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FINITE ELEMENT MODELING OF RUTTING FOR FLEXIBLE PAVEMENT

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Abstract: The aim of this research is studying the effect of base and subgrade layer local materials properties on the rutting damage of flexible pavement due to repeated traffic loading. The most roads in Baghdad city present severe rutting damage due to absence of quality control in the construction of granular unbounded pavement layer. Furthermore many trucks with overweight using the roads and high temperature in summer produced distresses and deterioration of flexible pavement. Flexible pavement analyses are performed using finite element method; a 3-D dimensional finite element model using ABAQUS (ver. 6.12-1) computer program are developed. The results obtained for base layer show reduction in rutting damage by about (58%) while subgrade layer provided damage reduction only (10%). Also the critical value for vertical compressive stresses is (480 kPa) below the wheel loading area which is about (70.9%) of the applied tire pressure and then decreased gradually with depth to about (118 kPa) approximately (17%) of the applied tire pressure within the base layer and remains almost constant with depth through the subgrade layer. And for horizontal stresses a high value was observed on surface of flexible pavement under the path of wheel load rather than the compressive stresses then decreased laterally with horizontal distance.The local untreated base material experience critical rut depth of (8 mm) at 1000 number of repetitions and for treatment base materials the number of load repetitions to cause damage rutting increased (10) times to about 10000 number of load repetitions.The treated base materials decreased the rutting damage factor. This implicates the main role of granular base layer in pavement system support to minimize the rutting damage.

Keywords: *ABAQUS; Flexible pavement; finite element; rutting; Stresses; Strains*

تمثيل التخدد للتبليط المرن باستخدام العناصر المحددة

الخلاصة: الهدف من هذا البحث هو دراسة تأثير خصائص طبقة الاساس وتحت الاساس للمواد المحلية على ضرر التخدد للتبليط المرن نتيجة الأحمال المتكررة . اغلب الطرق في مدينة بغداد تظهر ضرر كبير نتيجة غياب السيطرة النوعية في إنشاء طبقات التبليط الحبيبية المفككة. بالإضافة على ذلك الشاحنات الثقيلة التي تستخدم الطرق ودرجات الحرارة العالية في فصل الصيف تؤدي إلى عيوب وتلف في التبليط المرن. تحليل التبليط المرن باستخدام طريقة العناصر المحددة ، موديل ثلاثي الأبعاد باستخدام برنامج ABAQUS ver6/12-1 تم تطويره. النتائج المستحصلة لطبقة الأساس أظهرت نقصان بضرر التخدد بحوالي (58%) بينما طبقة ما تحت الأساس أعطت نقصان بحوالي (10%). كذلك القيم الحرجة لإجهاد الضغط العمودي 480 كيلو باسكال تحت منطقة حمل العجلة والتي تمثل 70،9 % من ضغط حمل العجلة ثم تتناقص تدريجيا مع العمق الى حوالي 118 كيلو باسكال تقريبا 17% من حمل العجلة الكلي في طبقة الأساس وتبقى القيمة ثابتة مع العمق حتى طبقة ما تحت الأساس. أما بالنسبة للإجهادات الأفقية تم ملاحظة قيمة عالية على سطح التبليط المرن تحت مسار العجلة مقارنة مع أجهادات الضغط العمودي ثم تقل جانبيا مع المسافة الأفقية. طبقة الأساس المحلية غير المعالجة تسبب التخدد

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الحرج بعمق 8 ملم بعد 1000 مرات تكرار الحمل اما بالنسبة لطبقة الأساس المعالجة فان عدد مرات تكرار الحمل للتخدد الحرج يزداد بحوالي 10 أضعاف أي 10000 . طبقة الأساس المعالجة تقلل معامل الضرر للتخدد .مما يؤكد أهمية الطبقة الحبيبية الساندة لنظام التبليط على تقليل ضرر التخدد.

1. Research Objective

The aim of this research is studying the effect of base and subgrade layer local materials (for Baghdad city) properties on the rutting damage of flexible pavement due to repeated traffic loading. To determine the damage of rutting per each pass of wheel load on the flexible pavement, moving load that varies in space and time has been simulatedusing ABAQUS (ver. 6.12-1) computer program to achieve the basic concept of this research. The pavement deformation, stress, strain and rutting damage are investigated taking into consideration different types of material characterization for base and subgrade layers.

2. Motivation

Most roads in Baghdad city presents severe rutting damage due to absence of quality control in the construction of granular unbounded pavement layer in terms of compaction methods and other standard specifications.Furthermore many trucks with overweight using the roads and high temperature in summer produced distresses and deterioration of flexible pavement. Based on this problem ; this research studied the rutting of flexible pavement taking into consideration the local materials for pavement constructions.

3. Back Ground

Rutting is one of the most performance criteria in flexible pavement that occurs due to deterioration and high temperature and axle load. Also it is considered as significant factor that influences on road roughness and safety. ***Ali, M. (2013)*** studied the impact of static axle load on rutting of flexible pavement taking into consideration the effect of temperature. Ansys (ver.11) was implemented to analyze three dimensional finite element structure of pavement. He found the increase temperature from 10 C^0 to 50 C C^0 results in an increment about (673%) and (740%) for plastic strain and rutting depth respectively [1].

