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EVALUATION THE PERFORMANCE OF TREATED BASE LAYER ON CRITICAL RESPONSES OF FLEXIBLE PAVEMENT

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Abstract: Often rehabilitation flexible pavement expensive process, especially if the pavement problems in the substrata, whether in the base layer or natural ground layer simple surface layer does not lead to long-term solution, and are being considered in many of the secondary materials for use as alternatives to the natural aggregate in paving roads as solutions engineering and economical way. The study includes laboratory experiments and analysis using finite element analysis model of the finite elements of the two-dimensional layer based on improved pavement under dynamic loading effect. The calculated damage such as fatigue, rutting and surface deformation of base materials and treated base materials using finite elements PLAXIS program (PLAXI V8.6) has been used different ratios of Reclaimed Concrete Aggregate and Foundry Sand, has the study using treated base materials with (50,15)% of Reclaimed Concrete Aggregate and Foundry Sand, respectively. It was suggested that an alternative method in this study, for the characteristics of the materials used for the flexible pavement required for finite element analysis by examining the compressive strength Using equations available in the literature available. It has been found that the improved base layer with Foundry Sand and Reclaimed Concrete Aggregate leads to a decrease in the estimated fatigue (90% and 14%, respectively). And the rutting reduced of Foundry Sand and Reclaimed Concrete Aggregate about (93% and 52%, respectively.

keywords: *Stabilization, Deformation, Finite Element Modelling, Cohesion, Internal friction angle.*

تقييم اداء طبقة الاساس المحسنة على التبليط المرن

الخلاصة: في كثير من الأحيان إعادة تأهيل التبليط عملية مكلفة، خاصة إذا كان في التبليط مشاكل في الطبقات التحتية سواء كان في طبقة الاساس او طبقة الارض الطبيعية والاكساء البسيط للطبقة السطحية لا يؤدي إلى حل طويل الامد، ويجري النظر في العديد من المواد الثانوية للاستخدام كبدائل للركام المستخدم في تبليط الطرق كحلول هندسية واقتصادية للطريق. تتضمن الدراسة التجارب المعملية والتحليل باستخدام طريقة العناصر المحددة، تحليل نموذج العناصر المحددة ثنائي الابعاد لطبقة اساس التبليط المحسنة تحت تأثير التحميل الديناميكي. وتحسب

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اضرار التبليط مثل الكلل، والانحناءات العامودية والتشوهات السطحية لطبقة الاساس المحسنة والغير محسنة باستخدام برنامج العناصر المحددة بلاكسز (PLAXI V8.6) وقد استخدمت مختلف النسب من الركام المعاد تدويره من الخرسانة الكونكريتية ورمل الصب، تمت الدراسة باستخدام النسب المثلى من (٥٠، ١٥) من الركام المعاد تدويره من الخرسانة الكونكريتية ورمل الصب على التوالي. وقد تم اقترح طريقة بديلة في هذه الدراسة، للحصول على خصائص المواد المستخدمة لطبقات التبليط اللازمة لتحليل العناصر المحددة من خلال فحص مقاومة الانضغاط باستخدام المعادلات المتوفرة في الكتابات المتاحة . وقد وجد أن طبقة الاساس المحسنة مع رمل الصب والركام المعاد تدويره من الخرسانة الكونكريتية يؤدي إلى انخفاض في الكلل بنحو (٩٠٪ و ١٤٪) على التوالي. و انخفاض الانحاء العمودي لرمل الصب والركام المعاد تدويره من الخرسانة الكونكريتية بنحو (٩٣٪ و ٥٢٪) على التوالي.

1. Introduction

Pavement structures are built to support loads induced by traffic vehicle loading and to distribute them safely to the subgrade soil. The economic role of the road infrastructure, and the amount of money invested in its construction and maintenance indicate the importance of good pavement design and management procedures. Poorly designed road pavements will suffer from premature failure, which will lead to high reconstruction costs and to great economic losses [1] .

Transfer of loading to the subgrade, the material must be capable of safely handling stresses without excessive deformation. Leading to further improve on the characterization of the unbound granular material UGM, the permanent deformation component must be accounted for and included with the resilient modulus to fully evaluate the engineering behavior of the UGM to ensure proper functionality of the base course layer. During the last few years, and as a consequence of the drive towards economic utilization of non-renewable natural resources a recycling existing road materials, the development of new, more innovative types of road construction has become essential [5] .

Many secondary materials such as bottom ash, slag, foundry sands, concrete debris, and other waste materials are being considered for use as substitutes for natural aggregates or materials in civil engineering applications due to suitable engineering and economic properties. These applications include road bases, shoulders, embankments, and other fill applications. However, the increased interest in new applications for waste utilization has resulted in concern over the long-term physical and environmental performance of the waste-derived products. Prediction of the future behavior of the proposed products, both physical and environmental, is critical for approval by both highway practitioners and environmental regulators. This concern has resulted in the need for accelerated aging techniques that reflect the physical and environmental long term behavior of the waste-derived products [9] .

In Iraq, materials of Al-Nibaee quarry at Al-Taji are locally available and used in road working. However, starting from use of waste materials in the world regards as encouraging way to use it in base layer instead of Al-Nibaee materials. Over the recent years, the recycling of industrial wastes and byproducts for use in construction applications have been a priority area of research at a global level [8] and since the quantity road aggregates have become costly in many places in Iraq, the use of recycled materials such as recycled Portland Cement Concrete (PCC) shows promise to be a technically-viable solution that also offers economic and environmental advantages.

