The Second Scientific Conference of Pure and Applied Sciences

Special Volume , Number 1, pp .63 - 82 , August 2010

Viscoelastic Finite Element Technique for Computing Rutting of Asphalt Concrete Pavement Including Aging Factor

A.Hussain Abdulameer
Assistant Professor
Department of Civil Engineering Techniques
Najaf Technical Institute

Montadher A. Muhammed
Lecturer
Department of Mechanics
Najaf Technical Institute
(Materials Engineer)

ABSTRACT

Rutting is often responsible for premature maintenance and rehabilitation activities reducing service life of the pavement. Several finite element computer programs for analyzing flexible pavements have been developed over the years. Most of these programs (like ANSYS)did not take into consideration the effect of the aging factor on the behavior of viscoelastic asphalt concrete layer.

The present work uses a displacement based finite element method to compute vertical compression strain and rutting depth for a flexible pavement system of three layers taking into consideration the aging (temperature) effect depending on Williams, Landel and Ferry (WLF) equation. Two popular tire/axle configurations with different tire pressure are investigated using the traditional approximate circular tire print.

The results showed that the difference between the proposed technique and some other methods neglecting aging effect ranges from 5% to 15% while the difference between the proposed technique and linear elastic Pro-Engineer (version 4) program ranges from 10% to 17%.

Key wards: Rutting , Viscoelastic , Asphalt concrete .

حساب الروطان في طبقة الخرسانة الإسفلتية كمادة لزجة مرنة بأسلوب العناصر المحددة وباعتبار عامل العمر

علي عبد الحسين عبد الأمير
استاذ مساعد
قسم تقنيات الهندسة المدنية
المعهد التقني – النجف

منتظر عبودي محمد
مدرس
قسم الميكانيك
المعهد التقني – النجف

الخلاصة:

يعتبر الروطان في الخرسانة الاسفلتية سببا رئيسيا لاعمال الصيانة والتأهيل التي تقلل من عمر الرصف. وقد استخدم الباحثون عدة برامج حاسوبية بطريقة العناصر المحددة ومتخصصة للتطبيق في الرصف وبرامج أخرى متعددة الأغراض. وكان أكثر هذه البرامج(مثل برنامج ANSYS) لايأخذ بنظر الاعتبار تأثير التقدم بالعمر على خواص مادة الاسفلت باعتبارها مادة لزجة مرنة.

يقدم البحث الحالي اسلوبا عدديا بطريقة الازاحات بالعناصر المحددة لحساب انفعال الضغط الرأسي وعمق الروطان لنظام رصف مرن من ثلاث طبقات وبادخال تأثير عامل العمر اعتمادا على معادلة WLF.
بينت النتائج ان الاختلاف بين الاسلوب المقترح وبعض الاساليب التي استخدمها باحثون آخرون أهملوا تاثير عامل العمر يتراوح من٥% الى ١٥% وعند المقارنة مع برنامج يعتمد المرونة الخطية (Pro- Engineer program) وطبعة إطار غير دائرية ظهر اختلاف بمقدار ١٠%الى ١٧ %.

NOMENCLATURE

Symbol	Definition	Units
a_T	WLF shift factor	-
C_1	WLF eqn. constant	-
C_2	WLF eqn. constant	^oC
E	Elasticity modulus	N/m^2
G	Relaxation modulus	N/m^2
J	Creep compliance	m^2/N
K	Bulk modulus	N/m^2
P	Pressure	N/m^2
RD	Rutting Depth	mm
R_N	*Nth* axle load repetitions	-
T_s	Reference temperature	^oC
T	Current temperature	^oC
t	Current time	hr
u	Horizontal displacement	mm
v	Vertical displacement	mm
AL	Axial Load	kN

Greeks letters	Definition	Units
ε	Strain	m/m
σ	Stress	N/m^2
μ	Viscosity	$N.hr/m^2$
ρ	Density	kg/m^3
τ	Current shifted time	hr.
υ	Poisson ratio	-
ξ	Local horizontal coordinate	m
η	Local vertical coordinate	m

Matrices	Definition
[B]	Strain matrix
[δ]	Displacements matrix
[D]	Stress matrix
[F]	Elastic load vector
[J]	Jacobian matrix
[N]	Shape function matrix
[T]	Thermal load vector
[X]	Coordinate matrix

Introduction

Rutting in flexible pavement is characterized by depressions that form in the wheel paths. Within about one year after construction, rutting distress was observed in Iraq at several locations in the highway especially due to higher loading and degree of temperature (Yassoub 2004). Excessive rutting is often responsible for premature maintenance and rehabilitation activities reducing service life of the pavement. AASHTO Joint Task Force on Rutting (AASHTO 1988) express the opinion that traffic and environmental (temperature) factors are the major causes of asphalt pavement rutting.

Several specialized finite element computer programs for analyzing flexible pavements have been developed over the years as well as many general purpose finite element programs like ABAQUS,DYA, and ANSYS (Ghasak 2008). Most of these programs did not take into consideration the effect of the aging factor on the behavior of viscoelastic asphalt concrete layer. The type of aging related to temperature effect is extremely important in the analysis of viscoelastic materials because temperature has three effects as reported by Oza (Oza 2003):

1-temperature change causes thermal strains, which must be combined with mechanical strains,

2-material module have different values at different temperatures,

3-heat flow may occur.

The present work uses a displacement based finite element program to compute vertical compression strain and rutting depth for a flexible pavement system of three layers (Fig 1) taking into consideration the aging (temperature) effect. Rutting distress is actually the cumulative plastic deformation in each of the composing pavement layer (El-Basyouny 2004). Two popular tire/axle configurations with different tire pressure are investigated using the traditional approximate circular tire print. Results are compared with the general purpose Pro-Engineer program and with results of other researchers. Fig-2- shows the dual tire arrangement.

