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# Developing a Performance Criteria for Stone Columns to Improve Surface Pavement for Weak Subgrade Conditions

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**Abstract**
Soft, saturated, fine grained subgrade soils are distinguished by their low undrianed shear strength and high compressibility. Such soils cover most of the middle and southern parts of Iraq. The effect of using stone column, encased in geogrid and steel mesh to improve pavement's performance is experimentally investigated and evaluated. To compare the experimental and analytical outputs, three dimensions finite element throughout elastic and elasto-plastic models using ABAQUS ver.6.12.3 software are developed to simulate and analyze the relations between the cycling load and deformation of the suggested pavement modes. Based on the results and the limitation of this study it is concluded that, using encased stone columns, is more practical and suitable alternative to improve weak subgrade against permanent deformation as compared with the other simulated pavement modes. The results of ABAQUS program are very close to results of laboratory tests.

*Keywords:* Soft subgrade; Geogrid; Steel mesh; Abaqus models

## 1 Introduction

The pavement foundation (subgrade) represents one of the key elements in the pavement design; its behavior will influence the overall pavement performance. In general, the main function of subgrade soils is to provide support to pavement structures. Under heavy traffic loads, subgrade soils may deform and contribute to distress in the overlying pavement structure. In asphalt pavements, this distress normally takes the form of cracking and rutting.

Rutting is one of the most serious distresses in asphalt pavements affecting the pavement performance and service life. The weak soft subgrade soils, in particular, contribute a significant portion (above 40%) of the total pavement rutting (Majidzadeh, 1978).

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# 2 Study Objective

- Investigating, evaluating experimentally the effect of using encased stone column, Geogrid and steel mesh to improve the performance of pavement.
- Developing a three dimensions finite element throughout elastic and elasto-plastic models using ABAQUS ver.6.12.3 software to simulate and analyze the relations between the cycling load and deformation of the proposed pavement modes; raw material model, encased stone column model, Geogrid model and steel mesh model.

# 3 Experimental Work

## 3.1 Materials Property

A brown lean clayey soil is brought from a depth of 5m from bridge site in the sport city within Al-Basra city. Standard tests are performed to determine the physical and chemical properties of the soil, details are given in Table 1.

| Property | Value | Standard |
|---|---|---|
| Liquid limit (LL) & Plastic limit (PL)% | 47,23 | ASTM D4318 |
| Plasticity index %(PI) | 24 | |
| Liquidity index %(LI) | 0.48 | |
| Specific gravity (Gs) | 2.7 | ASTM D854 |
| Total soluble salt% | 6.13 | |
| SO3 content% | 0.6 | |
| Organic matter O.M% | 1.09 | B.S.1377:1990 |
| Gypsum content% | 1.17 | |
| pH | 8.34 | |
| Classification (USCS) | CL | |

**Table 1:** Physical and Chemical Properties of Natural Clayey Soil Used.

The subbase is brought from Al_Nibaee/ quarry, north of Baghdad, this type of subbase is commonly used as a granular layer in flexible pavement section.

Base layer consists of weighting aggregate and filler according to the State Corporation for Roads & Bridges in Iraq (SCRB, 2003).

The asphalt cement used in this study is of (40-50) penetration grade, and brought from Daurah Refinery. Table 2 shows the physical properties of Asphalt Cement.

| Test | Result | Unit | SCRB Specs. |
|---|---|---|---|
| Penetration (25°C, 100g,5sec) ASTM D 5 | 48 | 1/10mm | 40 – 50 |
| Ductility (25°C, 5 cm/min).ASTM D 113 | 166 | Cm | ≥ 100 |
| Softening point (ring & ball).ASTM D 36 | 51 | °C | 50 – 60 |
| Flash point (cleave land open cup)ASTM D 92 | 252 | °C | ≥ 232 |
| Ductility of residue | 151 | Cm | > 25 |

**Table 2:** Physical Properties of the Asphalt Cement.

The (crushed) aggregate used in this work is brought from Al-Nibaee quarry. The physical properties of the aggregate (coarse and fine) are shown in Table 3.

| Property | Coarse Aggregate | Fine Aggregate |
|---|---|---|
| Bulk Specific Gravity (ASTM C127 and C128) | 2.672 | 2.633 |
| Apparent specific Gravity (ASTM C127 and C128). | 2.601 | 2.431 |
| Percent water absorption (ASTM C127 and C128) | 0.45 | 0.531 |
| Percent wear (Los- Angeles Abrasion) (ASTM C131) | 20.10 | - |

**Table 3:** Physical Properties of Nibaee Aggregates.

Steel wire reinforcement consists of a double twist, hexagonal shape, galvanized wire netting.

