Deformation Characteristics Of Soils In Sudan Impact On Structural Design Of Highways.

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Abstract:

This paper considers strength and deformation characteristics of some sub-grade soils in Sudan generally used for both geometric and structural design of highways. Laboratory tests were carried out to establish the deformation modulus of sub-grade soil as well as interrelationship between CBR and Modulus of elasticity is established.

Introduction:

The component of flexible pavement consists of surfacing, the road base and sub-base layer. The road base forms the structural component of the pavement and the sub-base is provided to help the base layer in distributing traffic stresses down into sub-grade, the sub-base also protects the base from adverse sub-grade conditions. Broadly pavement design methods are either theoretically based or empirical. Several empirical and semi empirical methods include varying modifications of CBR design method which was originally developed by the California State of Highway Department.

In the last two decades emphasis has shifted towards approach to pavement design involves the following steps:

- a- Development of mathematical models.
- b- Selecting the solution techniques for the equations developed under (a).
- c- Material characterization of the component layers of the pavement structure for the particular environment.
- d- Setting out design criteria in the form of allowable stresses and strains.

The success of the theoretical design methods is a direct function of the reliability of the strength parameters, which are used in the theoretical analysis. It is therefore, necessary that strength and deformative parameters of different sub-grade soils used in road pavement construction in a given climatic area are established. This paper outlines example of test carried out to establish strength and deformative parameters of the various sub-grade soils and also interrelationship between CBR and modulus of elasticity is established. Both parameter are useful for further investigation of common sub-grade soil used in road construction.

1- Test to establish strength and deformative parameters:

This paper outlines the tests carried out to establish strength and deformative parameters for sub-grade soil commonly used to construct the various layers of the pavement structure. The three types of sub-grade soils in Sudan include, heavy-clay (from Gadarief Area), heavy clay (Kosti), laterite (from Wau and eastern part of Lakes State).

Sub-grade Soils:

Laboratory investigations were conducted to establish deformation modulus of the three common sub-grade soils in Sudan under conditions simulating field loading and environmental conditions as far as was practical,The laboratory tests took into consideration the stress-strain conditions that prevail under a pavement structure due to natural overburden, and later due to additional stresses caused by embankment i.e. consolidation phase, distortion phase is caused by dynamic stresses due to traffic loading.

The test for the modulus of elasticity was carried out by unconfined test method. The specimens were prepared with different moisture contents the values of which are 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, from the liquid limits the density of specimen is equal to 0.95 to 0.98 of standard density. The value of the modulus of elasticity is determined by the following formula:

$$E_y = \frac{P.D\,(1-\mu^2)}{H_y}$$

E_y = modulus of elasticity

P = stress, MPa

D = Diameter of the specimen, cm

H_y = strain, mm

μ = Poisson's coefficient, 0.35

The result of the modulus of elasticity of the soil is tabulated in table (1).

Table (1): The values of Modulus of Elasticity of Investigated Soil in Sudan Depending on Relative Moisture

Relative Moisture m/LL	Modulus of Elasticity mpa for Soil Types					
	Laterite (Yay)		Heavy clay (Gadarif)		Heavy clay (Kosti)	
0.4	132		110		112	
	Δ=	42	Δ=	34	Δ=	32
0.5	90		76		80	
	Δ=	28	Δ=	24	Δ=	22
0.6	62		52		58	
	Δ=	24	Δ=	17	Δ=	21
0.7	38		35		37	
	Δ=	10	Δ=	9	Δ=	10
0.8	28		26		27	
	Δ=	4	Δ=	3	Δ=	3
0.9	21		23		29	

M = moisture content

LL = liquid limit

Δ = difference value of modulus of elasticity corresponding to relative moisture.

Discussion of test Results:

The values of modulus of elasticity in table (1) demonstrate that its values decreases with the increasing of relative soil moisture, especially from 0.7LL up to 0.8LL, the reduction of strength is remarkable. From this we can conclude if the soil moisture has a value range from 0.4LL to 0.66LL so the modulus of elasticity changes in the range of 28 to 42%, at the same time the value modulus of elasticity decreased three times at the value of relative soil moisture in the range of 0.8LL up to 0.9LL.

The relationship between Ey = f(w/LL) showed in Fig. (1). From the results in table (1). In this chart. Findings of different researchers and organization were also plotted. (BCH, Abu Baker, Mukhovech, Rhostos (Koba). We remark that the maximum value of Ed attained at the value of coefficient of compressibility in the range of K = 1.05 – 1.07 (Koba), K = 0.98 – 1.0 (BCH), K = 0.95 (Abu Baker) and K = 0.90 (XADU).

The results of tests of (Ed) had been processed and analyzed by computer on the bases of the following equation below.

$$E_d = a + BW + CW^2 + dW^3$$

$$E_d = A + \frac{B}{W} + \frac{C}{W^2}$$

$$E_d = a + 6^w$$

$$E_d = {}^{a}\!/_{w}{}^{-n}$$

$$E_d = \frac{A}{B + w}$$

The results of processed data showed in table (2).