Abed, A. and Alazzawi, A.(2012) Stated that the stress in leveling layer decrease by about (14%) and (27%) in the base layer and rut depth is increased by (12%) and (28%) in that layers respectively using ANSYS finite element program. A local model for rutting are applied to estimate parameters for related to pavement structure and environmental conditions [2].

Al-Khateeb, et. al ., (2011) developed two dimensional finite element program using (ABAQUS) software for pavement structure to investigate the static repeated load effect on rutting of flexible pavement. They demonstrated that the rut depth increases with increasing temperature and tire pressure and decreasing subgrade strength.

Huang , et.al. (2015) estimated the rutting behavior of steel deck pavement based on 3D-finite element method model. A good comparison is obtained of the FE results and full -scale testing. Approving its feasible to apply the finite element model to predict rutting behaviors of steel deck asphalt pavement [3].

4. Finite Element Modeling

The finite element method is one of the most powerful technique used to simulate the behavior response for different structural engineering problems. Which is considered as an numerical technique for obtaining approximate solution in the board field of continuum solid [4].In this research the behavior response of pavement system is investigated and modeled using the ABAQUS program (ver. 6.12-1). A 3 dimensional solid structural analysis of pavement using element (C3D8R).The C3D8R element is a general purpose linear brick element, has three degrees of freedom at each node, translations in the nodal x, y, and z directions with reduced integration (1 integration point) located in the middle of the element also not stiff enough in bending. To capture a tress concentration at the structure boundary; small elements are needed , see Figure (1) below, [5].

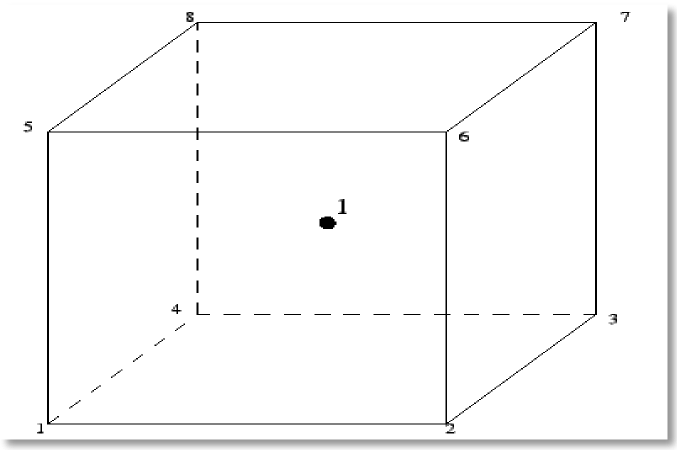
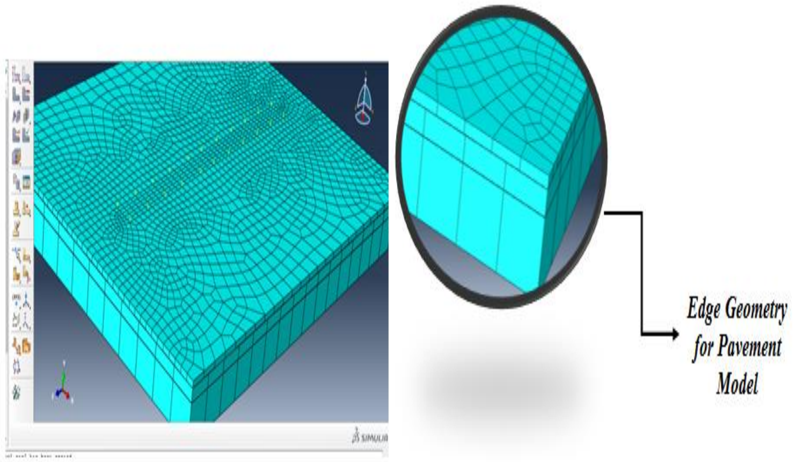


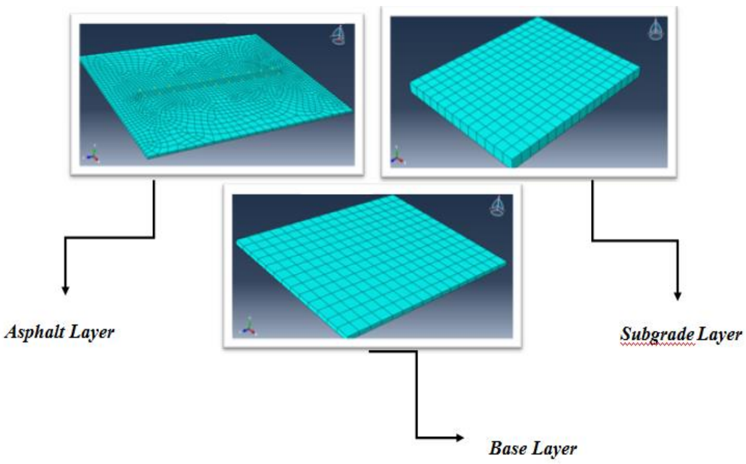
Figure (1): Integration Point Scheme in Hexahedral C3D8R Element [5].

Figure (2) shows the analytical 3D- Model mesh for pavement system including different layer properties asphalt (50mm thickness) , granular base (150 mm thickness) and subgrade soil (40 mm thickness) with suitable sizes in longitudinal and transverse directions (4000 mm x 5000mm) to limit the inaccuracy due to edge effect.