The geogrid material used in this study is Pars Mesh Polymer (PMP) Type SQ12 manufactured by the Iranian company Pars Mesh Polymer.

## 3.2 Preparation of Model Test

- Natural subgrade soil is mixed with quantity of water to get the desired consistency. After that, the soil is placed in a steel container (600*600*700) mm in five layer.
- The construction of the subbase layer start after four days from the preparation of the soft subgrade soil. A predetermined weight of subbase is mixed with water by hands at moisture content of 8.2%, this weight is sufficient to create a layer of thickness 15cm subbase layer.
- Preparation of base layer consists of weighting aggregate and filler according to the gradation of (SCRB, 2003) for base course. After the preparation of the base layer, the asphalt slab is placed on the surface of the base layer.
- The asphalt mixture slabs has a length of 40 cm, a width of 40 cm, and a thickness of 13 cm is made of two layers, binder layer height (8cm) and wearing Layer (5cm).

## 3.3 Experimental Setup

To study and investigate the optimal way to improve the strength of pavement layers over weak subgrade; an experimental setup is designed and assembled to achieve this goal as shown in Figure 1.

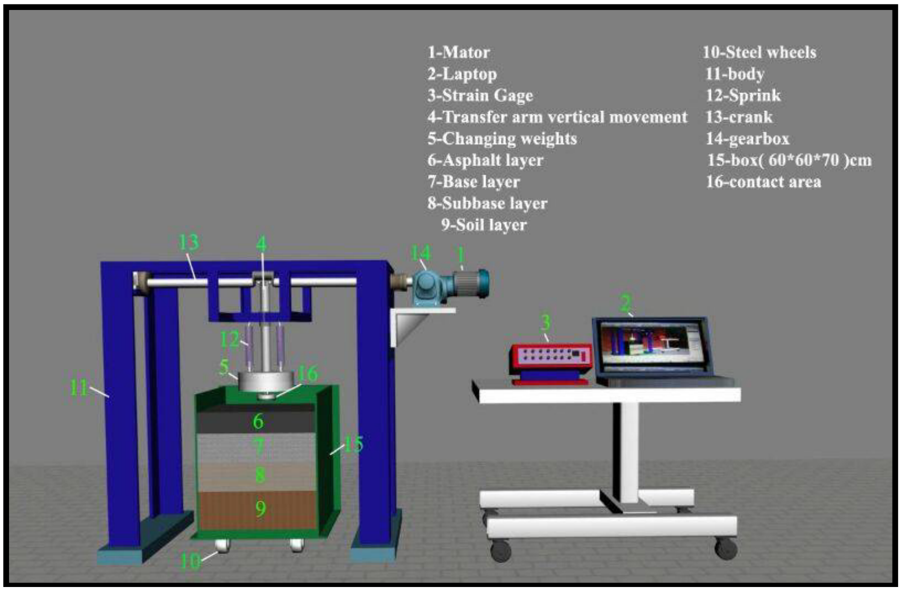

**Figure 1:** Experimental Test Container and Loading System.

## 3.4 Results of Experimental Work

The data obtained from the experimental work is permanent deformation for each layer as shown in following figures.

Figure 2 show the relation between permanent deformation and loading cycles for the asphalt surface layer. It is clearly noticed that, the permanent deformation increases with the increase in the number of cycle load.

The permanent deformation is recorded at 1600 cycle load and compared with the raw material model. Furthermore, the higher permanent deformation value can be noticed in the raw material, while the lowest permanent deformation can be shown in encased stone column.