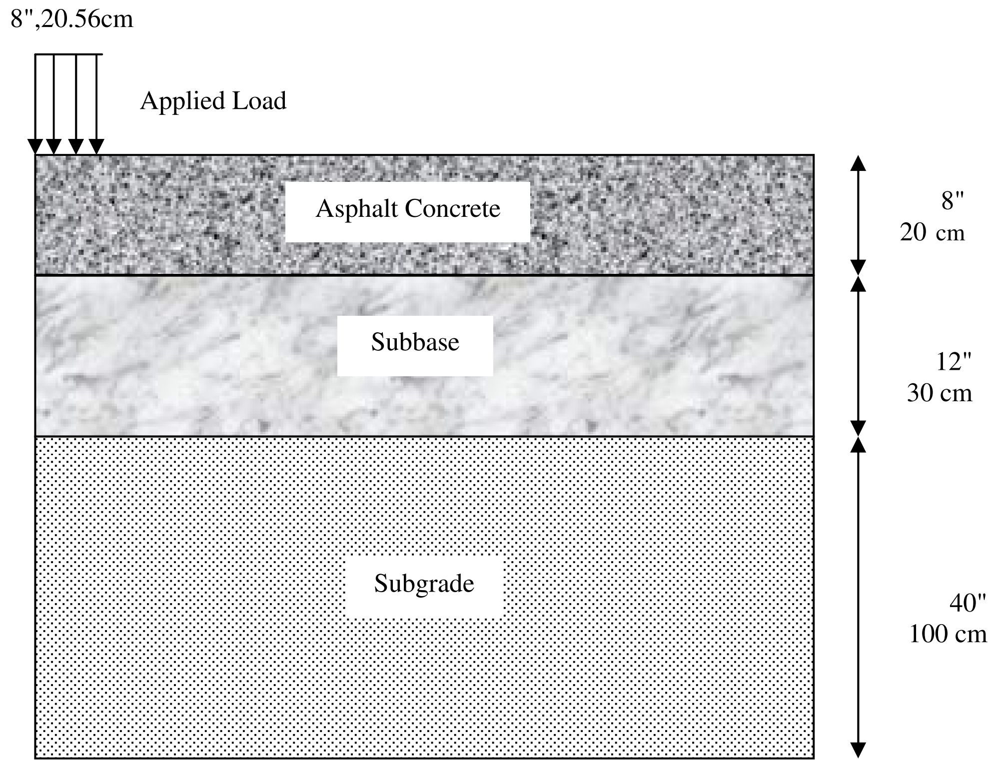


Fig. 1: Pavement layer configuration.

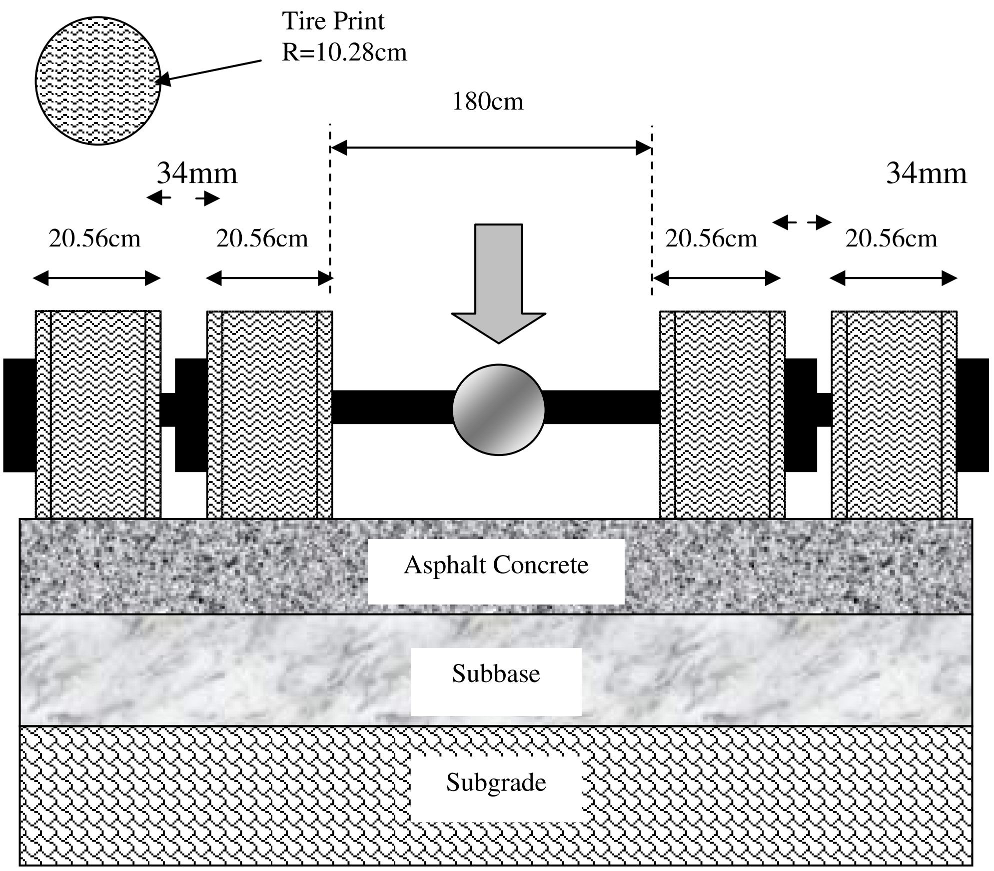


Fig. 2: Load applied on asphalt concrete by vehicle dual tires.

(Monismith 1992) Monismith summarized the using of elastic and viscoelastic multi-layer concepts in the pavement studies .He found that both models are based on engineering mechanics concepts but the multi-layer model is more simplified and therefore runs faster than the finite element model. The finite element model can deal with complicated loading conditions and is more accurate than the multilayer model, but the finite element model is more demanding in element boundary condition inputs and computation resource requirements.

(Feng Wang 2005) measured non-uniform tire-pavement contact stress data for different tire load and inflation pressure conditions for three popular tire/axle configurations by input these data to the finite element program ANSYS 8.1 and compute immediate pavement responses for various asphalt pavement structures. The typical computation results from ANSYS 8.1 were compared with the results of the linear elastic multilayer program using the traditional tire model in which tire-pavement contact stress is assumed uniformly distributed over a circular contact area and equal to tire inflation pressure. He found that the developed model could predict pavement responses in a good accuracy and be used to replace the linear elastic multilayer method.

(Ghasak 2008) studied the rutting problem for asphalt concrete which subjected to repeated axle loading using both elastic and viscoelastic model by finite element software (ANSYS 9).He found that the difference between the two approaches (Elastic and Viscoelastic) is about (12%). The rut depth was calculated and compared with two considerable models (Yassoub and Amjad models).

2-MATERIALS AND METHODS

2-1- Material Representation

For Asphalt concrete , a model can be used to relate components of strain to components of stress, the more convenient famous model to represent it is called “three parameter model”[Amada 1997], generally, this model used to represent most standard Viscoelastic solids as shown in Fig3.