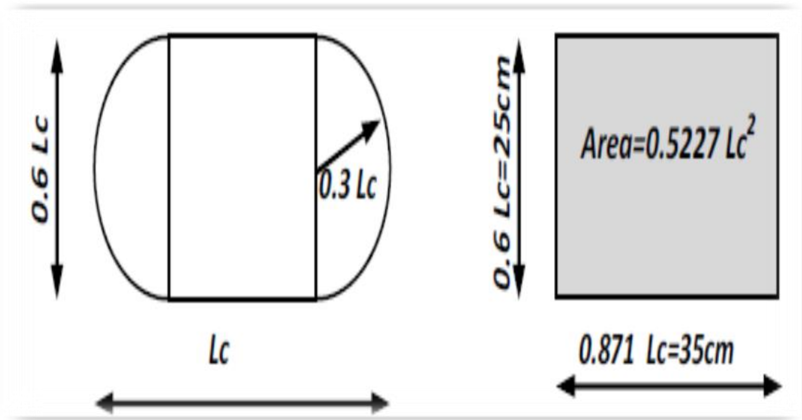
A standard axel load of one tire of (80 kN) [6] is assumed to transferred to pavement surface through uniform contact pressure of a single tire (690 kPa) with neglecting the stiffness effect of tire wall, the contact pressure will equal to tire pressure [7]. The tire pressure simulated by ABAQUS using the rectangle shape shown in Figure (2) [7].



a)3D -Geometry of Mesh Flexible Pavement.



b)3D- Geometry of Mesh Pavement Layers.



(C) :Contact Area of Tire Pressure [7].

Figure (2): 3D- Model Mesh Geometry for Flexible Pavement by ABAQUS.

To determine the damage of rutting per each pass of wheel load on the flexible pavement, moving load that varies in space and time has been simulated in this research using ABAQUS computer program which allows the user to applied several types of load, magnitude, location and directions through the application of Load Module.

The path of moving load is the longitudinal distance along which is divided into several steps (10 steps complete one wheel cycle) to simulate the moving load on the surface of pavement ,this can be achieved through the application of Step Module as shown in Figure (3),*[5]*. Also the boundary conditions are shown in Figure (3) for the pavement model which is fixed at the bottom of subgrade layer (no horizontal and vertical movement) and the edges for each part of pavement geometry model are allowed to move vertically only and fixed in the horizontal direction.

Finally the Interaction Module using ABAQUS is used to simulate the interaction between different pavement layers (asphalt , base and subgrade) with tie- contact for both (asphalt and base) and (subgrade and base) layers as shown in Figure (4).

