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EFFECT OF MOISTURE CONTENT ON DEFORMATION CHARACTERISTICS OF UNBOUND BASE COURSES

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ABSTRACT

The design of flexible pavements involves a study of the behavior of soils and paving materials under traffic and environmental conditions. The pavement may be exposed to different moisture contents. This variation in moisture content influences the flexible pavement performance causing plastic deformation or rutting.

The results of an experimental program utilizing a test-model for determination of the plastic and elastic deformation along the model centerline are presented for pavement unbound granular base materials. A limestone base course, which usually used in north Egypt was manually compacted and tested by plate loading test at four moisture contents. The four selected moisture contents are (optimum moisture content (OMC, OMC –2%, OMC+1.5% and OMC+3%). Moreover, the finite element program, FENLAP was selected to predict the base course deformation at different moisture contents.

It was found that the effect of moisture content was very significant on the modulus of elasticity and the deformation that accumulated in granular base materials. The highest modulus of elasticity and the lowest deformation were occurred at OMC.

إن تصميم الرصف المرن يتضمن دراسة سلوك التربة ومواد الرصف تحت الأحمال والظروف البيئية المختلفة ، ومن الممكن أن يتعرض قطاع الرصف إلى محتويات مختلفة من الرطوبة ، هذا التغيير فى محتوى الرطوبة يؤثر على أداء الرصف المرن مسببا تشكل لدن وتخدد لطبقات الرصف.

لقد تم تصميم برنامج عملى باستخدام نموذج اختبار لحساب التشكل اللدن والتشكل المرن لطبقتين من قطاع الرصف هما طبقة الأساس وطبقة التأسيس ، وتم قياس التشكل الرأسى على خط المحور للنموذج. وتم دمك طبقة التأسيس من الطمى الطيينى عند نسبة الرطوبة المثلى أما طبقة الأساس فكانت من الحجر الجيرى – والذى يستخدم على نطاق واسع فى مصر– وتم وضعها أعلى طبقة التأسيس ودمكها يدويا عند أربعة نسب مختلفة من الرطوبة هى (النسبة المثلى & المثلى – ٢% & المثلى + ١,٥% & المثلى + ٣%). بعد إتمام التجهيز تم اختبار القطاع الإنشائى والمكون من هاتين الطبقتين باستخدام اختبار قرص التحميل.

علاوة على ذلك تم استخدام برنامج الحاسب (Fenlap) والذى يعمل على أساس طريقة العناصر المحددة لمقارنة النتائج المحسوبة نظريا والنتائج التى تم الحصول عليها من التجارب المعملية.

لقد أظهرت النتائج أن محتوى الرطوبة له تأثير واضح جداً على معامل المرونة والتشكل المتراكم فى طبقة الأساس الحصوية ، ووجد أن أعلى معامل للمرونة وأقل تشكل حدث عند نسبة الرطوبة المثلى. كما وجد أن هناك تقارب شديد فى النتائج العملية والنظرية عند استخدام المعادلات الغير خطية من نموذج درسدن الرياضى (Dresdener Model).

Keywords: Deformation, Moisture content, Granular base materials, Plate loading test

1. INTRODUCTION

1.1. General

The pavement may be exposed to different moisture contents. For example, during the rainfall season, the pavement sublayers may be subjected to high moisture content and could possibly reach saturation. Then, by evaporation or moisture draining off, the pavement sublayers may go through a dry season and the moisture content may decrease significantly. This variation in moisture contents influences the flexible pavement performance causing plastic deformation or rutting [1]. Rutting leads to decrease in the pavement life, increase in the maintenance costs and may cause a complete failure of the pavement. If the resistance of flexible pavement layers against elastic and plastic deformation could be increased, then pavement life will be increased and costs of both maintenance and reconstruction will be decreased [2].

1.2. Objectives

The main objective of this research is to study the effect of moisture content variations on elastic deformation, plastic deformation, modulus of elasticity and accumulated deformation of unbound granular limestone base coarse measured by plate loading test. Also, to study the effect of cyclic

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loading on elastic and plastic deformation at different moisture contents. In addition to compare the measured deformations using the test model and calculated ones utilizing finite element (FE) method. In this research the finite element program, FENLAP was selected to predict the base course deformation at different moisture contents.

2. BACKGROUND

Thom and Brown [3] performed a series of laboratory tests, including triaxial compression test, and found that the elastic stiffness tends to decrease with increasing moisture content for broadly graded materials. They concluded that saturation in the base layer has a significant impact on the elastic behavior of pavements. In similar tests performed by Raaf, Minassian, and Gartin [4], it was also concluded that moisture had a significant impact on the compressibility of granular soils.

A study performed by Tian, Zaman, and Laguros [5] came to somewhat similar conclusions as the studies previously mentioned. They also found that an increase in moisture content leads to a decrease in resilient modulus (M_R) values. A report by Newcomb, et.al. [6] concluded that it is necessary to locate the water table and deformation modulus of the material. It is important that the water table information should be recorded each time and tests are performed due to its fluctuations.

There was a need to determine if embankment depths should be increased in order to keep the water table away from the structural layers of pavement systems [7]. In their study Ksaibati, Armaghani and Fisher [8] determined the effect of high water table levels on pavement modulus values. From their results it was clear that, as the depth from the pavement surface to water table level decreases, there were significant increase in the moisture content of base and subgrade layers. According to the tests, base and subgrade modulus values experienced 5 to 35% reductions due to increases in moisture content of these layers. Musharraf and Joakim [9] studied the effect of moisture content on resilient modulus of granular base materials (M_R). They found that an increase in moisture content leads to a decrease in (M_R) values.