2. Experimental Program

The materials tested in this study are locally available in Iraq and used in road working. Two types of aggregates are used in this study, crushed aggregate brought from the hot mix plant of Al-Nibaee quarry at Al-Taji and reclaimed concrete aggregate (RCA) from waste concrete blocks (taken from Structural Laboratory of Civil Engineering Department) and foundry sand brought form Baghdad city , Casting plants in the area of Sheikh Omar.

2.1 Materials

2.1.1 Aggregate

For coarse aggregate the sizes of coarse aggregate range between the size passing 3/4 in. (19.0 mm) and retained on No.4 sieve (4.75mm). For fine Aggregate the ranges of fine aggregates are between the size passing No.4 sieve (4.75mm) and retained on No.200 sieve (0.075mm). The fine aggregate refers to a combination of natural sand (river sand) and the crushed sand. The aggregate is brought from the hot mix plant of Al-Nibaee quarry at Al-Taji. The State Corporation for Roads & Bridges in Iraq *(SCRB, 2003)* established standard specifications for base course. The gradation used in this study is shown in Figure (1).

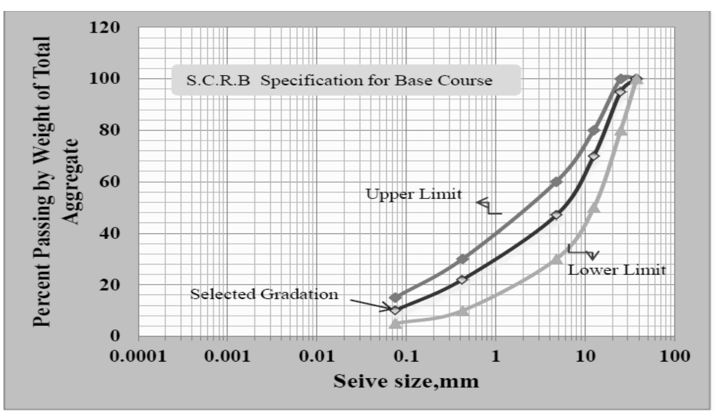

Figure 1.Specification Limits and Gradation for Base Course (SCRB, 2003).

2.1.2 Reclaimed Concrete Aggregate (RCA)

The use of reclaimed concrete aggregate promised to be a technically-viable solution that offers economic and environmental advantages. Reclaimed concrete aggregate, collected from waste materials, results from the waste concrete blocks of laboratory in the

College of Engineering Al-Mustansiriayah University. Reclaimed concrete aggregate is obtained through broken large parts of concrete blocks materials. Breaking process is made after cleaning recycled Portland cement concrete materials from unwanted materials. Then, from crushing process, reclaimed grains are produced with different gradients. These different gradients have been separated by sieve analysis and then prepared to be used.. The gradation used in this study according to SCRB specification for base course *(SCRB, 2003)*, as shown in Figure (1).

2.1.3 Foundry sand (FS)

Foundry sand is high quality silica sand that is a byproduct from the production of both ferrous and nonferrous metal castings. The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates. Foundries purchase high quality size-specific silica sands for use in their molding and casting operations. The raw sand is normally of a higher quality than the typical bank run or natural sands used in fill construction sites. Foundry sand is typically sub angular to round in shape.

Table (1) shows the results for bulk density, moisture content, specific gravity, dry density; optimum moisture content and permeability…etc. measured using the applicable ASTM standard.

Table 1. Typical Properties of Foundry Sand used in study.

Properties	Foundry Sand values	Standard Specification
Specific Gravity	2.63	ASTM D854
Bulk Relative Density, kN/m3	19.37	ASTM D4254
Standard Proctor Max Dry Density, kN/m3	17.3	ASTM D698
Optimum Moisture Content, %	12	ASTM D698
Hydraulic Conductivity (cm/sec)	10^{-7}	ASTM D2434
Plastic Index	NP	ASTM D4318
Internal friction angle (drained)	37	ASTM D3080
Cohesion intercept (drained), kN/m2	0	ASTM D3080

2.2 Preparing Test Specimens

The aggregates and filler for conventional materials (Al-Nibaee aggregate) and non-conventional materials (reclaimed concrete aggregate (RCA)) are prepared using the same procedure, except a washed sieve analysis is done for Al-Nibaee material only. For both types of materials, the aggregates are first dried to a constant weight, separated to the desired sizes by sieving and recombined with the mineral filler to conform to the selected graduation requirements of SCRB specification for base course *(SCRB, 2003).* The weight of each aggregate size and filler is determined by multiplying it's percent by the desired weight of final mix. Aggregate are used in this study as the following percentages are adopted below:

- RCA with (25,50,75)%
- Foundry sand (5,10,15,20)%

The modified Proctor compaction*(ASTM D 1557)* procedure requires compaction of the samples in five lifts; each lift consists of 56 blows.

Plat 1. Samples Prepared to UCS Test.

3. Unconfined Compressive Tests

The unconfined compressive tests were carried out on samples according to ASTM D 2166. The unconfined compressive tests were conducted on each sample, from which the ultimate compressive strength, failure strain, and the unconfined elasticity modulus were extracted and collated in Table 2, below.