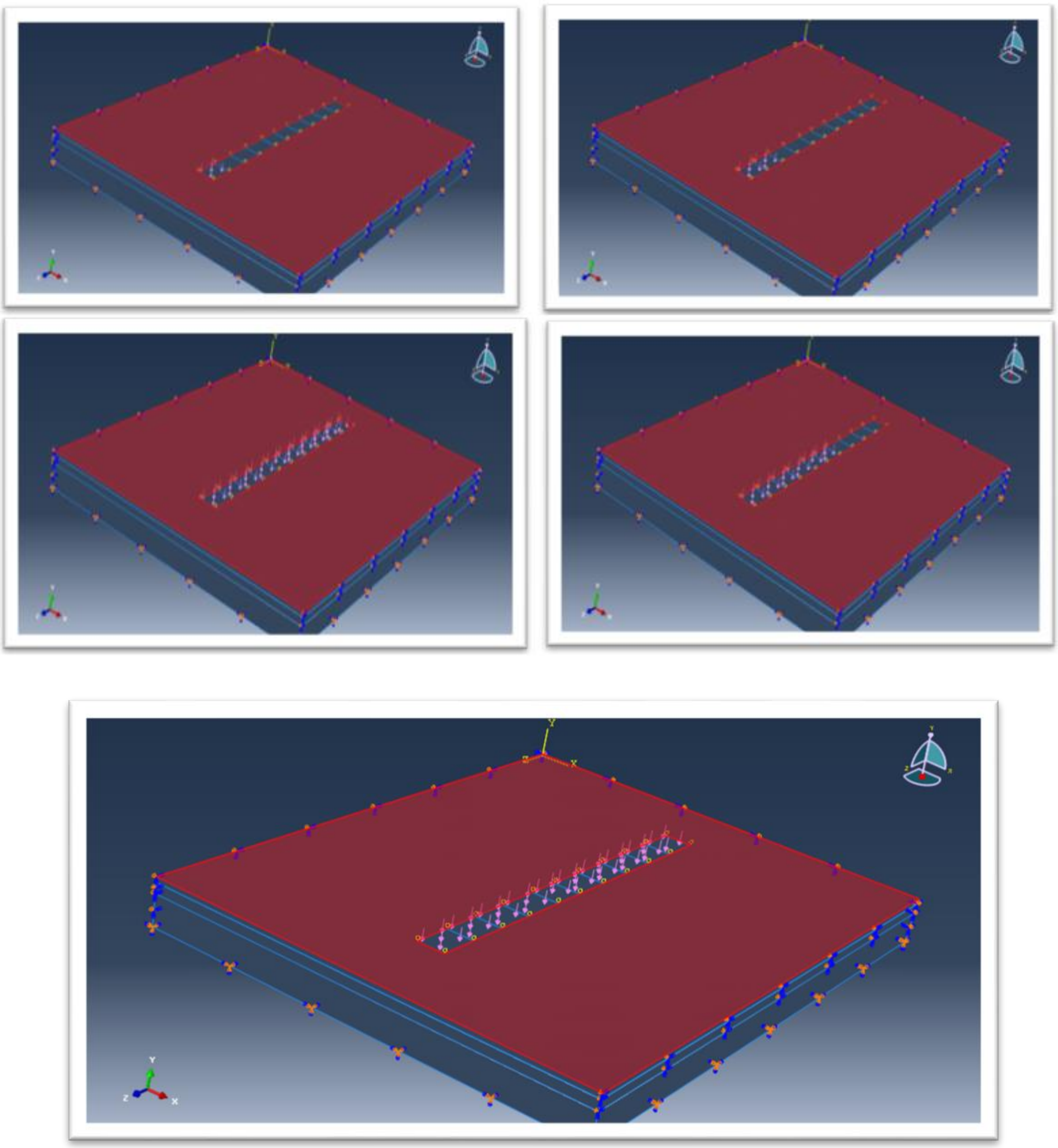
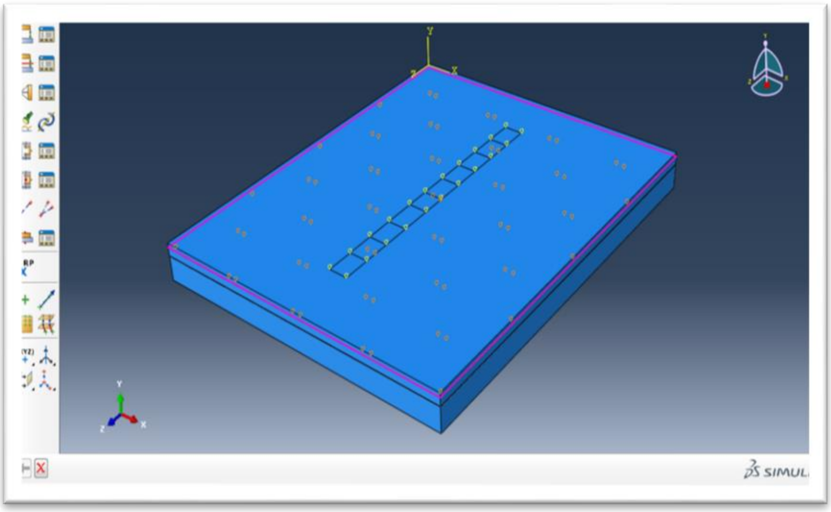
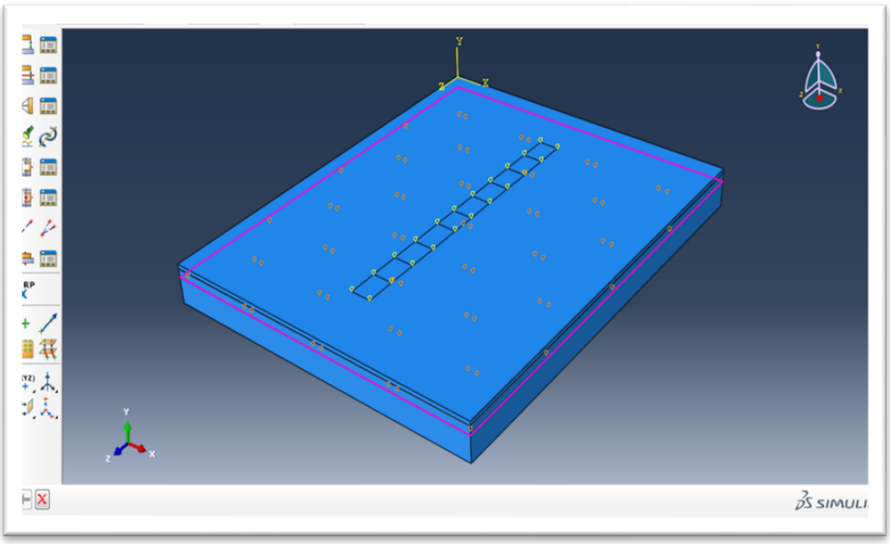


Figure (3): Step Module of Moving Load for 3D Pavement Model.



a) Interaction for base Layer.



b)Interaction for Subgrade layer

Figure (4): Interaction Module for 3D Pavement Model.

5. Materials Layers Characterization

The most important factor concerning in this research is the effect of base and subgrade layer local materials (for Baghdad city) properties on the rutting damage of flexible pavement due to repeated traffic loading, and to achieve this main goal; different layer properties before and after treatment have been considered for the finite element program as inputs for pavement layer characterization as shown in Table (1) below.

Table (1): Pavement Layer Properties [8]and[9].