To calculate the total vertical deformation at the surface of one or multi layers theoretically, the linear elastic computer programs as BISAR and ELSYM5 can be used for this purpose. Moreover, the modulus of subgrade reaction (K) and elastic modulus (E) of one or multi- layers can be determined [10]. Also a finite element programs as ABAQUS and FENLAP were used to model the pavement structure and predict deformation behavior at any point.

Several techniques can be used to represent the pavement structure in a FE program. These techniques include two-dimensional (2D) plane-strain, axisymmetric, and full three-dimensional (3D) modeling [11].

The FE program FENLAP was made by the University of Nottingham and developed at the University of Dresden- Germany. Using this computer program, axial symmetrical stress and deformation behavior could be calculated for the different layers of the pavement. The calculation duration increases however considerably with increasing the number of elements. The program uses eight knots rectangular elements, in which every knot available of two liberty degrees (vertical and horizontal moving), and all element angles are 90 ° (geometric linearity).

The load contact area is classified using outer and inner radius, since rows and columns in both directions up to the system edge always make the FE-network. The program has the possibility to determine the total displacement for the selected layers. For granular base courses, it is possible to put horizontal stress equals zero or to take it as a percent from maximum vertical stress. In FENLAP there are different non-linear elastic models already implemented plus to the linear elastic *Hook's* law, among this also the elastic Dresden model [2].

3. RESEARCH PROGRAM

The research program of this study divided to two parts, experimental – and theoretical program:

3.1.Experimental Program

The experimental program includes the use of a test-model facility, which simulates the subgrade and base components of a flexible pavement system and permits testing full-scale base sections constructed on a cohesive subgrade at four moisture contents (5.0%, 7.0%, 8.5% and 10.0%)

3.1.1.Subgrade and base material

A silty soil was used as subgrade. This soil was tested against Atterberg limits and maximum dry density. Hence, the subgrade is classified as (A-7-5) and its maximum dry density was 1.665 gm/cm^3. Crushed limestone was used as a base course. These aggregates were tested against gradation and Atterberg limits. The gradation is shown in Figure (1) and the physical properties for subgrade and base course are presented in Table (1).

3.1.2.The test- model description

The test-model basically consists of a square wood box 1.2 m wide by 1.2 m long and 0.9 m depth. The box contains two materials 0.5 m depth silty subgrade and 0.4 m depth limestone base course .A schematically diagram of the total test-model assembly is shown in Figure (2).

3.1.3.Compaction of the model layers

Optimum moisture content was added and mixed with the subgrade soil. The soil was spread in the wood box and compacted manually in five layers of 10.0 cm thickness using steel hammer. The relative density and moisture content measurements were obtained by sand cone replacement method.

The base course materials were prepared by addition of four moisture contents 5.0 %, 7.0 %, 8.5% and 10% (by weight). The base course materials were compacted in four layers then, sand replacement test was carried out to evaluate the relative compaction. Table (2) illustrates the results of sand replacement method and relative compaction for subgrade soil and for base course at different moisture contents.

3.1.4. Preparation of tests

The surface of base course was leveled to insure a good contact between the plate and the surface of the base course. The loading hydraulic jack was then centered over the plate. Five dial gauges were then mounted on the aluminum rod across the test model at the plate center, where the middle one resting on the plate while the other gauges placed directly on the base surface as shown in Figure (3), so the vertical deformation in base course surface could be obtained every 20 cm across the test – model.

3.1.5. Applied vertical pressure

In this study, a contact pressure of 0.5 N/mm^2 on asphalt surface layer was considered. BISAR-Linear elastic program was used to calculate the vertical stress at the surface of base coarse considering 5.0 cm asphalt wearing coarse and 5.0 cm asphalt binder coarse. The results indicated that vertical stress decreased to 0.35 N/mm^2 on the top of the base coarse.

3.1.6. Plate loading test

A vertical stress in five increments each of 0.07 N/mm2 was applied on the steel plate using hydraulic jack, the deflection allowed to reach almost the maximum value after 30 minutes then, the vertical deformation was measured at all points along the test-model center line. After these five increments the stress reached 0.35 N/mm2 and the total deformation was observed. After that, the total load was released and the material was allowed sufficient time to rebound. This process was repeated three times.

The elastic modulus obtained from the plate-loading test is based on the elastic theory. When a rigid plate is put on the surface of a granular base with Poisson's ratio of 0.35, the modulus of elasticity is as follows [12]:

$$E = \frac{1.38 p.a}{w} \qquad (1)$$

Where:

E = Modulus of elasticity (Mpa)
p = Uniform applied pressure (Mpa)
a = Radius of circular plate (mm)
w = Deflection corresponding to the third load on the rigid plate (mm).