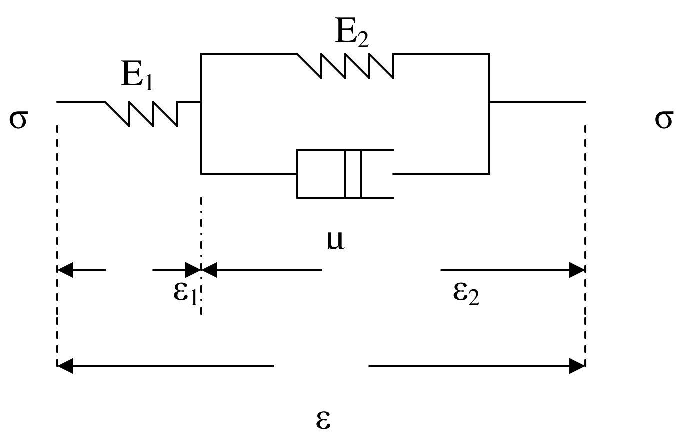


Fig 3. The three parameter model

It is useful to establish systematically the relaxation modules G and creep compliance J for This model using Laplace transform techniques [Gibiansky 1997] as following in **Table 1** :

Table 1 : The Laplace transform technique [Gibiansky 1997]

Constitutive equation.	Laplace transform
$\varepsilon_1 = \dfrac{\sigma}{E_1}$	$\bar{\varepsilon}_1 = \dfrac{\bar{\sigma}}{E_1}$
$\varepsilon_2 = \dfrac{\sigma'}{E_2};\ \mu \dfrac{d\varepsilon_2}{dt} = \sigma''$	$\bar{\varepsilon}_2 = \dfrac{\bar{\sigma}'}{E_2};\ s\mu\ \bar{\varepsilon}_2 = \bar{\sigma}''$
$\sigma' + \sigma'' = \sigma$	$\bar{\sigma}' + \bar{\sigma}'' = \bar{\sigma}$
$E_2 \varepsilon_2 + \mu \dfrac{d\varepsilon_2}{dt} = \sigma$	$(E_2 + s\mu)\bar{\varepsilon}_2 = \bar{\sigma}$
$\varepsilon_1 + \varepsilon_2 = \varepsilon$	$\bar{\sigma}\left(\dfrac{1}{E_1} + \dfrac{1}{E_2 + s\mu}\right) = \bar{\varepsilon}$

$$\bar{\varepsilon}(t) = \tilde{J}\bar{\sigma} \tag{1}$$

$$\tilde{J}(s) = \frac{1}{E_1} + \frac{1}{E_2 + s\mu} \tag{2}$$

$$\tilde{G}(s) = \frac{1}{\tilde{J}(s)} = E_1 \frac{s + E_2/\mu}{s + (1/\mu)(E_1 + E_2)} \tag{3}$$

Where: ε =strain , σ =stress , E =elasticity modulus , μ =viscosity, s= Laplace transform factor.

Applying the inverse Laplace transform and simplifying eqn (2),(3) can be reduced to :

$$J(t) = \left[\frac{E_1 + E_2}{E_1 E_2} - \frac{1}{E_2}\exp\left(-\frac{E_2}{\mu}t\right)\right] \tag{4}$$

$$G(t) = \left[\frac{E_1 E_2}{E_1 + E_2} - E_1 \exp\left(-\frac{E_1 + E_2}{\mu}t\right)\right] \tag{5}$$

And as the same by using Prony series bulk modulus can be obtained as:

$$K(t) = K_\infty + \sum_{i=1}^{n^k} K_i . \exp(-\frac{t}{\tau_i}) \tag{6}$$

Aging and Temperature Effects:

Materials are said to age when their properties change with time, usually the change is adverse. Such chemical or physicochemical degradation processes are not considered in this research and only aging processes of a physical nature will be treated (i.e. the type of aging that is due to temperature effects).

The properties of the asphalt concrete (AC) layer was shown to be exponentially influenced by pavement temperature.

As temperature increases, the viscosity of asphalt material decreases, thus changing the shear resistance of the material (bitumen).

Williams, Landel and Ferry [David Roylance 2001] have proposed that the variations in relaxation time are not primarily due to thermal activation, but to thermal expansion, i.e. the expansion of free volume V_f with increasing temperatures and by using an equation proposed by Doolittle. These authors derived the famous WLF equation:

$$\log a_T = -\frac{c_1 (T - T_S)}{c_2 + T - T_S} \qquad , \tau = \exp(a_T) \qquad (7)$$

Equation (7) will be used to coverage the temperature effect and Aging phenomena. The maximum temperature of the asphalt layer was predicted at the (10 cm) for effect layer at critical point below the surface and varied with the depth (Albayati, 2006). This equation was:

$$\mathrm{T_s} = 1.217 \times \mathrm{T_{air}} - 0.354 \times h \qquad (8)$$

2-2-Method of work (Finite Element Method)

The displacement based finite element method is one such numerical procedure ,the effectiveness of the method is due to its conceptual simplicity, assuming that the nodal point displacement of the finite element mesh completely specify the displacement in the Asphalt Concrete..

This finite element technique, which has demonstrated to provide an excellent analysis method for elastic case , has been extended to provide analysis capability for the Viscoelastic case in this research .

The relation of stress- strain for plane strain case are [Hughes 1987] :

$$\varepsilon_{xx} = \frac{1}{E}(\sigma_{xx} - \upsilon(\sigma_{yy} + \sigma_{zz})) \tag{9}$$

$$\varepsilon_{yy} = \frac{1}{E}(\sigma_{yy} - \upsilon(\sigma_{xx} + \sigma_{zz})) \tag{10}$$

$$\varepsilon_{xy} = \frac{2(1+\upsilon)}{E}\sigma_{xy} \tag{11}$$

But : $$K(t) = \frac{E(t)}{3(1-2\upsilon)} \tag{12}$$

$$G(t) = \frac{E(t)}{2(1+\upsilon)} \tag{13}$$

Then the stress matrix {D}(matrix of properties) can be obtained from eqns (9) to(11) in term of shear modulus “G” and bulk modulus “K” as following :

$$[D] = \begin{bmatrix} K+\frac{4}{3}G & K-\frac{2}{3}G & 0 \\ K-\frac{2}{3}G & K+\frac{4}{3}G & 0 \\ 0 & 0 & \mathrm{G} \end{bmatrix} \tag{14}$$

The global coordinate {X} of the node in terms of local coordinate (ξ, η) and displacement field { δ } in isoparametric element is [Zienkiewcz 1989] :

$$\{\ X\} = [\ N]\ \{X_{ii}\ \} = \begin{vmatrix} x(\xi,\eta) \\ y(\xi,\eta) \end{vmatrix} \tag{15}$$

$$\{\ \delta\ \} = [N]\ \{\delta_i\} = \sum_{i=1}^{n} \delta_i N_i \tag{16}$$

Where,{N} is a matrix of shape function, which is a function of local coordinate ξ and η.