Pavement Layers	Elastic Modulus (MPa)	Poisson's ratio (ν)	Density (Kg/m³)
Asphalt	508	0.35	2267
Local Base Layer	1.98	0.35	2141
Treated Base Layer with Cement Stabilizer	38.5	0.2	2280
Treated Base Layer with Silica Fume	129.39	0.2	2216
Local Subgrade Layer 1	211.53	0.4	1870
Local Subgrade Layer 2	37.92	0.45	-

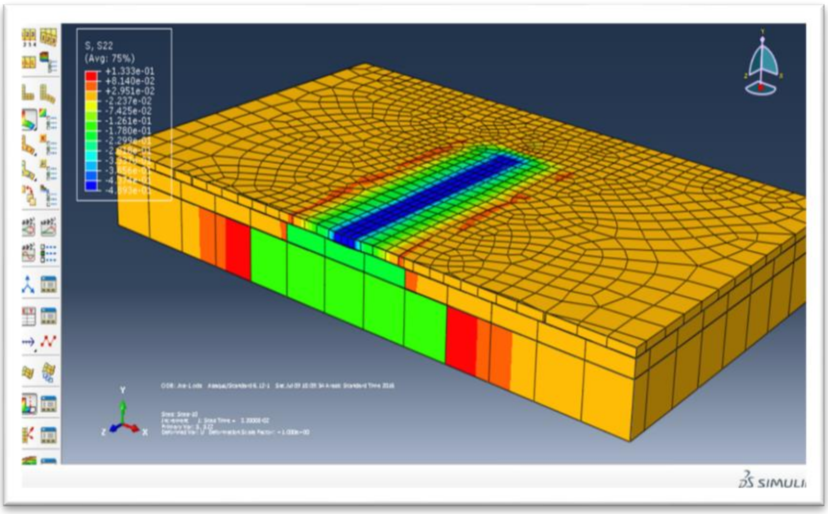
6. Finite Element Analysis Results

Flexible pavement analysis are performed using finite element method; a 3-D dimensional finite element model using ABAQUS (ver. 6.12-1) computer program are developed. The pavement deformation, stress, strain and rutting damage are investigated taking into consideration different types of material characterization for base and subgrade layers.

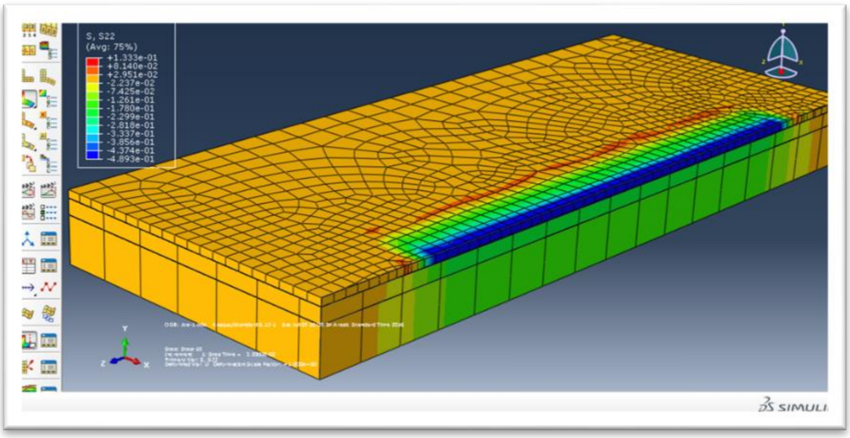
6.1. Stresses and Strains

The main output for pavement analysis are the critical response points which represent the vertical and horizontal stress and strain and surface deformation due to repeated applied traffic axle load. In this section The distribution of stresses and strains over the whole pavement structure are enumerated since the finite element technique is to obtained approximate solution in continuum structure of pavement (each divided small point in the mesh) not specific for one point stress and strain using one exact closed equation for the whole pavement structure such the multi-elastic layer theory. Figure (1) and (2) explain the transverse and longitudinal distribution of vertical and horizontal stresses for local pavement materials under the moving of wheel load.

The critical values for vertical compressive stresses are just under the wheel load as shown in figures below with blue color, at value of (480 kPa) which represent about (70.9%) of the applied tire pressure and then decreased gradually with depth to reach about (118 kPa) corresponding to approximately (17%) of the applied tire pressure consecutively.

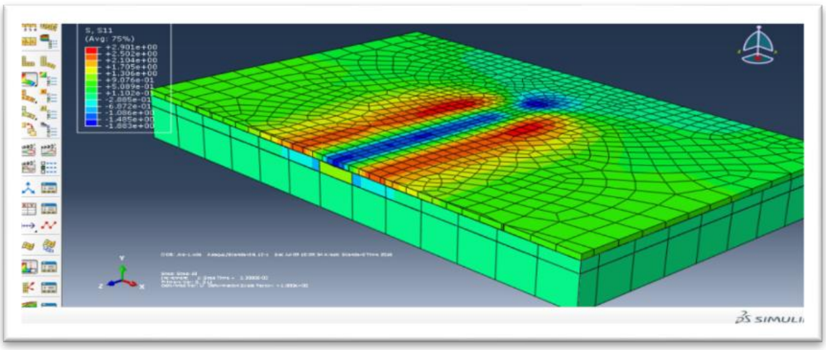


a) Transverse Distribution of Vertical Stresses.

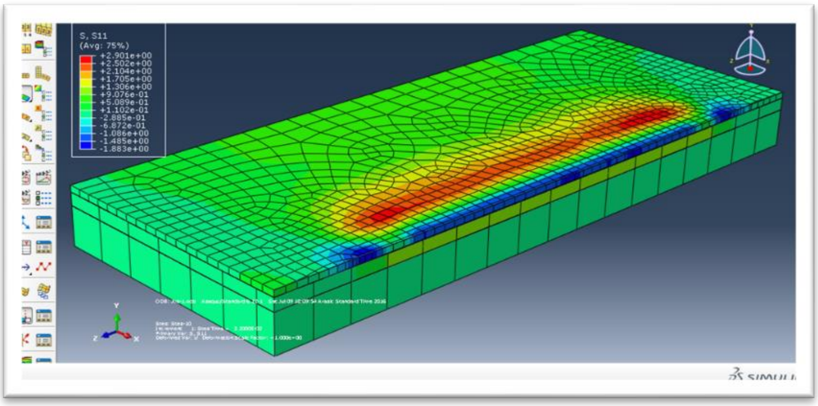


b) Longitudinal Distribution of Vertical Stresses.
Figure (5): Vertical Stresses Distribution within Flexible Pavement System.