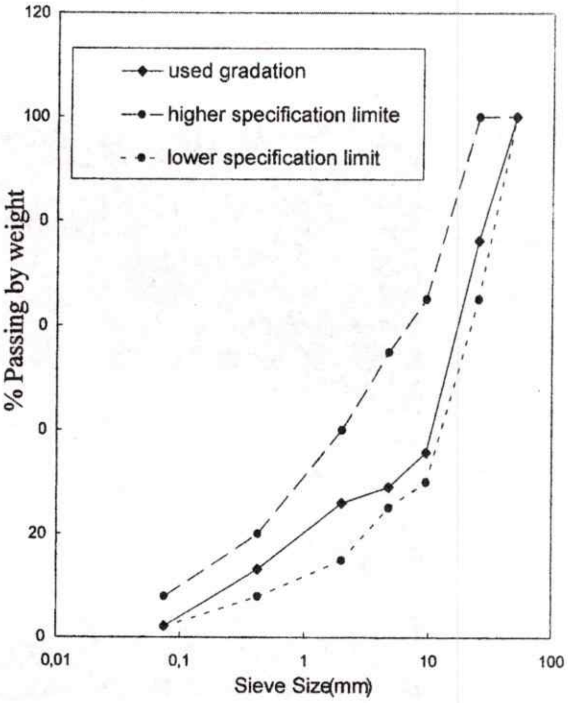

Figure (1): Grain Size Distribution of Base Aggregate

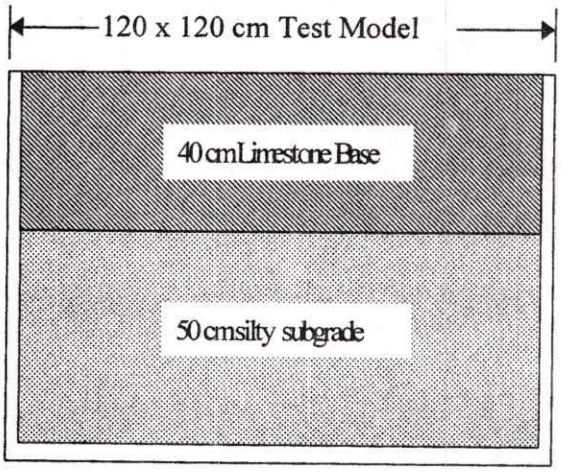

Figure (2): A schematically Diagram of the Test-Model

For accumulated deformation with time, a static load of 2.5 Ton was applied immediately upon the plate. The readings for all dial gauges were observed after 2.5, 5, 10 minute then after 0.25, 0.5, 1, 2, 3, 5, 10, 24, 48 hour to study the effect of loading time on the total deformation accumulated along the test model center line.

Table 1: Physical properties of subgrade and Base Course

Test	Subgrade soil	Base course
Natural moisture content, %	7.0	1.30
Liquid Limit, %	54.0	19.0
Plastic Limit, %	40.0	13.6
Specific Gravity, gm/cm^3	2.68	2.65
Loose density, gm/cm^3	1.33	1.70
Maximum dry density, gm/cm^3	1.665	2.12
Optimum moisture content, %	16.0	7.13
AASHTO classification group	A-7-5	A-2-4
Unified classification group	MH	GP

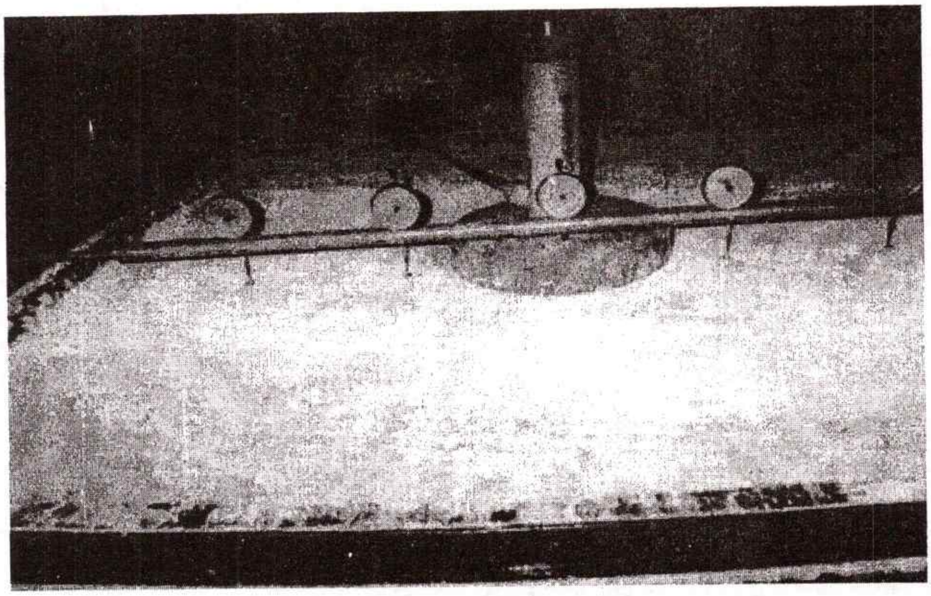

Figure (3): Plate loading test

3.2. Theoretical Program

Theoretical calculations of deformation were carried out using Finite Element method. Computer program FENLAP was used for this purpose. In finite element analysis, the structure and other auxiliary conditions have to be correctly modeled to obtain reasonable response results. Features of the finite element Fenlap model include material models, load model, boundary conditions, element type, and model geometry. The test-model is 120 cm width by 120 cm long by 90 cm height. The pavement sections built in the test model included 50 cm silty subgrade, 40 cm limestone base course as presented in the experimental program.

3.2.1. Implementing the material behavior

- Subgrade

The silty subgrade has been modeled as linearly elastic and had a unit weigh of 17.40 kN/m^3 at optimum moisture content, angle of internal friction (φ) equal 14°, the modulus of elasticity (E) of 4881 kN/m^2 and poison's ratio (μ) of 0.45. The subgrade was modeled with a thickness of 0.50 m.

- Unbound granular layer (UGL)

In this research the base course has been modeled with thickness of 0.40 m as linearly elastic and had average unit weigh of 1.95 kN/m^3 with four moisture content, angle of internal friction (φ) equals 23°, poison's ratio (u) of 0.35 and the modulus of elasticity (E) various according to the variation of moisture content.

- Loads

The vertical stress was taken as 0.35 N/mm^2 on the plate of radius 0.15 m to simulate the test model loading condition.

- Elements types and model geometry

A finite element mesh was created to represent the overlay. Four factors control the finite element (FENLAP) mesh geometry [13]:

1. Pavement geometry, which controls the general size of the mesh;
2. Load configuration, such as dimensions and spacing of contact areas;

3. Details such as locations where response parameters will be predicted;
4. Desired accuracy.

For this research the radius of the model becomes 0.6 m. The used mesh has a dimension of 0.6 X 0.9 m in the radial direction; this mesh consists of 15 columns and 20 rows (266 elements), which represent half of the test model. The geometry of the model is shown in Figure (4). In the vertical axis the height of the elements is 2.5 cm up to level 0.2 m then increased to 5 cm up to level 0.5 m then 10 cm to the bottom of subgrade. The width of the elements is 3 cm up to column of 0.15 m then increased to 5 cm to the mesh end as shown in Figure (4).