Table (2)
Comparison of Formula for Determination of Modulus of Elasticity of Soil (for laterite)

M/LL	$E_y = a+b_w+c_w w^2+dw^3$				$E_y = a+b/w+c/w^2$				$E_y = a+b^w$				$E_y = A/w^{-B}$				$E_y = A/B+w$			
	$E_y^{э}$ experi	E_y^T theor	$\Delta = E_y^T - E_y^{э}$	%	$E_y^{э}$ experi	E_y^T theor	$\Delta = E_y^T - E_y^{э}$	%	$E_y^{э}$ experi	E_y^T theor	$\Delta = E_y^T - E_y^{э}$	%	$E_y^{э}$ experi	E_y^T theor	$\Delta = E_y^T - E_y^{э}$	%	$E_y^{э}$ experi	E_y^T theor	$\Delta = E_y^T - E_y^{э}$	%
0.4	132	131.65	0.35	0.26	132	133.022	1.02	0.77	132	126.09	5.91	4.47	132	139.67	7.67	5.8	132	140		
0.5	90	91.138	14	1.26	90	87.53	2.47	2.74	90	88.18	1.82	2.02	90	85.09	4.9	5.4	90	99.52	9.52	10.5
0.6	62	60.45	1.55	2.5	62	60.35	1.65	2.66	62	61.67	0.33	0.5	62	56.77	5.23	8.4	62	55	6.81	10.9
0.7	38	39.28	1.28	3.36	38	42.48	4.48	11.7	38	43.12	5.12	13.5	38	40.39	2.3	6.0	38	38.18	0.186	0.04
0.8	28	27.29	0.71	2.5	28	1.94	1.94	6.93	28	30.16	2.16	7.7	28	29.96	1.96	7.0	28	29.19	1.19	4.24
0.9	24	24.19	0.19	0.79	24	3.33	3.33	13.9	24	21.09	2.91	12.1	24	23.07	0.93	3.8	24	23.62	9.37	1.56
	a = 398.19 b = 885.857 c = 569.692 d = 52.3701 η = 0.95238 standard error = 0.998				a = 37.6394398.19 b = 39.8562 c = 11.3634 standard error = 2.7335				a = 527.088 b = 0.0279 standard error = 3.6013				a = 18.2601 b = 2.22042 standard error = 4.47782				a = 12.3921 b = 0.3755			

The results witnessed the least value of standard error when using (Binomial Theory) which will be used for further analysis of experimental results for clay of Sudan. Table (3).

Table (3); Manipulation of Results (by-Nomil theory)

Relative soil Moisture	Clay (Gadarif)				Clay (Kosti)			
	$E_y^{Э}$	E_y^{T}	Δ	%	$E_y^{Э}$	E_y^{T}	Δ	%
0.4	110	109.80	0.2	0.182	112	111.66	0.34	0.30
0.5	76	76.42	0.42	0.55	80	81.229	1.23	1.54
0.6	52	51.76	0.24	0.46	58	56.356	1.64	2.9
0.7	35	35.11	0.11	0.31	37	37.93	0.93	2.5
0.8	26	25.79	0.21	0.81	27	26.84	0.16	0.59
0.9	23	23.11	0.11	0.48	24	23.98	0.02	0.08
	a = 344.377, b = -811.746 c = 609.620, d = -115.900 η = -0.95 (coefficient of correlation) Standard error = 0.2388				a = 271.166, b = -444.666 c = 55.439, d = -148.296 η = -0.96 (coefficient of correlation) Standard error = 0.9326			

The change of CBR values depending on relative soil moisture for clay and lateritic soil showed in Table (4).

Table (4): Data of CBR Values Depending on m/LL

M/LL	Laterite CBR %	Clay CBR%
0.4	30	28
0.45	20	18
0.5	14	13
0.6	9	3
0.65	6	2

The above data witnessed that, when the relative soil moisture decreases, the CBR decreases. The received values can be used for further calculation of computive strength of road regions of Sudan, and also for interrelationship between E_d and CBR.

2- Establishment of Interrelationship Between CBR and Modulus of Deformation

Th calculation of road structure (for flexible pavement), usually carried out by CBR index at the same time, the new trend for structural design of highways carried out by modulus of elasticity of soil when it comes to solve the question of structure design. It is necessary to have a possibility of conversion factor from one index to another. Therefore, it is necessary to determine interrelationship between E_d and CBR.

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0.7	35	35.11	0.11	0.31	37	37.93	0.93	2.5
0.8	26	25.79	0.21	0.81	27	26.84	0.16	0.59
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The index of CBR is the relationship between stress (p) in Kg. and penetration corresponding settlement of 2.5mm of standard value resisting penetration for compacted gravel (P_o = 1360 Kg.)

$$CBR = \frac{P}{P_o} 100\%$$

The major disadvantage of CBR can be summarized as follows:

- The disadvantage of CBR characterize relative value of strength which can not directly related to the main factors regulating the strength of soil (m, γ_d, LL).
- The most difficult stage of test represent the preparation of samples (specimen) its physical and mechanical characteristics which have to correspond to the state of soil in road structure in computive period (the most severe climatical condition). According to the finding of research, the specimen for four days did not reach full saturation. Distribution of moisture in the overall length was non uniform (in the upper part of specimen less than 3cm m = 0.68 – 0.72 in middle part m = 0.58).
- Impossible to remark the degree of deformability of soil.
- Reference (2), and (5) showed, that there are different form of interrelationship between CBR and Modulus of deformation showed in table (5).