Furthermore, it is possible to add that the vertical compressive stresses reduced to minimum value which is about (17 %) of applied tire pressure within the base layer and remains almost constant with depth down to the subgrade layer. This behavior is clear according to the detection of vertical compressive stress distribution in Figure (1).

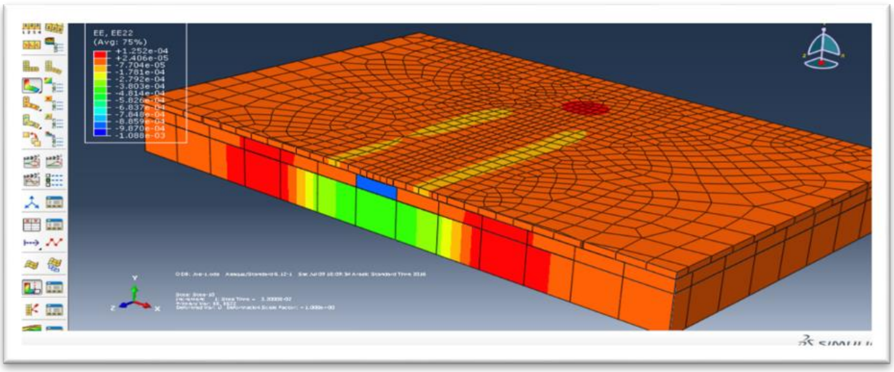


a) Transverse Distribution of Horizontal Stresses.
Figure (6): Horizontal Stresses Distribution within Flexible Pavement System.

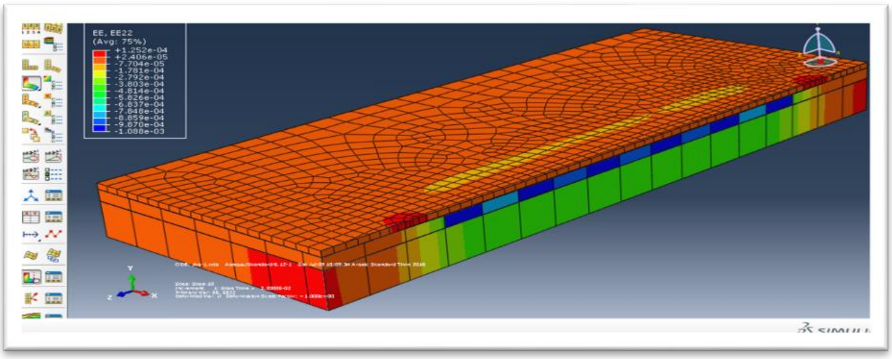


b) Longitudinal Distribution of Horizontal Stresses.
Figure (6): Continuous.

With regards to the horizontal stresses; a high value was observed on surface of flexible pavement under the path of wheel load rather than the compressive stresses then decreased laterally with horizontal distance which is may be more evident and express by the tensile vertical strain generated under the moving wheel load that illustrated in Figure (3) below. This behavior contributes to the different types of distresses appeared at the surface of flexible pavement due to repeated applied traffic loading such as fatigue cracking.

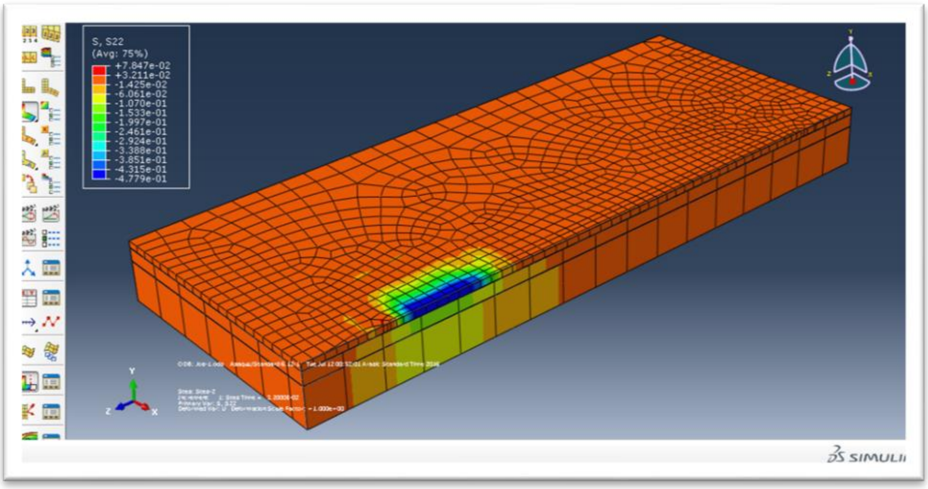


a) Transverse Distribution of Vertical Strains.