4. ANALYSIS OF EXPERIMENTAL RESULTS

For all studied moisture contents it can be noticed that in the first load cycle the cumulative deformation under the plate increased rapidly with increasing the vertical pressure on the plate. When the total load released and the material took a sufficient time to rebound, one part of vertical deflection is return and the residual part is remained as shown in Figure (5), which obtains the plate loading test results at 5.0% moisture, content. The returned division represents the elastic deformation, while the remained part symbolizes the plastic deformation.

The values of total vertical deformation after the third loading cycle could be observed, they were 2.03, 1.40 ,2.76 and 4.08 mm for 5.0%, 7.0%, 8.5% and 10% moisture contents respectively. It can be noticed that the lowest value of accumulated deformation is achieved at optimum moisture content (OMC).

4.1. Effect of Moisture Content on Modulus of Elasticity

The modulus of elasticity (E) was calculated using Equation (1) considering a uniform applied pressure equals 0.35 N/mm^2 and the radius of circular plate equal to 150 mm .Modulus of elasticity values at each moisture content is presented in Table (2). It could be noticed that the highest modulus of elasticity is achieved at OMC. This indicates that the highest resistance of base course to deformation was achieved at optimum moisture content.

4.2. Plastic and Elastic Deformation Along the Test- Model Center Line

The effect of moisture content on plastic and elastic deformation is represented in Figures (6) and (7) which correlate the relation between deformation (mm) and the distance along the plate centerline. It could be noticed from these Figures that the lowest value of plastic deformation at all points is approximately at optimum moisture content and the highest value of plastic deformation was accomplished at 10% moisture content . This may be because the soil particles move closer together at OMC, thus lead to increase in the density to the maximum. The lowest value of elastic deformation is achieved at optimum moisture content. But as the distance increased more than 0.2 m, the elastic deformation increased with decreasing moisture content.

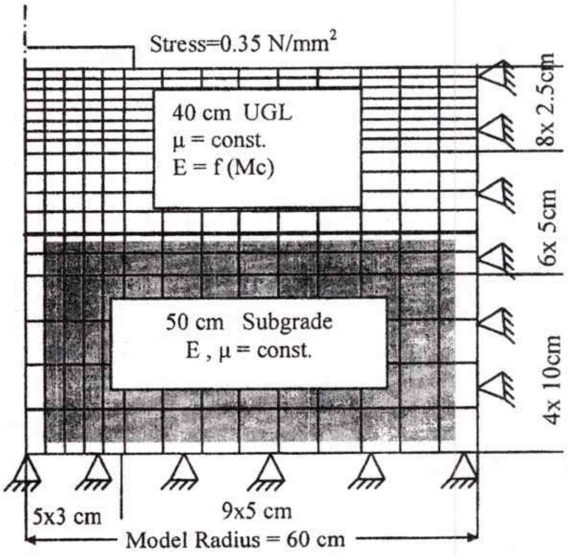

Figure.(4): Geometry of the Axial Symmetric Model for the UGL and Subgrade.

Table 2: Results of Sand Cone for Subgrade and Base Course at Different Moisture Content

Layer type	Moisture content (%)	Bulk density (gm/cm^3)	Dry density (gm/cm^3)	Laboratory dry density (gm/cm^3)	Relative compaction (%)
Silty subgrade	16.0	1.74	1.5	1.66	90
Limestone base course	5.0	1.99	1.895	2.07	91.4
	7.0	2.13	1.99	2.118	94
	8.5	2.1	1.935	2.1	92.1
	10.0	2.145	1.95	2.08	93.7

Table 3: Effect of Moisture Content on Modulus of elasticity

Moisture contents	5.0%	7%	8.5%	10%
Modulus of elasticity (N/mm^2)	35.69	51.75	26.17	17.75

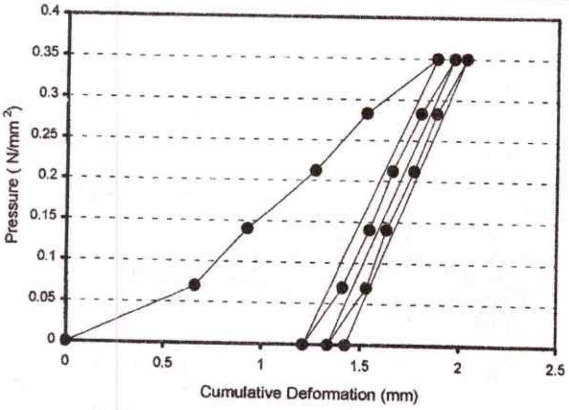

Figure (5) Plate Loading Test Results at M.C =5.0 %

4.3. Effect of Loading Cycles on Plastic and Elastic Deformation

At the end of each loading cycle, the elastic and plastic deformations were determined under the plate center. As shown in Figure (8), at all moisture contents the plastic deformation increased with increasing the loading cycles. This probably due to the expulsion of additional parts of compressed air and water, which fill the pores of base material after each loading cycle hence, the soil particles replace these parts of air and water so, the plastic deformation increases gradually .As shown from Figure (9), the elastic deformation decreased with increasing the number of loading cycles. This may be because the total deformation consists of plastic and elastic deformation , if one of them increases, the second decreases automatically.

