TECHNICAL NOTE

CONTROL OF ENGINEERING PROPERTIES OF ASPHALT CONCRETE BASED ON PERMANENT DEFORMATION CONSTRAINT OF SUBGRADE AT TROPICAL ZONES IN IRAN

M. A. Gaznon and H. Behbahani

Department of Civil Engineering, Iran University of Science and Technology
Tehran, Iran, ameri@iust.ac.ir - behbahani-hamid@yahoo.com

S. A. Tabatabie

Department of Civil Engineering, Shahid Chamran University
Ahwaz, Iran, tabataba-abbas@yahoo.com

(Received: November 13, 1999 - Accepted in Final Form: July 30, 2001)

Abstract The permanent deformation pavement of roads and streets at tropical zones (if layers are sufficiently compacted) is due to increase of asphalt layers temperature and consequential decrease of modulus of elasticity. Therefore, the asphalt mixture moves aside of the wheels of heavy vehicles and cause permanent deformations without volume variation. On the other hand, if the asphalt layer modulus of elasticity is not appropriate, additional stresses will be moved to the soil subgrade and thus causes permanent deformation. The materials used for the asphalt layers can be controlled by the proposed method so that additional stresses can be avoided. This study includes three types of pavements (thin, intermediate and thick) on three kinds of subgrades (weak, intermediate and strong) at tropical zones of Iran. Modulus of elasticity and Poisson ratio of layers are selected based on the earlier studies. The heavy axles of vehicles in Iran which cause the most damages are considered in this study (13 tons with two axle trucks). Then the modulus of elasticity of the asphalt mixtures is changed and stress-strain analysis is performed by the Elsym5 computer software to produce the maximum normal strain at the subgrade for all above mentioned types. The number of passing axles used in the analysis is obtained by the formula proposed by the Asphalt Institute ($N=1.6\,(10^{-9}(e)^{-4.477}$). Nomographs showing number of passing axles versus modulus of elasticity for all cases based on the computer analysis are drawn. The designed pavement can be compared to the corresponding nomograph mentioned above to control the modulus of elasticity of asphalt mixtures which prevent the subgrade from additional stresses by using the predicted passing axles.

Key Words Tropical Zones, Modulus, Strain, Rutting, Permanent Deformation, Subgrade

چکیده افزایش دمای لایه‌های آسفالت در مناطق گرمسیر به دلیل کاهش مدول الاستیسیته مخلوط آسفالت موجب تغییر شکل دائمی روسازی در راهها و خیابانها می‌شود. در اثر نوع خاصی از این تغییر شکل، تنشهای اضافی به سطح بستر خاکی وارد شده و تغییر شکل دائمی در اثر تردد وسایل نقلیه سنگین در آسفالت بوجود آمده و پدیده گود افتادگی سازه‌ای رخ می‌دهد. برای مطالعه این پدیده، سه نوع سازه روسازی (نازک - متوسط و ضخیم) روی سه نوع بستر (ضعیف، متوسط و قوی) در مناطق گرمسیر ایران می‌توان انتخاب کرده و روشی برای جلوگیری از بروز این پدیده ارائه نمود. به این منظور بعد از تعیین پارامترهای لایه‌ها (ضخامت، مدول الاستیسیته و ضریب پواسون) و در نظر گرفتن سنگین‌ترین بار محوری غالب در جاده‌ها و با تغییر مدول الاستیسیته آسفالت از برنامه کامپیوتری Elsym5 به تحلیل تنش - کرنش لایه‌های مختلف پرداخته و با استفاده از رابطه انستیتوی آسفالت ($N=۱/۶\times۱۰^{-۹}\times(\varepsilon_c)^{-۴/۴۷۷}$) تعداد محور مجاز ۸/۲ تنی براساس محدودیت کرنش ایجاد شده در بستر خاکی را بصورت منحنی‌هایی برای کنترل مشخصات مخلوط آسفالت ارائه می‌دهیم.