By differentiation of shape function with respect to global coordinate we can obtain strain quantities. This can be done by a transformation using Jacobian matrix{J} which can be obtained by differentiate Eqn 15 using chain rule.

$$\{\ J\ \} = \sum_{i=1}^{n} \begin{pmatrix} \frac{\partial N_i}{\partial \xi} x_i & \frac{\partial N_i}{\partial \eta} y_i \\ \frac{\partial N_i}{\partial \eta} x_i & \frac{\partial Ni}{\partial \xi} y_i \end{pmatrix} \tag{17}$$

Then local coordinates can be obtained as:

$$\begin{pmatrix} d\xi \\ d\eta \end{pmatrix} = [J]^{-1} \begin{pmatrix} dx \\ dy \end{pmatrix} \tag{18}$$

For plane strain case the relation between strain and displacement is [Hughes 1987]

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} \tag{19}$$

$$\varepsilon_{yy} = \frac{\partial v}{\partial y} \tag{20}$$

$$\varepsilon_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \tag{21}$$

Then the strain matrix {B} is obtained by writing eqns (19),(20)and(21) in terms of matrix notation and using the following relations:

$$\frac{\partial u}{\partial x} = \sum_{i=1}^{n} \frac{\partial Ni}{\partial x} u_i \tag{22}$$

.

$$\frac{\partial u}{\partial x} = \sum_{i=1}^{n} \frac{\partial Ni}{\partial x} u_i \tag{23}$$

It is incorrect to vary only stress matrix {D} with time (the Quasi – static solution) since properties of viscoelastic material varies with time, but it is convenient to differentiate this matrix with respect to time depending on the superposition theory of viscoelasticity,

So that:

$$[\frac{\partial D}{\partial t'}] = \frac{-\partial G(\tau-\tau')}{\partial t'} \begin{bmatrix} \frac{4}{3} & -\frac{2}{3} & 0 \\ -\frac{2}{3} & \frac{4}{3} & 0 \\ 0 & 0 & 1 \end{bmatrix} + \frac{\partial K(\tau-\tau')}{\partial t'} \begin{bmatrix} 1 & 1 & 0 \\ 1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} = \left\{ \bar{D} \right\} \tag{24}$$

From the chosen model in Fig.3 and for the incompressible linear viscoelastic material undergoes environmental temperature change, the total stress will be:

$$\sigma_{total} = \sigma_{elastic} + \sigma_{viscoelastic} + \sigma_{thermal} \tag{25}$$

$$\{\sigma(t)\} = [D]\{\varepsilon(t)\} + \int_0^t [\bar{D}]\{\varepsilon(t)\}dt - 3\alpha K\,[T\,(x_1 t) - T\,(x_1 0)] \tag{26}$$

α - thermal expansion which is constant in time .

By minimizing the equation of potential energy we can solve Eqn.- 26

The minimum potential energy M can be expressed as [Bath 1995]:

$$M = \frac{1}{2}\int_v [\sigma(t)]\,\varepsilon^T(t)dv - \int_v [\delta]^T Fv\; dv - \int_s [\delta]^T Fs\, ds \tag{27}$$

F_v : is the body force per unit volume

F_s : is the load of surface traction

By substituting Eqns 16, 26 into Eqn 27 and minimization with respect to nodal displacements the total potential energy can be written as :

$$\frac{\partial M}{\partial\left[\delta^e\right]^T} = 0 = \int_{ve} B^T DBdv\left\{\delta^e\right\} + \int_{ve} B^T \bar{D}\left[\int_0^t \left\{\varepsilon(t)\right\}dt\right]dv - \int_{ve} N^T Fvdv - \int_{se} N^T Fsds -$$

$$3K\alpha\int_{ve} B^T (T(X,t) - T(X,0))dv \qquad (28)$$

Solving Eqn 25 will give the values of displacements for all nodes in the structure of interest. Then stresses can be obtained by solving Eqn 26.

A solution called assembly elimination were used in solving FE matrices equations (Bath 1995) ,this allow to use the individual elements in matrix step by step instead of using the whole elements structure.

In order to minimize both the Finite Element program and **Pro-Engineers 4** software computation times as well as to have good computation accuracy, finer mesh sizes were used for the tire-pavement contact areas and increasingly larger mesh sizes were used for areas away from the contact areas (Fig 4).The fine mesh size at the contact area is 15.0 mm in *X* by 12.5 mm in *Y*. Generally, better computation accuracy is expected for the pavement
responses computed at the contact area than the results at other areas where larger mesh
sizes are used.

It should also be noted that negative signs are used for compressive strains in accordance with the **Pro-Engineers 4** program.

Rut Depth

Because of rutting is caused by the accumulation of permanent deformation over all composing layers, it is more reasonable to determine the permanent deformation in each layer and sum up the results by using the following equation (Uzan *2004*).

$$R_D = \sum_{i=1}^{n_i} \varepsilon_p^i \, h^i \qquad (29)$$

R_D = total rut depth in inches;

ε_p^i = plastic vertical strain in the *i*-th layer;

h^i = layer thickness in the *i*-th layer in inches; and

n_i = the number of pavement layers or sub layers;

As shown in Equation (29) the total permanent deformation or rut depth (R_D) is actually the sum of cumulative plastic deformations in the n_i pavement layers. Each layer plastic deformation equals the product of plastic vertical strain (ε_p^i) and layer thickness (h^i) in the i-th layer. The factors affecting material properties such as mixture stiffness, viscosity of asphalt and environmental conditions (temperature) will be taken into consideration during the numerical solution.

Results and Discussion

The parameters input for the proposed rut depth prediction method are:

- Materials response properties and climatic factor (Temperature effects).
- Geometry of the pavement structure and traffic loading Figures 1 & 2.

First the proposed procedure will be tested and compared with other approaches using the same geometry of the pavement structure and traffic loading shown in Figures 1 & 2, with **tire print diameter=300 mm(actual contact area) and tire load=80 kN**, **Pressure=550 kPa** for the Single tire.

Data input in software of Asphalt concrete are exhibit in Table (2), the elastic solution is used for subbase and subgrade layers except asphalt material will be treat as a viscoelastic material.

Table 2:Viscoelastic Material Properties for Asphalt Layer under Temperature T_s= 23 C (Ghasak 2008).

Time of loading (sec)	Creep compliance J(t) (1/MPa)	Relaxation modulus G(t) (MPa)	Bulk modulus K(t) MPa
0.1	0.0048	208.43	231.6
0.25	0.0063	158.1	175.7
0.5	0.0084	118.12	131.25
1	0.0092	108.47	120.5
2	0.01	94.63	105.14
4	0.012	83.5	92.78
8	0.0132	75.5	83.9
15	0.017	58.37	64.9
30	0.0198	50.34	55.9
45	0.021	46.75	52

The elastic properties for Subbase is E=350 MPa, υ=0.3and Subgrade is E=100 MPa υ=0.4 respectively. The finite element mesh is shown in Figure 4 (1518 element of 4 nodes).

