ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 6, Issue 12 , December 2019

Prediction of Flexible Asphalt Pavement Performances under Material Properties in Variation Influence

farag Khodary , hesham akram , Ayman Othman

qena faculty of engineering south valley university - Qena, Egypt
qena faculty of engineering south valley university- Qena, Egypt
Aswan faculty of engineering Aswan University – Aswan, Egypt

ABSTRACT: Flexible pavement structural is a complex system, which consists of multilayers, have different materials. Rutting is most commonly pavement distress, However laboratory studies not effective on rutting prediction for multi-layers pavement. Finite element programs can be employed to study effect complex structural properties for pavement rutting behavior. The 3D model analyzed by ABAQUS program for rutting prediction. Finite element (FEM) analysis and KENLAYER method were used to study material properties (elastic modulus) and layers thickness on flexible asphalt pavement rutting behavior. KENLAYER method FEM and model are assumed elastic behavior to described complex pavement structural responses. The subgrade modulus is a key to improve the resistance pavement section for rutting. Subgrade modulus has an effective influence on rutting reduction compared with surface, base and subbase modulus. The rutting phenomenon is not sensitive to change layers thickness compared with material properties. Rutting depth calculated from KENLAYER is lower than the equivalent depth obtained from FEM investigation. The FEM simulation illustrates that the instantaneous rutting depth on surface of base, subbase and subgrade layer is decreased by about (4.50%), (9.50%) and (20%) respectively from rutting depth on asphalt layer.

KEY WORDS: Flexible pavement, ABAQUS, Vertical surface deflection, Numerical analysis, Permanent deformation.

I.INTRODUCTION

The flexible asphalt pavement is one of the great infrastructures of civil engineering projects for all societies around the world. It is consisting of multilayers (asphalt, base, subbase, and subgrade). All layers are designed to move the heavy vehicle's load to a strong sub-base foundation. The construction errors and loads conditions during a long span of flexible pavement sections lead to many common types of distress includes cracks, rutting, and potholes. Rutting is the most dangerous pavement distresses and influenced by vehicles' paths. It, loosely defined as longitudinal depressions in wheel paths as a result of continued densification by the traffic load [1]. Rutting performance can be predicted to asphalt mix layer by using many laboratory methods such as flow number, dynamic modulus, and repeated load tests. The flow number (FN) test use to evaluate asphalt sample responses for rutting as shown in Fig.1. The asphalt samples test under deviator stress between 68.9 and 206.8 kPa, temperature 50 °C and 10,000 loading cycles from repeated compressive Haversine loading (1 cycle with 0.1 s loading time and 0.9 s resting time) [2]. The dynamic modulus test measured dynamic complex modulus and viscoelastic properties for asphalt samples. The dynamic modulus test is including applying repetitive dynamic compressive axial load to unconfined sample [3]. The repeated loading test is used to describe deformation response of unconfined asphalt samples under compressive Haversine loading. The test specimen size is 152 mm diameter and 305 mm high [4]. Asphalt binder performance can be improved by adding nanomaterial such as nano-silica where The accumulative strain for asphalt decreases nano-silica influence is apparent on high stress [5].

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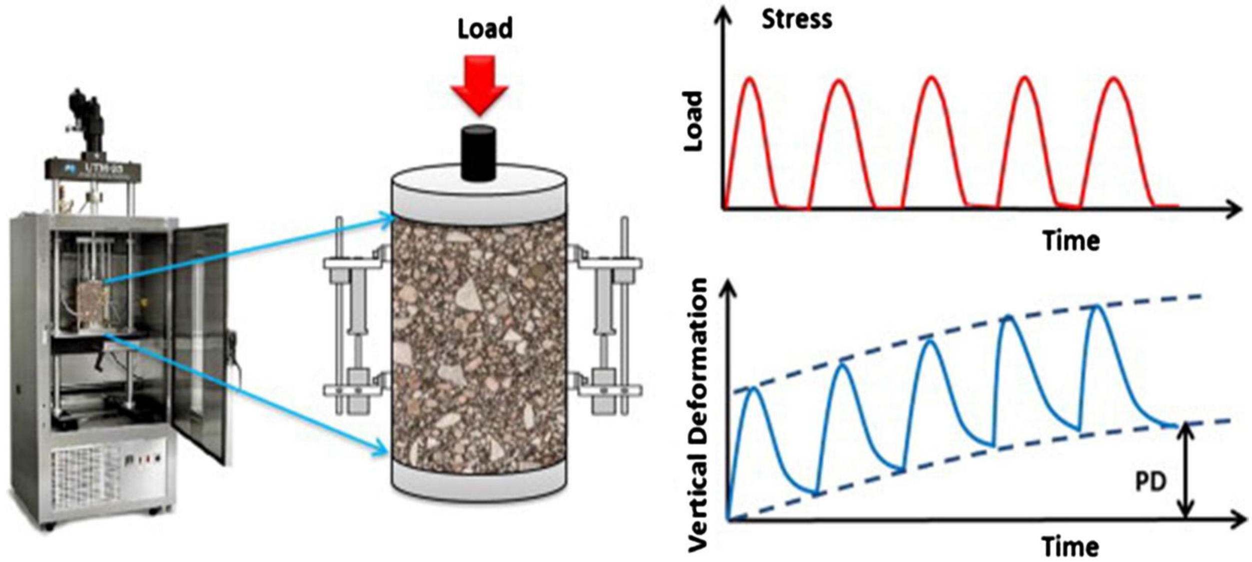

Fig.1 Flow number test setup and configuration [6].