INTRODUCTION

One of the major objectives of this study is to introduce a method for controlling engineering properties of asphalt layer mixtures in order to assure their appropriate function against applied loads and environment conditions. Additional stresses should also be avoided in order to protect the pavement from structural

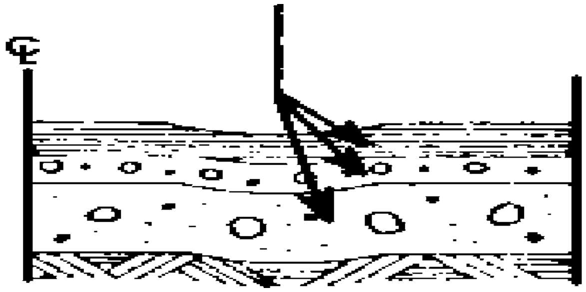

Figure 1. Structural rutting.

rutting phenomena [1]. These phenomena may occur due to the Considerable settlements caused by heavy vehicles traffic. Usually, a significant portion of the settlement is due to non-elastic (plastic) strains which make aconcave area in the tire paths. This is called structural rutting as illustrated in Figure 1.

In tropical zones, the asphalt temperature may rise to 70 degrees centigrade because of increase air temperature and the direct sun radiation [2,3]. Also, the asphalt modulus of elasticity decreases due to temperature rise which in turn causes the additional stress to be transferred to the bed of the pavement easily. Therefore,it can be concluded that a relationship between the decrease of the modulus of elasticity and the additional stresses transfer to the pavement bed exists which leads to the structural rutting.

INITIAL DATA

The modulus of elasticity and poison ratio of the base and subbase asphalt layers obtained from previous investigations are illustrated in Table 1 [4,5]. Based on investigations conducted in Iranian tropical zones, three pavement types with different thicknesses are introduced in Table 2. Different bed types based on C.B.R strength are also introduced in Table 3.

TABLE 1. Layer Properties (Kg/cm^2).

Property Layer		Modulus of Elasticity	Poison Ratio
Asphalt Layer		7000 to 42000	0.35
Base		1750	0.3
Subbase		1050	0.35
Bed	Weak	350	0.50
	Intermediate	525	0.4
	Strong	980	0.35

TABLE 2. Types of General Pavements.

		Thickness(cm)		
Layer		**Asphalt**	**Base**	**Subbase**
Type	Thin	10	20	25
	Intermediate	12	25	35
	Thick	15	25	40

TABLE 3. Bed Types Properties.

Bed type	Strong	intermediate	weak
C.B.R	>12	8-12	3-7

LOADING

Many softwares such as Elysm5, Kenlayer, Michpave, Flexpass, Vesys and Dama are used for structural analysis of flexible pavements. Analyses preformed by these software indicate that Elsym 5 and kenlayer give almost similar results [6]. In this study , Elsym5 has been used because of its simplicity and reasonable accuracy. The version of this computer software presented in 1986 was reviewed by Koperman [7].

The Elsym5 computer software was employed for the stress-strain analysis. This program affords ten circular loads with uniform intensities simultaneously. Different common commercial vehicles in Iranian routs were studied to get the critical heavy load applied by the tires on the rout surface. Maximum weights which can be tolerated by different axles are introduced in Table 4.

Referring to Table 4, it is observed that the two axle trucks apply the maximum load on

TABLE 4. Maximum Weights on Different Axle Types.

Axle	Single 6 ton (Single tire)	Single 13 ton (double tire)	Combined 20 ton
Weight on every tire (Kg)	$\frac{6000}{2} = 3000$	$\frac{13000}{4} = 3250$	$\frac{2000}{8}$ =2500

TABLE 5. Equivalence coefficients.

Type of axle	Single 6 ton	Single double tires	Combined 20 ton
Weight On axle	**6**	**13**	**20**
Equivalence Coefficient	**0.3225**	**6.4566**	**3.1092**

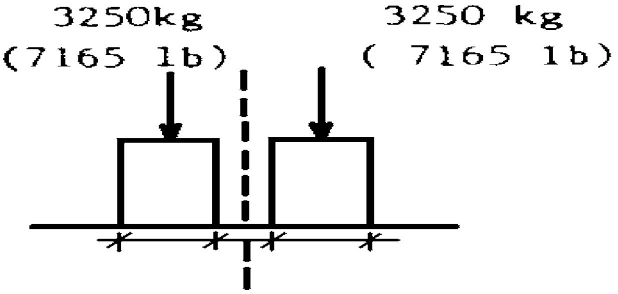

Figure 2. Schematic representation of a 13 ton trucks rear axle.

TABLE 6. Location of Points for Analysis.