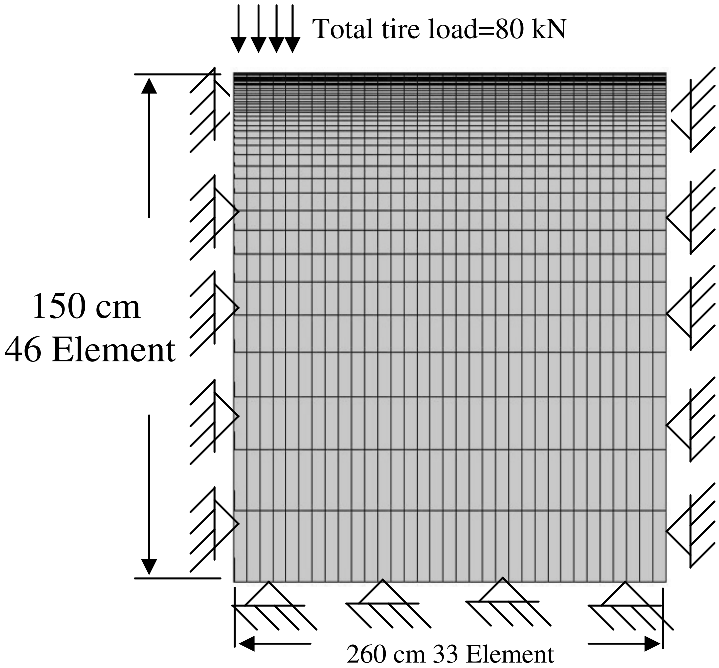


Fig 4. : Finite Element mesh, Boundry conditions (Fixed) and total tire load for pavement layers configuration.

Fig 5 :Comparison between the Proposed procedure and other methods (Single Tire Configuration).

Figure 5 shows the comparison of rut depth for various number of axle load repetitions between the proposed technique and other methods used by several researchers (Feng Wang 2005) (Ghasak 2008) (Yassoub 2004) (Amjed 2006) who had neglected the aging factor.

It can be seen that generally there is a small difference between the proposed technique and other researchers' techniques and its ranges from 5% (Feng Wang Procedure) to 15%.(Ghasak model) .

Compared with others approaches, the results obtained are suitable for pavement analysis, also the Finite Element simulation based mechanistic-viscoelasticity method has the potential to better address the problem of the effect of increased truck tire pressure on pavement performance.

Tables (3) and (4) show a comparison between the proposed technique and the Pro-Engineers software (version 4).There is a difference (10%-17%) in tensile strains in X ,Y and XY directions at the bottom of asphalt concrete layer for both single and dual tire configurations. This difference may be due to the difference in contact area (circular or not circular), the elastic theory used in Pro-Engineer program ,as well as different finite element technique.

Table 3: Predicted Critical Pavement Strains for Single Tire Configuration Taken at mid-point of AC,T=25^{o}C.

Tire load	Tire Pressure	Finite Element (viscoelastic) Circular contact area			Pro-Engineers software Non-circular contact area		
kN	kPa	ε_{yy} (10^{-6})	ε_{xx} (10^{-6})	ε_{xy}(10^{-6})	ε_{yy} (10^{-6})	ε_{xx} (10^{-6})	ε_{xy}(10^{-6})
20	602	-83	-77	-111	-82	-84	-101
24	722.6	-90	-83	-124	-93	-91	-110
28	843	-117	-102	-174	-113	-113	-149
30	903.25	-130	-119	-178	-131	-127	-154
35	1035.8	-185	-128	-194	-182	-143	-195

Table 4:Predicted Critical Pavement Strains for Dual Tire Configuration taken at mid-point of AC,T=25^{o}C

Tire load	Tire Pressure	Finite Element (viscoelastic) Circular contact area			Pro-Engineers software Non-circular contact area		
kN	kPa	ε_{yy} (10^{-6})	ε_{xx} (10^{-6})	ε_{xy}(10^{-6})	ε_{yy} (10^{-6})	ε_{xx} (10^{-6})	ε_{xy}(10^{-6})
20	150.6	-37	-24	-47	-35	-37	-43
24	180.8	-41	-36	-54	-43	-46	-47
28	211	-54	-48	-60	-57	-57	-52
30	226	-57	-52	-63	-62	-63	-59
35	263.7	-61	-57	-69	-64	-67	-63

Tables (5)and (6) show the predicted tire load and pressure effects on pavement rutting caused by single and dual tires respectively. $R_{N=1E3}$, $R_{N=1E5}$, and $R_{N=1E6}$ are maximum wheel path rut depths predicted after N axle load repetitions with N = 1000, N = 100,000, and N = 1,000,000 respectively. It is obvious that increasing tire load increase rut depth. The rate of development of rutting decreasing with number of load repetitions because of the effect of aging phenomena which make the asphalt concrete layer denser and stiffer with time .

Table 5: Tire Pressure Effects on Performance (Rutting) for Single Tires taken at mid-point of AC, T=25^{o}C

Tire load	Tire Pressure	Finite Element (viscoelastic) Rutting|(mm)			Pro-Engineers software Rutting|(mm)		
kN	kPa	$R_{N=1E3}$	$R_{N=1E5}$	$R_{N=1E6}$	$R_{N=1E3}$	$R_{N=1E5}$	$R_{N=1E6}$
20	602	-0.9	-2.3	-3.4	-1.2	-3.7	-4.8
24	722.6	-1.3	-3.8	-5.7	-1.4	-4.2	-6.1
28	843	-1.7	-4.6	-6.2	-2.9	-6.1	-8.1
30	903.25	-2	-5.2	-6.8	-3.4	-6.7	-8.5
35	1035.8	-2.3	-5.7	-7.2	-3.7	-7.3	-8.9

Table 6 :Tire Pressure Effects on Performance (Rutting) for Dual Tires taken at mid-point of AC,T=25^{o}C

Tire load	Tire Pressure	Finite Element (viscoelastic) Rutting|(mm)			Pro-Engineers software Rutting|(mm)		
kN	kPa	$R_{N=1E3}$	$R_{N=1E5}$	$R_{N=1E6}$	$R_{N=1E3}$	$R_{N=1E5}$	$R_{N=1E6}$
20	150.6	-0.6	-0.9	-1.7	-0.72	-1.4	-2
24	180.8	-1.03	-1.2	-2.1	-0.99	-1.73	-2.64
28	211	-1.1	-2.1	-2.3	-1.3	-2.4	-2.9
30	226	-1.4	-2.3	-2.9	-1.7	-2.7	-3.4
35	263.7	-1.7	-2.9	-3.4	-2.1	-3.2	-3.8