Pavement structure composed of several layers, which consist of materials with different properties. Rutting performance in pavement structure influenced by material properties for complex pavement construction. Experimental tests used to predict the effects of asphalt layer properties on rutting behavior. Multi-layers pavement structure study is difficult by using laboratory tests. Recently finite element programs play a great role in simulated full dimensions asphalt pavement structure. The ANSYS program was used to simulate the 2D finite element model to explicate the effects of a based layer in resulting stress. Pavement simulation clarified stress decreased by 27% in base layer, however rutting depth increased by 28% in the same layer [7]. The ANSYS was used to analyze the 2D asphalt pavement model. The finite element model assumed pavement structure is linear elastic behavior. Model analysis clarified elastic modulus of subgrade layer has a significant influence in rutting performance for flexible pavement, Therefore the increasing in subgrade modulus is a key to reduce surface rutting. According to study layer properties effect, ANSYS solution proved modulus of elasticity for surface and base layer has lithely effect in pavement deflection [8]. The ABAQUS program outputs were used to study effect waste glass in asphalt mix properties. Simulation results for rutting performance of asphalt mix achieve by experimental testes. ABAQUS program used 2D model,which assumed nonlinear behavior for asphalt mix. The final results show that the relation between simulation results and experimental testes results is perfect, therefore simulation model canappropriately expect rutting behavior in asphalt mix samples under different stresses. The glasphalt model achieves low rutting values compared with conventional model [9]. The traffic loads and temperature change influences were studied in the flexible asphalt pavement by using ABAQUS program. The 3D model consists of surface, base and subgrade layer. The model under effect both traffic load and high temperature appeared a reduction in rutting resistance. Surface rutting depth under the combined condition from high temperature and traffic load is high value compared to traffic load only [10].The rutting depth was predicted on a flexible pavement model under repeated loads by using the finite element ABAQUS program. The 3D model was used to study effects material properties for base and subbase layer in surface rutting depth. Simulation results showed each of base and subbase reduces rutting performance by 58% and 10% respectively. Stresses' study offered that vertical compressive stress on surface asphalt and base layer are approximately 70.9% and 17% respectively. The surface asphalt layer exposed to high horizontal stress under the contact area and decreases horizontally with the distance [11, 16].

II.METHODOLOGY

The different layers of flexible pavement structural have complex structural behavior. The surface asphalt mix has been constructed from bitumen material with viscous behavior, and solid aggregate with the elastic property. Therefore, the surface asphalt mixture performance which is influenced by load and time is called visco-elastic behavior. A granular base layer material includes crushed stone, aggregate, and crushed slag have non -linear characteristics. The natural soil forms the subgrade layer which has elastic features. It is very difficult to simulate complex structural multi-layers pavements. So, the current models assumed linear elastic behavior to analysis the flexible pavement section [12]. The

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linear elastic theory is widely used in structural analysis of pavements. The linear relation between stress and strain is theory essence, therefore a general relationship between stress and strain was represented in matrix form as:

$$\begin{bmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{33}\\ \varepsilon_{12}\\ \varepsilon_{13}\\ \varepsilon_{23}\end{bmatrix}=\begin{bmatrix}1/E & -V/E & -V/E & 0 & 0 & 0\\ -V/E & 1/E & -V/E & 0 & 0 & 0\\ -V/E & -V/E & 1/E & 0 & 0 & 0\\ 0 & 0 & 0 & 1/2G & 0 & 0\\ 0 & 0 & 0 & 0 & 1/2G & 0\\ 0 & 0 & 0 & 0 & 0 & 1/2G\end{bmatrix}\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \sigma_{12}\\ \sigma_{13}\\ \sigma_{23}\end{bmatrix} \quad (1)$$

Where ε is a predictable strain, σ is applied stress, E is Young's modulus, V is Poisson's ratio and G is shear modulus [13].The axle load effect of asphalt pavement on the surface is transferred to bottom layers by contact between grains. However, the output stress is major on the surface layer and then continuously reduced on the bottom layers. The producing strain is divided into dual different types of vertical compressive strain; εc at the top of the subgrade layer and the horizontal tensile strains; εt at the bottom of the surface asphalt layer [8].

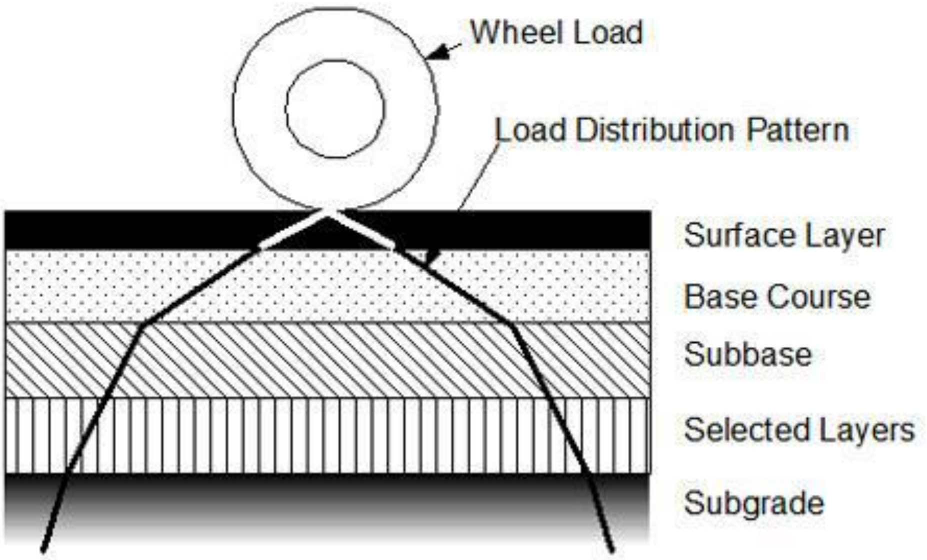

Fig.2 Load distribution on different pavement layers [8].