Surface of asphalt layer	Thin **Pavement**	Intermediate Pavement	Thick Pavement
Middle of asphalt	**1.97**	**2.36**	**2.96**
Beneath asphalt	**3.94**	**4.72**	**5.91**
Middle of base	**7.87**	**9.65**	**10.83**
Beneath base	**21.65**	**28.35**	**31.50**
Middle of subbase	**16.73**	**21.46**	**23.63**
Beneath subbase	**21.65**	**28.35**	**31.50**
10 cm beneath subgrade	**25.60**	**32.28**	**35.44**

pavement surface compared to other truck types. Equivalent coefficients of standard 8.2 ton axle which reflect the damage rate on routs are given in Table 5 [5].

Table 5 indicates that the 13 ton axle has the maximum equivalence coefficient. The research carried out by the authers indicates that the 13 ton trucks rear axle gives maximum stress and strain in pavement layers [8] (Figure 2).

According to the information given by truck drivers and repair centers, the tire pressure of the 13 ton truck is 85 Psi.

Locations and selection of coordinates for analysis. (1) Center between two tires(x= 0.0 y=0.0)
(2) Internal edge of tire (x=2.56 y=0.0)
(3) Center of tire (x=7.11 y=0.0)
(4) External edge of tire (x=11.56 y=0.0)
(5) 10 cm out of tire (x=15.74 y=0.0)

Beneath the above mentioned coordination locations at surface, middle and below the asphalt, base,subbase and subgrade layers are considered to compute the stresses. Strains and displacements are introduced in Table 6.

STRAIN OF DIFFERENT LAYERS

The results of normal displacements obtained by Elsym5 concerning 54 pavement structures are given in Table 7. These results at different depths for the central points between the tires are given in Table 7.

The number of allowable passing loads N_d which avoid the structural rutting can be calculated form the equation:

$$N_d = f_4(\varepsilon_c)^{-f_5} \quad (1)$$

Where e_c represents the maximum normal strain on the subgrade surface; f_4 and f_5 are given in Table 8 [9,10].

COMPARISON OF METHODS

The normal strain on the subgrade versus number of 8.2 ton axles computed by the methods suggested in Table 8 is illustrated by the nomographs given in Figure 3. Comparing these nomographs indicates that the shell company has a considerable difference with the others.

Probably, the criteria of the Shell company method has a substantial difference with other criteria. On the other hand, the Asphalt Institute nomograph seems very close to TRR method at high strain and indicates a relative agreement with the Belgium method at low strains. Therefore, the Asphalt Institute method is considered a basis for the analysis performed in this study.

Based on Equation 1, proposed coefficients by Asphalt Institutes referred to in Table 8, and subgrade strain of different pavement

TABLE 7. Maximum Normal Strain.

Pavement Type	Elasticity Modules Bed type	7000	14000	21000	28000	35000	42000	Unit Kg/cm^2
Thin	**Weak**	**7.419**	**6.87**	**6.53**	**6.27**	**6.05**	**5.85**	$(10^{-4}$
	Intermediate	**6.54**	**6.08**	**5.79**	**5.56**	**5.38**	**5.21**	
	Strong	**5.77**	**5.38**	**5.13**	**4.43**	**4.76**	**4.62**	
Intermediate	**Weak**	**4.78**	**4.41**	**4.19**	**4.02**	**3.88**	**3.76**	
	Intermediate	**4.26**	**3.95**	**3.76**	**3.61**	**3.49**	**3.39**	
	Strong	**3.79**	**3.53**	**3.36**	**3.23**	**3.13**	**3.04**	
Thick	**Weak**	**3.29**	**3.57**	**3.35**	**3.19**	**3.06**	**2.94**	
	Intermediate	**3.51**	**3.21**	**3.02**	**2.87**	**2.76**	**2.65**	
	Strong	**3.13**	**2.87**	**2.70**	**2.57**	**2.48**	**2.39**	

TABLE 8. Values of f_4 and f_5.