4.4. The Relationship between CBR values and Modulus of Elasticity

CBR values for base course material at 5%, 7%, 8.5% and 10% moisture content were measured using CBR test. The relationship between CBR values and the modulus of elasticity of unbound granular base course was determined. It could be indicated that the modulus of elasticity increased with increasing CBR value.

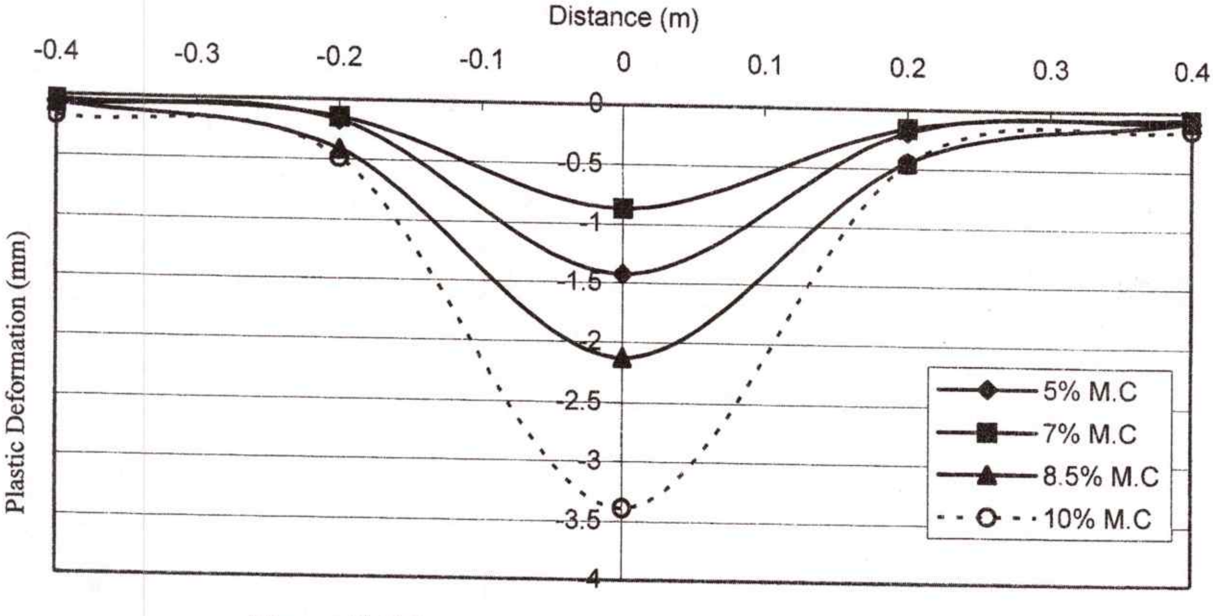

Figure (6) Effect of Moisture Content on Plastic Deformation

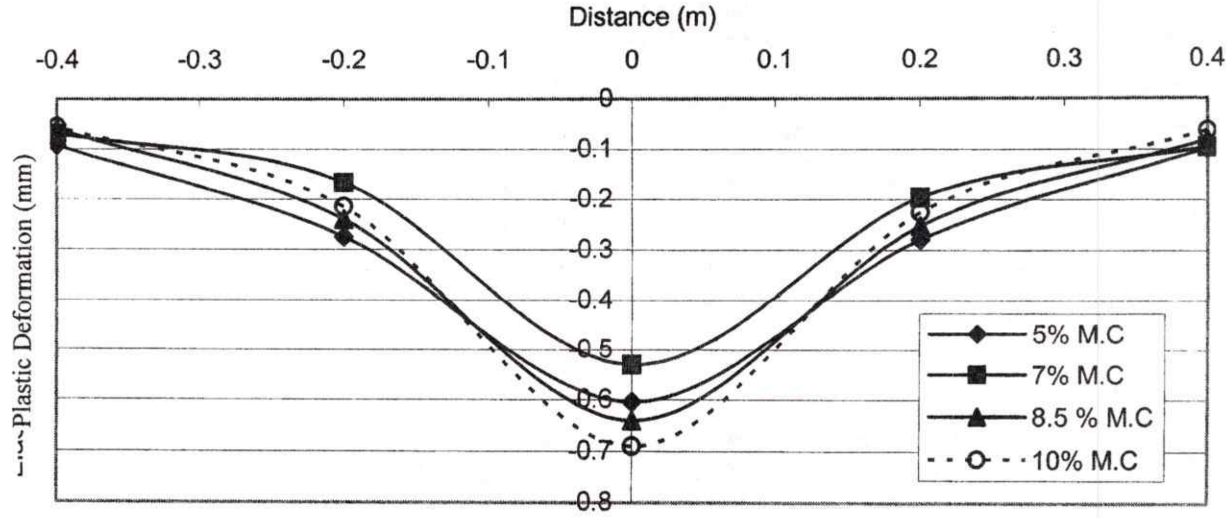

Figure (7) Effect of Moisture Content on Elastic Deformation

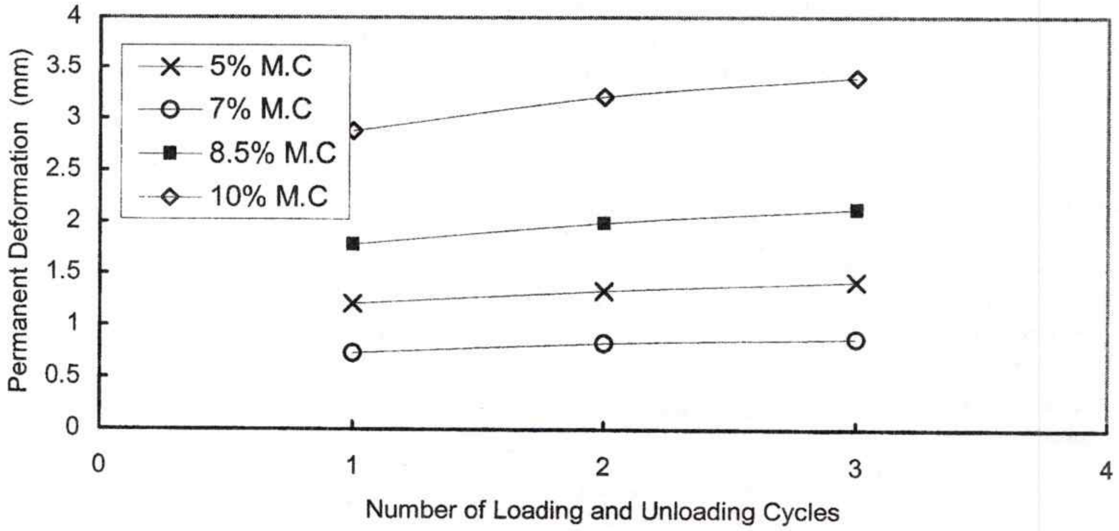

Figure (8) : Plastic Deformation Versus Loading Cycles

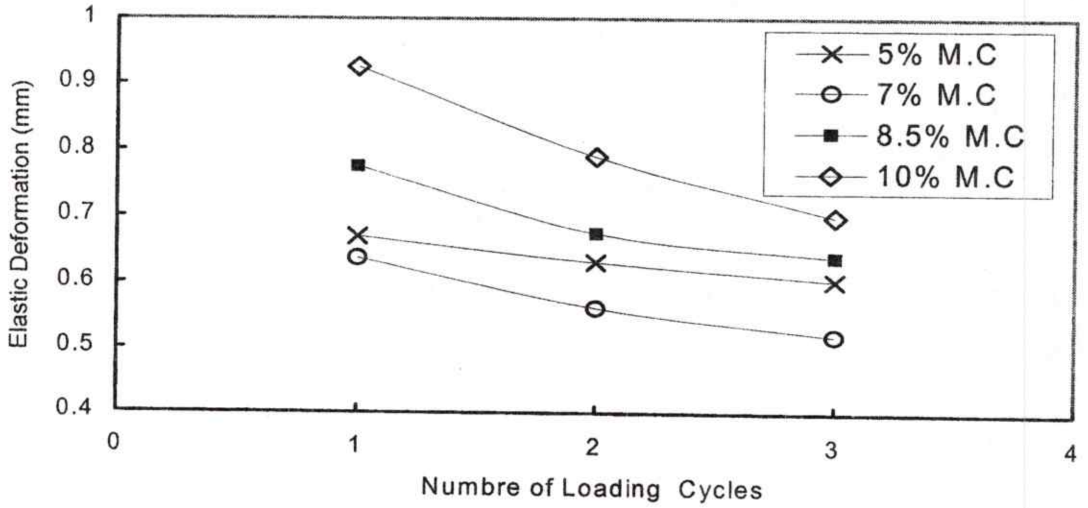

Figure (9) : Elastic Deformation Versus Loading Cycles

By using a computer program " DATA FIT ", the modulus of elasticity could be calculated as a function of the CBR value .The coefficient of multiple determination (R^2) was equaled to 0.99 . The empirical equation for modulus of elasticity is as follows:

E =-15.1+0.653 (CBR) + (343.3/CBR).......(2)

Where :

E:	Modulus of elasticity of base course (N/mm^2)
CBR :	California bearing ratio of base course of 0.35 poison's ratio

4.5.Accumulated Total Deformation

Accumulated total deformation with time was determined at plate center, at 0.2m and 0.4 m from plate center. Fig.10 shows this relationship at plate center. It should be noted from the Figure that the accumulated deformation in the first 10 to 15 minutes increased rapidly with increasing loading time and more than 80% of total def. occurs in this period for all moisture contents. The curve in this region was almost linear.