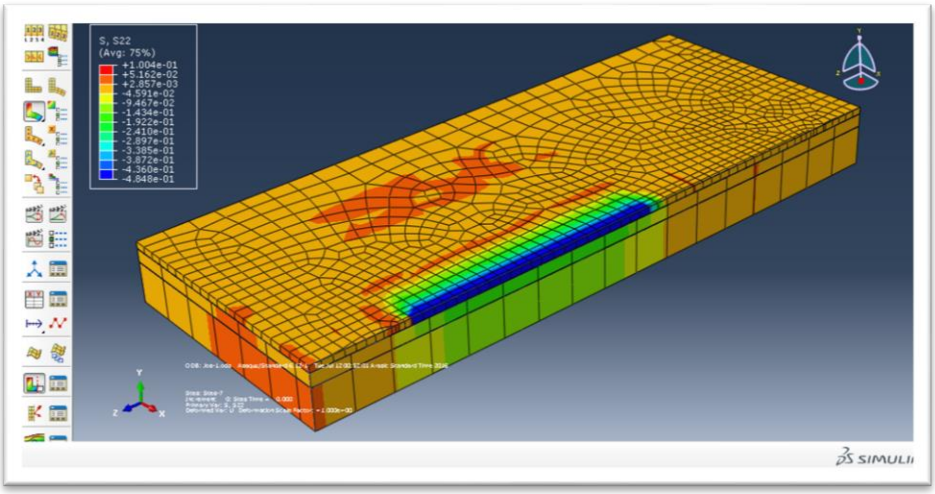


b) Longitudinal Distribution of Vertical Strains.
Figure (7): Vertical Strain Distribution within Flexible Pavement System.

Figure (4) presents the stresses generated under the moving load. An increment value of stresses is observed after the movement of the load away from the region of interest. To explain with resulted values , (477.9 kPa) is generated as a result of applied wheel load then after keep moving load longitudinally this value increased to (484.8 kPa) as illustrated in Figure (4). A suitable clarification for this behavior is the dynamic impact of moving wheel load and the interaction response of the foundation base and subgrade layers.



a) Applied Moving Load.



b) Moving Applied Load away from Interested Region.

Figure (8): Vertical Stresses Distribution under Applied Moving Wheel Load.

6.2. Rutting

Rutting is the most influential distresses in local region due to high temperature and heavy traffic loading. To gap the most factors affect on the rutting in flexible pavement several types of locally pavement foundation layers (untreated and treated with cement ,silica fume) are included in this parametric study as explained in section 4. The non linear elastic model under repeated applied wheel load is developed by ABAQUS program to simulate the case study for flexible pavement system ; and based in this model the main significant parameter to applied this model is the modulus of elasticity **(E)** Elastic modulus and , Poisson's ratio **(ν)** as shown in Table (1).

Figure (6) presents the relation between the rut depth value and number of load repetitions for locally untreated and treated base materials with cement and silica fume and two types of locally subgrade materials from different locations at Baghdad city.

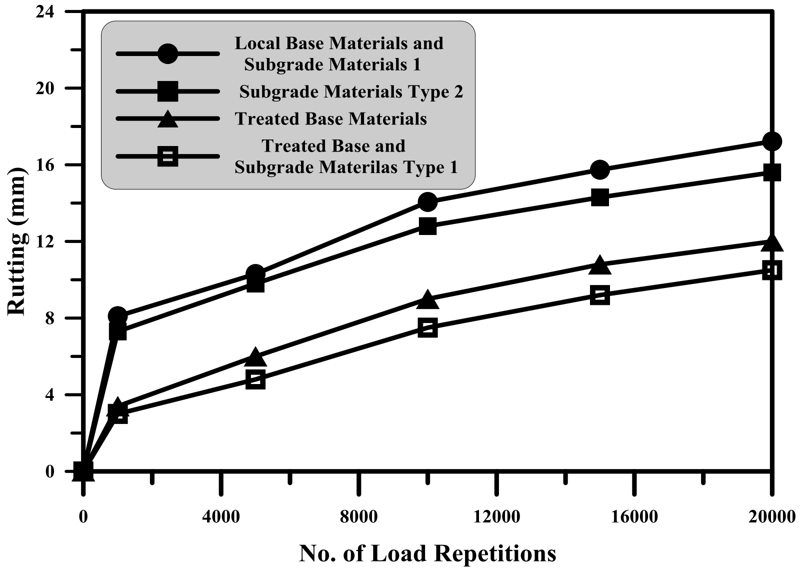


Figure (9): Rut Depth versus Number of Load Repetitions for Local Material and Different Treated Base Materials.

Increase the number of load repetitions increase the permanent deformation at the surface of flexible pavement excessively due to high value of vertical compressive strains within base layer as shown in Figure (7) below. The rutting damage decreased with increased stiffness of base materials; since the local base material experience critical rut depth of (8 mm) at 1000 number of repetitions and after treatment to produce higher strength of base material the number of load repetitions to cause damage rutting increased (10) times to about 10000 number of load repetitions. Also Figure (8)and (7) show another aspect for subgrade and base layers that is clarified the subgrade layer reduced the rutting damage by about (10%) which is less significant as compared with base layer that reduced about(58%) of rutting damage in flexible pavement.

Figure (10) illustrate the effect of treated base materials and different types of local subgrade materials on rutting damage factor (rutting damage factor is the inverse of number of load repetitions to cause damage rutting) . This implicate the main role of granular base layer in pavement system support to minimize the rutting damage. And unfortunately it's not get the proper design requirements in most Baghdad road pavement construction and design.