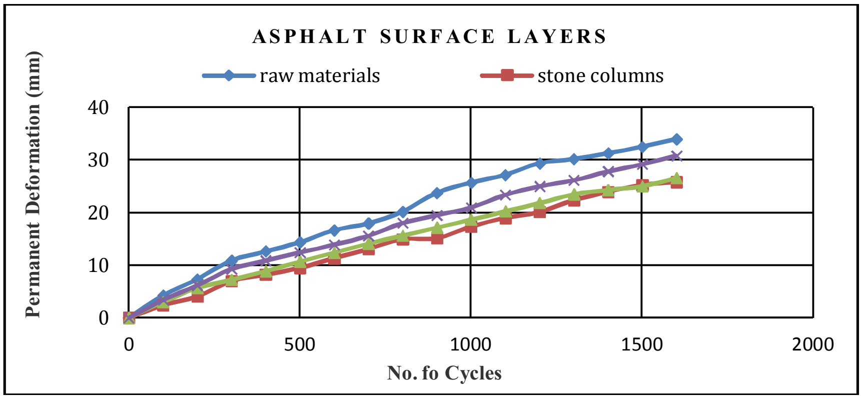

**Figure 2:** Permanent Deformations versus the Number of Cycle for Asphalt Concrete Layers.

# 4 Finite Element Modeling

## 4.1 Pavement Layers Modeling Based on ABAQUS

Three-dimensional continuum solid elements are often selected to simulate the problem in consideration. The model consists of a 130 mm of asphalt surface layer (wearing and binder) placed on 150 mm of subbase and 150 mm base over 200 mm of sub-grade soil.

The most important aspect of Finite Element Analyses is the simulation of the material characteristics. In the present study, several materials are involved with different properties, but basically they are divided into two categories: linear elastic and elasto-plastic. The material properties for pavement layers are summarized in Table 4.

| Layer | Density ($Kg/m^3$) | Young's Modulus (MPa) | Poisson Ratio ($\nu$) | Internal Friction ($\theta$) |
|---|---|---|---|---|
| Wearing layer | 1922 | 2413 | 0.35 | - |
| Binder layer | 1734 | 2375 | 0.35 | - |
| Base layer | 2141 | 241 | 0.4 | 45 |
| Subbase layer | 2200 | 110 | 0.4 | 40 |
| Subgrade layer | 982 | 8 | 0.45 | 15 |

**Table 4:** Material Properties (Input Data).

The pavement structure is meshed using an 8-node continuum linear brick reduced integration element (C3D8R element). The total number of element is 12096 and the mesh convergence study is executed to find this optimum number of element. All layers are simulated with the same shape to preserve the continuity of nodes between consecutive layers. Figure 3 shows meshing of total model.

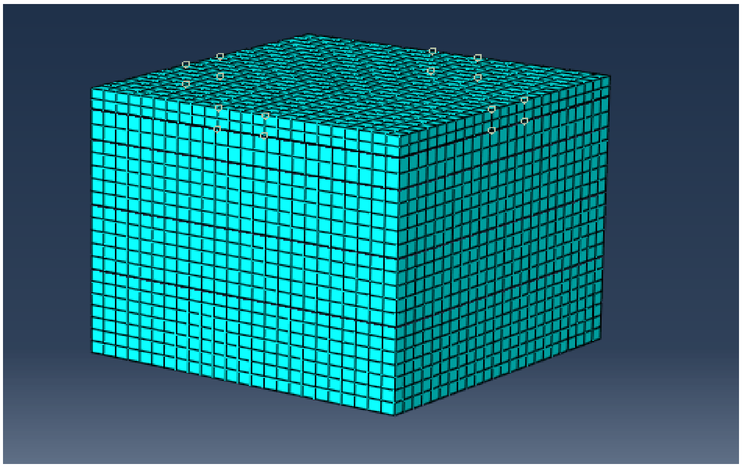

**Figure 3:** 3D Finite Element Mesh Model.

The F.E is then run simulating a dynamic load, modeled as a pressure load applying at the same location of the pavement, as shown in Figure 4. The load applied in the ABAQUS is 280 Kg (2.8 KN).