Table 2. Summary of Unconfined Compressive Strength tests Results.

Material type		Average Compressive Strength(kPa)	Average Strain(%)	Average Modulus of Elasticity(kPa)
AL-Nibaee Aggregate		80	6.2	1300
RCA	25%	214	6.4	2500
	50%	436	7.17	5700
	75%	246	5.76	3200
FS	5%	237	4.97	2500
	10%	262	4.84	5500
	15%	335	4.71	10000
	20%	157	3.97	2700

To study the effect of stabilizer on fatigue and rutting damage the optimum percent of (50,15) reclaimed concrete aggregate and foundry sand respectively, as obtained from UCS test results based on compression strength test.

4.Estimating Relations

order to use the results of soil improvement in finite element simulations, the strength parameters of stabilized soil, cohesion and friction angel must be firstly determined by application of estimating relations. The estimating relations of Sharma et al. [11] are described subsequently.

When the amount of (σ) is reduced to zero (unconfined compressive test), the amount of (τ) equals to the amount of real cohesion of materials (Cr):

$$Cr=Pa[0.115(q_u /p_a)+1.242][0.035q_u/p_a] \quad (1)$$

And the tangent friction angel (φ) at any arbitrary confining pressure of (σ) is calculated by following relation:

$$Tan(\varphi)= [0.115(q_u /p_a)+1.242]^n / [\sigma +0.035q_u/p_a]^{1-n} \quad (2)$$

Where q_u ,P_a ultimate compressive and atmospheric pressure. n varies from 0.5 to 1.0 and must be calibrated for different soil types. In this research, the cohesion and friction angel of the mixtures are determined by the application of the estimating relations of Sharma et al [11].

5. Finite Element Simulation

5.1 Geometry model

Finite element simulations for each materials were carried out using a commercial finite element analysis (FEA) package namely, PLAXIS 8.6. The information required for defining the material characteristics to generate the models was obtained from a combination of laboratory experiments and estimating relations presented by Sharma et al [10]. Properties like elasticity modulus and dry density were extracted from laboratory tests. Strength parameters such as the cohesion and the internal friction angel were attained by implying the compressive strength in estimating relations (information presented in Table (2). Elaso-plastic analysis on an plain strain material body having by a 25 cm stabilized base material, with dimensions of 7 m and 5 m in height and diameter respectively, was performed with the special characteristics of each material type. Figure (2) demonstrates the geometry of the model together with the applied meshing system. In order to obtain more precise results, the base layer and the upper of the subgrade .

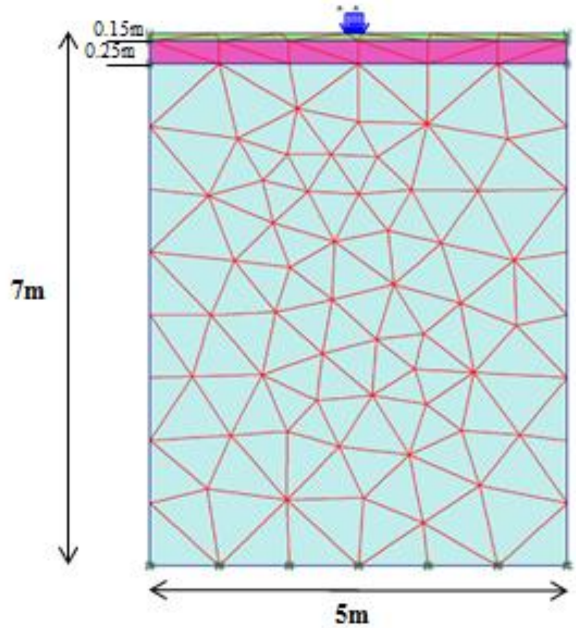

Figure 2: Typical Mesh Generation in PLAXIS.

5.2 Subgrade and Base Layer Geotechnical Properties

The modulus of elasticity (E) of untreated (AL-Nibaee) base material and the optimum percent of (50,15) reclaimed concrete aggregate and foundry sand respectively treated base materials were obtained by the unconfined compressive test and has already been presented in section (3).

In order to obtain the cohesion and friction angles of the mixture types, a combination of laboratory experiments and the relationship proposed by Sharma et al. [11] are applied. The calculation process and discussions are described in details in Azadegan et al [3]. Tables (3 to 5) present the amounts of cohesion and friction angles that are assigned to the subgrade and base materials in the finite element model.

Table 3. AL-Nibaee Aggregate Properties and Parameters used in the Finite Element model Analysis.

Parameter	Subgrade	Base layer	Asphalt layer
Material Model	Morh- coulomb	Morh-coulomb	Linear-elastic
Material behavior	Un drained	Drained	Non-porous
Cohesion (c, kPa)	15	9	-
Angle of internal friction (ϕ)	11	68	-
Un drained shear strength (Cu, kPa)	127.68	-	-
Dry unit weight(ɤdry, kN/m3)	13.56	21	22

Saturated unit weight(ɤsat, kN/m3)	19.93	22	-
Permeability(k, m/s)	0.000000873	0.0001	-
Young's modulus(E, kPa)	1947	1300	1500000
Poisson's ratio (ν)	0.35	0.3	0.15

Table 4. Foundry Sand (FS) Properties and Parameters Used in the Finite Element Model Analysis.