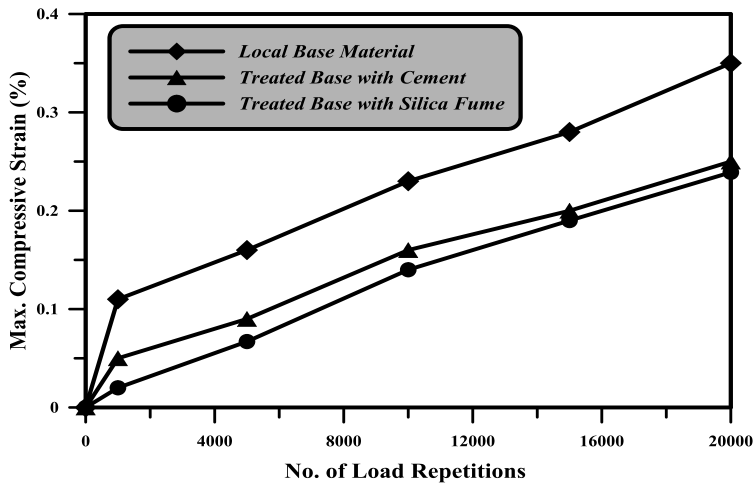


Figure (10): Vertical Compressive Strain versus Number of Load Repetitions for Local Material and Different Treated Base Materials.

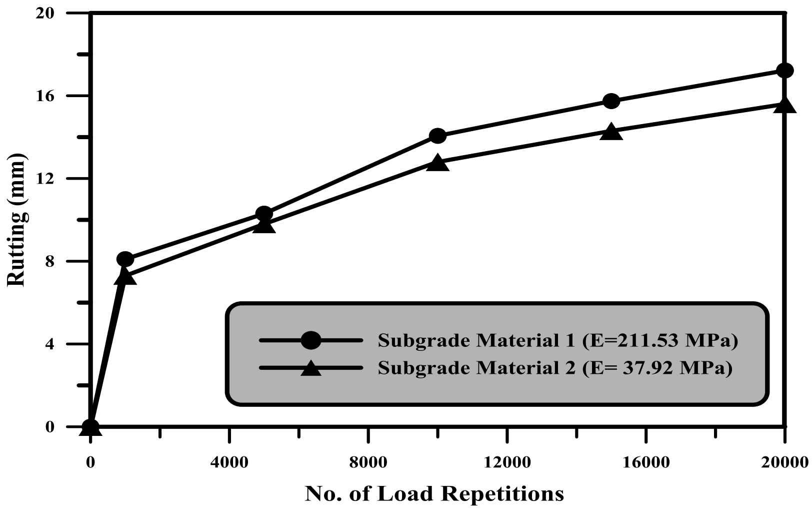


Figure (11): Rut Depth versus Number of Load Repetitions for Local Subgrade Materials.

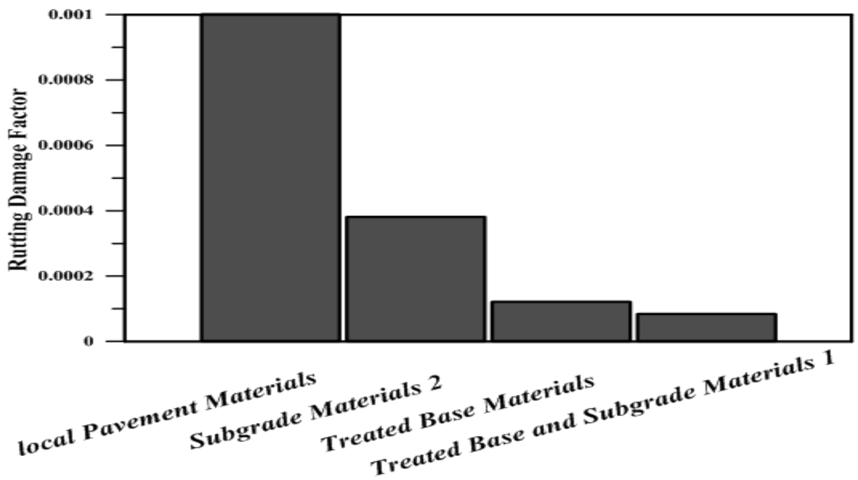


Figure (12): Rutting Damage Factor versus Local Untreated and Treated Base and Different Local Subgrade Materials.

7. Conclusions

Depending on the established results from the finite element program ABAQUS and the type of methodology to simulate the flexible pavement system under moving wheel load , the following concluding remarks can be drawn:

1. Base Layer reduced rutting damage by about (58%) while subgrade layer decreased only (10%) of rutting damage in flexible pavement which is less significant as compared to the base layer.
2. The critical value for vertical compressive stresses is (480 kPa) below the wheel loading area which is about (70.9%) of the applied tire pressure and then decreased gradually with depth to about (118 kPa) corresponding to approximately (17%) of the applied tire pressure within the base layer and remains almost constant with depth through the subgrade layer.
3. A high value for horizontal stresses was observed on surface of flexible pavement under the path of wheel load rather than the compressive stresses then decreased laterally with horizontal distance.
4. The local untreated base material experience critical rut depth of (8 mm) at 1000 number of repetitions and for treatment base materials the number of load repetitions to cause damage rutting increased (10) times to about 10000 number of load repetitions.

8. References

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