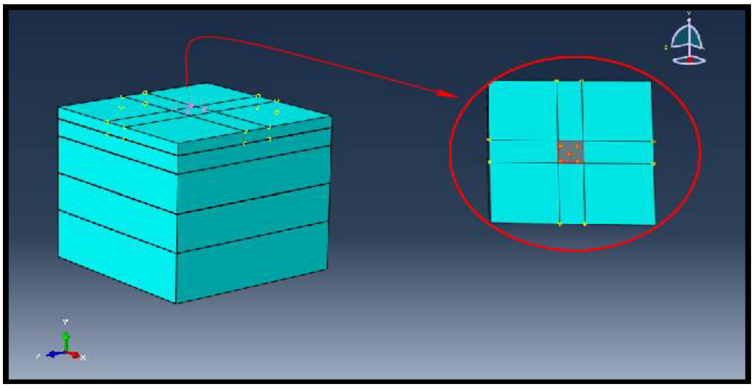

**Figure 4:** Loading Applied in ABAQUS Program.

The boundary conditions (see Figure 5) have a significant influence in predicting the response of the model, the bottom surface of the subgrade and sides of layers is assumed to be fixed, shows the boundary conditions used in the analysis.

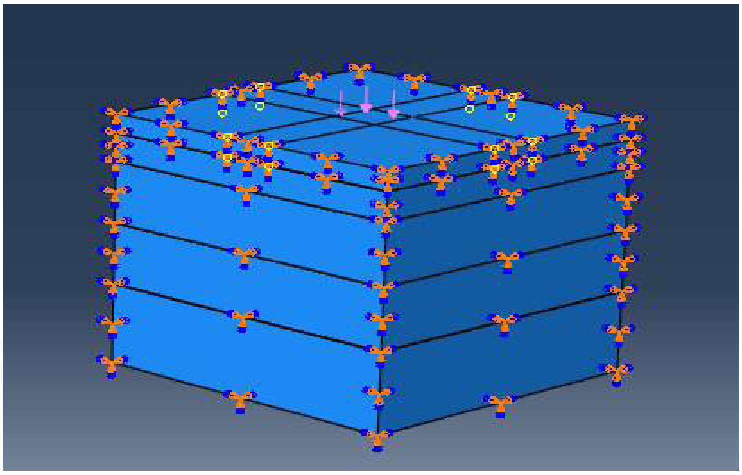

**Figure 5:** Boundary Conditions for Model.

## 4.2 Abaqus Program's Output

Rutting is simulated as a vertical displacement in the ABAQUS model analysis. The magnitude of the displacement U beneath the center of the load at 1000 cycles load is shown in Figure 6.

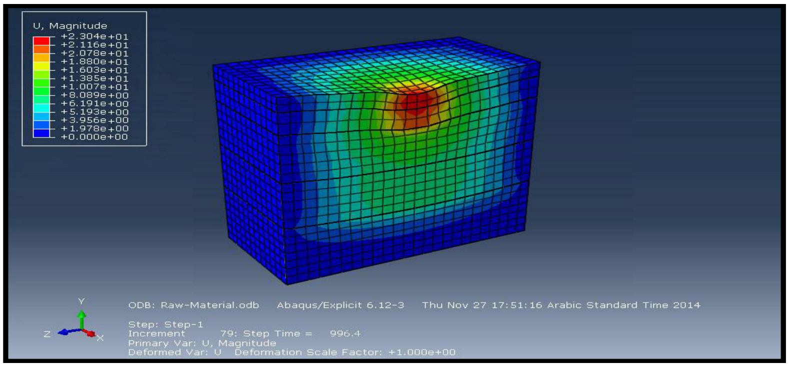

**Figure 6:** Vertical Displacement for the Model with Elastic Raw Materials.

ABAQUS results for elasto-plastic mode can be seen in Figure 7.