Parameter	Sub grade	Base layer	Asphalt layer
Material Model	Morh-coulomb	Morh-coulomb	Linear-elastic
Material behavior	Un drained	Drained	Non-porous
Cohesion (c, kPa)	15	32	-
Angle of internal friction (ϕ)	11	68	-
Un drained shear strength (Cu, kPa)	127.68	-	-
Dry unit weight(ɤdry, kN/m3)	13.56	22	22
Saturated unit weight (ɤsat, kN/m3)	19.93	24	-
Permeability(k, m/s)	0.000000873	0.0001	-
Young's modulus(E, kPa)	1947	10000	1500000
Poisson's ratio (ν)	0.35	0.3	0.15

Table 5. Reclaimed Concrete Aggregate (RCA) Properties and Parameters used in The Finite Element Model Analysis.

Parameter	Sub grade	Base layer	Asphalt layer
Material Model	Morh-coulomb	Morh-coulomb	Linear-elastic
Material behavior	Un drained	Drained	Non-porous
Cohesion (c, kPa)	15	42	-
Angle of internal friction (ϕ)	11	67	-
Un drained shear strength (Cu, kPa)	127.68	-	-
Dry unit weight (ɤdry, kN/m3)	13.56	22	22
Saturated unit weight(ɤsat, kN/m3)	19.93	23	-
Permeability (k, m/s)	0.000000873	0.0001	-
Young's modulus(E, kPa)	1947	5700	1500000
Poisson's ratio (ν)	0.35	0.3	0.15

5.3 Loading

To model the surface load of the dual wheel the total load is transferred to the pavement surface through an average contact pressure of 550 kPa as shown in Figure (3).

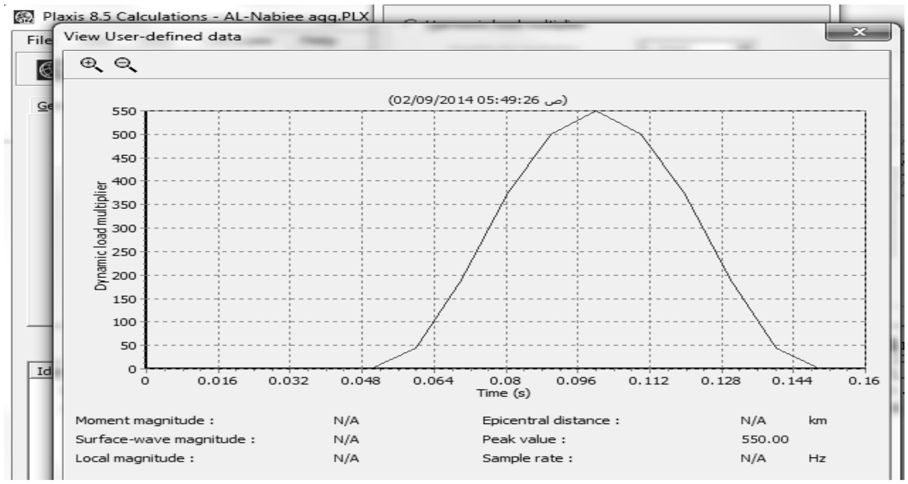

Figure (3): Haversine Load Pulse of 0.1 sec. Duration with a Peak Stress Intensity of 550 kN/m2.

The stiffening effect of the tire wall is being neglected. The tire contact pressure on the road is equal to the tire inflation pressure with a circular tire imprint of 200 mm radius [10] Haversine stress pulse of 0.1 sec. duration simulating an average speed of 30 km/h and peak pressure of 550 kPa is used to obtain dynamic response at a given point in the pavement system.

6. Results and Discussion

This study has been carried out to investigate the effect of applying a combination of foundry sand and reclaimed concrete aggregate material in order to improve the mechanical characteristics of untreated base courses over clay subgrades in flexible pavement roads. To this end, the two material types were treated with various amounts of foundry sand and reclaimed concrete aggregate material to prepare the test specimens. Using the test results and utilizing the estimating relations recommended by Sharma et al. [11] . The results of the analysis are discussed from two aspects: vertical deformation under dynamic load, and the impact of stabilizer on fatigue and rutting damage.

6.1 Surface Deformation

Analytical model is used to simulate the unbound materials which is a nonlinear elasto-plastic model. The deformation model’s equation is founded on the theory of dynamic loading. This stipulates that the strength of base layer to resist permanent deformation can take place either in the granular base or subgrade under the imposed traffic changes with the type of stabilizer which either increases foundry sand stabilized base material or decreases (reclaimed concrete aggregate).

For foundry sand stabilized base material, shows higher reduction in surface deformation of about (77%) than unstabilized Al-Nibaee base layer model. Reclaimed base layer model indicates (40%) increase in surface deformation. A likely cause for increased deflections in RCA material is the reduced modulus of elasticity of the RCA **[6]** The low Young's modulus indicates that the material is easier to deform; thus, a lower load may cause greater deformation in an RCA material than in a conventional material. The most important thing to consider, however, is if the increase in deformation is enough to rule out RCA concrete as a viable structural material. Since the standard predictions deflection was greater for RCA than for NA materials [7] .