Table (5): Formula of Interrelationship between CBR and E_y

Author	Formulae of Interrelationship E_d Kg/cm^2
Evanof NN (2)	E_d = 14 CBR
Cherkasov	E_d = 12.6 CBR
Nacementot	E_d – 20 CBR
Bolgarry	E_d = 14 CBR
Mukovech. CE (5)	E_D = 23 CBR

The results in Table (5) witnessed that the coefficient of conversion (α) from CBR to E_d varied in the range of 12.6 up to 23 according to the condition of carrying out the test.

The most interested relationship represent the Formulae

$$E_d = (20 - 27)\ CBR$$

For further calculation we can apply the formulae formulated by Mukhovech with conversion factor equal to α = 23.

Transition between modulus of elasticity and modulus of deformation had been realized on the Basis of Data and BHC 46-83

$$Ed = BEd$$

Where: B - conversion factor the value of which ranges from 2.5 – 3, therefore, for transition purposes from CBR and modulus of deformation the following formulae can be applied.

$$E_d = 23\ BCBR = 23\ CBR \qquad (1)$$

Also Khostos Evalu formulated the following relationship for conversion purposes from modulus of elasticity and CBR for the conditions of Koba shown below:

$$E_d = 606 + 30.3\ CBR\ Kg/cm^2 \qquad (2)$$

$$E = 606 + 3{,}03\ CBR\ mpa$$

On the basis of the relationship in (1) and (2); a relationship between CBR and Ed was established and plotted in Fig. (2).

The analysis of data by the equation (2) shown that the graph did not pass through the beginning of the coordinate, when CBR = 0, Ed =60.6 ,which has no concept ,as in the usual case when CBR =0 ,Ed=0 therefore, the relationship in equation (2) can be realized in the range of CBR values from 10% up to 50%.

The tabulated data in Table (6) witnessed about the maximum number of occasions related to the variations of CBR for the case (4-8) in the range of (37.34%). The majority of events related to the variability of CBR in the range of (82.9%) related for the case (1-12).

Table (6): Analysis of CBR Values from the Main Roads of Sudan

	Khartoum-medani	Sennar-Kosti	Singa-Danazeun	Geli-Shendi	Kosti-Tandelti	Tandelti – Umraw-aba	Jabel Aulia-Kostei	Atbara-Hyia	Shendi-Atbara	Khartoum-Jabel Aulia	Total
CBR values	3 – 5	4 – 8	8 – 12	12 – 16	16 – 20	20 – 24	24 – 28	28 – 32	23 – 36	36 - 40	
Number of	35	59	37	8	7	6	2	-	-	4	158
%	22.15	37.34	23.42	5.0	4.4	3.8	1.2	-	-	2.69	100

The results of findings carried out by different authors are also plotted in Fig. (2). The presented results witnessed a close relationship of results in the range from 5 to 20 CBR values. Therefore the data of different authors analyzed and processed, and the following equation between modulus of elasticity (E_d) and of California bearing ratio (CBR) was obtained.

$$E_d = 33.94 + 4.10\ CBR$$

The above relationship may be used for CBR value in the range 2 – 40 with coefficient of coloration (η = 0.964).

References:

1- Soil of Sudan lack head,1957 152p.

2- Evan of N. N. determination of modulus of Deformation of Flexible pavement, Transport 195.200p.

3- Highway Design Manual, part 7.657 California department of Transportation, 1981.

4- American Association of State Highway and Transportation Officials, 1914, 990 p.

5- Mukhovech S. Methods of Investigation for strength of flexible pavement, Kharkof 1963.

6- Anfimof V.A, The Effect of Soil Structure of Sub-grade in its Design and Deformation Modulus Transport, 1952, 114 p.,

7- BCH. 46-83 Design of Flexible pavement "Moscow Transport" 1995, 155 p.

8- Brown S.F.A., "A simplified Fundemental Procedure for the Design of Bituminous pavement", 2nd edition, University of Nottingham 1986.

9- Crowney, Dand Bullman. J.N. "The Influence of Climatic Factors on the Structural Design of Flexible pavements, proceeding, 3rd International Conference on Structural design and Asphalt pavement, London 1992.250p.

10- Gichaga. F.J. "A Study of Deflection Characteristics and Response of Flexible pavement in Kenya", M.Sc. Thesis, University of Nairobi, 1976.

11- Cichaga, F.J., "Structural Behaviour of Flexible Pavements in Kenya, "Ph.D Thesis, University of Nairobi, 1979.