The lowest def. occurs at OMC. By decreasing OMC 2% or increasing it 1.5%, total def. increased. Yet the value of increase in dry side was smaller than it in wet side. This may be because the grains of base soil are forced apart by adding moisture content more than optimum value (8.5% and 10%), and consequently the bond between the soil particles break up and the material become looser.

4.6.Measured and Predicted Deformation of base course

The influence of moisture content variation upon the total vertical deformation of unbound granular base material is measured experimentally by using a test-model and predicted theoretically by using finite-element program "FENLAP". The calculations were made using linear elastic- and non-linear elastic model (Dresdener model).

4.6.1.Dresdener Model

This non-linear elastic model is expressed in terms of modulus of elasticity E and Poisson's ratio μ, where the values of E and μ depend on the applied stresses as follows:

$$E = \left(Q + C \cdot \sigma_{\mathrm{I}}^{\,Q_1}\right) \cdot \sigma_{\mathrm{III}}^{\,Q_2} + D \qquad \text{........(3)}$$

$$\mu = R \cdot \frac{\sigma_{\mathrm{III}}}{\sigma_{\mathrm{I}}} + A \cdot \sigma_{\mathrm{I}} + B \qquad \text{.........(4)}$$

where:

θ_I [kPa]	Minor principal stress (absolute value);
θ_{III} [kPa]	Major principal stress (absolute value);
D [kPa]	Constant term of modulus of elasticity
Q, C, Q_1, Q_2, R, A, B [-]	Parameters of the model.

The properties of granular base material for Dresdener model were carried out using repeated Triaxial test of Dresden University for a similar material (Lime stone base course). The values of different parameters at 5 and 10% moisture content are presented in Table (4).