Finally, ability to reach strengthens base layer model and less surface deformation value can be obtained from this program.

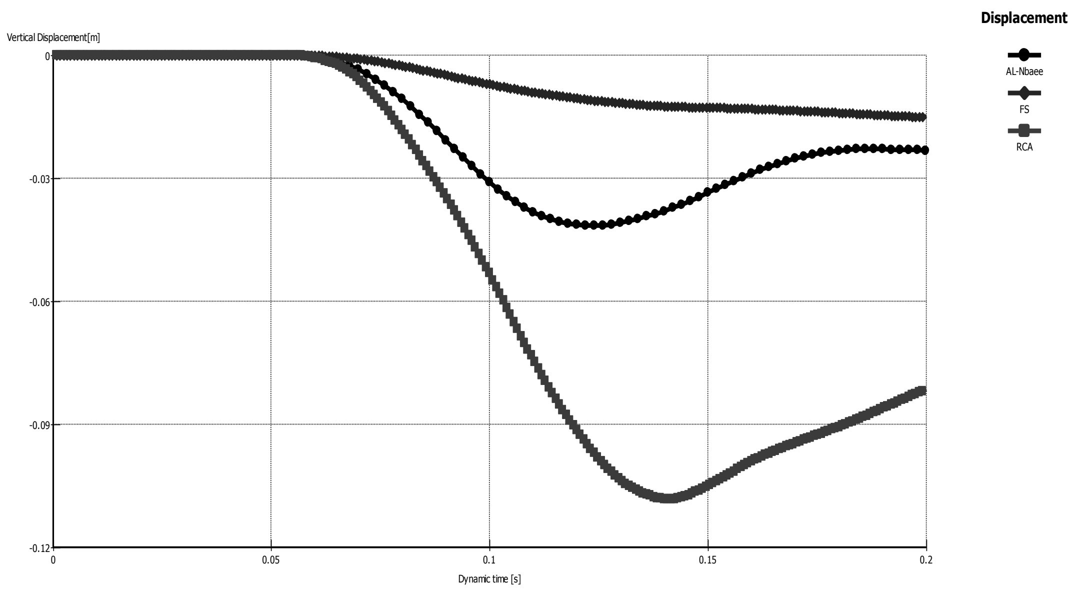

Figure 4. Vertical Displacement for AL-Nibaee Aggregate Base Material and different Stabilized Base Material

6.2 Effect of Stabilized Base Layer Flexible Pavement Damage

Critical pavement responses i.e. fatigue strain; rutting strain and vertical surface deflection of pavements are calculated under dynamic loading condition. The fatigue and rutting strains, ϵt max and ϵc max are evaluated respectively, at bottom of the bituminous layer (element A) and top of subgrade (element B) as shown in Figure (4). Table (6) illustration the ϵt max and ϵc max respectively, at bottom of the bituminous layer (element A) and top of subgrade (element B) under dynamic load.

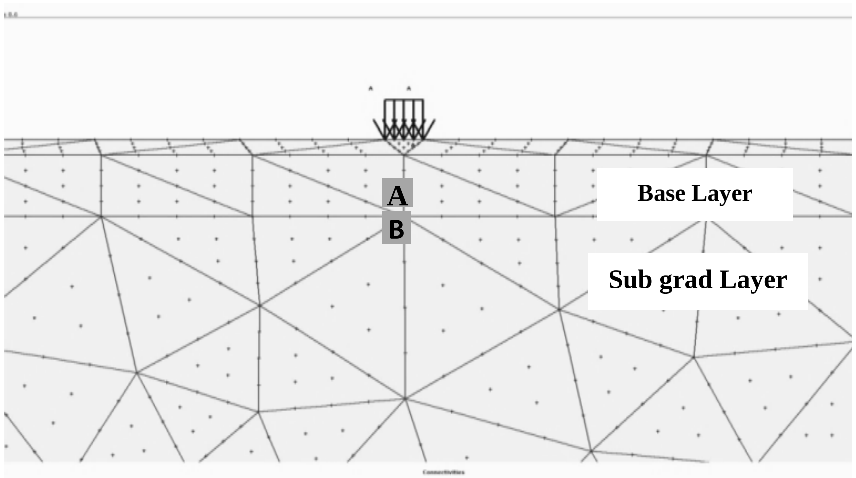

Figure 4.The Horizontal and Vertical compression Strain Critical Points Predicted through Finite Element Model.

Table 6. Horizontal Strain and Vertical Strains Predicted through Finite Element Model.

Material type	Under dynamic load	
	(ϵt max.)	(ϵc max.)
AL-Nibaee	5.01E-03	0.048
Foundry sand(FS)	5.04 E-04	2.90 E-03
Reclaimed concrete aggregate (RCA)	4.29 E-03	0.023

It is found that horizontal strain at the bottom of the asphalt layer under dynamic loading condition is reduced by (90% and 14%)of foundry sand (FS) and reclaimed concrete aggregate (RCA) respectively. The variation of the horizontal strain on the bottom of asphalt layer on the center of loading is (0.00501) for untreated base material and stabilized base material (0.00429 and 0.0000504) for (RCA and FS) respectively. Figure (5) illustration the horizontal strain on the bottom of asphalt layer and subgrade.