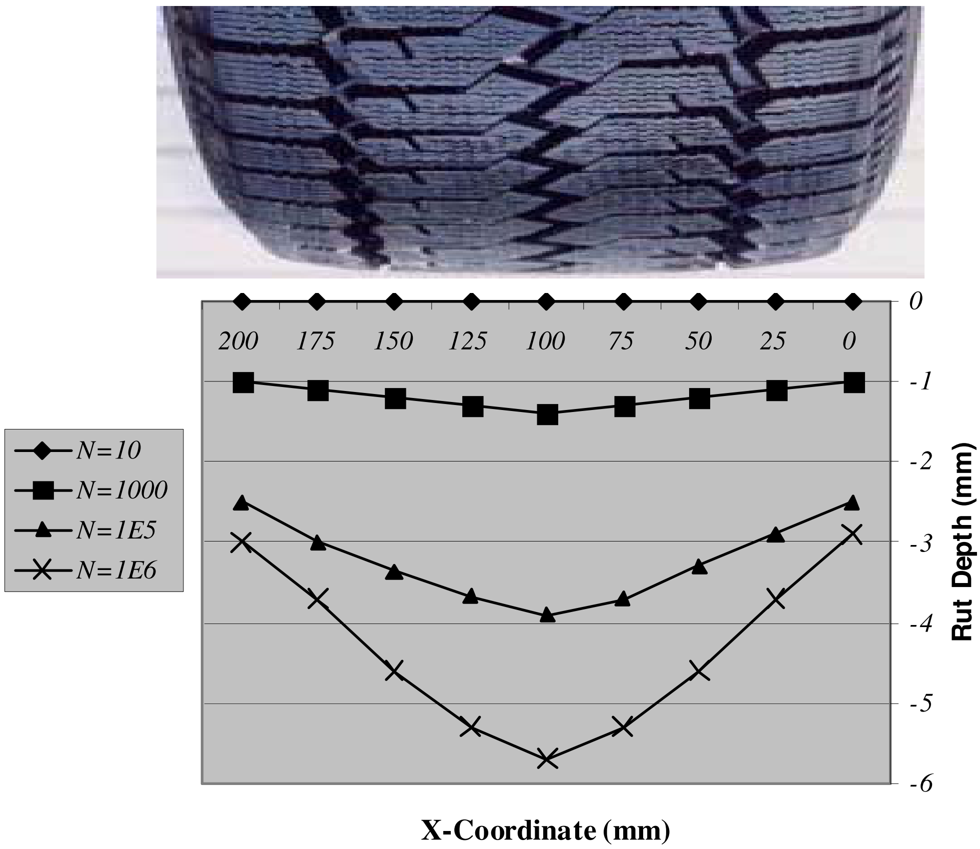


Fig 6: Rutting Computed for locations along X-Axis (Single,TL=24KN).

Figure 6 show the magnitude and shape of rutting under the tire print. It can be concluded that maximum rut depth occurred directly in the middle of tire print for difference load repetitions..

The reviews of **Pro-Engineers** computation results revealed that for Single and Dual tire configurations , the maximum tensile strains and rutting at the bottom of the asphalt concrete layer appeared directly under the center of the contact area of each tire as shown in Figures (7) and (8). It can be inferred that the largest rut depth is depend on the combination of tire load, tire pressure, and tire configuration.

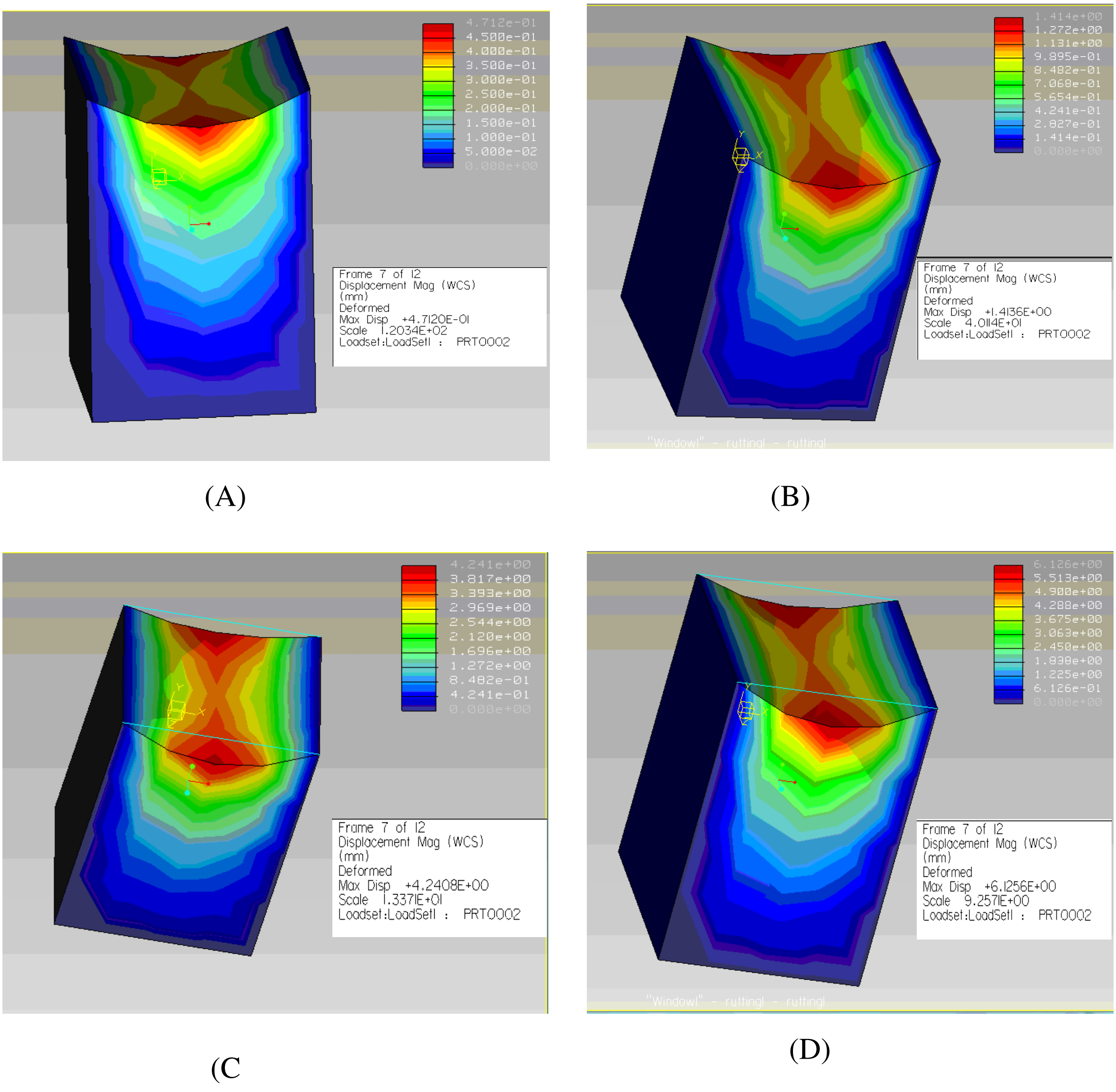
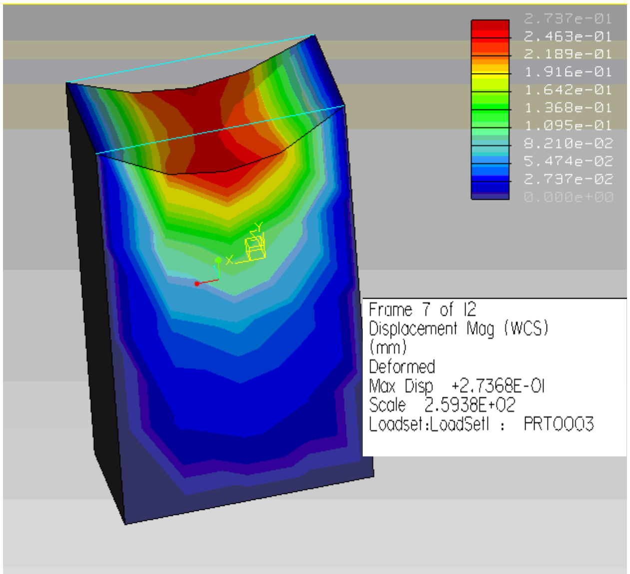
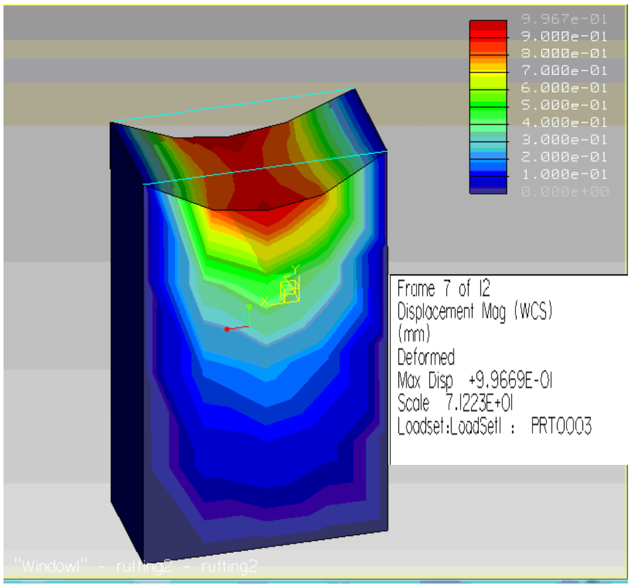