Table 4: Parameters for the elastic Dresden-Model, density = 2.26 g/cm^3 [14]

Parameter		Moisture content	
Elastic Dresden-Model		5.0%	10.0%
Q	$[kPa]^{1-Q2}$	5386.1	18772.2
C	$[kPa]^{1-Q1-Q2}$	4315.6	599.1
Q1	[-]	0.693	0.990
Q2	[-]	0.333	0.333
R	[-]	0.037	0.097
A	$[kPa]^{-1}$	-0.0012	-0.0004
B	[-]	0.352	0.260

4.6.2. Comparison between measured and predicted deformation

It can be indicated that the measured and predicted deformation values are generally in good agreement as shown in Figure (11), whereas the predicted deformation values are higher than measured values at all studied moisture contents. For linear elastic model, the difference range is between 10% to 20% under the plate center , and about 45% at a distance of 0.2 m from the plate center in both sides. At a distance of 0.4 m, the predicted deformation values are higher than the measured values for about 15% to 40% with variation of moisture content. Using non-linear elastic model, the predicted deformations were also higher than the measured ones, yet the difference between measured and predicted values were very small.

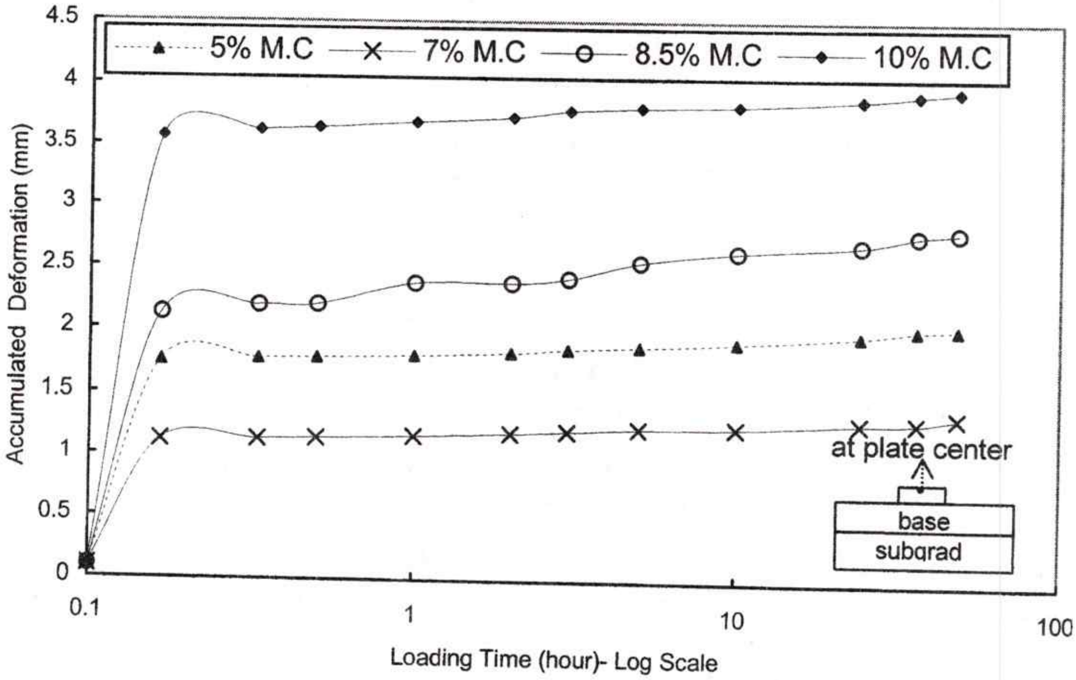

Figure (10) : Accumulated Vertical Deformation Under the plate Center at various Moisture Contents