Nd =1.365 ×10-9(εc)-4.477 (2)

where,Nd = number of load repetitions applied to limit rutting.
εc = vertical compressive strain at the top of the subgrade.

A) Finite element model

The 3D modelingcan be simulated with ABAQUS software program. The 3D modeling predicts rutting that will be occurred in flexible asphalt pavement. ABACUS program results are validated by KENLAYER. The finite element model consists of surface asphalt layer with thickness 50mm, base layer with thickness 150 mm, sub-base layer with thickness 300 mm and 3600 mm with thickness express about infinite bottom layer (subgrade). The appropriate horizontal projection for finite element model is (3600mm ×4000mm)to prevent wheel loads interfering[10]. Surface asphalt, base, subbase, and subgrade layer are permissible to move in a vertical direction. Which it represents by (U2) in ABAQUS program results. The previous layers are fixed in horizontal direction (U1). The bottom of subgrade layer is fixed in each horizontal and vertical direction (U1=0, U2=0) [14]. Moreover, Tie–contact behavior is used in finite

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element model to simulate the interaction between flexible pavement layers such as the interaction between (surface asphalt and base layer), (base and sub-base layer) and (sub base and subgrade) according to model boundary conditions [11], as shown in Fig.3. Furthermore, the model has meshed as shown in Fig.4.

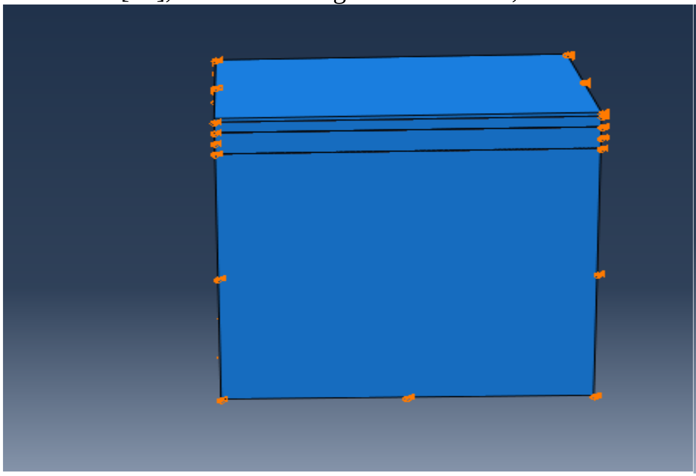

Fig.3Finite element boundary condition.

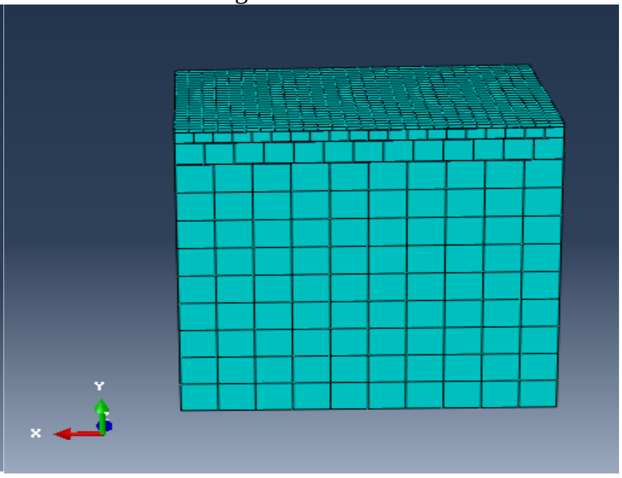

Fig.4Finite element model mesh.

B) Pressure load

Asphalt pavements are designed to resist many different vehicles, which have different axis loads, wheels and vary axis types (single, tandem, triple-axis). The stander axel is 80 kN on dual tires with contact pressure (0.6 MPa) which is used to simulate the different traffic loads acting on the pavement section [7].

