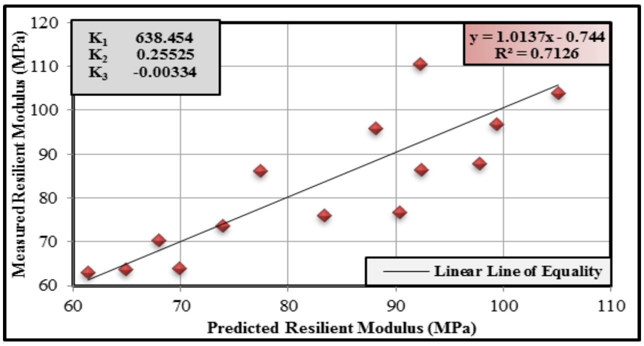

Fig - 5: Measured and Predicted Resilient Modulus for 75% Al- Silait+25% Wadi Sand Blend

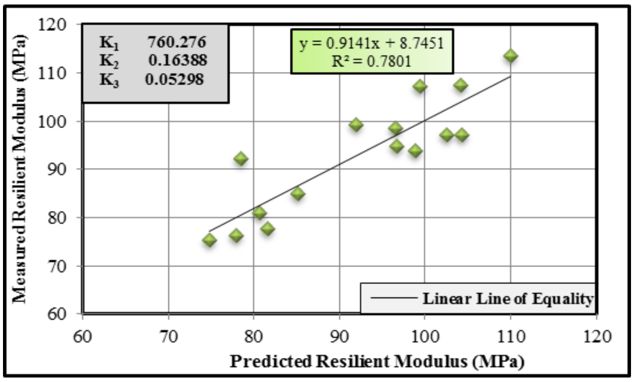

Fig - 6: Measured and Predicted Resilient Modulus for 75% Huttab Gravel+25% Wadi Sand Blend

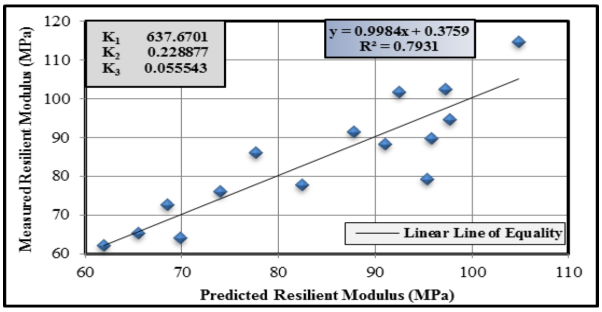

Fig - 7: Measured and Predicted Resilient Modulus for 61% Umm-Ketti+39% Rock Dust (5-0 mm) Blend

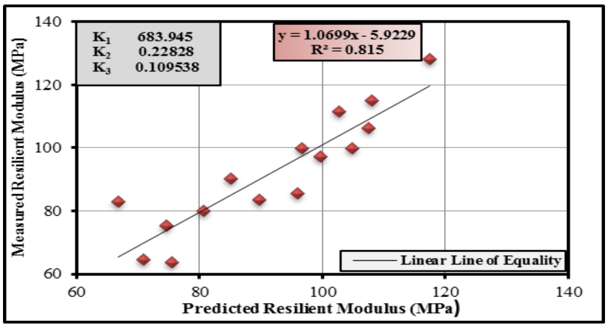

Fig - 8: Measured and Predicted Resilient Modulus for 50% Al-Silait+7% (19-12 mm)+8% (12-5 mm)+35% (5-0 mm) Blend

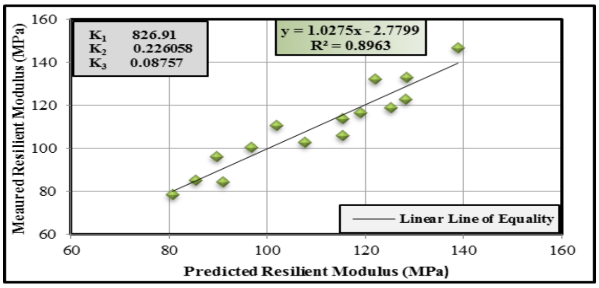

Fig - 9: Measured and Predicted M_R for 65% Huttab+20% (19-12 mm) + 15% (12-5 mm) blend

IV. Results Analysis And Discussions

From the measured resilient modulus values of the six treated samples in the study an excel program was used to solve for the material regression constants (K1, K2 and K3 in equation (4)). The obtained values are given in Table 2.

The predicted resilient modulus values were calculated using the NCHRP 1-28 (equation (4)) and the regression constants given in Table (2) for each corresponding measured MR value. The measured and predicted resilient modulus values are plotted as shown in Figures 4 to 9 for the six different blends.

Table - 2: Resilient Modulus Regression Constants

Satisfied TRL GB3 Specs	Resilient Modulus					
	Generalized Constitutive Model NCHRP 1-28					
	Material Dependent Regression Constants for Blended gravel with WS			Material Dependent Regression Constants for Blended gravel with CR		
	K_1	K_2	K_3	K_1	K_2	K_3
C1	908.211	0.18047	0.10584	637.6701	0.228877	0.055543
M2	638.454	0.25525	-0.00334	683.945	0.22828	0.109538
F3	760.276	0.16388	0.05295	826.91	0.226058	0.08757

Figures [4 - 9] depict the good agreement of the predicted to the measured resilient modulus for the blends satisfying or closely satisfying TRL GB3 base requirements. It is observed that the predicted resilient modulus for the six treated gravelly materials reported values slightly lesser with slight small differences when compared to the measured ones. This slight difference/or tolerance can be considered as a factor of safety when using the predicted resilient modulus in the mechanistic- empirical design.

The average reported tolerance compared to the measured resilient values for the given blends ranges approximately between 7.8% and 10%. Therefore NCHRP 1-28 regression equation can be used with confidence to predict the resilient modulus values for blended unbound natural materials from Khartoum. The computed R2 values that displayed in the six plotted figures for the given blends in the study showed values greater than 0.7 which indicated the fitness of applying NCRHP model for characterizing these typical granular materials in Sudan.

V. Conclusion

The main objective of this investigation was to study the application of NCHRP-1-28 model for predicting resilient modulus for mechanically blended natural unbound base material in Khartoum State. Three selected unbound gravels from Khartoum state representing coarse, medium and fine gradations were treated with wadi sand (WS) and crushed stone (CR) to obtain blends satisfying TRL GB3 base requirements. Dynamic triaxial test was used to measure their resilient (MR). A simple excel soft program was used for solving the NCHRP 1-28 model and the materials regression constants (K1, K2 and K3) were obtained; then the predicted resilient modulus values of the treated samples were computed and plotted with their respective measured ones. Some conclusions can be drawn as follows:

- The predicted and the measured resilient modulus values showed good agreement, therefore NCHRP 1 – 28 model suits the treated natural unbound aggregates.
- It was observed that the predicted resilient modulus for the six treated gravelly materials reported values slightly lesser with slight small differences when compared to the measured ones. This slight difference/or tolerance can be considered as a factor of safety when using the predicted resilient modulus in the mechanistic- empirical design. The average reported difference for the six blends ranges between 8% and 10%.
- The NCHRP 1-28 regression equation can be safely used to predict the resilient modulus values for the treated unbound gravelly materials from Khartoum state.
- It was found that the displayed R-square values on the presented charts for the six treated gravels gave values > than 0.7 which might reflect the application suitability of NCHRP 1-28 for characterizing these typical granular materials in Sudan.

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