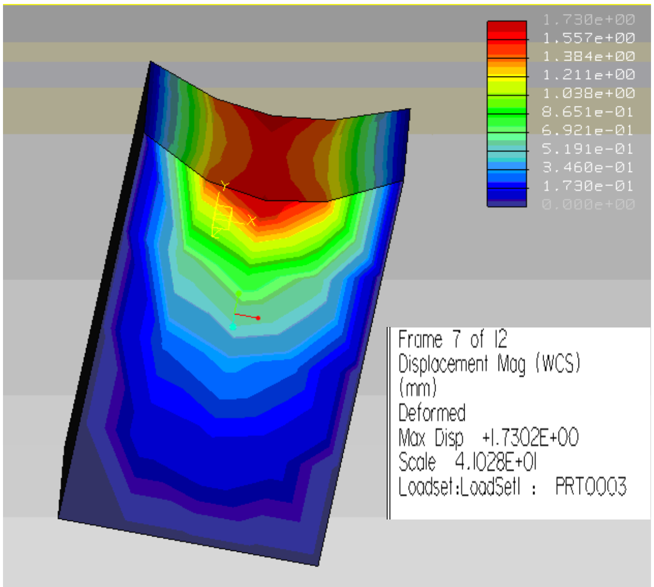
Fig 8: Results of Rutting From Pro-Engineers Software (Single TL=24KN).(A) $R_{N=10}$ (B) $R_{N=1E3}$ (C) $R_{N=1E5}$ (D) $R_{N=1E6}$



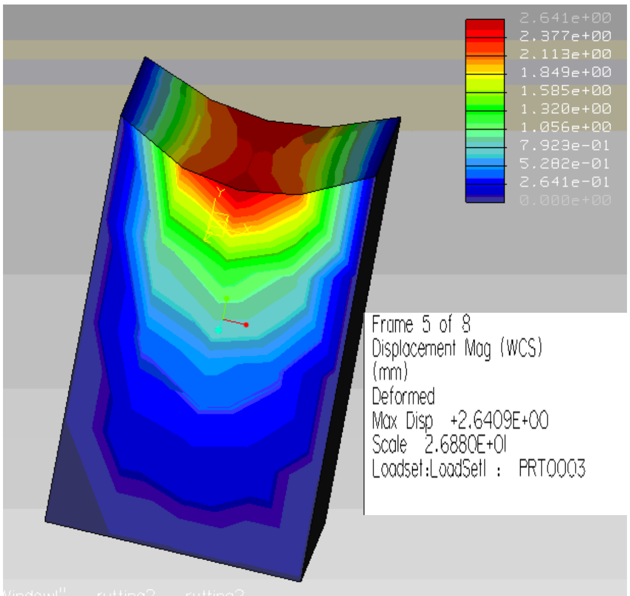
(A)



(B)



(C



(D)

Fig 9: Results of Rutting From Pro-Engineers Software (Dual TL=24KN).(A) $R_{N=10}$(B) $R_{N=1E3}$(C) $R_{N=1E5}$(D) $R_{N=1E6}$

Conclusions

Within the limitations of the present work and depending on the results of applying the proposed techniques the following conclusions may be reported

1-The difference between the proposed technique and some other methods neglecting the aging factor ranges between (5-15)% when computing rut depth.

2-The deference's between the proposed technique and the elastic linear Pro-Engineer program ranges from (10-17) % when computing strains in X, Y and XY directions.

3-The rate of rut development decreases when the number of load repetitions is increased reflecting the effect of aging factor.

References

Albayati Amjed ,"Permanent Deformation Prediction of Asphalt Concrete under Repeated Loading", Ph D thesis, civil Engineering, University of Baghdad, 2006.