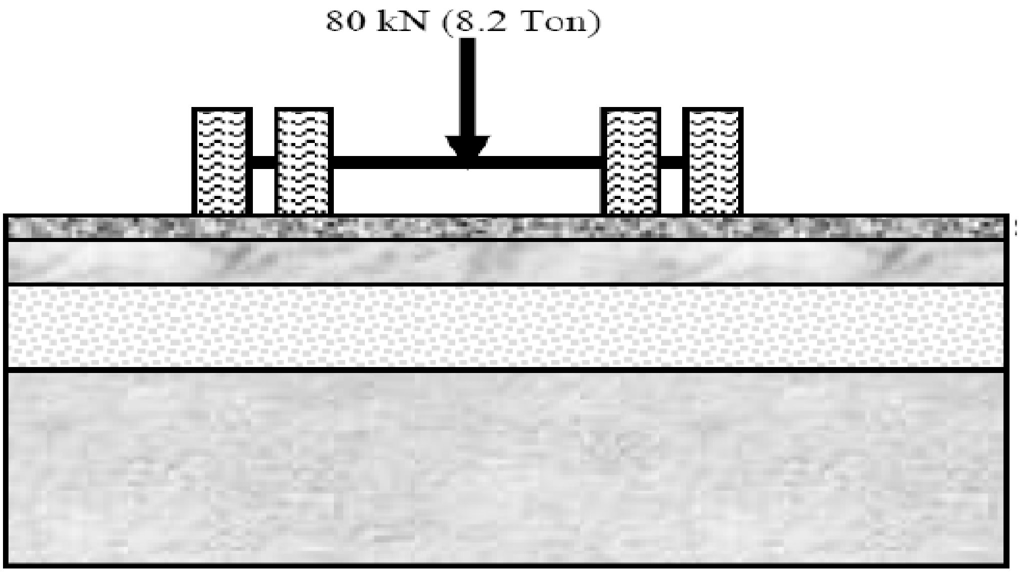

Fig.5Pavement design load due to rutting performance [7].

C) Contact area.

The area contact between surface asphalt layer and wheel during movement vehicles above the pavement section depends on tire pressure, which is increased when tire pressure is decreased. In general, the contact area has an irregular shape which consists of the middle rectangular part and two side semicircular parts. The equivalent area for standard load 100 kN is effected as single axle with the dual wheel is the rectangular area.

ISSN: 2350-0328
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Vol. 6, Issue 12 , December 2019

$$Lc=\sqrt{\frac{F}{0:5227\ p}} \quad (3)$$

where,
F= single wheel load.
p = tire pressure.
For the simulated rectangular area the length L=.8712Lc and width B =.6Lc [15].

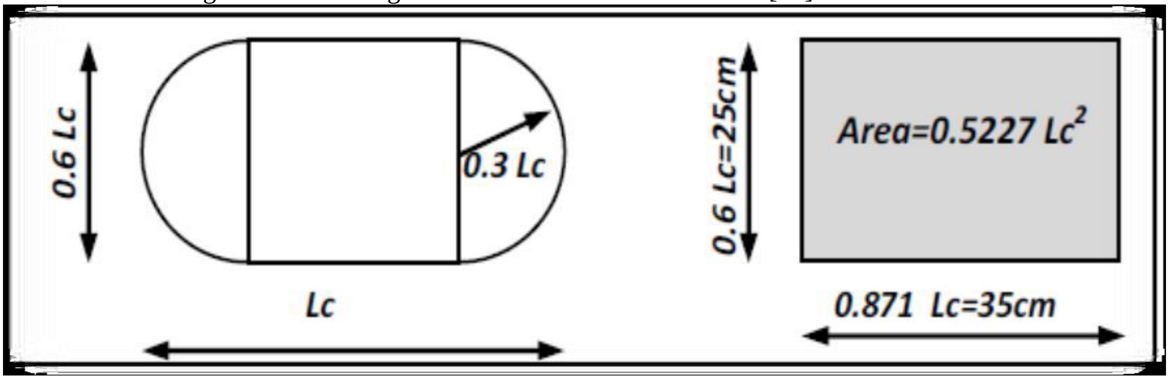

Fig.6The contact is for wheel load pressure[11].

III. RESULTS AND DISCUSSIONS

A) Rutting

The main reason for asphalt pavement failure is the rutting which it defined as longitudinal depressions in wheel paths as a result of continued densification by the traffic load. ABAQUS program with KENLAYER is used to study effect traffic loads on rutting values on flexible asphalt pavement that have the following materials properties.

Table 1 Inputs of Flexible Pavement Layers martials Properties[7]

Pavement layers	Elastic Modulus (MPa)	Poisson's ratio
Surface asphalt layer	2689	0.35
Base layer	1655	0.35
Sub base layer	110	0.4
Subgrade layer	35	0.499

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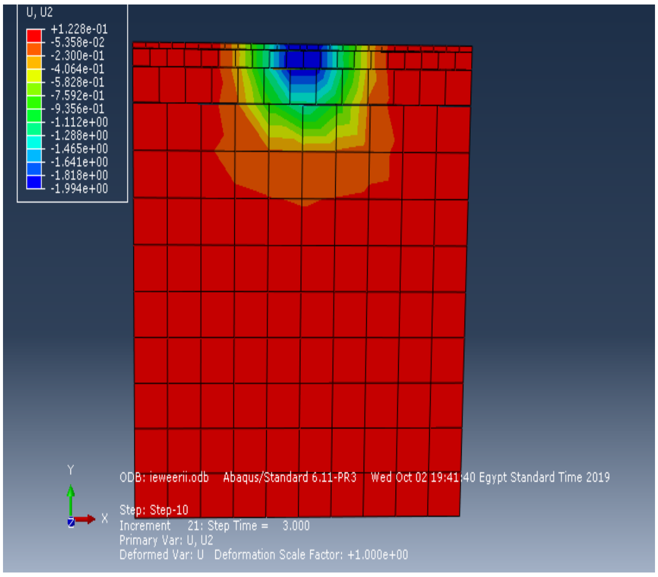