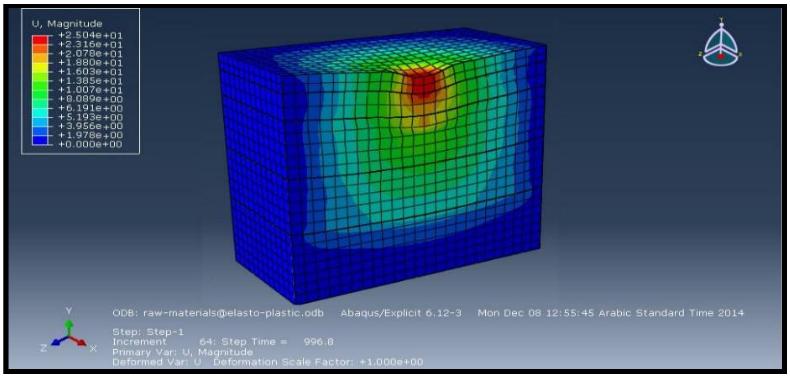

**Figure 7:** Vertical Displacement for the Model with Elasto Plastic Raw Materials.

Figure 8 and Figure 9 show the comparison between vertical displacements (rutting) obtained by experimental work and ABAQUS results at different number of cycle load. It can be seen that there is no significant difference appears between experimental and ABAQUS results.

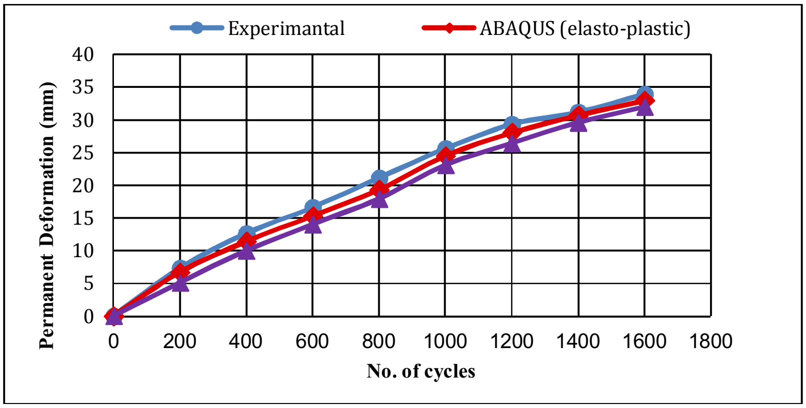

**Figure 8:** Comparison between Experimental Results and ABAQUS (Elastic, Elasto plastic) for Raw Materials Model.

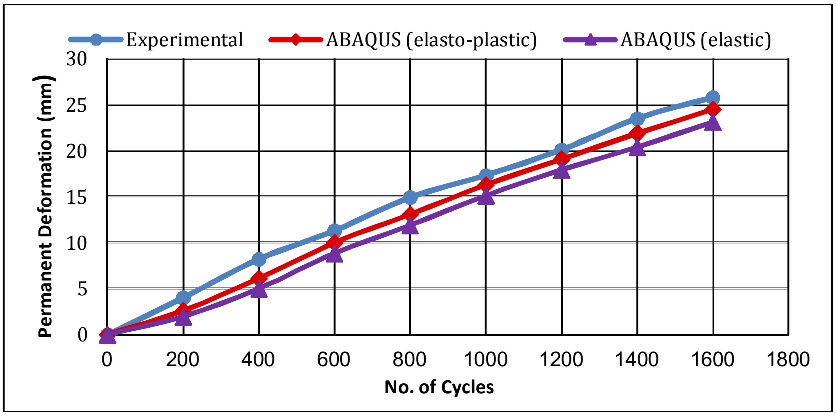

**Figure 9:** Comparison between Experimental Results and ABAQUS (Elastic, Elasto plastic) for Encased Stone Columns Model.

## 5 Conclusions

1. It is found that, using encased stone columns, is a more practical and suitable alternative to improve weak subgrade against permanent deformation as compared with the other simulated pavement modes. It shows a typical increase in the ability to support repeated and dynamic loads transmitted from the pavement structure.
2. ABAQUSE program was successful in simulation pavement structure models, so ABAQUS program can be used in analysis of paved road.

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