Name of Organization	f_4	f_5
Asphalt Institute	$1.365(10^{-9}$	4.477
Shell Company, 1985 **50%**	**$6.15(10^{-7}$**	**4**
85%	**$1.94(10^{-7}$**	4
95%	**$1.05(10^{-7}$**	4
U.K. TRR **85% safety**	**$6.18(10^{-8}$**	3.95
Belgium road research center	$3.05(10^{-9}$	4.35

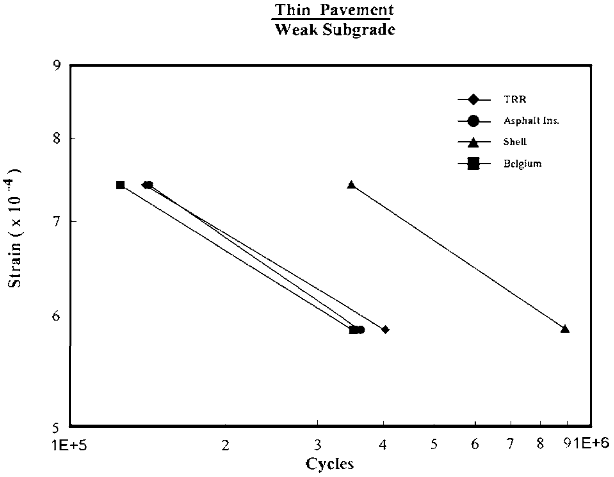

Figure 3. Effect of number of allowable passing loads on normal strain exerted in intermediate pavement of weak subgrade.

structures referred to in Table 7, the number of 8.2 ton axles concerning the limitation of structural rutting introduced in Table 9 are calculated. Table 9 also introduces the vertical strain on subgrade and the allowed number of 8.2 ton axles of 54 pavement structures.

Number of elasticity drawn on a logarithmic scale for three pavement types (thin, intermediate and thick) with various bed conditions (weak, intermediate and strong) are shown in Figures 4, 5 and 6.

Thus, the mixture properties can be controlled by using these nomographs, the initial data as the number of 8.2 ton equivalent axles within the design period of the road which is designed on the basis of one of the methods, knowing the C.B.R of the bed, and selecting the appropriate nomograph from Figures 4 and 5 or 6. Proper use of the mentioned nomographs is illustrated in Figure 7.

RESULTS

The design of pavement thickness and asphalt mixture can be checked by using the proposed method. The asphalt mixture and the pavement layer thicknesses should be checked so that no additional stresses and strains are obtained in the soil bed and also no structural rutting occurs in the tire paths.

Example A pavement Layer thickness

TABLE 9. Number of Allowable Traffic Based on Asphalt Institute Method.

Pavement Type	Modules Elasticity Bed type	7000	14000	21000	28000	35000	42000	Unit Kg/cm^2
Thin Pavement	**Weak Bed**	**0.742** **140066**	**0.687** **197732**	**0.653** **248179**	**0.627** **297691**	**0.605** **349312**	**0.586** **402953**	(**10^{-3}** **N**
	Intermediate Bed	**0.654** **246485**	**0.608** **341661**	**0.579** **425226**	**0.566** **509838**	**0.538** **590772**	**0.521** **682103**	
	Strong Bed	**0.577** **431865**	**0.538** **590772**	**0.513** **731033**	**0.493** **873488**	**0.476** **1022083**	**0.462** **1168235**	
Intermediate Pavement	**Weak Bed**	**0.478** **1003076**	**0.441** **1438735**	**0.419** **1809174**	**0.402** **2177773**	**0.388** **2552307**	**0.376** **2937762**	
	Intermediate Bed	**0.426** **1679832**	**0.376** **2355957**	**0.361** **2937762**	**0.349** **3525111**	**0.399** **4101126**	**0.399** **4671201**	
	Strong Bed	**0.379** **2835077**	**0.353** **3897133**	**0.336** **4860844**	**0.323** **5800066**	**0.313** **6676988**	**0.304** **7608650**	
Thick Pavement	**Weak Bed**	**0.329** **2437759**	**0.357** **3705416**	**0.355** **4926143**	**0.319** **6132841**	**0.306** **7388526**	**0.294** **8837748**	
	Intermediate Bed	**0.351** **3997538**	**0.321** **5963615**	**0.302** **7836850**	**0.287** **9844539**	**0.276** **11726885**	**0.265** **14068923**	
	Strong Bed	**0.313** **6676988**	**0.287** **9844539**	**0.270** **12939487**	**0.258** **15860293**	**0.248** **18930952**	**0.239** **22338049**	

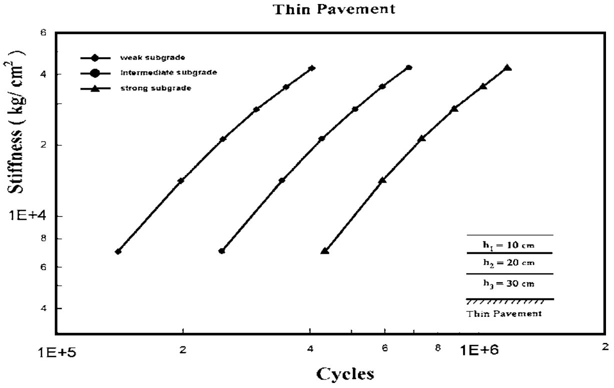

Figure 4. Effect of number of allowable passing loads on stiffness of thin pavement.