Fig.7 Rutting deformation of Pavement under traffic Loading

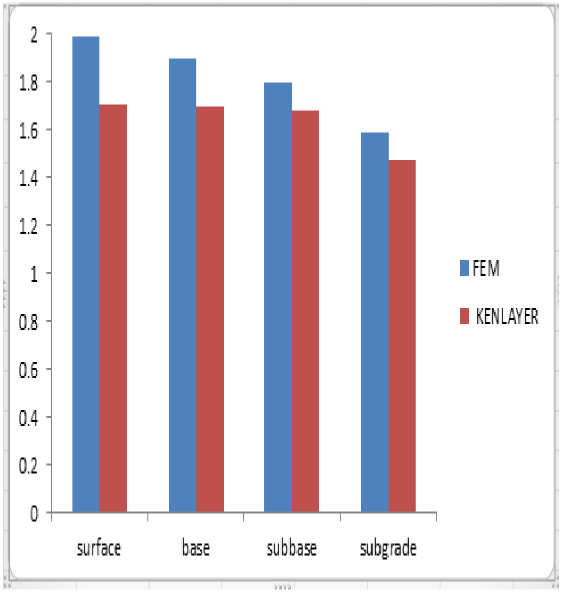

Fig.7 Rutting depth on pavement layer under traffic Loading

Fig.7 Presentsinstantaneous rutting for pavement section layers by using the ABAQUS program. The results confirmed the dynamic loads' effects decreased with layers depth as a result of granules friction, therefore intraday rutting depth reduces by 4.5%, 9.5%and 20% from surface rutting for the base, subbase, and subgrade layer. On the other side granules friction influence on extension instantaneous rutting for a horizontal distance about vehicle tires on pavement layers.Fig.8 shows the comparison values of instantaneous rutting for FEM and KENLAYERmethods. KENLAYER achieves fewer results than FEM for all asphalt pavement layers. The relationship between pavements is the main reason for this difference. The result analysis indicates the rutting reduce in KENLAYER 0.29, 0.2,0.12 and 0.1mm for surface asphalt, base, subbase, and subgrade layer compared with FEM.

B) Effect of resilient modulus.

Rutting performance depends on traffic loads, environmental conditions and material properties (elastic modulus and Poisson's ratio). To study the effect of material resilient modulus change on rutting performance, the resilient modulus of asphalt layer E1 is varied from 1000 to 7000 MPa , resilient modulus of a granular base layer E2 is varied from 1000 to 3000MPa , , resilient modulus of sub-base layer E3 is varied from 50 to 500 MPa and resilient modulus of subgrade layer E4 is varied from 35 to 200 MPa .

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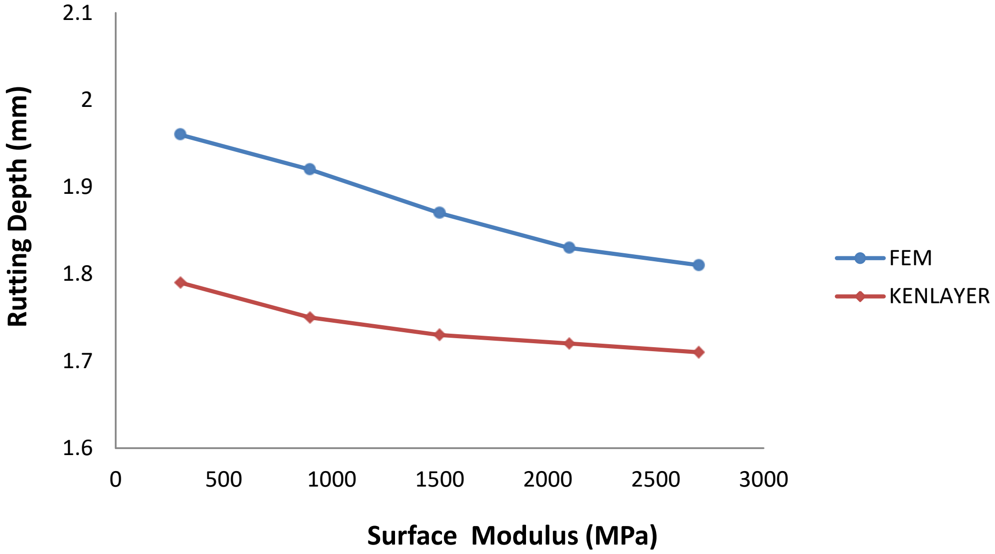

Fig.9 Effect surface modulus on rutting depth.