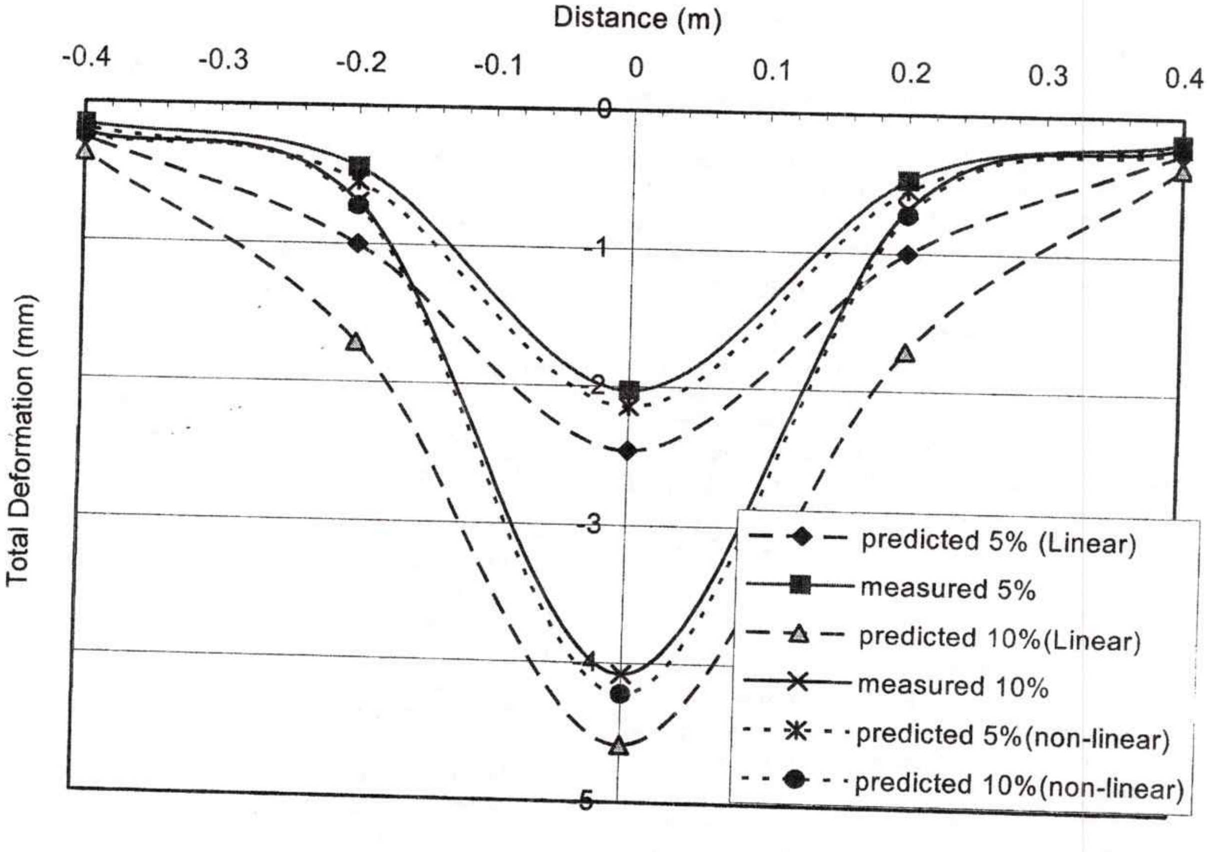

Figure (11) Measured and Predicted Deformation at 5% and 10% M.C

5. CONCLUSIONS

1. After the third loading cycle , the plastic deformation curve gave approximately the same values around the plate center where the maximum value accumulated under the plate center . Also the elastic deformation curve was approximately similar around the plate center . As the distance from plate center increases the plastic and elastic deformation decreases gradually. Moreover, the highest modulus of elasticity is obtained at optimum moisture content.

2. The lowest value of plastic deformation at all points were approximately at optimum moisture content and the highest value of plastic deformation was accomplished at 10% moisture content. The lowest value of elastic deformation is achieved at optimum moisture content. As the distance increases more than 0.2 m, the elastic deformation increases with decreasing moisture content.

3. With increasing the loading cycles, the plastic deformation increased and the elastic deformation decreased .On the other hand, the highest CBR value is achieved at optimum moisture content and the modulus of elasticity increased with increasing CBR value.

4. The predicted deformation values are higher than the measured values at all studied moisture contents using both linear-and nonlinear models. The difference ranged between 10% to 20% under the plate center for linear calculations, while it was less than 6% for nonlinear model. This means that using Dresdener model is more significant.

5. The accumulated deformation in the first 10 to 15 minutes increased rapidly with increasing loading time and more than 80% of total vertical deformation occurred in this period for all moisture contents. The lowest def. occurred at OMC. By decreasing OMC 2% or increasing it 1.5%, total deformation increased. Yet the value of increase in dry side is smaller than it in wet side.

REFERENCES

[1] Dai, S.T. and Deusen, V. D., "Field Study of in-Situ Subgrade Soil Response Under Flexible Pavements"., 77th Annual Transportation Research Board Meeting , Washington, D.C,, January, 1998.

[2] Hamrawy, S., "Advanced Highway Engineering"., Minufiya University Press, Chapter 2: Deformation of Pavements , pp. 33-83 , Minufiya , Egypt ,2003.

[3] Thom, N.H., and Brown, S.F., " Effect of Moisture on the Structural Performance of a Crushed-Limestone Road Base", In Transportation Research Record 1121, TRB, National Research Council, Washington D.C., pp. 50-56, 1987.

[4] Raaf, L., Minassian, G.H., and Gartin, S., "Characterization of Saturated Granular Bases Under Repeated Loads", In Transportation Research Record 1369,TRB, National Research Council, Washington D.C., pp. 73-91, 1992.

[5] Chen, D.H., Zaman, M.M., and Laguros, J.G., "Resilient Moduli of Aggregate Materials: Variability due to Testing Procedure and Aggregate Type", Transportation Research Record No.1462, pp.57-64, Washington, DC, 1994.

[6] Newcomb, D.E., Duesen, D.A., Jiang, Y., and Mahoney, J.P., "Considerations of Saturated Soil Conditions in Back-calculation of Pavement Layer Moduli.", In Transportation Research Record 1473, TRB, National Research Council, Washington D.C., pp.63-71,1995.

[7] Kim, D., and Kweon, G., "Deformational Characteristics of Subgrade Soil in Korea",79th Annual Transportation Research Board Meeting , Washington, D.C., January, 2000.

[8] Ksaibati, K., Armaghani, J., & Fisher, J., " Effect of Moisture on the Modulus Values of Base and Subgrade Materials", 79th Annual Transportation Research Board Meeting , Washington, D.C., January, 2000.

[9] Ping,T., Musharraf, M.Z., and Joakim, G.L., " Gradation and Moisture Effects on Resilient Modulus of Aggregate Bases", In Transportation Research Record 1619, TRB, National Research Council, Washington D.C., pp. 75-84 , 1998.

[10] Hamrawy, S., and Shourbagy, M., "Deformation Behavior of Unbound Materials Using Plate Loading Test", The second Minia International Conference for Advanced Trends in Engineering, Minia, Egypt, 2002.

[11] Chandrupatla, T.R. and Belegundu, A.D., "Introduction to Finite Elements in Engineering", Second Edition, Prentice-Hall, Inc.,USA, 1997.

[12] Ping, Yang, and Ho, " Effect of Moisture on Resilient Characteristics of Compacted Granular Subgrades",77th Annual Transportation Research Board Meeting , Washington, D.C., January, 1998.

[13] Huang, H., and White, T.D., "Modeling And Analysis of Accelerated Pavement Tests", 77th Annual Transportation Research Board Meeting , Washington, D.C., January, 1998.

[14] NUMRICH, R.; GLEITZ, T. Mechanisches Verhalten von Tragschichten ohne Bindemittel, Forschungsbericht, TU Dresden, 2001.