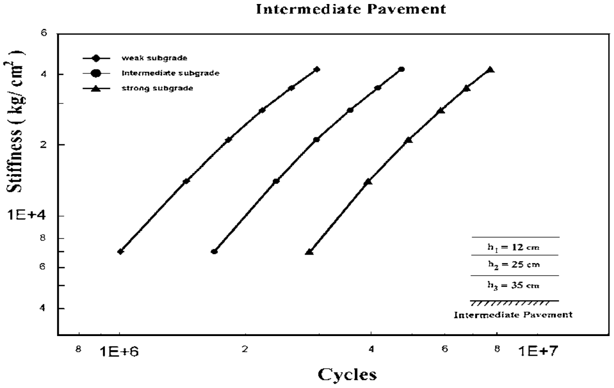

Figure 5. Effect of number of allowable passing loads on stiffness of intermediate pavement.

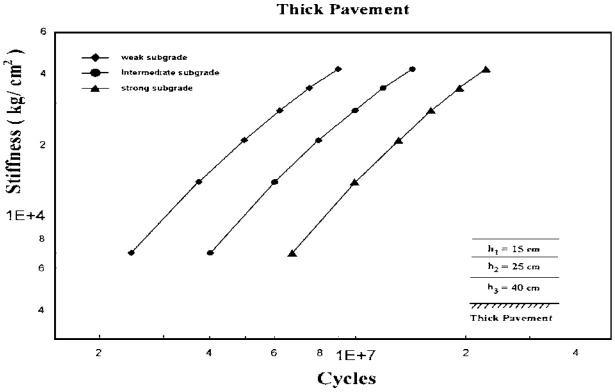

Figure 6. Effect of number of allowable passing loads on stiffness of thick pavement.

design is given as: $h_{subbase}$= 38 cm; $h_{asphalt}$= 15 cm; h_{base}= 23 cm; C.B.$R_{subgrade}$= 11; EAL= 10^7. Number of axles of 8.2 tons vehicle is 10^7. Characteristics of materials such as volume percent of rock and asphalt materials and PI of asphalt can be determined by the Marshal test.

Solution Comparing the thicknesses of the designed pavement layers with thicknesses given in Table 2, it is concluded that the pavement is thick. According to Table 3, the give C.B.R