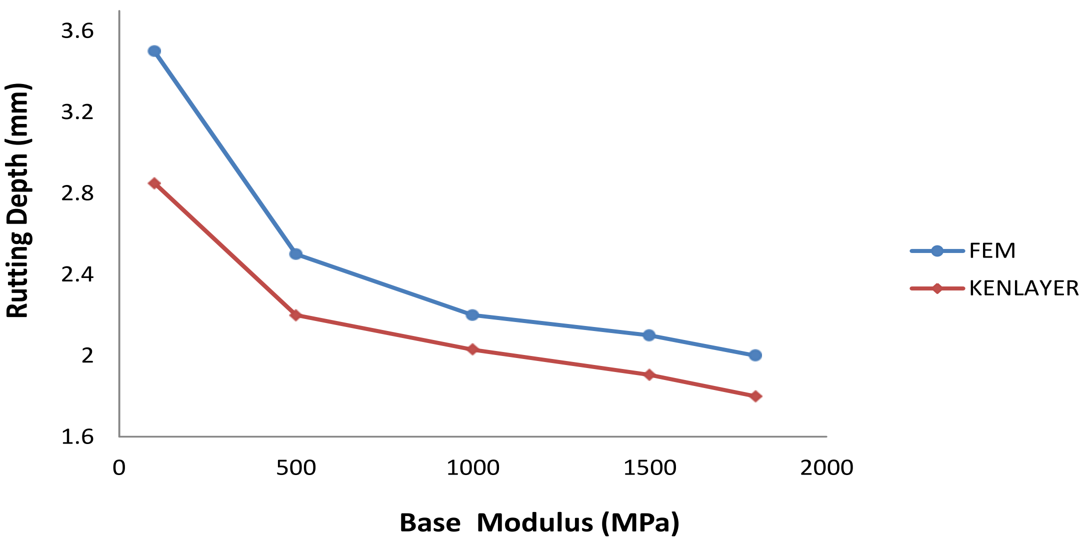

Fig.10 Effect base modulus on rutting depth.

ISSN: 2350-0328
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Vol. 6, Issue 12 , December 2019

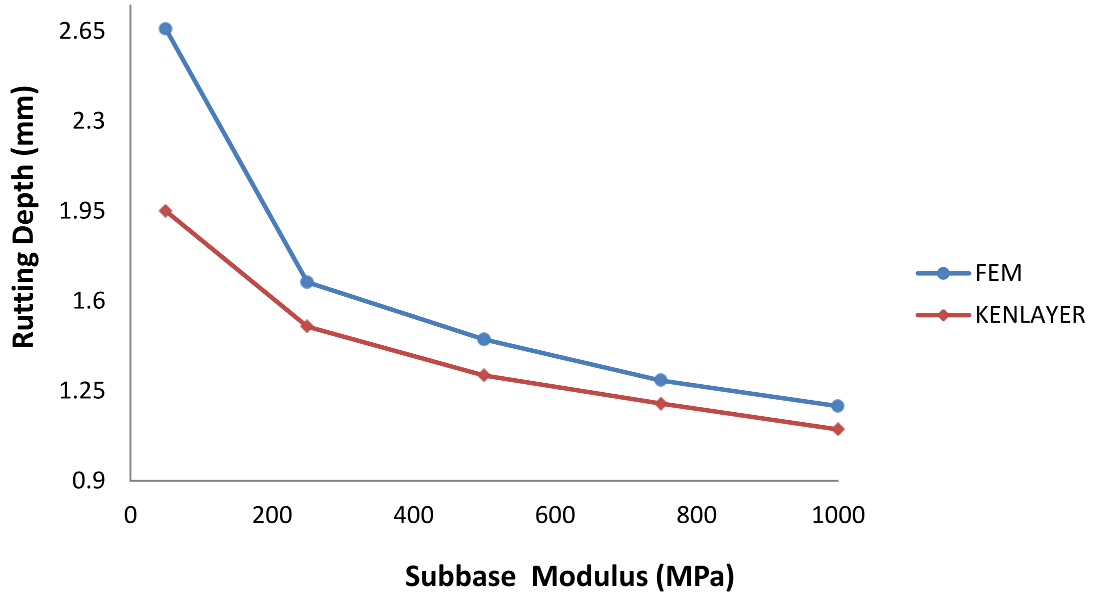

Fig.11 Effectsubbase modulus on rutting depth.

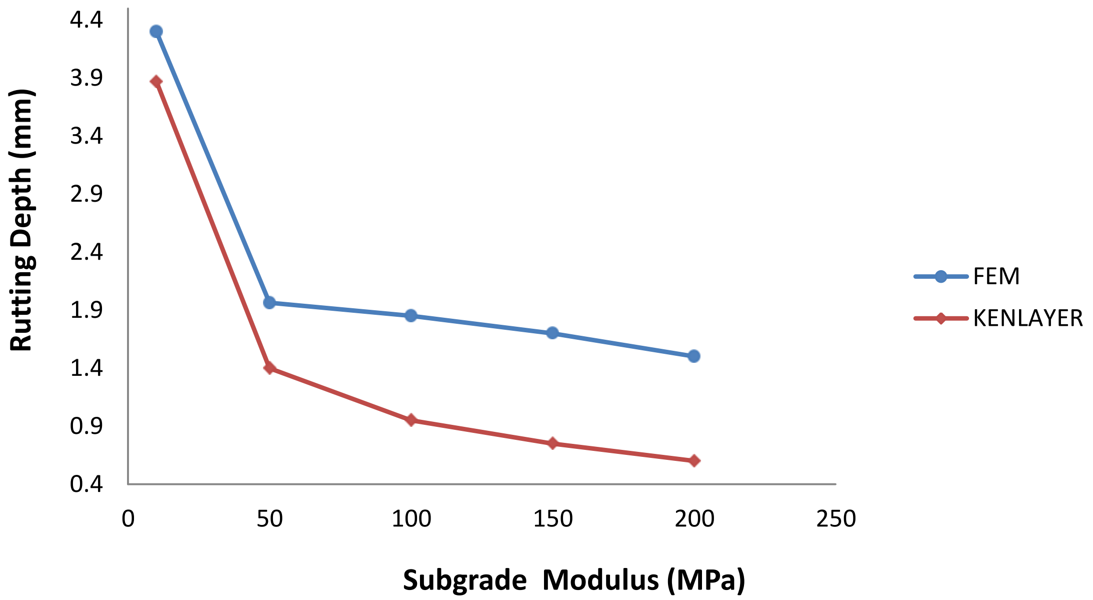

Fig.12 Effect subgrade modulus on rutting depth.