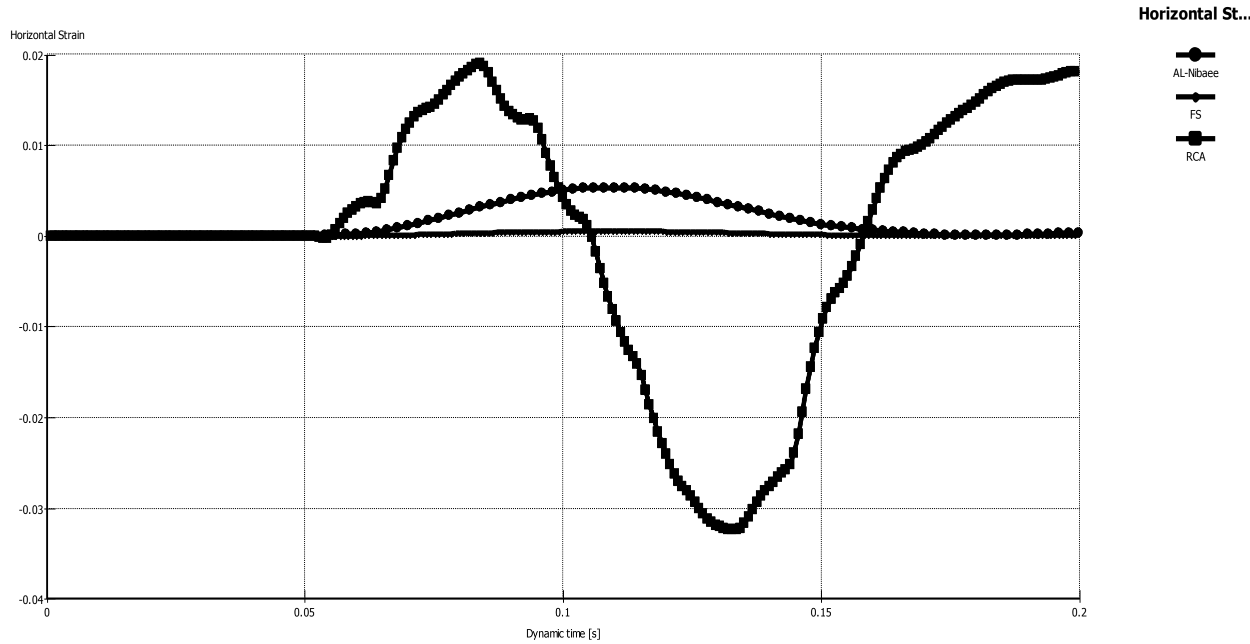

Figure 5. Horizontal Strain on the bottom of Asphalt layer.

The reduction in vertical strain at the top of the subgrade layer under dynamic loading condition is about (93% and 52%) of foundry sand (FS) and reclaimed concrete aggregate (RCA) respectively. That related to increase, the strength of treated base materials with RCA and FS , By about (5.45), (4.18) more than untreated materials. Figure (6) illustration the reduction in vertical strain in the top of subgrade layer.

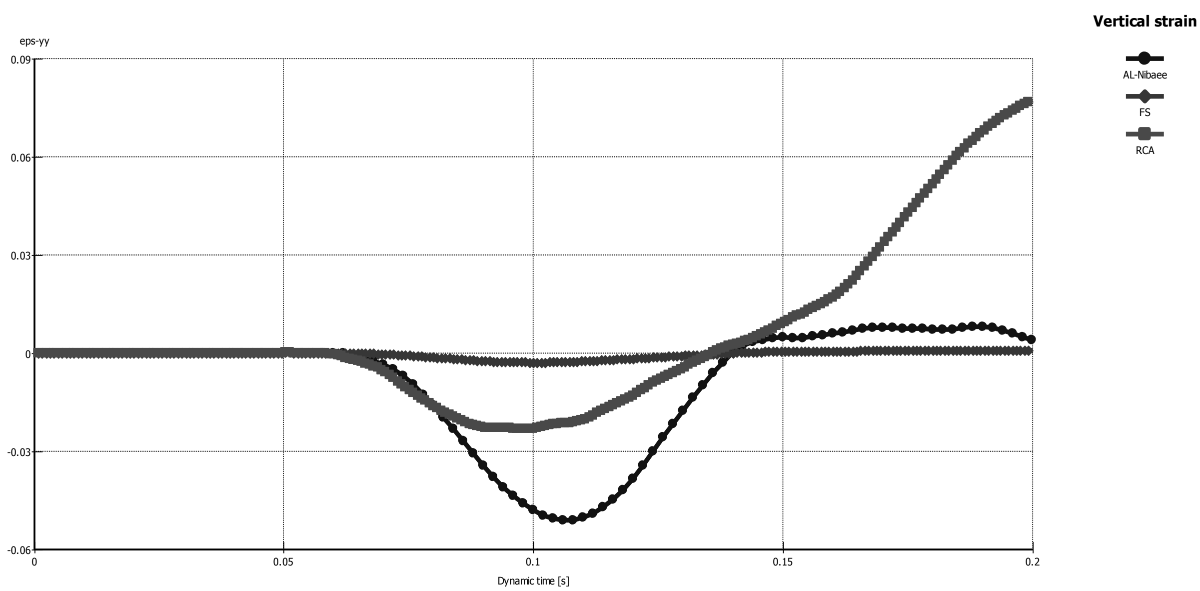

Figure 6. Vertical Strain on the Top of Subgrade Layer.