Amada, S. and Lakes, R. S., "Viscoelastic properties of incompressible material", *Journal of Materials Science*, 32, 2693-2697, (1997)

AASHTO (1988). "Report of AASHTO Joint Task Force on Rutting", American Association of State Highway and Transportation Officials, Washington, D.C.USA.

Bath ,K.J., Finite Element Procedures , Prentice-Hall, Englewood Cliffs,NJ,1995.

David Roylance ,Engineering Viscoelasticiry, Department of Materials Science and Engineering ,Massachusetts Institute of Technology, Cambridge, MA 02139,October 24, 2001.

El-Basyouny, M.M. Calibration and Validation of Asphalt Concrete Pavements Distress Models for 2002 Design Guide. Ph.D. Dissertation, Arizona State University, 2004.

Feng Wang, B.S., Mechanistic-Empirical Study Of Effects Of Truck Tire Pressure On Asphalt Pavement Perforance, PhD. Thesis, The University of Texas at Austin, December 2005.

Ghasak E.A, Studying of Rutting in The Flexible Pavements Using Viscoelastic Finite Element Method , thesis, Civil Eng., Babylon University ,2008.

Gibiansky, L. V. and Lakes, R. S., "Bounds On The Complex Bulk and Shear Module Of a Two-Dimensional Two-Phase Viscoelastic Composite", Mechanics of Materials, 25, 79-95, (1997).

Hughes ,T.J.R,*The Finite* Element Method-Linear Static and Dynamic Finite Element Analysis,Printice Hall ,Englewood Cliffs, NJ, 1987.

Monismith, C.L., Analytically Based Asphalt Pavement Design and Rehabilitation*: Theory to Practice*, 1962-1992. *Transportation Research Record No. 1354*, Transportation Research Board, Washington DC, 1992, pp 5-26.

Oza, A., Lakes, R. S. and Vanderby, R., "Interrelation of Creep and Relaxation For Nonlinearly Viscoelastic Materials" ,Rheologica Acta, Vol.42, 557-568 (2003).

Pidwerbesky, B.D. ,Strain Response and Performance of Subgrades and Flexible Pavements under Various Loading Conditions., Transportation Research Record No. 1482, Transportation Research Board, Washington DC, pp 87-93 , 1995.

Uzan, J. ,Permanent Deformation in Flexible Pavements. Journal of Transportation Engineering, Vol. 130, No.1, pp 6-13 ,January 2004.

Yassoub Nahla , "Prediction Model of Rutting Potential in Flexible Pavements" Ph D thesis, Civil Engineering, University of Baghdad (2004)..

Zienkiewcz,O.C. and R.I. Taylor, *The Finite Element Method*,(4th ed) Vol. 1.Basic Formulation and linear problems, 1989

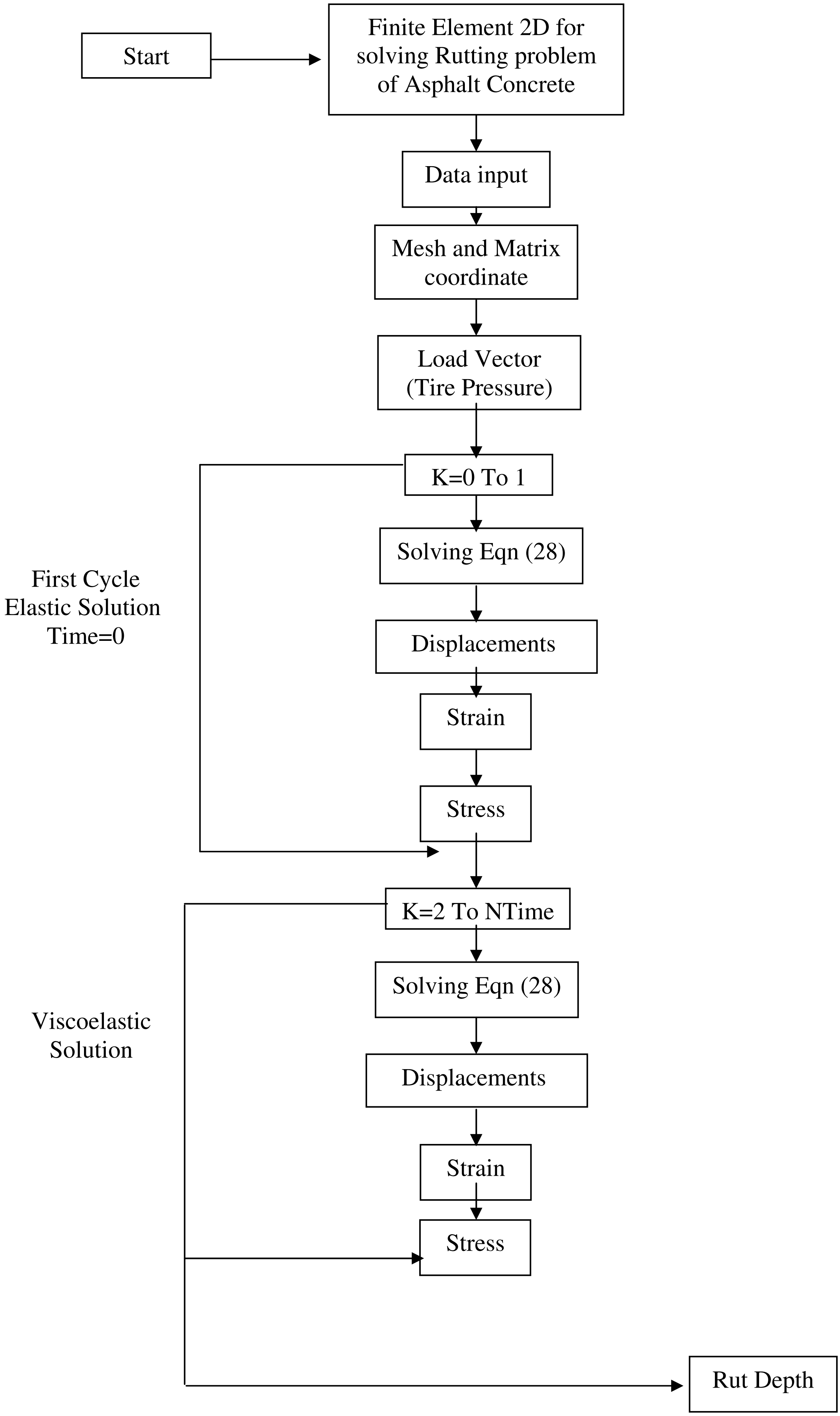


Fig .(A-1) :The Flow Chart of Finite Element 2-D for Calculating the Rut Depth.