The simulation results of the asphalt pavement model depict that the increase in the resilient modulus of bituminous, granular base and sub-base layer treated rutting damage by minor ratio. While the elastic modulus of foundation soil is considered a key to improvement flexible pavement resistance for rutting performance under effect traffic loads.
Fig.9 presents to affect the varies asphalt modulus values on rutting depth of asphalt section. Both FEM and KENLAYER refer to increase asphalt modulus reduces rutting depth. increase the small values from asphalt modulus decrease rutting depth in reasonable proportions, after asphalt modulus 1500 MPa the decrease in rutting depth with increase asphalt modulus is minuscule. Finally effect asphalt modulus on rutting treatment is ineffectual compared with the spent cost to achieve these values of asphalt modulus.

Fig.10 shows the influence base layer modulus on pavement rutting phenomena. The simulation result proves that the effect of granular base modulus is radical until base modulus 500MPa, then the relation between rutting depth and base

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 6, Issue 12 , December 2019

layer thickness is converted to flat curve, which the reduction on rutting depth is slight compared base modulus increment. Basically, base layer modulus is considered the right solution for rutting reduction compared with asphalt modulus.

The effect of the subbase layer modulus is demonstrated in Fig.11. In general, the pavements with subbase layer modulus less than 250 MPa have a great response for rutting reduction with increase subbase modulus.The increment of the subbase layer more than 250 MPa is not substantially a solution for rutting treatment.The result analysis has shown the base layer modulus effect on rutting performance is more than asphalt modulus but less than base modulus effect.

Fig.12 depictsthe relation between natural foundation subgrade modulus and amount damage on the pavement section.The increment on subgrade modulus until 50 MPa is basically a solution for rutting resistance. The results analysis for FEM and KENLAYER indicate that an increase subgrade layer by 5-time from design value reduces rutting depth for half of the value. After 50 MPa the increment on subgrade modulus has not salient effect on rutting depth.

C) Effect layer thickness

Layer's thickness is designed to achieve safety design against traffic loads and environmental conditions, which causes pavement distress. Layers thickness is the most critical parameter on the pavement rutting study. To study effect layers thickness, surface asphalt thickness changed between 50 to 100 mm, base layer changed between 100 to 300 mm and subbase layers changed between 100 to 300 mm.

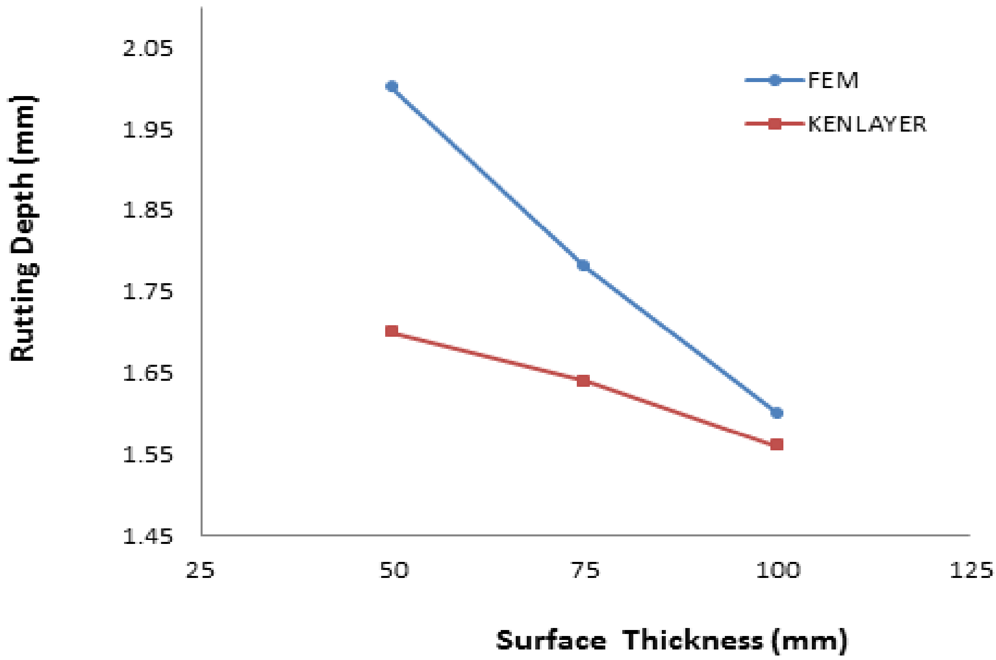

Fig.13 Effect surface layer thickness on rutting depth.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 6, Issue 12 , December 2019