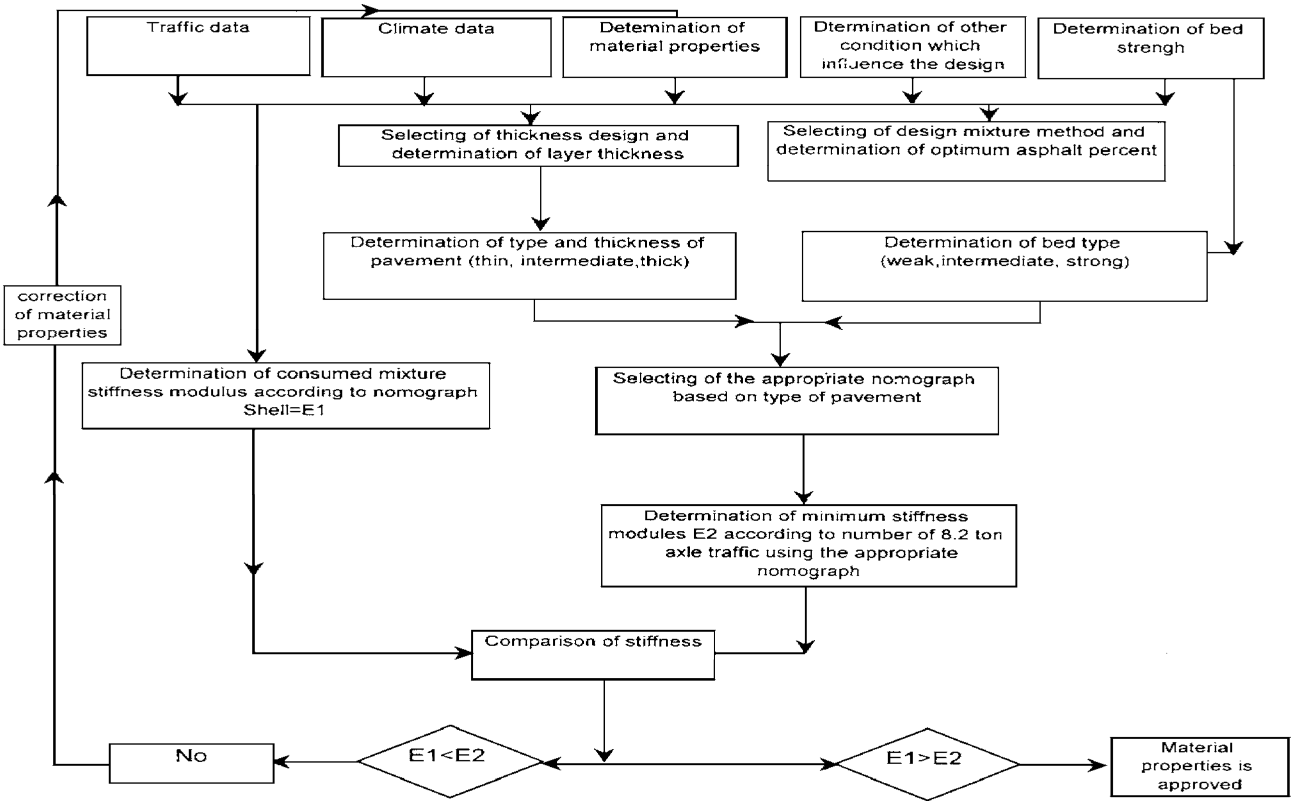

Figure 7. Flowchart of nomograph used in this study.

indicates that the bed is intermediate. Hence, using Figure 6 concerning Eal = 10^7, the stiffness coefficient of the required asphalt mixture which can avoid additional stress in bed yields: $E_{\mathbf{required}}$ = 2756 MPa. Considering the Vander Poel nomograph [5,6], the stiffness of the existing asphalt mixture which is supposed to be used will be as: E_{existing} = 3238 MPa. Since $E_{\text{existing}} > E_{\text{required}}$ the mixture is considered to be acceptable.

REFERENCES

1. Dawby, C. B., Hegewide, B. L. and Anderson, K. O., "Mitigation of Instability Rutting of Asphalt Concrete Pavement in Lethbridge, Alberta, Canada", ***AAPT***, Vol. 59, (1990), 481-509.
2. Abdul Wahab, M. I. A. L. and Balghunaim, F. A., "Asphalt Pavement Temperature Related to Arid Saudi Environment", ***ASCE***, Vol. 6, No. 1, (Feb. 1994), 1-14.
3. Bissada, A. F., "Asphalt Pavement Temperature Related to Kuwait Climate", ***ASCE***, Ministry of Public Works, Kuwait, 71-85.
4. "AASHTO Guide for Design of Pavement Structures", American Association of State Highway and Transportation Officials, (1986), I3-I31.
5. Yoder, E. J. and Witezak, M. W., "Principal of Pavement Design", John Wiley, New York, (1975).
6. Huang, Y. H., "Pavement Analysis and Design", Prentice-Hall, Inc., Engleweed Cliffs, New Jersay, (1993), 7632.
7. Kopperman, S., Tillor, G. and Tseng, M., "Elsym5, Interacting Micro-Computer, Version, User's Manual", Report No. FHWA-TS-87-206, Federal Highway Administration, (1986).
8. Tabatabaie, S. A. and Safa, E., "Performance Analysis of Single and Tandem Axles Load on Deterioration of Flexible Pavements", ***Proceedinges of the Second International Conference in Civil Eng.***, Vol. 2, 6-8th April 1996, Bahrain, 757-762.
9. Monismith, C., et.al, "Permanent Deformation Characteristics of Subgrade Soils Due to Repeated Loadings", TRR 537, (1975).
10. Leahy, R., B. and Witczak, M. W., "The Influence of Test Conditions and Asphalt Concrete Mix Parameters on Permanent Deformation Coefficients Alpha and Mu", ***AAPT-1991***, Vol. 60, 333-364.
11. "Thickness Design-Asphalt Pavement for Highway and Streets", Manual Series, No. 1, Asphalt Institute, Printed in USA, (1993).