In Figure above the vertical strain observed under the center of the load for untreated base material (AL-Nibaee aggregate) is 0.048 and this reduces to (0.00290 and 0.023) for stabilized base material with foundry sand and treated with reclaimed concrete aggregate respectively. This shows the effectiveness of stabilizer in controlling the deflection when used.

6.3 Impact of Fatigue and Rutting Life of Flexible Pavement

Rutting and fatigue cracking are the most important pavement distresses due to high severity and density levels, and accordingly their high effects on the pavement condition. Cracking in the asphalt layer is due to fatigue, caused by repeated application of load by moving traffic.

Rutting is developed due to accumulation of permanent deformation in various layers along the wheel path. Horizontal tensile strain (ϵt max) developed at the bottom of asphalt layer or the vertical compressive strain (ϵc max) developed at the top of subgrade, respectively, have been considered as indices of fatigue and rutting of the pavement structure. By these values, the number of load repetitions to prevent fatigue cracking and the number of load applications to limit rutting are estimated based on two equations shown below and suggested by Asphalt Institute [2] .

$$N_f = 0.0796[(1/\boldsymbol{\epsilon_t}]^{3.291}(1/E_1)^{0.854} \quad (3)$$

$$N_r = 1.365*10^{-9}[1/\boldsymbol{\epsilon_c}]^{4.477} \quad (4)$$

where:

N_f: number of load repetitions to prevent fatigue cracking.

$\boldsymbol{\epsilon_t}$: tensile strain at the bottom of asphalt layer.

E_1: elastic modulus of asphalt layer (kPa).

N_r: number of load applications to limit rutting.

$\boldsymbol{\epsilon_c}$: vertical compressive strain, at the top of subgrade.

flexible pavement, generates damage (Di) which is calculated from Equation (3) shown below (Huang, 2004).

$$\boldsymbol{D_i = 1/N_i} \quad (5)$$

Where:

Ni: minimum number of load repetitions required to cause either fatigue or rutting failure, as given by Equations (3) and (4) respectively. Figures (7) and (8) show number of load repetitions to prevent fatigue (Nf) and number of load repetitions to limit rutting (Nr) for all types of stabilizer material used.

Table (7) shows foundry sand stabilizer produces the minimum fatigue and rutting damage. Improvement of base layer reduces damage caused by both fatigue and rutting distresses and thus longer pavement design life is maintained.

Table 7. Fatigue and Rutting Failure Analysis Based on Asphalt Institute Response Model (1982).

Material type	No. of repetitions to Failure (N_f)	Fatigue Damage	No. of repetitions to Failure (N_r)	Rutting Damage
AL-Nibaee	3.37E+04	2.96E-05	1.09E-03	9.14E+02
Foundry sand	1.12E+07	8.89E-08	3.13E+02	3.19E-03
Reclaimed concrete aggregate	1.58E+04	6.33E-05	2.94E-02	3.40E+01

The figures (7) and (8) show that, the maximum value for (*Nf*) is obtained with foundry sand stabilizer .On the other hand, Figure (9) and (10) present the estimated fatigue and rutting damage for all types of stabilizers are used in the base layer stabilized with different types of stabilizer.

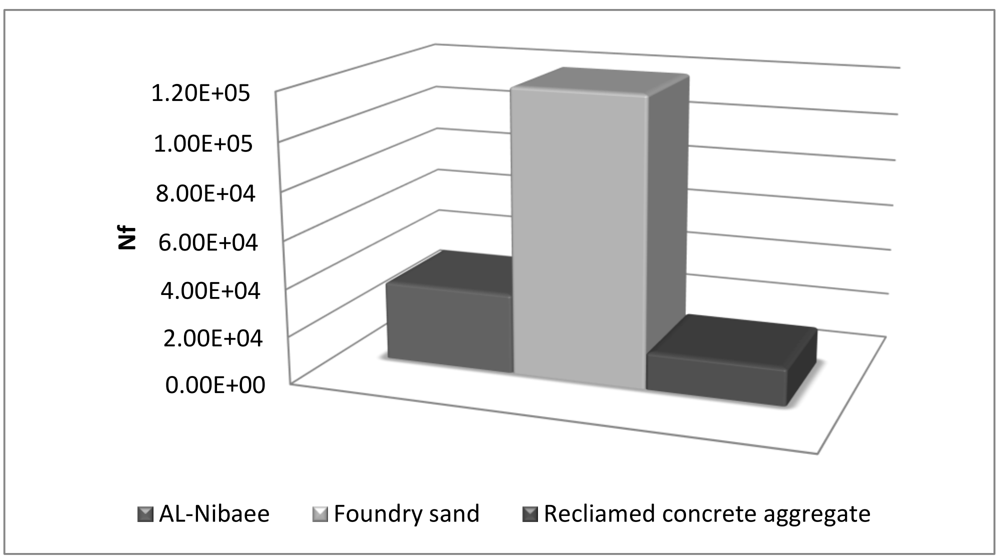

Figure 7. Number of Load Repetitions to Prevent Fatigue Cracking versus Pavements of Different Base layer.