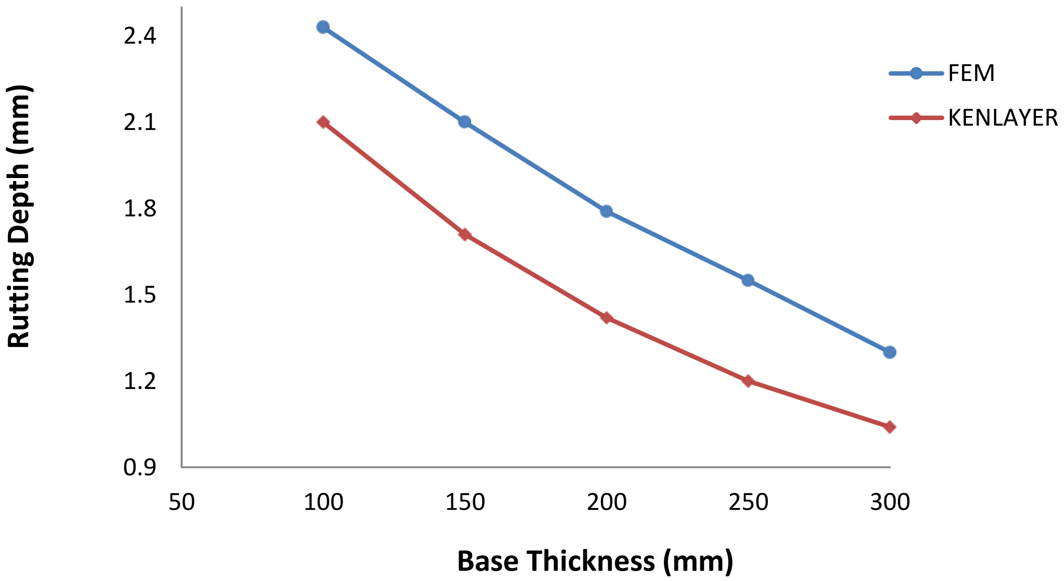

Fig.14 Effect base layer thickness on rutting depth.

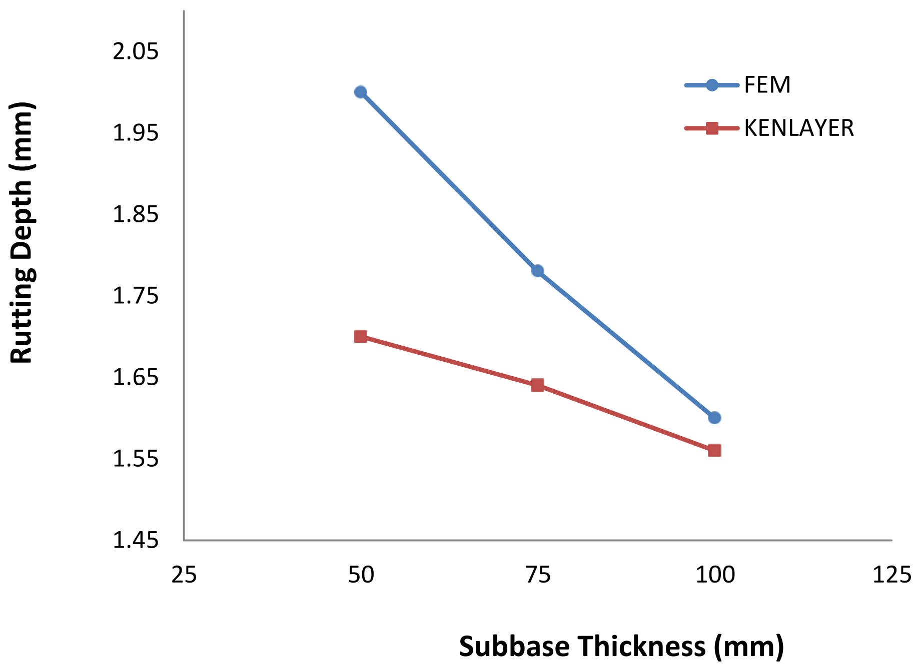

Fig.15 Effectsubbase layer thickness on rutting depth.

Fig.13 shows the variance in rutting depth with changed surface asphalt layer thickness. The validation results from FEM with KENLAYER substantially suggest to the layer thickness has no significant effect on rutting resistance compared to asphalt modulus influence. Asphalt thickness has a minimal consequence on pavement section rutting, it reducted about 0.45and 0.1 mm for FEM and KENLAYER method respectively with increment asphalt thickness from 50 to 100 mm. Fig.14 presents the relation between base layer thickness and transient rutting on the asphalt section.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 6, Issue 12 , December 2019

Base thickness influence indicates slightly different behavior from the asphalt layer thickness effect.The results prove that rutting depth decrease by 1.40 and 1mm for FEMand KENLAYER when base layer thickness increases three times the design value.Fig.15 depicts the amount of damage for asphalt pavement section with different subbase layer thicknesses. The tensile strain results from traffic load effect on the surface of base layer, therefore subbase thickness does not play a fundamental role in rutting treatments. In generally layers thickness increment can not be used as a single solution to treatment rutting performance.

IV. CONCLUSIONS

- The analysis of simulation results based on the theoretical previous study of flexible pavement model leads to several important considerations such as:
- FEM results analysis indicated that the instantaneous rutting depth on the surface of base, subbase and subgrade layer is decreased by (4.50%), (9.50%) and (20%) respectively from rutting depth on asphalt layer.
- Rutting performance on the surface of the asphalt model is sensitive to change on elastic modulus of layers material and is not sensitive to change on layers thickness.
- Subgrade elastic modulus has a significant effect on rutting depth on the surface pavement until elastic modulus 50 MPathen, subgrade modulus has a slight effect on surface rutting.
- Increment subbase thickness is not an engineering solution to reduce rutting depth, increase subbase thickness from 100 to 300 mm decrease rutting depth by 8.5% according to FEM results.
- Asphalt mixture and base layer elastic modulus have a small influence on rutting performance.

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