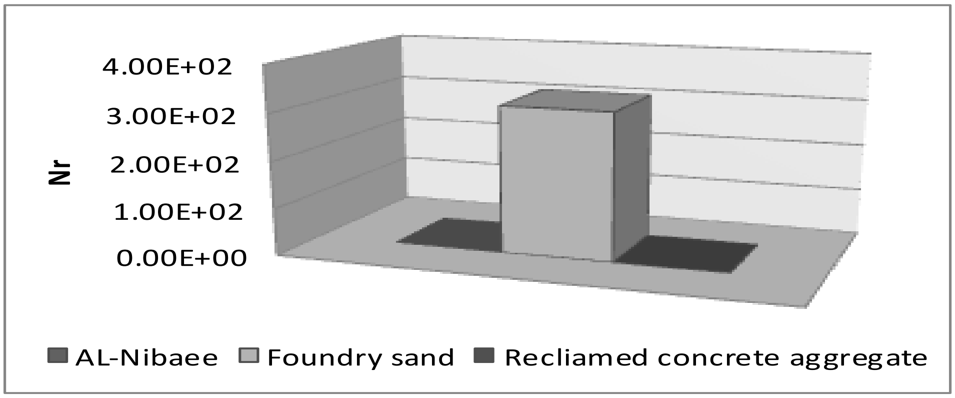

Figure 8.Number of Load Repetitions to Limit Rutting for Different Stabilized Base layer

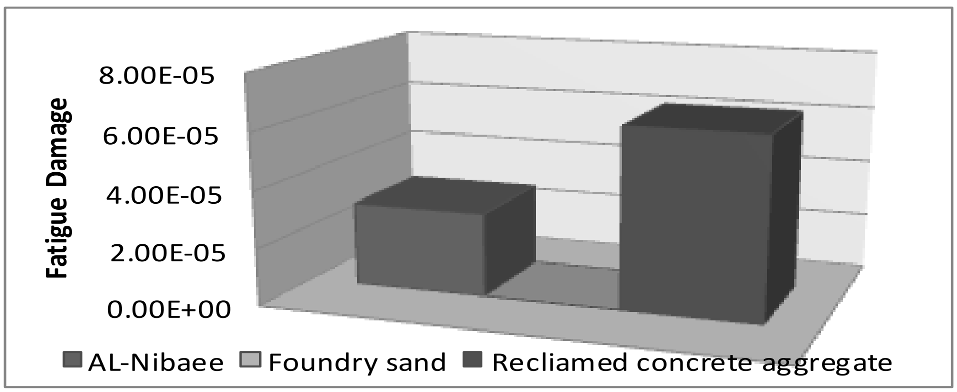

Figure 9. Fatigue Damage for all types of Stabilizer.

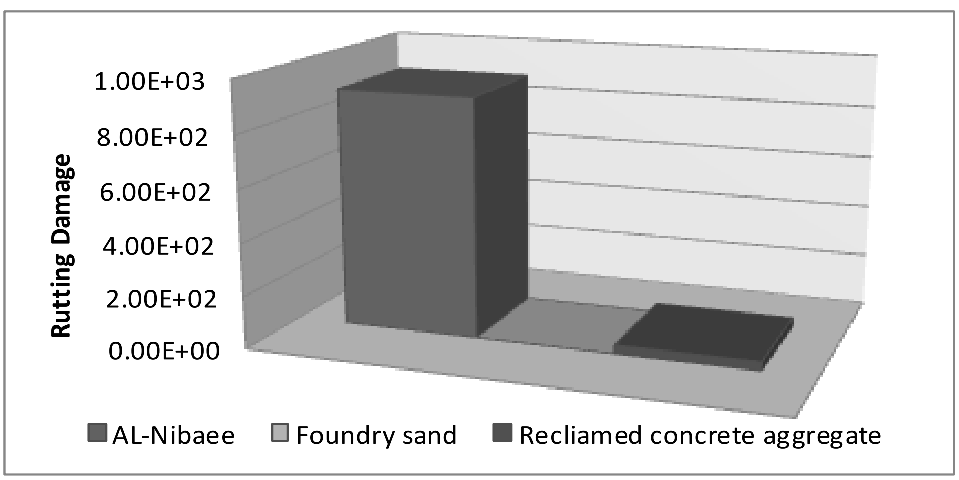

Figure 10. Rutting Damage for all Types of Stabilizer

7. Conclustions

The simulations are conducted under a parametric study to find out the beneficial effects of stabilized base material to the fatigue and rutting strain criteria. The following important conclusions can be drawn from the model parametric study.

1. The treated base material with foundry sand (FS) stabilizer , it leads to the highest reduction in horizontal tensile strain amounting to (90%) under dynamic loading conditions. For treated base material with reclaimed concrete aggregate the tensile strain reduced about (14%) at the bottom of asphalt layer.
2. The treated base material with foundry sand (FS) and reclaimed concrete aggregate decreasing the vertical strain (93% and 52%) respectively under dynamic loading condition at top of subgrad layer.
3. Pavement having treated base layer with foundry sand and reclaimed concrete aggregate, reduces damage caused by both fatigue and rutting distresses and thus longer pavement design life is maintained.

Abbreviations

C Cohesion of Soil.
E Young Modulus.
ν Poisson Ratio.
ϕ Friction angle.
γ Unit Wight of Material.

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